Cape Peninsula
University of Technology

The Design and Implementation of a Computer-Controlled Pneumatic Device to Replace the Deadweight in Standard Exercise Equipment

by

Zheng Wang

Thesis submitted in fulfilment of the requirements for the degree

Master of Technology: Information Technology

in the Faculty of Informatics and Design

at the Cape Peninsula University of Technology

Supervisor: Bennett Alexander

Bellville
September 2007

Declaration

I, Zheng Wang, declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed **Date**

Declaration

I, Zheng Wang, declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed **Date**

ABSTRACT

The increasingly sedentary lifestyle of the past 30 years has contributed to declining health. Consequently, exercise is vital for good health maintenance. The global Health and Fitness Industry repeatedly indicates the need for optimally managed exercise with accurate information feedback. Compared to other industries, the fitness industry is lagging behind in incorporating Information Technology into its operations. On the other hand, the most current exercise equipment impose fixed-trajectory exercise on users with the dominance of static equipment designs. These exercise equipment are normally deadweight-based equipment. In deadweight-based exercise equipment, the weights generally can be changed only when the equipment is inactive. Therefore, a more novel exercise environment is required for current exercisers in the fitness industry.

This thesis explores to develop a computer-controlled pneumatic dynamic resistance exercise equipment with onboard data management. This new technology optimises exercise effectiveness for users. Exercisers will have advanced diagnostic capacity, and will capture user data which can be manipulated into meaningful information for use by Health and Fitness Industry stakeholders.

This thesis will explore all the key concepts about computer-controlled equipment. The key concepts to be investigated will include FX (force-displacement) control technology, pneumatic system control, fail-safe mechanics, and Graphical User Interface design. The primary aim of the project is to replicate and enhance the functionality, performance, and sensation of deadweight-based equipment. A further aim of the project is to investigate the feasibility of designing a compact retrofit-able pneumatic unit to replace the deadweights of existing standard exercise equipment. The computer control will be implemented on a "National Instruments PXI" computer featuring Data Acquisition and Control (DAQAC) capacity, and the software will be

implemented using “LabVIEW 7.0”, which is a graphic object-oriented computer language developed to facilitate hardware / software communications.

GLOSSARY

Software Development / Engineering: is a systematic and disciplined approach to developing software. It applies both computer science and engineering principles and practices to the creation, operation, and maintenance of software systems.

Deadweight-based Exercise Equipment: the unrelieved weight of a heavy, motionless mass. The weights generally can be changed only when the equipment is inactive.

Force-Displacement Control Technology: a bi-directional pneumatic cylinder has each chamber connected via an electronically controlled pressure control valve to a high pressure reservoir. By reducing or increasing pressure force can be controlled through differential pressure.

Pneumatic Actuation: converts energy typically in the form of compressed air into motion. The motion can be rotary or linear, depending on the type of actuator. Some types of pneumatic actuators include: tie rod cylinders, rotary actuators, grippers, rodless actuators with magnetic linkage, rodless actuators with mechanical linkage, pneumatic artificial muscles, speciality actuators that combine rotary and linear motion-frequently used for clamping operations, and vacuum generators.

Closed-loop Control System: is one in which an input forcing function is determined in part by the system response. The measured response of a physical system is compared with a desired response. The difference between these two responses initiates actions that will result in the actual response of the system to approach the desired response. This in turn drives the difference signal toward zero. Typically the difference signal is processed by another physical system, which is called a compensator, a controller, or a filter for real-time control system applications.

PID Controller: a Proportional Integral Derivative controller is a generic control loop feedback mechanism widely used in industrial control systems. A PID controller attempts to correct the error between a measured process variable and a desired setpoint by calculating and then outputting a corrective action that can adjust the process accordingly.

Fail-safe Mechanics: capable of compensating automatically and safely for a failure, as of a mechanism or power source. Acting to discontinue a military attack on the occurrence of any of various predetermined conditions.

Exercisers: during this thesis, exercisers have two meanings, which one meaning reflects exercise equipments. Another meaning reflects the persons who will use the equipment to exercise.

ACKNOWLEDGEMENTS

I am deeply indebted to many people who have provided help, support and encouragement. I would like to thank my supervisor, Mr. Bennett Alexander, for his invaluable help and unselfish support throughout the preparation of this thesis. I thank him for teaching me to be a researcher.

Secondly, I would like to thank all the participants who graciously offered time to participate in this study. Your willingness and co-operation was an invaluable contribution to this study.

I would also like to thank the Cape Peninsula University of Technology, and the department of Information Technology for providing a conductive environment to undertake my research.

Finally, I would like to express my warmest gratitude to my family and all my friends for making my life rich and joyful. I express my heartfelt thanks to my parents for their support, care, and love.

TABLE OF CONTENTS

ABSTRACT i

GLOSSARY iii

ACKNOWLEDGEMENTS v

TABLE OF CONTENTS vi

LIST OF FIGURES ix

LIST OF TABLES xii

LIST OF EQUATIONS xiii

CHAPTER 1
INTRODUCTION 1
- 1.1 Background to the research problem 2
- 1.2 Motivation 7
- 1.3 Statement of the research problem 8
- 1.4 Research questions, sub-questions and objectives 8
  - 1.4.1 Research question statement 8
  - 1.4.2 Research sub-questions and objectives 8
- 1.5 Current status of studies on physical activities used in modern exercise equipment developing and related technologies 10
  - 1.5.1 Physical activity 10
  - 1.5.2 Health-related fitness 11
  - 1.5.3 Health-related exercise equipment 11
  - 1.5.4 Dynamic variable resistance 12
  - 1.5.5 Intelligent exercise equipment 12
- 1.6 Research design 13
- 1.7 Delineation of the research 15
- 1.8 Contribution of the research 16
- 1.9 Project plan 16

CHAPTER 2
LITERATURE REVIEW ON HEALTH AND FITNESS 22
- 2.1 Physical activity 22
  - 2.1.1 Physical activity mode 25
  - 2.1.2 Physical activity intensity 25
  - 2.1.3 Physical activity frequency 26

2.1.4 Physical activity duration 26
2.2 Fitness and health 27
2.2.1 Performance-related fitness 27
2.2.2 Health-related fitness 28
2.3 Exercise 29
2.3.1 Aerobic exercise 30
2.3.2 Anaerobic exercise 32
2.4 Exercise equipment 34
2.4.1 Cardio (aerobic) exercise equipment 34
2.4.2 Strength training (anaerobic) exercise equipment 37
2.5 Intelligent exercise equipment 39
2.6 Fitness organisation 40
2.7 Key concepts and technologies of building intelligent related software 43
2.7.1 Intelligence and intelligent control 44
2.7.2 Computer-controlled 47
2.8 Summary 50

CHAPTER 3
DESIGN METHODS OF A COMPUTER-CONTROLLED PNEUMATIC SYSTEM 51
3.1 The pneumatic system 51
3.1.1 Role of the pneumatic system 52
3.1.2 Components of the pneumatic system 53
3.1.3 Design overview of the pneumatic system 59
3.1.4 Process control pneumatics 66
3.2 Monitoring and control software 72
3.2.1 National instruments LabVIEW 73
3.2.2 Object-oriented design methodology 75
3.3 Summary 80

CHAPTER 4
COMPUTER-CONTROLLED PNEUMATIC EXERCISE EQUIPMENT 81
4.1 Design environment 82
4.1.1 Hardware environment 82
4.1.2 Software environment 89
4.2 Pneumatic mechanical linkage 92
4.2.1 Experiment 1 – one valve open and close another valve 92
4.2.2 Experiment 2 – two valves open 98
4.3 Computer-controlled exercise systems 100
4.3.1 Database design 100
4.3.2 System architecture design 103
4.3.3 System analysis with object-oriented 106
4.3.4 Software features and functionalities 110
4.3.5 System integration 127
4.3.6 Software testing 133

4.4 Summary 140

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS 141
5.1 Conclusions 141
5.2 Recommendations 143
5.3 The future of intelligent exercise machine 147

REFERENCES 151

APPENDICES 166
Appendix A: Interview questions 166
Appendix B-1: Personal observation of the training equipment functionalities 169
Appendix B-2: Personal observation of the training equipment functionalities 170
Appendix C: MPZ setpoint module user manual 171
Appendix D: Proportional pressure regulator type VPPM... user manual 172
Appendix E: MLO-POT-450-LWG displacement transducer data sheet 188
Appendix F: U2B force transducer data sheet 196
Appendix G: Air treatment use manual 200
Appendix H: INA 128 amplifier data sheet 202
Appendix I: OPA 2132 amplifier data sheet 212
Appendix J: National instrument TBX-68 DAQ card data sheet 227

LIST OF FIGURES

Figure 1-1: The components of physical fitness portrayed in the weight lifter, modern dancer, and basketball player (Robergs & Robers, 2000) 3
Figure 1-2: The usability engineering lifecycle (Mayhew, 1999) 14
Figure 1-3: Work schedule 20
Figure 2-1: Key technologies for intelligent control systems - Martin & Hideki (1996) 47
Figure 2-2: Schematic diagram of a computer-controlled system – Björn et al. (2002) 48
Figure 3-1: System Architecture 52
Figure 3-2: DNC-50-450-PPV-A double-acting cylinder 54
Figure 3-3: Double-acting pushes in action 54
Figure 3-4: Double-acting pulls back action 54
Figure 3-5: MPZ setpoint module 55
Figure 3-6: MPZ display and operating elements 55
Figure 3-7: Operating elements and connections of VPPM 56
Figure 3-8: MLO-POT-450-LWG displacement transducer 57
Figure 3-9: U2B force transducer 58
Figure 3-10: MS..-LFR-/LR(B)-..., MS-LF(M)-/LFX-... air treatment 59
Figure 3-11: Simulate exerciser 60
Figure 3-12: Differential pressure control principle 61
Figure 3-13: Simulate exercise equipment 61
Figure 3-14: Response time 63
Figure 3-15: Increase pressure on one side 64
Figure 3-16: Pressure vs. response time 65
Figure 3-17: Increase on one side and decrease on other side 65
Figure 3-18: 40 bars force applied on both side working cylinder 65
Figure 3-19: Intake valve 66
Figure 3-20: Exhaust valve 66
Figure 3-21: Closed loop control 67
Figure 3-22: System responses 68
Figure 3-23: Block diagram of a PID controller 69
Figure 3-24: Modified closed loop control 72
Figure 4-1: Diagram of design environment 82
Figure 4-2: Interface of PXI modular instrumentation 84
Figure 4-3: Pneumatic rig 85
Figure 4-4: Instrument amplifier 87
Figure 4-5: Block diagram of instrument amplifier 87
Figure 4-6: Block diagram of INA 128 88
Figure 4-7: Single, dual, and quad versions of OPA 2132 89
Figure 4-8: A simple LabVIEW VI example – front panel 90
Figure 4-9: A simple LabVIEW VI example – block diagram 91

Figure 4-10: Controls palette 91
Figure 4-11: Functions palette.......... 91
Figure 4-12: Experiment 1 – valve 1 & valve 4 open.......... 93
Figure 4-13: Experiment 1 – valve 2 & valve 3 open.......... 94
Figure 4-14: Experiment 1 – block diagram.......... 94
Figure 4-15: National Instrument TBX-68 DAQ Card 95
Figure 4-16: TBX-68 – I/O connector.......... 96
Figure 4-17: TBX-68 – I/O of experiment 1 & 2.......... 96
Figure 4-18: Pneumatic rig – signal control unit.......... 96
Figure 4-19: Block diagram of signal control unit 97
Figure 4-20: Wires connection diagrams.......... 98
Figure 4-21: Experiment 2 – both sides valve open 99
Figure 4-22: Experiment 2 – block diagram.......... 99
Figure 4-23: Related data tables.......... 102
Figure 4-24: Macro cross-functional diagram 104
Figure 4-25: Diagram of system functionality 105
Figure 4-26: Class diagram – FX control.......... 107
Figure 4-27: Class diagram – Exercise Motion control.......... 107
Figure 4-28: Class diagram – Smart card control.......... 107
Figure 4-29: Class diagram – Heart-rate control.......... 107
Figure 4-30: Class diagram – Exercise data recording control 107
Figure 4-31: Class diagram – Fail safe control.......... 107
Figure 4-32: Class diagram – Data warehouse control 108
Figure 4-33: State diagram – Exercise motion control 108
Figure 4-34: Sequence diagrams – Heart-Rate control.......... 110
Figure 4-35: Collaboration diagrams – Heart-Rate control 110
Figure 4-36: FX control – Define FX profiles 112
Figure 4-37: Lift exercise – forward 112
Figure 4-38: Lift exercise – backward.......... 112
Figure 4-39: One of lift exercise FX profiles 113
Figure 4-40: Spring exercise.......... 113
Figure 4-41: One of spring exercise FX profiles.......... 114
Figure 4-42: FX profile for aerobic exercise 114
Figure 4-43: Actual force outputs.......... 115
Figure 4-44: State diagram – FX control.......... 115
Figure 4-45: Sequence diagram – FX control.......... 115
Figure 4-46: Collaboration diagram – FX control 116
Figure 4-47:LabVIEW spreadsheets – Load programs.......... 116
Figure 4-48: Exercise motion status 117
Figure 4-49: State diagram – Exercise motion status.......... 118
Figure 4-50: Sequence diagram – Exercise motion status.......... 118
Figure 4-51: Collaboration diagram – Exercise motion status 118
Figure 4-52: State diagram – Smart card control 119
Figure 4-53: Sequence diagram – Smart card control 119

Figure 4-54: Collaboration diagram – Smart card control 120
Figure 4-55: Smart card control – User administration 120
Figure 4-56: Heart-Rate control 121
Figure 4-57: State diagram – Heart-rate control 122
Figure 4-58: Exercise data recording control 123
Figure 4-59: Exercise data sampling 123
Figure 4-60: State diagram – Exercise data recording control 123
Figure 4-61: Sequence diagram – Exercise data recording control 123
Figure 4-62: Collaboration diagram – Exercise data recording control 124
Figure 4-63: The general scheme for fail-safe systems (Dobiáš, 2005) 124
Figure 4-64: Fail-safe design 126
Figure 4-65: State diagram – Array updates and database control 126
Figure 4-66: System integration inputs and results (GSAM, n.d.) 127
Figure 4-67: System integration planning (GSAM, n.d.) 128
Figure 4-68: System integration process (GSAM, n.d.) 129
Figure 4-69: Iterative, progressive nature of integration (GSAM, n.d.) 130
Figure 4-70: Iterative, progressive nature of integration in application 130
Figure 4-71: Interfaces between system parts and between systems (GSAM, n.d.) 131
Figure 4-72: Integrated system interface between subsystems 131
Figure 4-73: Integrated system GUI 132
Figure 4-74: Testing process 134

LIST OF TABLES

Table 1-1: Specific works 17
Table 4-1: Exerciser details 100
Table 4-2: FX profile 101
Table 4-3: Exercise data record 101
Table 4-4: Heart-rate 102

LIST OF EQUATIONS

Equation 3-1 62
Equation 3-2 62
Equation 3-3 69
Equation 3-4 70
Equation 3-5 71
Equation 4-1 86
Equation 4-2 86

CHAPTER 1
INTRODUCTION

This research aims at designing and implementing a computer-controlled pneumatic device to replace deadweight in standard exercise equipment. The functioning of this exercise equipment is based on a force-displacement (FX) relationship. A counter force (F) is presented by the equipment against the exerciser's effort. In deadweight-based equipment, the weight (force) at which the exercise is performed can be set. For a given setting, the weight will remain constant with respect to displacement (X) of the point of application of the exercise, that is, *F(X) = constant*.

In standard deadweight-based equipment, the weights generally can be changed only when the equipment is inactive. This research presents an approach where the "weights" *of the exercise equipment can be changed dynamically in exercise*, that is, *F(X) = variable*.

In this research, the deadweights will be replaced by (a) pneumatic cylinder/s and directional control valves, which will allow the FX relationship to by dynamically varied under computer control. The computer control will be implemented on a "National Instruments PXI" computer featuring Data Acquisition and Control (DAQAC) capacity, and the software will be implemented using "LabVIEW 7.0".

The *software implementation* will feature fail-safe design approaches to safeguard both human and machine. The software will also feature performance monitoring of both the human and the machine.

The primary aim of the research is to replicate and enhance the functionality, performance, and sensation of deadweight-based equipment. A further aim is to investigate the feasibility of designing a compact retrofit-able pneumatic unit to replace the deadweights of existing standard exercise equipment.

Although this research also explores innovation of the mechanics of exercise equipment, it is essentially the development of the control and monitoring algorithms and its implementation in software that is at the heart of the research. The control algorithms will feature state-of-the-art software-based PID control.

(Note: In spring-based exercise equipment, the FX relationship could be represented by $F(X) = kX$. In damper-based exercise equipment, the FX relationship could be represented by $F(X) = k\, dX/dt$).

1.1 Background to the research problem

According to Wittenmark, Astrom, and Arzen (2002), computers are today essential for implementing controllers in many different situations. The computers are often used in embedded systems. An embedded system is a built-in computer/microprocessor that is a part of a larger system. Many of these computers implement control functions of different physical processes, for example, vehicles, home electronics, cell phones, and now in exercise equipment.

The increasingly sedentary lifestyle of the past 30 years has contributed to declining health (Alexander, 2006). Consequently, exercise is vital for fitness and maintaining good health maintenance. The term “exercise” needs to be defined. The *Webster's dictionary* (1984) gives three important definitions of “exercise”. The first relates to “regular or repeated use of a faculty or body organ”; the second to “bodily exertion for the sake of developing and maintaining physical fitness”; and the third to “something performed or practiced in order to develop, improve, or display a specific power or skill”. Another definition is given by The New Encyclopedia Britannica (Micropaedia Volume 4, 2005) which states that “exercise is the training of the body to improve its function and enhance its fitness." In terms of the above definitions, "exercise" can, therefore, be used to denote activity that is performed for the purpose of improving, maintaining, or expressing a particular type of physical fitness.

Rebecca (2005) categorises exercises into three types, depending on the overall effect they have on the human body. According to Rebecca, the first type of exercise is "flexibility exercises such as stretching that improve the range of motion of muscles and joints"; the second is "aerobic exercises such as walking and running that focus on improving the cardiovascular endurance"; and the third type is "anaerobic exercises such as weight training, functional training or sprinting that increase the short-term muscle strength". Figure 1-1, shows examples of these three types of exercises.

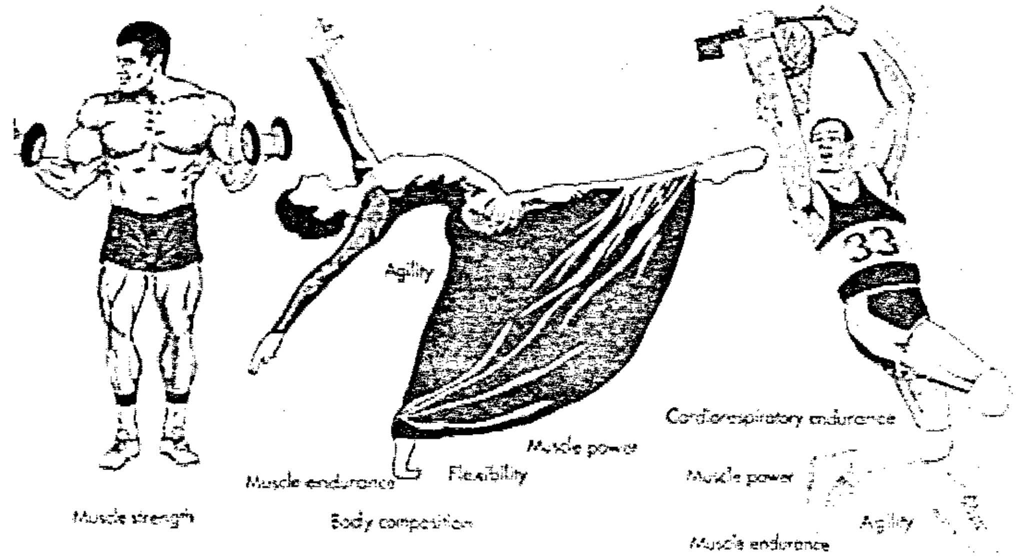

Agility
Cardiorespiratory endurance
Muscle power
Muscle endurance
Flexibility
Muscle power
Muscle strength
Body composition
Agility
Muscle endurance

Figure 1-1: The components of physical fitness portrayed in the weight lifter, modern dancer, and basketball player
Source: Robergs & Robers (2000)

The weight lifter is doing muscle strength training in order to improve the capacity of muscles to generate force and make the muscles tone; the modern dancer is performing flexibility training that enables the ability to maximise joint range of motion, and the basketball player is engaged in aerobic exercise to improve his cardio-respiratory endurance, increase the capacity of the lungs to exchange gases, and the heart and blood vessels to circulate blood around the body.

More people are committed to, and are undergoing exercise sessions today, for many health-related benefits. Exercise can lower our blood glucose, blood pressure, and cholesterol; it also reduces our risk for heart disease and stroke, relieves stress, and strengthens our heart, muscles, and bones. In addition, regular activity helps insulin work better, improves our blood circulation, and keeps our joints flexible. Furthermore, if we are trying to lose weight, a combination of physical activity can help us reach our target weight and maintain it (American Diabetes Association, 2006). To this end, researchers indicate that individuals should perform exercises continuously for 15 minutes up to an hour, 3 to 5 times a week (World Book A Volume 1, 2006).

As it has become well known, exercise gyms and clubs have grown in popularity over the last decade, largely because of increasing awareness and desire for more expert exercise environment and the need to communicate with other exercisers. In addition, exercisers are no longer only focusing on exercise processes, but are also interested in the relevance and quality of various types of exercises. For this purpose, many exercise equipment have been produced to enhance the quality of exercise processes for improved outcomes. Exercise equipment fall into two categories based on the type of exercise provided: cardiovascular or strength training (Wisegeek, n.d.; Standhousehotel, n.d.).

Cardiovascular exercise helps to increase heart health and to burn fat by raising the heart rate. Cardiovascular exercise equipments include stationary bikes, treadmills, elliptical trainers, and stair climbers (Wisegeek, n.d.; Standhousehotel, n.d.). Most of these exercise equipment include a display screen which tracks our heart rate and provides options for customising our workout, the amount of miles or kilometres we have travelled and our total calories burned (Wisegeek, n.d.; Standhousehotel, n.d.).

Strength training helps to build muscular strength and to maintain the results of cardio exercise (Wisegeek, n.d.; Standhousehotel, n.d.). Exercise equipment for strength training is more varied. One of the more common types of exercise equipment is the weight type which uses weights to provide the necessary resistance. This type of equipment has a stack of incremental weights attached to a pulley which we can lift by pulling or pushing other parts of the machine (Wisegeek, n.d.). In addition, this weight equipment has largely been used in most gyms and clubs because of the ease of use, and low cost. While there are numerous benefits derived from the use of the deadweight equipment, they are not without disadvantages. They are cumbersome to move since they are generally associated with a frame and bench assembly and the weights have to be moved when the equipment is moved (Cook & Gerry, 1989). They may cause injury to inexperienced users since the weights may be accidently dropped suddenly. Furthermore, when weights are lifted, an inertia of movement is created which tends to provide unevenness in the operating resistance during the exercising process (Cook & Gerry, 1989).

To overcome these disadvantages, various hydraulic systems have been developed. Hydraulic equipment was first developed for the Henley Corporation in the 70's, and are becoming an increasingly popular form of exercise (Wikipedia, n.d.). Unlike deadweight type equipment, the resistance provided by hydraulic exercise equipment depends on the force exerted by the user (Beyondmoseying, n.d.). The fundamental principle of hydraulic equipment is based on fluid dynamics. Force is applied at one point and transmitted to another point using an incompressible fluid (Wikipedia, n.d.). Hydraulic exercise equipment comes with a combination of various pieces. Circuit training hydraulic exercise systems, helps to tune the body into perfect shape by exercising all the parts of the body (Hydraulic-equipment-manufactures, n.d.). The versatile exercise system appeals to all groups of exercisers, and adapts well to any fitness level and operates (Hydraulic-equipment-manufactures, n.d.). Even though hydraulic exercise equipment is better and more convenient than weight type equipment, their disadvantages are apparent when used. Most hydraulic equipments use a frame or bench assembly to which the apparatus is mounted. As a result, the equipment is not easily transportable (Cook and Gerry, 1989). Furthermore, this equipment has the disadvantage of requiring somewhat complicated setup procedures before a person can exercise a particular muscle group (Cook and Gerry, 1989). This is a problem for physical therapists who want to have equipment which is easily transportable from the office to a patient's home and which can be easily used by the patient without the necessity of providing expensive accessory equipment (Cook and Gerry, 1989).

To overcome the disadvantages of both deadweight and hydraulic equipment, pneumatic systems have been developed. Pneumatic equipments generate and use compressed air to provide necessary resistance. Compared with pneumatic equipment, the hydraulic system is a hard system since fluid is not compressible. A pneumatic system is a much softer system since air is compressible to a certain degree (Rqriley, n.d.). The advantages of using compressed air to provide resistance in exercise equipment have been known for years. During the 80's and 90's pneumatic equipments were adopted by many upscale commercial fitness centres in order to provide their customers the finest equipment available (Rqriley, n.d.). With pneumatic exercise equipment, exercisers future use compressed air to open the way for dynamically adjustable resistance; smooth and silent operation; with no adverse effect of inertia (Rqriley, n.d.).

Whether weight type equipment, hydraulic equipment, or current pneumatic equipment, they all cannot absolutely satisfy every exerciser's desires and requests. Today, exercisers pay more and more attention to exercise and health status data, made possible by the fast development of IT technology. In addition, the fitness industry is lagging behind on incorporating IT into its operations (Alexander, 2006). That is why the need to integrating IT technology into the fitness industry is becoming urgent. In this research, we will present a novel exercise equipment, that is, a computer-controlled pneumatic equipment. This new technology will optimise exercise effectiveness for exercisers. Exercisers will have advanced diagnostic capacity (exercise and health status monitoring), and will capture user data which can be manipulated into meaningful information for use by health and fitness industry stakeholders.

1.2 Motivation

The global Health and Fitness Industry repeatedly indicates the need for optimally-managed exercise with accurate information feedback (Alexander, 2006). Compared to other industries, the fitness industry is lagging behind in incorporating Information Technology into its operations (Alexander, 2006). As the researchers investigated, there are many shortcomings and inconveniences that exist in the current weight type equipment. Exercisers have to adjust the weight physically, and remember all the exercise items without any exercise data and body status feedback (Wang 1, 2006). The current weight type equipment is mostly manually controlled. The capturing and gathering of exercise data is, therefore, difficult (if not impossible) to achieve using the current weight type equipment (Wang 2, 2006). On the other hand, safety is often a problem in current weight type equipment (Deril, 2006). Deril, an experienced exercise instructor at the Virgin Active Gymnasium, points out that although the current weight type equipment have some basic physical protections, they still have highly dangerous characteristics that may not always be obvious. Some inexperienced exercisers, for example, may not often know where the physical protections are and how to use them when they get trouble or injuries, because they do not understand the procedures of how to use equipment before they train, adds Deril (2006). The general conclusion, therefore, is that most of exercisers and athletes hope the fitness industry could supply a multifunctional exercise equipment to help them to concentrate on the exercise without manual adjustment, interruptions and related inconveniences. There is a need for an enhanced secure exercise environment. For this purpose, pneumatic systems that generate and use exercise effectiveness for exercisers. Exercisers will have advanced diagnostic capacity (exercise and health status monitoring), and will capture user data which can be manipulated into meaningful information for use by health and fitness industry stakeholders.

1.2 Motivation

The global Health and Fitness Industry repeatedly indicates the need for optimally-managed exercise with accurate information feedback (Alexander, 2006). Compared to other industries, the fitness industry is lagging behind in incorporating Information Technology into its operations (Alexander, 2006). As the researchers investigated, there are many shortcomings and inconveniences that exist in the current weight type equipment. Exercisers have to adjust the weight physically, and remember all the exercise items without any exercise data and body status feedback (Wang 1, 2006). The current weight type equipment is mostly manually controlled. The capturing and gathering of exercise data is, therefore, difficult (if not impossible) to achieve using the current weight type equipment (Wang 2, 2006). On the other hand, safety is often a problem in current weight type equipment (Deril, 2006). Deril, an experienced exercise instructor at the Virgin Active Gymnasium, points out that although the current weight type equipment have some basic physical protections, they still have highly dangerous characteristics that may not always be obvious. Some inexperienced exercisers, for example, may not often know where the physical protections are and how to use them when they get trouble or injuries, because they do not understand the procedures of how to use equipment before they train, adds Deril (2006). The general conclusion, therefore, is that most of exercisers and athletes hope the fitness industry could supply a multifunctional exercise equipment to help them to concentrate on the exercise without manual adjustment, interruptions and related inconveniences. There is a need for an enhanced secure exercise environment. For this purpose, pneumatic systems that generate and use compressed air to produce necessary resistance are developed in the market. This research aims to develop a novel exercise equipment that uses a pneumatic unit to replace deadweight / weight stack in standard deadweight equipment in order to enhance exercisers to meet their fitness objectives more seamlessly. The novelty of this research lies in the exercises configured for individuals and without the need for physically adjusting weights. Exercisers will have advanced diagnostic capacity for their body status, and will also capture user data for future exercise plan, maximally satisfy all different exercisers' needs and optimise exercise effectiveness for exercisers.

1.3 Statement of the research problem

The lack of dynamic in-exercise load variation capability will result in the poor efficient and unsafe in deadweight-based standard exercise equipment.

1.4 Research questions, sub-questions and objectives

1.4.1 Research question statement

The main research question, the research addresses is:
Can the dynamic in-exercise performance of standard deadweight-based exercise equipment be enhanced by using dynamic load variation capability in replacing the deadweights with a computer-controlled pneumatic actuator?

1.4.2 Research sub-questions and objectives

Four sub-questions need to be answered to address the main research question. There are:

- **Sub question 1**

What deadweight-based equipment or environments are available?

Proposed Research Method: Literature analysis

Objective: To understand the categories of deadweight-based equipment, the environment and composition of deadweight-based equipment.

- **Sub question 2**

  What deadweight-based equipment exists for aerobic exercise?

  Proposed Research Method: Literature analysis

  Objective: To know few or none deadweight-based equipment cannot only train anaerobic exercise, but also train aerobic exercise in the current market.

- ***Sub question* 3**

  What is exercise optimisation?

  Proposed Research Method: Literature analysis

  Objective: To understand how to make exercise more effective based on physical capability (i.e. heart rate) to best achieve exercise goals for different group of exercisers.

- **Sub question 4**

  Why do we need to, and how do we manage, exercise effectively?

  Proposed Research Method: Literature analysis, Interviews, Case study

  Objective: Exercise load (and number of repetitions, and repetition rate) is based on exercise goal, fitness profile of the exerciser, and the (in-exercise) heart rate of the exerciser.

1.5 Current status of studies on physical activities used in modern exercise equipment developing and related technologies

This literature review starts by discussing physical activity in order to illuminate why health outcomes are becoming more and more emphasised in the fitness field. Afterwards, health-related exercise equipment are introduced to show us the process of developing exercise equipment, from simple mechanical-based exercise equipment to complex computer-controlled exercise equipment. It will facilitate the understanding of why exercise equipment developed so fast during the recent decades. After that, the concept of dynamic variable resistance (DVR) is presented to show how exercise load can be changed without any physical adjustments but based on health status (i.e. heart rate). Finally, some design issues of intelligent exercise equipment are investigated that must be considered.

1.5.1 Physical activity

Movement is an essential aspect of life for most animal species, but over the course of civilisation, movement has become a less critical component of everyday life for humans (Torun, 1984). Advances in modern technology have made it possible to live, work, and even play without much effort or movement (Torun, 1984). While these developments have contributed to the ease and perhaps the quality of life, they have been the scourge of our public health system (Torun, 1984). It has become increasingly evident that the movement made possible by the body is also essential for its health and maintenance (Torun, 1984). Corbin, Lindsey, and Welk (2001) states that a number of diseases are directly associated with physical inactivity and can be viewed as "hypo-kinetic" conditions. With respect to public health, Powell and Blair (1994) estimated that sedentary living habits account for a third of the deaths from coronary heart disease, colon cancer, and diabetes. McGinnis and Foege (1993) also reported that physical inactivity is second only to smoking as a leading cause of preventable mortality. These statistics are often cited to indicate the overall impact of physical inactivity on society. Although the absolute impact on public health can be debated, there can be no denying the overwhelming evidence documenting the critical importance of regular physical activity for optimal health (Torun, 1984).

1.5.2 Health-related fitness

Health-related fitness refers to the state of physical and physiological characteristics that define the risk levels for the premature development of diseases or morbid conditions presenting a relationship with a sedentary mode of life (Bouchard & Shepard, 1993). Important determinants of health-related fitness include such factors as body mass for height, body composition, subcutaneous fat distribution, abdominal visceral fat, bone density, strength and endurance of the abdominal and dorso-lumbar musculature, heart and lung functions, blood pressure, maximal aerobic power and capacity, glucose and insulin metabolism, blood lipid and lipoprotein profile, and the ratio of lipid to carbohydrate oxidised in a variety of situations (Bouchard, Shephard, & Stephens, 1994). A favourable profile for these various factors presents a clear advantage in terms of health outcomes as assessed by morbidity and mortality statistics (Bouchard, Shephard, & Stephens, 1992). The components of health-related fitness are numerous and are determined by several variables, including cardiovascular fitness, strength, flexibility, and muscular endurance.

1.5.3 Health-related exercise equipment

Current exercise equipment imposes fixed-trajectory exercise on users with the dominance of static equipment designs (Alexander, 2006). Some advancements include the mechanisation of resistance systems, and visual-interfaces recording exercise activities on computerised systems (Alexander, 2006). Many exercise equipment developed are tending to health-related characters, especially in cardio exercise equipment, such as stationary bikes, treadmills, elliptical trainers, and stair climbers. This type of equipment always includes a display screen which tracks our heart rate and provides options for customising our workout.

1.5.4 Dynamic variable resistance

According to Ariel (1983), in conventional resistive exercises, loads are moved through a range of motions. The muscular force and the load are not constant because of the modifying effects of the lever system throughout the range of motion. In an exercise such as the bench press, for example, the resistance achieves maximum effect at a specific point, and becomes less anywhere above or below that point. This illustrates a phenomenon that the muscle works at maximum potential during a very small range of motion throughout an exercise stroke. To facilitate maximum muscular involvement, we must vary the resistance. In some exercises, this resistance must be varied as much as 100% in order to maintain the maximum moment of force. The resistance must be varied according to biomechanical data obtained under dynamic conditions.

1.5.5 Intelligent exercise equipment

In exercise equipment, the user has to determine the amount of resistance and the number of repetitions desired. The reason the user makes the choices is, that the exercise equipment itself is inherently incapable of any intellectual participation. However, with the advent of computers, it is possible to design exercise equipment with artificial intelligence enabling the computerised machine to select the best exercise method based on each individual user. Thus, the user need not be an expert in any biologic, physiologic, or exercise area, since the exercise equipment is programmed with information from many scientific fields, thereby, correctly benefiting the different individual users.

1.6 Research design

The key purpose of the research is based on case study design and implement in order to face a real-world problem. It includes a bi-directional pneumatic cylinder fastened to the points of application on a fitness equipment. An air accumulator receives compressed air from the air cylinder and to give a gradually increased air resistance to the points of application, and a pressure control system to control the pressure of the air accumulator by a programmable control unit. The FX control unit will replace the weight stacks of standard deadweight-based exercise equipment thereby greatly enhancing its functionality in respect of exercise optimisation and exercise data gathering. Fail-safe mechanics is provided to safeguard both human and machine.

Parts of the research will be based on the literature analysis, and personal interviews with role players who are working in the fitness industry. Literature analysis is used to develop understanding the structures, algorithms, and elements of research areas. Interviews are used to explore the enlightenment and empirical information in the fields of research and also will be the resources for further study.

The research will address user requirements in combination with an analysis of the existing problems of dynamic variable resistance ability in exercising based on health-related status. The research will be employed and implemented into the project design with an integrated Object-oriented method. The design will base on the usability engineering lifecycle (UEL).

The usability engineering lifecycle is divided into three phases each one involving a set of tasks (Mayhew, 1999). The lifecycle is illustrated in Figure 1-2.

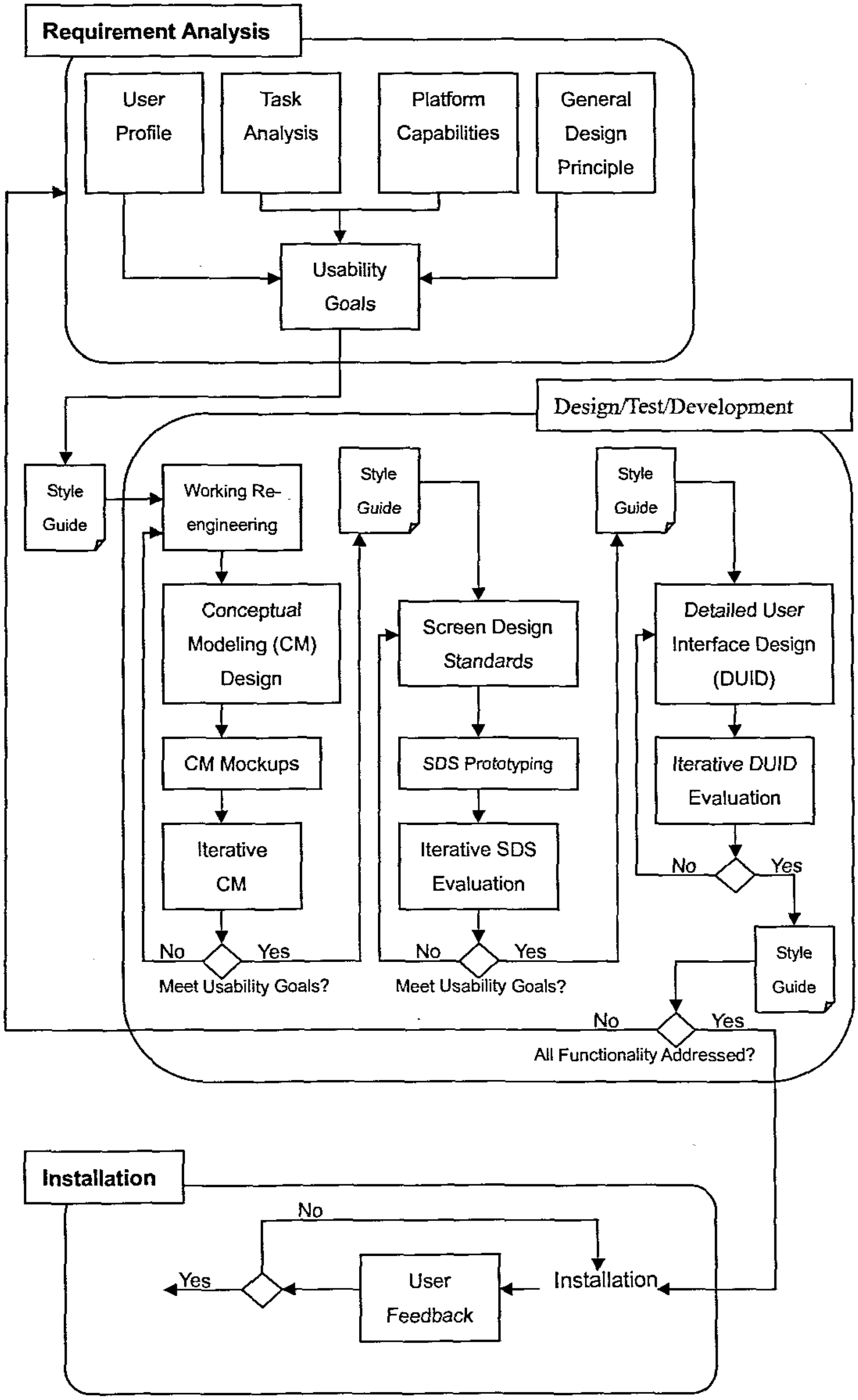

Requirement Analysis
User Profile
Task Analysis
Platform Capabilities
General Design Principle
Usability Goals
Design/Test/Development
Style Guide
Working Re-engineering
Style Guide
Style Guide
Conceptual Modeling (CM) Design
Screen Design Standards
Detailed User Interface Design (DUID)
CM Mockups
SDS Prototyping
Iterative DUID Evaluation
Iterative CM
Iterative SDS Evaluation
No
Yes
No
Yes
No
Yes
Meet Usability Goals?
Meet Usability Goals?
Style Guide
No
Yes
All Functionality Addressed?
Installation
No
Yes
User Feedback
Installation

Figure 1-2: The usability engineering lifecycle

Source: Mayhew (1999)

Phase one is requirements analysis and involves five tasks. Phase two is design/testing/development and divided into three levels each one dealing with different design issues. Level 1 is concerned with high-level design issues and contains four tasks; level 2, the design/testing/development phase involves four additional tasks; finally, level 3 of the design/testing/development phase involves two tasks. The final phase of the UEL is installation. It involves only one task corresponding to user feedback.

The UEL approach also provides guidelines for integration with Object-Oriented Software Engineering (OOSE) (Mayhew, 1999). The integration is based on coupling OOSE models and workflows with UEL tasks (Jacobson, 1992). Therefore, the user profile and contextual task analysis should parallel the development of the requirements model in OOSE. The work re-engineering task corresponds roughly with the development of the analysis model. Finally, the actual design starts with the conceptual model design in order to enhance the design model.

1.7 Delineation of the research

The acknowledge data which concerns to define the optimal exercise are collected through personal interviews (gym consultants, original concepts and product developer of the project), from exercise magazines, and internet resources. Only existing proven technologies, examples, and peer-reviewed journals will be considered, such as books, journals, internet publications, emails, and forums.

Because this research is based in the IT area, most work will be from the IT perspective, that is, the research is only devoted to software development and implementation, but will not be concerned with any new powerful evidence about health-related exercises. Furthermore, the setting up of the mechanical devices is not part of the research. Corporate companies are going to support it. On the other hand, the components used in this testing model machine will not be used in the actual physical product because their size is much bigger than those used in the product. The current research, only focuses on the feasibility of the concepts, but does not consider the best and smallest components available in the market because of limited funds. To pursue miniaturisation of components and use of suitable technology instead of using computer for a PC with the PXI LabVIEW that needs to be incorporated or integrated into a sort of micro chip scenario, so those is the kind of levels of issues that need to be explored in future studies.

1.8 Contribution of the research

This research will be geared to related industry such as exercise machine manipulation and design to give exercisers more useful, efficient, and safe exercise environment, so that exercisers meet their fitness objectives more seamlessly. In this research, medical specialists and fitness consultants will, via technology inputs, define the dynamics of exercise to help some special patients to recovery. The data statistics of machine users will be remotely stored for manipulation by various third parties.

1.9 Project plan

The general plan for this research can be divided into six phases, as follows:

1. Establishment and clarification
2. Building up the computer laboratory
3. Design and implementation
4. Testing
5. Reporting
6. Publishing

In the establishment and clarification phase, specific interviews help to work out the existing real-world problem, abundant books, articles, and other reading materials (such as internet publications and journals) are considered in order to clarify the solutions to problem. This part was done in 2006.

In the second phase involved setting up of the computer lab, installation of software and mechanical devices. This part was done in 2006.

The third phase consisted mostly of project activities, including design, coding, and implementation of software development.

Three testing methods will be used in the testing phase, namely unit test, integration test, and system test.

The specific tasks are shown in **Table 1-1**:

Phases	Tasks	Deliverables	Resources
Establishment & Clarification	1. Problem Statement 2. Feasibility Analysis 3. Data Gathering 4. Assumptive Solution 5. Reports	A solution idea is proposed in order to solve the current problem.	Books, articles, journals, internet publications, and related reading materials; interviews
Building up the computer lab	1. Computer set up 2. Purchasing software and related mechanical devices 3. Software installation 4. Purchasing exercise simulators	Computer lab is build up, includes software and hardware design environments.	Related equipments manuals and specifications; Technical supports from the related companies.

	5. Reports		
Design	1. Database design 2. Object relationship model 3. High level event models 4. Report progress 5. Prototype user interface 6. Prototype event dialogues 7. Preliminary design review 8. Report progress 9. System architecture 10. Design reusable components 11. Design unique components 12. Communications prototype 13. Critical design review 14. Report progress	A prototype control system has been designed.	Programming design books; Internet source codes; Internet forums; Technical supports from the related companies.

	15. Code reusable modules 16. Code unique components 17. Report progress		
Testing	1. Unit test reusables 2. Unit test uniques 3. Report progress 4. Integration test 5. System test 6. Report progress	The specific test plans are defined.	Testing methods and testing plans
Implementation	1. Debugs 2. Report progress 3. Regression test 4. Report progress 5. Write user manual 6. System implement 7. Report progress	The user manual and specification are defined.	User manual and specification
Reporting	Reporting is existed during the whole process.	Phases reports	Status of phases tasks
Publishing	System training	Implemented system	User manual and specification

Figure 1-3 is shown a draft work schedule of the whole project.

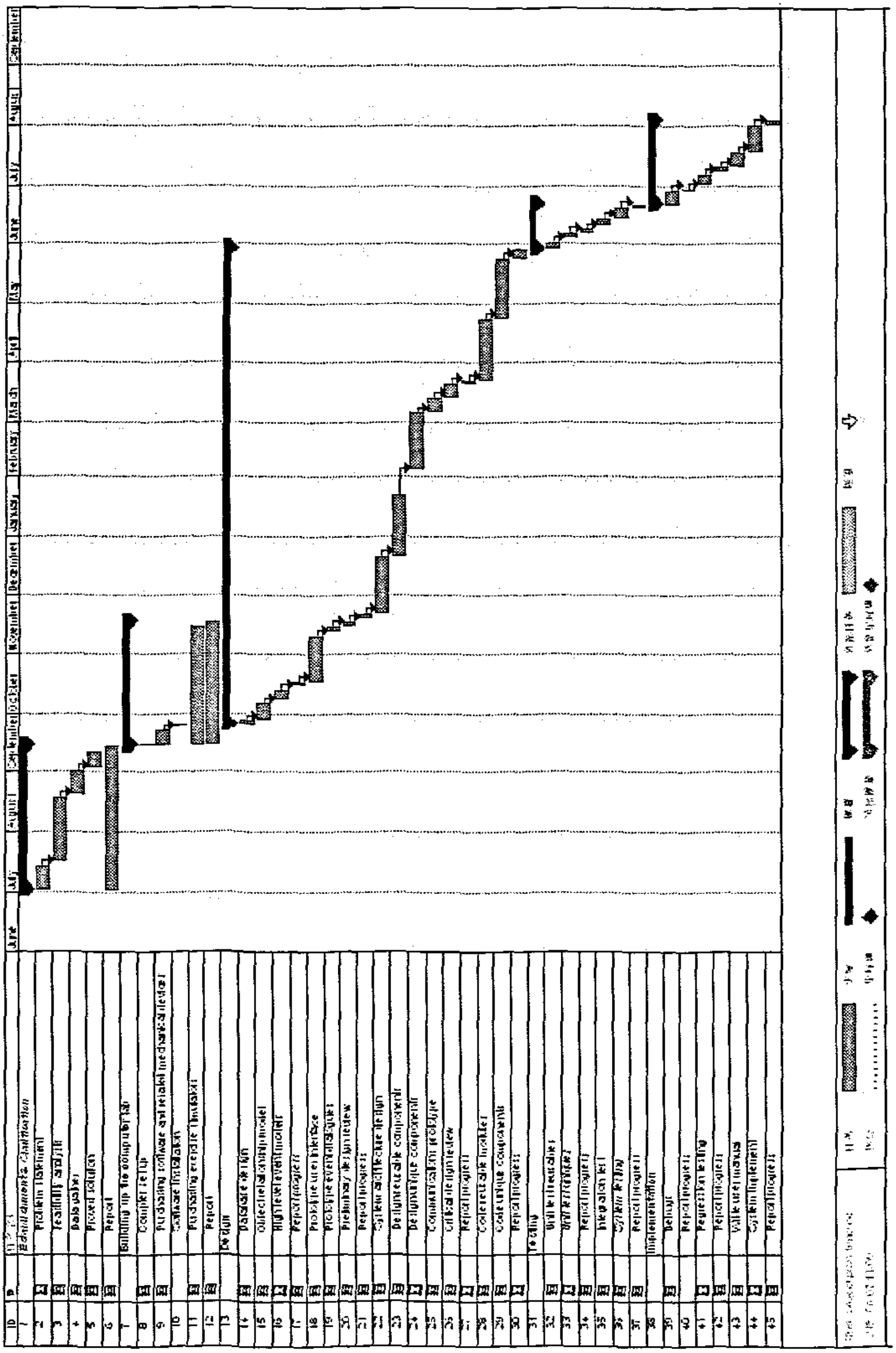


Figure 1-3: Work schedule

The actual times will depend on how the funding alliance is built up. Since most tasks are spread across the life of the project, presenting a standard chart of timelines would add little value to this document. The actual times for project execution are

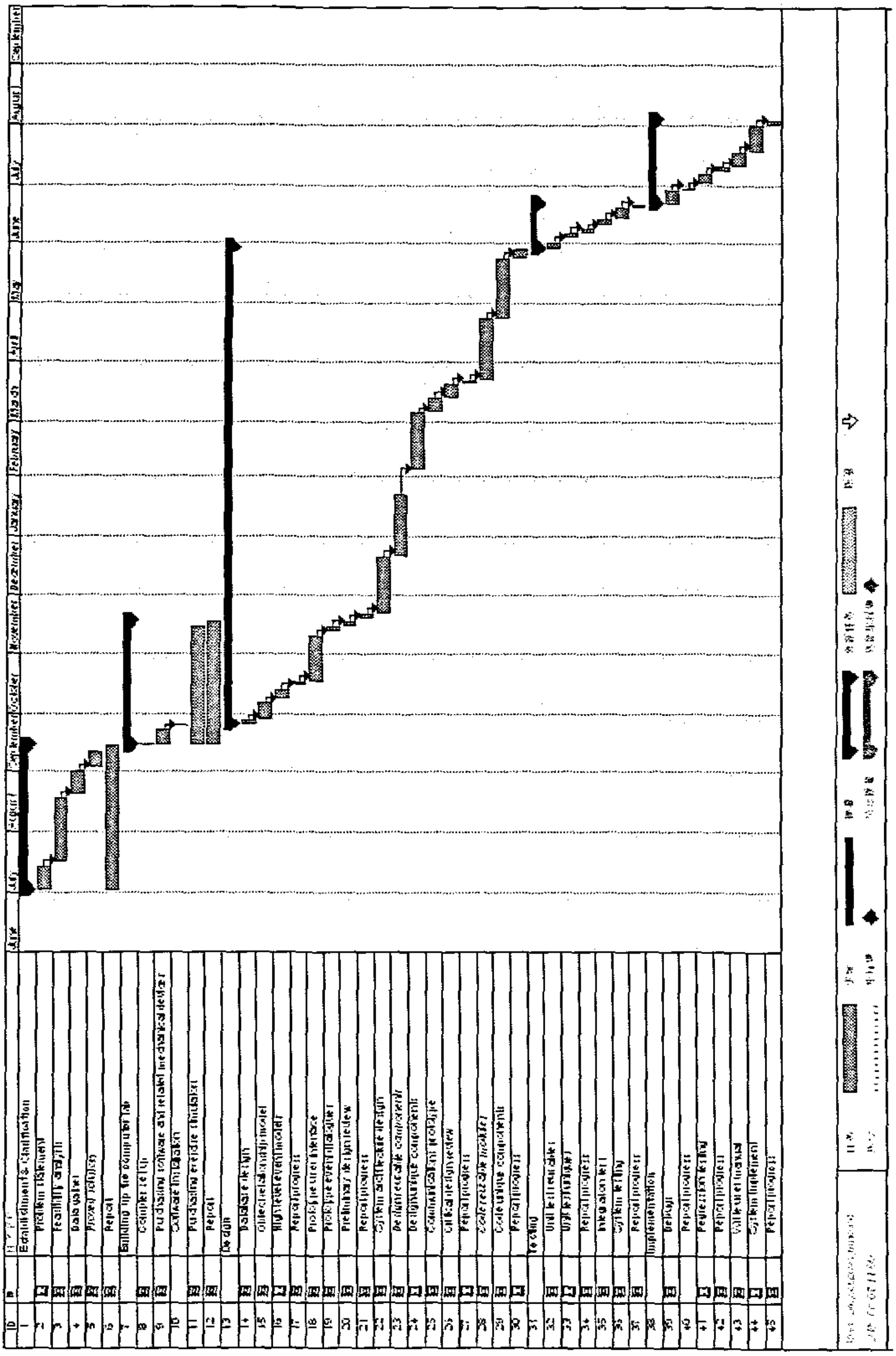


Figure 1-3: Work schedule

The actual times will depend on how the funding alliance is built up. Since most tasks are spread across the life of the project, presenting a standard chart of timelines would add little value to this document. The actual times for project execution are based on two years framework, assuming full funding. Because different sponsors are funding different aspects of the project, the timelines will need to have flexibility depending on which aspects are prepared to fund.

CHAPTER 2

LITERATURE REVIEW ON HEALTH AND FITNESS

This chapter starts by describing the relationships between physical activity, health-related fitness, and health. This section specifies that physical activity can influence fitness which, in turn, may modify the level of physical activity. For instance, with increasing fitness, people tend to become more active while the fittest individuals tend to be the most active. This section also specifies that fitness is related to health in a reciprocal manner. That is, fitness not only influences health, but health status also influences both physical activity level and fitness level. The second section presents health-related equipment which is used to maintain and promote fitness ability. Following the fast developed IT areas, the build-in computer system became popular using in all manufacturing, of course includes fitness industry, thereby, intelligent exercise machine is developed to provide appropriate responses in order to obtain optimal exercise. Finally, the design issues of developing intelligent machine will be concerned in this chapter.

2.1 Physical activity

In the 2000 World Health Report, the World Health Organisation (WHO) recognised the ten leading killer diseases worldwide (WHO, 2000). Coronary heart disease was ranked number one, killing 7.09 million people. Cancers followed with 7.06 million deaths. The remaining top worldwide killer diseases are cerebrovascular disease, acute lower respiratory infection, tuberculosis, chronic obstructive pulmonary disease, diarrhea, HIV/AIDS, and malaria. However, a number of these diseases can be reduced and even prevented by living a healthy lifestyle based on regular physical activity, exercise and sports.

U.S. Department of Health and Human Services (USDHHS) gives two definitions of physical activity. The first, any form of exercise or movement, may include planned activity such as walking, running, basketball, or other sports; it may also include other daily activities such as household chores, yard work, walking the dog (2002). The second definition is any bodily movement produced by skeletal muscles that result in an expenditure of energy (1996).

Physical activity which is an important public health issue has received a lot of attention in recent years. In response to the numerous harmful effects of today's sedentary lifestyles, governmental as well as non-governmental organisations have recognised the need to increase physical activity across the whole population (Brownson, Baker, Housemann, Brennan, & Bacak, 2001). Indeed, physical inactivity is recognised as one of the most important population health risk factors. Its role as a risk factor is at least as significant as hypertension or high cholesterol in contributing to cardiovascular disease (Armstrong, Bauman, & Joanne, 2000). On the contrary, physical activity protects against several cancers, reduces the risk of diabetes, improves mental health and may reduce the risk of falls and injuries in the elderly (Armstrong *et al.* 2000). Regular physical activity, fitness, and exercise are critically important for the health and wellbeing of people of all ages. Research has demonstrated that virtually all individuals can benefit from regular physical activity, whether they participate in vigorous exercise or some type of moderate health-enhancing physical activity. Even among frail and very old adults, mobility and functioning can be improved through physical activity (Butler, Davis, & Lewis, 1998). Despite the well-known benefits of physical activity, most adults and many children lead a relatively sedentary lifestyle and are not active enough to achieve these health benefits. In 1996, the Department of Health (DoH) in England issued a strategy statement on physical activity, outlined a new policy promoting 30 minutes of moderate intensity physical activity on at least five days of the week and for those already taking some vigorous physical activity, three periods per week of vigorous intensity physical activity of 20 minutes each (DoH, 1996). Unfortunately, in 1998 statistics showed that just 40% of men and 26% of women were physically active at either of these levels (DoH, 2000).

Keeping regular physical activity, you can get many benefits for your body health. People who participate in moderate to vigorous levels of physical activity and / or have high level of cardiorespiratory fitness have a lower mortality rate than those with a sedentary lifestyle or low cardiorespiratory fitness (Armstrong *et al.*, 2000). The effects of physical activity on reducing all-cause mortality are strong and consistent across studies and populations (Blair *et al.,* 1996; Lee & Paffenbarger, 1997; Villeneuve, Morrison, Craig, & Schaubel, 1998). Even among diverse elderly populations in studies in Israel and in Holland, relationships between regular physical activity and reduced risks of death are consistently demonstrated (Bijnen, Feskens, Caspersen, Nagelkerke, Mosterd, & Kromhout, 1999; Stessman, Maaravi, & Cohen, 2000). In 1996, the USDHHS also pointed out that regular physical activity improves health in many ways – regular physical activity reduces the risk of dying prematurely from heart disease and other conditions; reduces the risk of developing diabetes; reduces the risk of developing high blood pressure; reduces blood pressure in people who already have high blood pressure; reduces the risk of developing colon and breast cancer; helps to maintain a healthy weight; helps build and maintain healthy bones, muscles, and joints; helps older adults to become stronger and better able to move about without falling; reduces feelings of depression and anxiety; and promotes psychological wellbeing.

Exercise is a form of physical activity that is usually performed on a repeated basis over an extended period of time (exercise training) with a specific external objective such as the improvement of fitness, physical performance, or health (Bouchard, Shephard, & Stephens, 1994). American College of Sports Medicine (1990), when prescribed by a physician or exercise specialist, the optimum regimen advised typically covers the recommended mode, intensity, frequency, and duration of such activity.

Although physical activity is recommended for health, selecting an appropriate setup of upper factors is the most important and has to be considered before doing any physical activity. An example of issues surrounding measurement relate to the quantum of activity needed for different health outcomes. For example, the primary mode of physical activity required to prevent cardiovascular disease (that is, moderate intensity regular physical activity) is not the same as that required to prevent falls in the elderly (i.e. weight bearing and strength training activity). In other words, different intensities and duration of activity are needed for different purposes. For example, more vigorous and sustained activity may confer additional benefits for disease prevention, but may be required for weight loss or improvements to lipid profiles (Armstrong *et al.*, 2000).

2.1.1 Physical activity mode

This mode of exercise covers not only the type of activity to be performed (that is, fast walking, jogging, or swimming), but also the temporal pattern of activity, recommended (that is, continuous or intermittent activity), with a detailed specification of the duration of exercise and rest periods in the case of intermittent activity bouts (Bouchard, 1994). The issues of intensity, frequency, and duration of exercise are, therefore, considered important to prescription and activity assessment.

2.1.2 Physical activity intensity

USDHHS (1996) described intensity as the self-perceived and self-reported intensity at which a respondent participated in physical activity. Generally, to obtain health benefit, physical activity at a moderate intensity is required. For example, brisk walking is a moderate intensity physical activity. Participation in vigorous intensity physical activities confers even greater health benefits than does participation in more moderate activity. The primary measurement goal is to provide examples within questions of the kinds of activity that reach a sufficient energy expenditure threshold to be of health benefit. This is usually activity that results in energy expenditure of at least three times the resting rate or activities which correspond to at least three metabolic equivalents (METs). Brisk walking and other moderate intensity activities (for example, gentle swimming and social tennis) correspond to around 3-5 METs. More vigorous activities such as aerobics, jogging and competitive tennis correspond to around 7-9 METs (USDHHS, 1996).

2.1.3 Physical activity frequency

Frequency is defined as the number of times the respondent self-reported participating in physical activity within a reporting period (Armstrong *et al.*, 2000). This period of time can be undertaken in a week, or month, or even year.

2.1.4 Physical activity duration

Duration is defined as the length of time spent participating in physical activity. This item is generally reported in minutes or hours, and may be summed to provide an indication of total time participating in physical activity over the reporting period (Armstrong *et al.*, 2000). It is important that only the period of actual physical activity be considered, omitting travel, socialising, and preparations for participation (Shephard, 1977).

From the above it can be summarised that regular physical activity makes important contributions to one's health, sense of wellbeing, and maintenance of a healthy body weight. In contrast, physical fitness is a multi-component of a set of attributes a person has in regard to the person's ability to perform physical activities that require aerobic fitness, endurance, strength, or flexibility and is determined by a combination of regular activity and genetically inherited ability (USDHHS, 1996). Maintenance of good physical fitness enables one to meet the physical demands of work and leisure comfortably (USDA, 2005). People with higher levels of physical fitness are also at lower risk of developing chronic disease.

2.2 Fitness and health

Quality of life is what we all want. Good health helps us achieve a high quality of life. Fitness makes us want to live it every day. The World Health Organisation (1968) defines fitness as "the ability to perform muscular work satisfactorily." In keeping with this definition, fitness implies that the individual has attained those characteristics that permit a good performance of a given physical task in a specified physical, social, and psychological environment (Bouchard *et al.*, 1994). The components of fitness are numerous and are determined by several variables including the individual's pattern and level of habitual activity, diet, and heredity (Bouchard *et al.*, 1994). Fitness is operationalised in present day Western societies with a focus on two goals: performance and health related fitness (Bouchard *et al.*, 1994).

2.2.1 Performance-related fitness

Performance-related fitness refers to those components of fitness that are necessary for optimal work or sport performance (Bouchard, Shephard, Stephens, & McPherson, 1990; Gledhill, 1990; Pate & Shephard, 1989; Pate, 1988). It is defined in terms of the individual's ability in athletic competition, a performance test, or occupational work (Bouchard *et al.*, 1994). Performance-related fitness depends heavily upon motor skills, cardiorespiratory power and capacity, muscular strength, power or endurance, body size, body composition, motivation, and nutritional status (Bouchard *et al.*, 1994). In general, performance-related fitness shows a limited relationship to health (Pate & Shephard, 1989). The next section focuses on health-related fitness which can be achieved through regular physical activity.

2.2.2 Health-related fitness

The theme of health-related fitness is explored, with recognition of its increasing importance for health promotion in schools, the community and commerce (Health Promotion International, 1988). Health-related fitness refers to those components of fitness that are affected favourably or unfavourably by habitual physical activity and relate to health status (Bouchard *et al.*, 1994). Health-related fitness has been defined as a state of being able to perform daily activities with vigour, and traits and capacities that are associated with a low risk of premature development of hypokinetic diseases and conditions (Pate, 1988).

Important determinants of health-related fitness include such factors as body mass for height, body composition, subcutaneous fat distribution, abdominal visceral fat, bone density, strength and endurance of the abdominal and dorso-lumbar musculature, heart and lung functions, blood pressure, maximal aerobic power and tolerance to submaximal exercise glucose and insulin metabolism, blood lipid and lipoprotein profile, and the ratio of lipid to carbohydrate oxidised in a variety of situations (Bouchard *et al.*, 1994). A favourable profile for these various factors presents a clear advantage in terms of health outcomes as assessed by morbidity and mortality statistics (Bouchard *et al.*, 1994).

Fitness is best understood in terms of the components that should be taken into consideration for its assessment, and the context in which the concept is operationalised. According to the Toronto model presented by Bouchard *et al.* (1994), the components of health-related fitness are defined as morphological, muscular, motor, cardiorespiratory and metabolic fitness. Morphological fitness refers to body composition and bone strength (Skinner & Oja, 1994). Body composition describes the amount of fat mass and fat free mass and considers also whether body fat is peripherally or abdominally distributed (Howley, 2001). Muscular or musculo-skeletal fitness refers to muscular strength, muscular endurance and flexibility, and motor fitness refers to postular control (Skinner & Oja, 1994). Cardiorespiratory fitness reflects the ability of cardiovascular and respiratory systems to supply oxygen to the working muscles during heavy dynamic exercise (Howley, 2001), and direct measurement of maximal oxygen uptake (VO_{2max}) during a maximal exercise test is regarded as the gold standard for the evaluation of cardiorespiratory fitness. Metabolic fitness refers to carbohydrate and lipid metabolism usually defined by glucose tolerance, insulin sensitivity, lipid profile and the ratio of lipid to carbohydrate oxidised at rest during steady-state exercise (Bouchard *et al.*, 1994). As discussed, exercise is a form of physical activity that is performed to improve fitness, physical performance, and health.

2.3 Exercise

Exercise is an essential part of a healthy lifestyle. Regular exercise helps to maintain fitness and health. Not only does exercise increase energy levels, it also helps to improve general health, circulation and posture. Doing exercise can have a positive impact on health.

Exercises are generally grouped into three types, depending on the overall effect they have on the human body:

- Flexibility exercises such as stretching improves the range of motion of muscles and joints (O'Connor, Crowe, & Spinks, 2006).
- Aerobic exercises such as cycling, walking and running focus on increasing cardiovascular endurance (Wilmore & Knuttgen, 2003).
- Anaerobic exercises such as weight training, functional training or sprinting increases short-term muscle strength (Singh, de Vos, Ross, & Stavrinos, 2005).

Many benefits appear when doing exercise. It is important for maintaining physical fitness and can contribute positively to maintaining a healthy weight; building and maintaining healthy bone density, muscle strength, and joint mobility; promoting physiological wellbeing; reducing surgical risks; and strengthening the immune system (Wikipedia, n.d.).

Frequent and regular aerobic exercise has been shown to help prevent or treat serious and life-threatening chronic conditions. Strength training appears to have continuous energy-burning effects that persist for about 24 hours after the training, though they do not offer the same cardiovascular benefits of aerobic exercises (Wikipedia, n.d.). Exercise can also increase energy and raise one's threshold for pain (Wikipedia, n.d.).

Exercise has been shown to improve cognitive functioning via improvement of hippocampus-dependent spatial learning, and enhancement of synaptic plasticity and neurogenesis (van Praag, & Kempermann, 1999). In addition, exercise has been shown to be neuroprotective in many neurodegenerative and neuromuscular diseases (Grondard, 2005). Exercise is thought to have other beneficial effects related to cognition as it increases levels of nerve growth factors, which support the survival and growth of a number of neuronal cells (McAuley, Kramer, & Colcombe, 2004,). Both aerobic and anaerobic exercise work to increase the mechanical efficiency of the heart by increasing cardiac volume (aerobic exercise), or myocardial thickness (strength training) (Wikipedia, n.d.).

2.3.1 Aerobic exercise

Many people already know that regular aerobic exercise and eating properly contributes to great overall health and wellness. Aerobic exercise includes taking part in physical activities that make the heart and lungs work harder than they do at rest for a continuous period of time, therefore keeping blood oxygenated and flowing smoothly throughout the entire body getting to key components that need to function properly (Vincent, n.d.). Aerobic means 'with oxygen'. It is exercise that is lower in intensity and longer in time. Aerobic metabolism occurs when the body breaks down fat and glucose by combining with oxygen (Betterhealth, n.d.). During intense aerobic exercise, the body uses more oxygen, and breathing and heart rate increase (Betterhealth, n.d.). There are plenty of aerobic exercises to choose from which include, but are not limited to, dancing, skating, skiing, jogging, walking, swimming and any sport that requires physical activity.

Different kinds of aerobic exercises can be performed for varying lengths of time depending on how strenuous the exercise is. People can get aerobic exercise at home, at work, or at school. For example, thirty minutes of walking at a moderate pace is the same as jogging or running for fifteen to twenty minutes (Vincent, n.d.). Stair climbing is also a good aerobic exercise that can be done on a lunch break or at home. With prolonged aerobic exercise, the heart muscles become more efficient and are, therefore, better able to supply blood flow throughout the body. In addition, aerobic exercise can actually open up arteries clogged with cholesterol (Lige, 2002). An increase in heart rate will not only help to improve circulation, but it will also stimulate the lymphatic system to feed and clean cells (Lige, 2002).

The most profound impact of aerobic activity may be on our long-term health. There is a great deal of research that clearly indicates the enormous long-term health benefits related to aerobics. According to the College of Sports Medicine, aerobic exercise helps to decrease coronary disease, blood pressure, the risk of diabetes, osteoporosis and some forms of cancer (Lige, 2002). The probability of heart problems and strokes decreases up to 44% for those who maintain a healthy, active lifestyle (Lige, 2002). Public health reports indicate that aerobic exercise helps to build strong bones, increases lean muscle mass, helps lower body fat and increases the body's tolerance for glucose, it helps combat aging conditions such as lack of coordination and balance, decreased muscle strength and flexibility, as well as wards off high lipid cholesterol levels in the bloodstream (Lige, 2002).

Working a certain group of muscles for a specific amount of time to reach and maintain one's target heart range is the point of aerobic exercise. Target heart range, is the safest range of heart-beats per minute during exercise (Newfitness, n.d.). This works the heart out better and makes the body burn more calories. Commonly, exercisers will hit the aerobic curve when they start working out and increase their intensity level to the top then slow down gradually. Target heart range (THR) can be calculated based on maximum heart rate (MHR) which is determined by subtracting age from 220, and multiplying answer by 50% and by 80%. The lower number suggests a safe rate for beginners, while the higher number would be the goal as fitness level improves. For example, for a 40-year old, MHR would be 220 – 40 = 180 beats per minute, multiplied by 50% (180 x 50% = 90) and 80% (180 x 80% = 144), the THR would be between 90 and 144 beats per minutes.

Aerobic exercise may be somewhat difficult to do at first, but it is absolutely obligatory for cardiovascular fitness, because maintaining a steady heart rate is more efficient. A healthy body takes steady aerobic sessions and is a continuous process. The body has another energy system, the anaerobic energy system, which it relies on during brief periods of high intensity activity.

2.3.2 Anaerobic exercise

"Anaerobic" means "without oxygen". Anaerobic exercise uses muscles at high intensity and a high rate of work for a short period of time. It relies on energy sources that are stored in the muscles. Unlike aerobic exercise, it is not dependent on oxygen from the air (Sparkpeople, n.d.). Anaerobic exercise helps increase one's muscle strength and stays ready for quick bursts of speed (University of Iowa, n.d.).

Examples of anaerobic exercise include heavy weight-lifting, sprinting, or any rapid burst of hard exercise. Anaerobic exercise is typically used by athletes in non-endurance sports to build power and by body builders to build muscle mass in order to develop biologically differently giving them greater performance in short duration – high intensity activities (Answer, n.d.; Wikipedia, n.d.).

There are two types of anaerobic energy system, the ATP – PCr energy system, which uses creative phosphate as the main energy source, and the lactic-acid system that uses glucose in the absence of oxygen (Answer, n.d.; Wikipedia, n.d.). The latter is the dominant energy system during high to maximal intensity exercise over short durations.

Lactic acid contributes to muscles fatigue and must be burned up by the body during a recovery period before another anaerobic bout of exercise can be attempted (University of Iowa, n.d.). The recovery period also allows the muscles to use oxygen to replenish the energy used during the high intensity exercise (University of Iowa, n.d.). When lactic acid accumulates at high levels in the blood, it causes muscular fatigue. This is why anaerobic exercises cannot last long. The body produces 'buffers' that delay the onset of fatigue during anaerobic exercise (Sparkpeople, n.d.). Studies have shown that with anaerobic training, the muscle's buffering capacity is increased by 12% to 50%. With this increased buffering capacity, more lactic acid can accumulate during high intensity exercise without causing fatigue (Sparkpeople, n.d.).

Most experts recommend not immediately starting with high intensity activity. Beginners should start at about 50% intensity and increase gradually. Anaerobic exercise is not recommended if one is pregnant. It is recommended that one does a 5-10 minute warm up before starting any anaerobic exercise, and a 5-10 minute cool down a workout session (Sparkpeople, n.d.).

Overall, anaerobic exercise burns fewer calories than does aerobic exercise and may be somewhat less beneficial for cardiovascular fitness. However, it is better at building strength and muscle mass and still benefits the heart and lungs (Sparkpeople, n.d.). Both aerobic and anaerobic exercises are needed for the development of physical fitness. For some special groups, it is advisable to check with their healthcare providers before starting an exercise programme.

One can participate in exercise anywhere. However, people are no longer only focusing on exercise processes, but also interested in the relevance and quality of various types of exercises. For this purpose, many exercise equipment have been produced to enhance the quality of the exercise processes for improved outcomes. Exercise gyms and clubs have become more and more popular in the last decades. In most exercise gyms or clubs, both aerobic and anaerobic exercise equipment are provided.

2.4 Exercise equipment

Exercise equipment fall into two categories based on the type of exercise provided: cardio (aerobic) and strength training (anaerobic).

2.4.1 Cardio (aerobic) exercise equipment

Cardiovascular, or cardio, exercise helps to increase heart health and burns fat by raising the heart rate. This kind of exercise equipment includes stationary bikes, treadmills, elliptical trainers, stair climbers, and so on (Standhousehotel, n.d.; Wisegeek, n.d.). Most of these exercise equipment include a display screen which tracks the heart rate and provides options for customising workout, the amount of miles or kilometers travelled and total calories burned (Standhousehotel, n.d.;

Wisegeek, n.d.). Heart rate monitoring has been widely used in cardio exercise equipment. A person's heart rate provides a direct indicator of the physiological response associated with physical activity.

Heart rate monitor

Investigators have been interested in assessing physical activity using a physiological variable that is easy to measure since at least the early 1900s, when Benedict proposed the use of heart rate as an indirect indicator of energy expenditure (Torun, 1984). This concept was refined in the 1950s when Berggren and Christensen (1950) recognised that the acute response of heart rate to increasing levels of physical activity is directly proportional to the intensity of movement and driven by an increasing need to deliver oxygen to skeletal muscles. However, the practical use of heart rate method to assess physical activity and energy expenditure in epidemiology only became possible in the 1970s with the development of heart rate monitors (Torun, 1984).

Early portable monitors either (1) accumulated heart rate over time providing an average heart rate or (2) accumulated heart rate over time and stored values into distribution ranges (Andrews, 1971; Saris, Snel, & Binkhorst, 1977). However, earlier monitors precluded precise estimates of physical activity and energy expenditure (Andrews, 1971; Montoye, Kemper, Saris, & Washburn, 1996; Saris *et al.*, 1977). Advances in microtechnologies during the 1980s and 1990s have provided what is now the standard in ambulatory heart rate monitoring: lightweight, continuous heart rate recorders with extended data storage capacities (Torun, 1984). Continuous recorders have improved the precision of activity and energy expenditure estimates, and have expanded the use of the heart rate method in epidemiology to include the study of the temporal patterns of physical activity: intensity, duration, and frequency (Armstrong *et al.*, 1990; Armstrong, Welsman, & Kirby, 2000; Kelly, 2000; Vuori, 1998). Recent advances in electrocardiogram (ECG) signal transmission, recording functions, programming, and software features make heart rate monitors versatile and unobtrusive instruments for use in epidemiology as well as in athletics, physical education, and psychophysiology (Berntson, Bigger, Eckbert, Grossman, Kaufmann, Malik, Nagaraja, Porges, Saul, Stone, & van der Molen, 1997; O'Toole, Douglas, & Hiller, 1998; Steptoe, 2000; Stratton, 1996).

Almost all of the continuous heart rate monitors use the ECG signal to detect the beat-to-beat heart rate via an ECG transmitter attached to the chest (Leger & Thivierge, 1998). In contrast to gymnasium equipment, this transmitter consists of circuitry packaged in a small, lightweight unit usually attached using an elastic strap that encircles the chest, a specially designed sport bra, or disposable ECG electrodes (Torun, 1984). Wireless (radio) signals are sent to a microprocessor receiver, which is designed to resemble a wristwatch (Torun, 1984). When the ECG signals are transmitted to the receiver, a timing circuit measures the interval between heartbeats (Torun, 1984). The receiver then processes the values by calculating a moving heart rate average for short periods of time (usually 5 to 15s), which is updated and displayed as beats per minute (b/min) (Karvonen, Chwalbinska-Moneta, & Saynajakangas, 1984). Because the number of heart rate values determine the averaging time, the calculation period is shortened during vigorous physical activity and the averaged heart rate value nearly approximates real-time heart rate (Karvonen *et al.*, 1984; Montoye, Kemper, Saris, & Washburm, 1996).

Heart rate monitor is not only used to assess physical activity and energy expenditure in health-related observational, but also has other applications. For example, heart rate monitor can be used to optimise training programmes for athletic or exercise performance. Setting training intensity based on heart rate rather than speed or pace is particularly useful in bicycling, cross-country skiing, and other sports where an athlete's speed varies depending on environmental conditions and other athletes (Torun, 1984). Monitoring heart rates with or without equipment has been an important component of physical programmes for decades. However, as the cost of monitors decreases, using continuous heart rate monitoring to present cardiovascular responses, to provide exercise intensity feedback, and to individualise aerobic training programmes has become a real option for many physical programmes. Based on these benefits of heart rate monitoring, heart rate monitor as a tool has been appropriate in corporate health promotion programmes and fitness clubs in the last decades.

2.4.2 Strength training (anaerobic) exercise equipment

Strength training helps to build muscular strength and maintain the results of cardio exercise (Standardhousehotel, n.d.; Wisegeek, n.d.). Exercise equipment for strength training are more varied. Free weights, weight type equipment, and balancing or resistance equipment can all be used for strength training.

Free weights come in many different shapes, sizes, and weights. Many people prefer free weights to weight type equipment because muscles are used these equipment. Throughout the entire body to maintain balance as one lifts them (Standardhousehotel, n.d.). However, weight type equipment is safer and easier to use than free weights and may allow one to lift greater amounts (Wisegeek, n.d.).

Weight type equipment, as one common type of exercise equipment, use weights to provide the necessary resistance. Many features exist for this type of equipment, including deadweight equipment, hydraulic equipment, and pneumatic equipment. In deadweight equipment, has a stack of incremental weights attached to a pulley which one can lift by pulling or pushing other parts of the machine (Wisegeek, n.d.). A pin is used to select the amount of weight to be lifted and adjust the equipment to accommodate the body type (Standardhousehotel, n.d.). Deadweight equipment have largely been used in most gyms and clubs because of the ease of use, and low cost. However, they are not without disadvantages. They are cumbersome to move; do not have enough protection for inexperienced users since the weights may be dropped suddenly; and an inertia of movement is created when weights are lifted. In order to avoid these disadvantages, various hydraulic equipment have been developed and are becoming an increasingly popular form of exercise. Unlike deadweight equipment, the resistance provided by hydraulic exercise equipment depends on the force exerted by the user (Beyondmoseying, n.d.). Therefore, depending on whether one pushes or pulls harder and performs faster movements, one will be met with more resistance than if one were to perform the same movements, but slower or with less strength involved.

Hydraulic equipment offer resistance only when the users are exerting force, and because of this, they are less likely to experience soreness. Many people prefer hydraulic equipment to deadweight equipment as they are able to go at their own pace. For this reason, hydraulic exercise equipment is ideal for children, seniors, and women, as well as those people who are simply too daunted by the stacks of weight that are evident on deadweight equipment. Hydraulic exercise equipment are popular today because they come with a combination of various pieces. Circuit training hydraulic exercise systems help to tune the body into perfect shape by exercising all the parts of the body (Hydraulic-equipment-manufactures, n.d.).

There are, however, both advantages and disadvantages to hydraulic exercise equipment. The disadvantages have come out when used. The equipment does not move as smoothly as other types of exercise equipment, and there is an upper limit to the amount of resistance that most models can provide. This makes them less desirable, especially to more advanced athletes and body builders. To overcome the disadvantages of both the deadweight and hydraulic equipment, pneumatic equipment has been developed. Pneumatic equipment generate and use compressed air to provide necessary resistance. Compared with hydraulic equipment, the hydraulic system is a hard system since fluid is not compressible. On the other hand, a pneumatic system is a much softer system since air is compressible to a certain degree (Rqriley, n.d.). With pneumatic exercise equipment, exercisers use compressed air to open the way for dynamically adjustable resistance. They have smooth and silent operation and no adverse effect of inertia (Rqriley, n.d.).

Whether deadweight equipment, hydraulic equipment, or pneumatic equipment, they all cannot absolutely satisfy every exerciser's desires and requests. Today, exercisers pay more and more attention to data (such as exercise and health status data), because of the fast developing IT technology. Indeed, IT technology has become the most important contributor working in most manufactures. On the other hand, the fitness industry is lagging behind in incorporating IT into its operations. Therefore, how to integrate IT technology into the fitness industry is becoming urgent. Because of this, another advanced technology has been proposed in recent years. That is intelligent exercise equipment, which has the capability to achieve goals under conditions of uncertainty.

2.5 Intelligent exercise equipment

In all of the various descriptions of exercise equipment, the user has to determine the amount of resistance and the number of repetitions desired. The reason the user makes the choices is that the exercise equipment itself is inherently incapable of any intellectual participation. However, with the advent of computers, it has possible to design exercise equipment with artificial intelligence enabling the computerised equipment to select the best exercise method for each individual user. Thus, the user need not be an expert in any biologic, physiologic, or exercise area since the exercise equipment is programmed with information from many scientific fields, thus correctly benefiting the different individual users.

The exercise equipment described here is the result of the application of many unique, innovative features and mechanisms to the long-established fields of resistive exercise or training for athletics, rehabilitation, and physical fitness. The underlying principle behind these innovations is that of a computer-controlled feedback that is able to maintain any desired pattern of force and motion throughout the range of each exercise, regardless of the magnitude or rate of force applied by the person exercising. Therefore, the advantages of an intelligent feedback-controlled mechanism over existing resistive exercise mechanisms are many (Ariel, 1983).

2.6 Fitness organisation

With exercise equipment widely used in the fitness industry, more and more advanced technologies and equipment are required in today's exercise equipment development. For this purpose, many companies and enterprises are devoted to developing intelligent exercise equipment. Polar Fitness, one of these companies, has developed many products to support intelligent exercise. The Polar Fitness system provides many intelligent exercise functions. The new Polar ProTrainer 5 is an advanced and dynamic training, planning and analysing software. Easily prepare a detailed training programme and transfer it to other compatible Polar products via infrared.

Polar Sport Zones help to train at the right intensity. It provides an easy way to select and monitor the intensity of one's training and to follow Polar's sport zones based training programmes (Polar Fitness, n.d.). The training is divided into five zones based on percentages of the exerciser's maximum heart rate (HRmax): very light (50-60%HRmax), light (60-70%HRmax), moderate (70-80%HRmax), hard (80-90%HRmax) and maximum (90-100%HRmax) (Polar Fitness, n.d.).

The Polar Own Workout Program guides exercisers to reach their personal fitness goals, how often, how hard, and how long they need to exercise to reach their personal fitness goals (Polar Fitness, n.d.). Each setting is given a number, and the number of exercise files stored in the heart rate monitor includes total exercise time, time in target zone and average heart rate. Furthermore, one can create training sessions with individual settings for duration and heart rate limits with multiple interval and recovery sessions. Each exercise profile may include up to six pre-programmable exercise phases. Each phase may include up to 30 interval and recovery periods, which alternate continuously throughout the phase.

Polar Fitness also provides special programs to help one lose and maintain weight. The weight management program gives guidance on how many calories to eat and how many to expend through exercise in order to achieve target body weight in chosen duration (Polar Fitness, n.d.). Polar OwnCal counts and displays calorie expenditure. This Polar OwnCal feature shows energy expenditure during one exercise session as well as accumulated kilocalories during several exercise sessions. In Polar M-series heart rate monitors, OwnCal calculation takes into account gender, body weight and exercise heart rate. The calculation starts when exercise intensity reaches 100 bpm (Polar Fitness, n.d.). In Polar S-series heart rate monitors, OwnCal calculation takes into account VO_{2max}, HRmax and exercise heart rate (Polar Fitness, n.d.). The calculation starts when exercise intensity reaches 60% of one's HRmax or 90 bpm. In Polar weight management products, the calculation starts when one puts the transmitter on and starts exercising (Polar Fitness, n.d.). One can set daily and weekly exercise goals in terms of calorie expenditure with the OwnCal feature, and then monitor the accumulated amount of calories expended during one week or during a single exercise session or a set amount of time, for example, one week (Polar Fitness, n.d.).

On heart rate, Polar OwnZone determines personal heart rate limits for a training session. It guides one through an appropriate warm-up routine and automatically determines a safe and effective exercise heart rate zone, while taking into account one's current physical condition (Polar Fitness, n.d.). Polar heart rate monitors use multiple methods for determining an exerciser's OwnZone. The primary method is to measure heart rate variability during the warm-up period before exercising. If the measurement is not successful, the exerciser's latest saved OwnZone limits are used.

If there are no previous limits in the memory, the Polar heart rate monitor will automatically calculate OwnZone limits based on one's age-predicted maximum heart rate (220 minus age) (Polar Fitness, n.d.). One should determine one's OwnZone at the beginning of workout whenever one changes exercise environment and/or exercise mode. The OwnZone Basic corresponds to 65-85 % of the maximum heart rate. Exercise at the lower end of this intensity level can be conducted for extended periods safely and often yields the best results for weight control, while exercise at the upper end of this intensity produces the best results for improving cardiovascular (aerobic) fitness (Polar Fitness, n.d.). The OwnZone Advanced feature consists of two training areas: OwnZone Low and OwnZone High, providing greater variations in exercising than the OwnZone Basic area, which can be rather wide for more focused training (Polar Fitness, n.d.). The OwnZone Light corresponds to 60-70% of one's maximum heart rate. This intensity still feels fairly easy for most people. It helps in weight control and improves endurance and cardiovascular fitness. The OwnZone Moderate corresponds to 70-80% of one's maximum heart rate. This intensity is especially good for people who exercise regularly. Exercising in this zone is particularly effective for improving cardiovascular fitness. The OwnZone Hard corresponds to 80-90% of maximum heart rate. Using this, one finds oneself breathing heavily, having tired muscles and feeling fatigued. This intensity is recommended occasionally for fit people. The OwnZone Weight corresponds to about 60-75% of one's maximum heart rate. This is ideal for weight loss exercise for less fit individuals and for those recovering from sickness or intensive training (Polar Fitness, n.d.).

Polar data recording depends on the Polar product model and accessories used, the samples of one's heart rate, speed, intensity stored in a defined time interval (Polar Fitness, n.d.). A long interval gives one more recording time, while a shorter interval allows recording of more detailed data. A shorter recording rate uses up the memory of the running and cycling computer more rapidly. The remaining recording time is shown at the start of the exercise or on the bottom row of the product display when setting the recording rate (Polar Fitness, n.d.). The samples recorded during exercise are transferred to the software where they can be used to further analysis on.

The pervious descriptions of exercise equipment, illustrate some common functions that are available in today's intelligent exercise equipment. Researchers are still working on trying to add more human ideas into exercise software. In order to deeply understand intelligent control related to software development, the following sections present some key concepts and technologies that are usually used.

2.7 Key concepts and technologies of building intelligent related software

According to Antsaklis and Passino (1992), the ever increasing technological demands of today call for very complex systems, which, in turn, require highly sophisticated controllers to ensure that high performance can be achieved and maintained under adverse conditions. There are needs in the control of these complex systems which cannot be met by conventional controllers and this is primarily due to the lack of precise knowledge about the process to be controlled. Acquisition of adequate system knowledge is often problematic or impractical due to system complexity and the fact that the structure and parameters in many systems change in significant and unpredictable ways over time. Moreover, to reduce design complexity control designers often utilise less detailed models for control than what they have access to. To address the control demands of such highly complex and uncertain systems one can enhance today's control methods using intelligent control systems and techniques.

2.7.1 Intelligence and intelligent control

Intelligence is a property of mind that encompasses many related mental abilities, such as the capacities to reason, plan, solve problems, think abstractly, comprehend ideas and language, and learn. Although intelligence is sometimes viewed quite broadly, psychologists typically regard the trait as distinct from creativity, personality, character, knowledge, or wisdom (Wikipedia, n.d.).

Two major consensus definitions of "intelligence" have been proposed. First, from *Intelligence: Knowns and Unknowns*, a report of a task force convened by the American Psychological Association (1995):

> *Individuals differ from one another in their ability to understand complex ideas, to adapt effectively to the environment, to learn from experience, to engage in various forms of reasoning, to overcome obstacles by taking thought. Although these individual differences can be substantial, they are never entirely consistent: a given person's intellectual performance will vary on different occasions, in different domains, as judged by different criteria. Concepts of "intelligence" are attempts to clarify and organize this complex set of phenomena. Although considerable clarity has been achieved in some areas, no such conceptualization has yet answered all the important questions and none commands universal assent. Indeed, when two dozen prominent theorists were recently asked to define intelligence, they gave two dozen somewhat different definitions.*

The second definition of "intelligence" comes from "Mainstream Science on Intelligence", which was signed by 52 intelligence researchers in 1994:

> *A very general mental capability that, among other things, involves the ability to reason, plan, solve problems, think abstractly, comprehend*

> *complex ideas, learn quickly and learn from experience. It is not merely book learning, a narrow academic skill, or test-taking smarts. Rather, it reflects a broader and deeper capability for comprehending our surroundings – "catching on", "making sense" of things, or "figuring out" what to do.*

Intelligent control is currently a well-established field within the discipline of control systems. It represents a generalisation of the concept of control to include autonomous anthropomorphic interactions of a machine with the environment and has been successfully represented by a Technical Committee of the EEE Control Systems Society. The technical results of many researchers in the area are regularly reported in many of the annual conferences in the USA and around the world (Antsaklis & Passino, 1992).

The area of intelligent control is a fusion of a number of research areas in systems and control, computer science and operations research, among others, coming together, merging and expanding in new directions and opening new horizons to address the new problems of this challenging and promising area (Antsaklis and Passino, 1992). Intelligent control systems are typically able to perform one or more of the following functions: planning actions at different levels of detail, learning from past experience, identifying changes that threaten the system behaviour, such as failures, and reacting appropriately. This identifies the areas of planning and expert systems, fuzzy systems, neural networks, machine learning, and failure diagnosis, to mention but a few, as existing research areas that are related and important to intelligent control (Antsaklis and Passino, 1992).

It is difficult and quite subjective to limit the scope of intelligent control. In general, intelligent control can be the following:

- Integrating sensor, actuator, and software into a mechatronic (which is fused by mechanical, electrical, and computer engineering (Martin & Hideki, 1996) module is one step towards but short of realisation of intelligent systems;

- Hierarchical control systems with increasing levels of abstractness in information processing;
- Structure changing adaptive systems including parameter adaptation on low-level control and more sophisticated adaptation mechanisms on higher levels in the control hierarchy;
- Intelligent "reference generating algorithms" for hierarchical control systems such as cars, mobile robots, robotic mechanisms, and numerically controlled manufacturing equipment. The term "reference generating" means algorithms which flexibly generate appropriate reference trajectories depending on the measured environment state;
- Flexible intersystem communication among distributed semi-autonomous systems and system components with defined and guaranteed global behaviour; networked mechatronics through a computer network information infrastructure;
- Optimisation schemes for automatic and optimal intelligent control system design;
- Intelligent human interaction to make the system be perceived as an intelligent control system;
- Discrete event dynamic systems – DEDS, hybrid systems; as such gain scheduling and structure adaptation redefined from a DEDS point of view;
- Increased flexibility, robustness, and fault-tolerance; and

- Ability for careful iterative improvements, learning, and self-organisation.

Martin & Hideki (1996)

To summarise the proposition for an approach to intelligent control system and technology integration may include mechatronics, computer science, system design optimisation, communication, and human interaction. This view of intelligent control is illustrated in Figure 2-1.

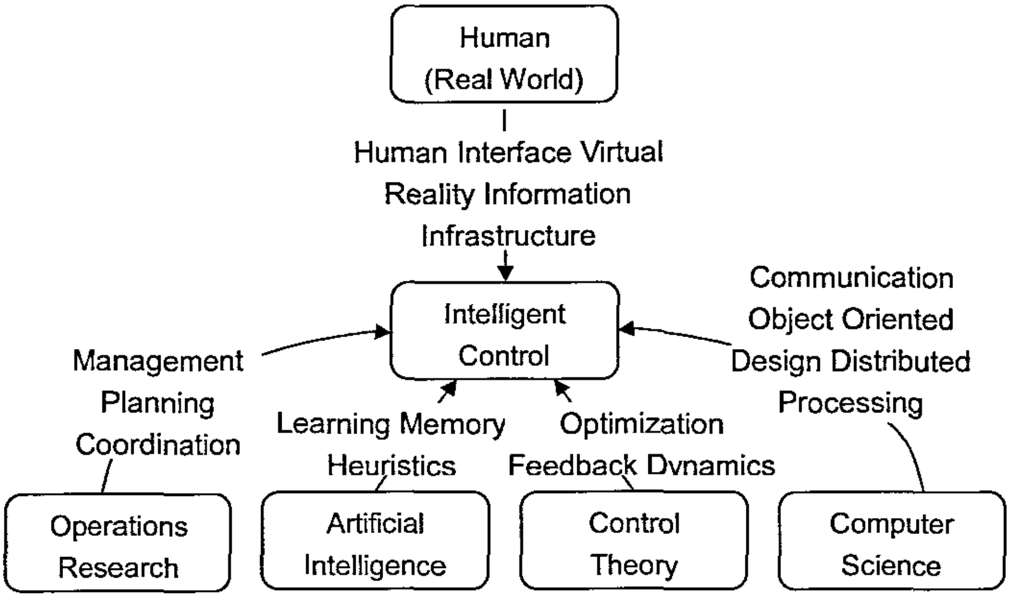

Human
(Real World)
Human Interface Virtual
Reality Information
Infrastructure
Intelligent
Control
Communication
Object Oriented
Design Distributed
Processing
Management
Planning
Coordination
Learning Memory
Heuristics
Optimization
Feedback Dynamics
Operations
Research
Artificial
Intelligence
Control
Theory
Computer
Science

Figure 2-1: Key technologies for intelligent control systems
Source: Martin & Hideki (1996)

2.7.2 Computer-controlled technologies

Computers are today essential for implementing controllers in many different situations. The computers are often used in embedded systems. An embedded system is a built-in computer that is a part of a larger system. Many of these computers implement control functions of different physical processes, such as vehicles, home electronics. Of course, it can be used in the exercise environment as well.

Åström and Wittenmark (1997) indicate that using computers to implement controllers has substantial advantages. Many of the difficulties with analog implementation can be avoided. For example, there are no problems with accuracy or drift of the components. It is very easy to have sophisticated calculations in the control law, and it is easy to include logic and nonlinear functions; tables can be used to store data in order to accumulate knowledge about the properties of the system; it is also possible to have effective user interfaces.

A computer-controlled system can be presented schematically as shown in Figure 2-2. Essentially, the system contains five parts:

- Process;
- Sampler together with Analog-to-Digital (A-D) converter;
- Digital-to-Analog (D-A) converter with a hold circuit;
- Control algorithms;
- Computer with a clock, and software for real-time applications.

Wittenmark, Åström, & Årzén (2002:4-5)

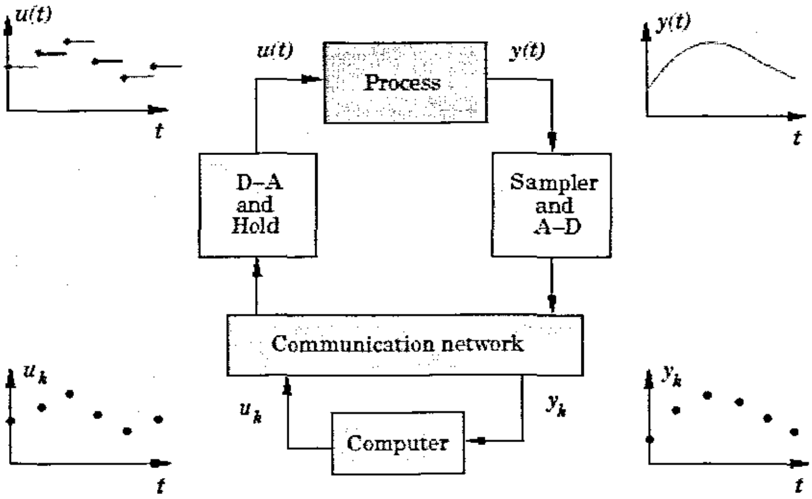


Figure 2-2: Schematic diagram of a computer-controlled system

Source: Wittenmark *et al.* (2002)

The process is a continuous-time physical system to be controlled. The input and output of the process are continuous-time signals. The AD converter converts the analog output signal of the process into a finite precision digital number depending on how many bits or levels are used in the conversion. The conversion is also quantised in time determined by the clock. This is called the *sampling process.* The control algorithm, thus, receives data that are quantised both in time and in level. The control algorithm consists of a computer program that transforms the measurements into a desired control signal. The control signal is transferred to the DA converter which, with finite precision, converts the number in the computer into a continuous-time signal. This implies that the DA converter contains both a conversion unit and a hold unit that translates a number into a physical variable that is applied to the process. The communication between the process, or more accurately the AD and DA converters, and the computer is done over a communication link or network. All the activities in the computer-controlled system are controlled by the clock with the requirement that all the computations have to be performed within a given time. In a distributed system there are several clocks that have to be synchronised. The total system is, thus, a real-time system with hard time constraints.

In many situations, it is not necessary to know anything about computer control or real-time systems to implement a simple controller. There are, however, many situations where the result will be much better when the sampled-data aspects of the system are taken into consideration when the controller is designed. Also, it is very important that the real-time aspects are regarded. The real-time system influences the timing in the computer and can thus minimize latency and delays in the feedback controller (Wittenmark *et al.* 2002).

2.8 Summary

This chapter has described the relationships between physical activity, health-related fitness, and health, indicating that physical activity can influence fitness, and also that fitness is related to health in a reciprocal manner. That is, fitness not only influences health, health status also influences both physical activity level and fitness level. Health-related equipment which are used to maintain and promote fitness ability are presented. Following the fast developed IT areas, not only the traditional exercise equipment are required and used, but intelligent exercise equipment are also developed and devoted to provide appropriate responses in order to optimally exercise with a build-in computer system. Finally, the key concepts and technologies that are usually used in developing intelligent exercise equipment are presented.

CHAPTER 3

DESIGN METHODS OF A COMPUTER-CONTROLLED PNEUMATIC SYSTEM

This chapter presents an approach where the weight of the exercise equipment can be changed dynamically in exercise. In standard deadweight-based equipment, the weights generally can be changed only when the equipment is inactive. In this chapter, the deadweights will be replaced by pneumatic cylinders and directional control valves, which will allow FX control to be dynamically varied. On the other hand, a single PID control circuit is provided for regulating the output pressure response provided to a load under computer-controlled situation. The computer control will be implemented on a "National Instruments PXI" computer featuring Data Acquisition and Control (DAQAC) capacity, and the software will be implemented using "LabVIEW 7.0" to control a FX mechanical linkage via the accompanying electro-pneumatic components with friendly GUI design.

3.1 The pneumatic system

One of the important features of the research is a pneumatic system. The control system includes two double-acting electro-pneumatic cylinders which are used to simulate an exerciser and exercise equipment, respectively (Figure 3-1). The core of this research is based on a force-displacement (FX) relationship. A displacement transducer scales the precision measurement of positions that respond to a change in condition. On the other hand, a counter force is presented by the equipment cylinder against the exercisers effort and generated by a force transducer. Four pressure control valves are included for producing control pressure signals and a booster for providing an output pressure response to a pneumatic load in accordance with the control pressure signals. The built-in pressure sensors are further provided for measuring the output pressure response to the load and for generating a corresponding feedback voltage signal to the control circuit. The control circuit compares the feedback signal to a command signal input in accordance with a predetermined transfer function having proportional, integral and derivative (PID) components, and generates a control voltage signal for stably controlling the output pressure response provided to the load.

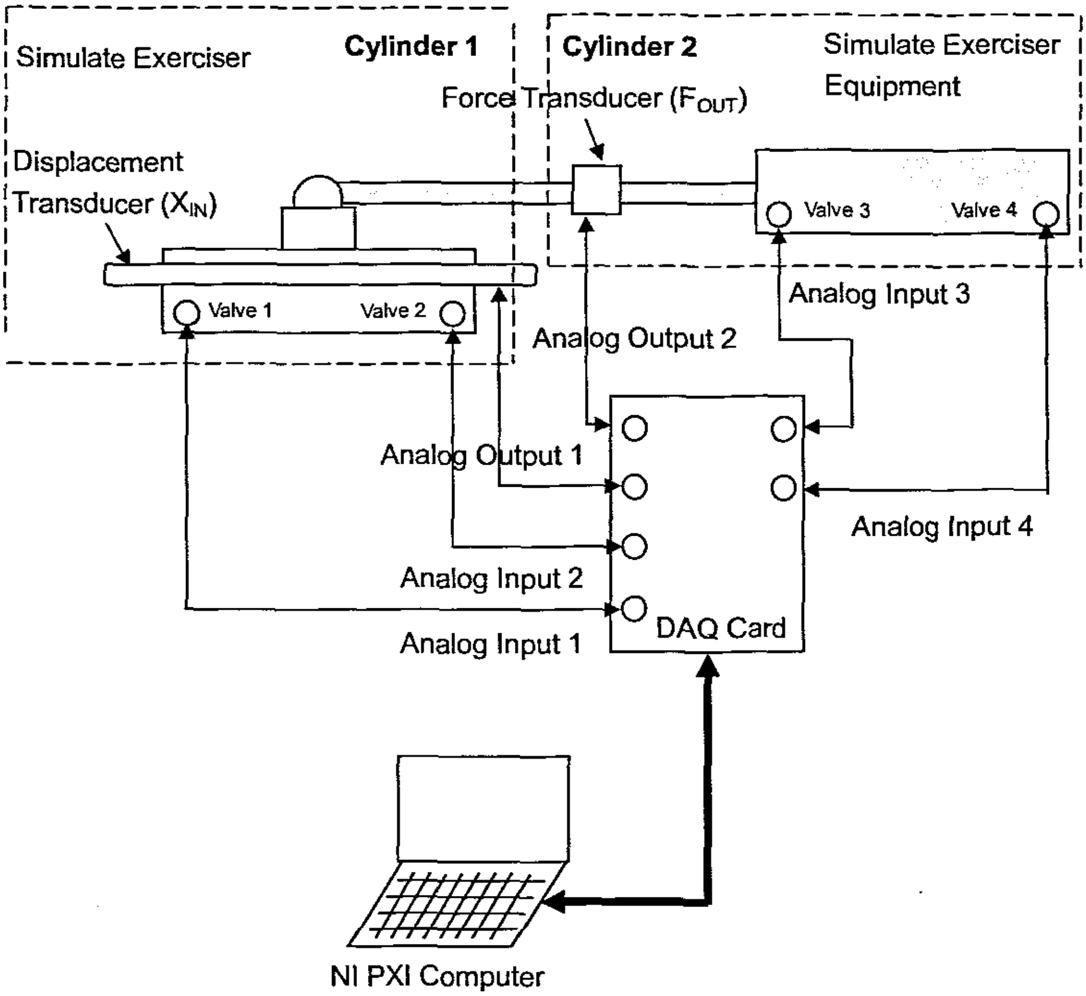

Simulate Exerciser
Cylinder 1
Cylinder 2
Simulate Exerciser Equipment
Force Transducer (F_{OUT})
Displacement Transducer (X_{IN})
Valve 1
Valve 2
Valve 3
Valve 4
Analog Input 3
Analog Output 2
Analog Output 1
Analog Input 4
Analog Input 2
Analog Input 1
DAQ Card
NI PXI Computer

Figure 3-1: System architecture

3.1.1 Role of the pneumatic system

The pneumatic system has two main roles. In Figure 3-1, pneumatic system can be seen as two separate frames. Cylinder 1 combines with a displacement transducer to simulate an exerciser. The directional valves (valve 1, valve 2) are used for controlling, pushing or pulling action of the simulated exerciser. On the other hand, cylinder 2 is used to simulate an exercise equipment combined with a force transducer, connected to the first frame by a rod. The simulated exercise equipment will generate correct forces in order to match the power from cylinder 1, depending on the position of the displacement transducer, calculated by the formula F(X).

3.1.2 Components of the pneumatic system

In considering the design of the pneumatic system, the development will focus on the following major parts:

3.1.2.1 Double-acting cylinders

Two DNC-50-450-PPV-A (DNC...) double-acting cylinders are included in the pneumatic system. Each DNC... cylinder has two ports for compressed air, which means that fluid under pressure can be applied to either side of the piston to apply force and provide movement. When the piston is to be returned to its resting position, pressure is applied to the second port, but also open up the first port so that the air in it can be expelled. Figure 3-2 shows the feature of DNC... cylinder, with neither valve operated, both sides of the piston are exhausted so the piston rod is free to move in either direction. If valve V_1 is operated alone the piston rod extends. Conversely, if valve V_2 only is operated the piston rod will retract. If both valves are operated at the same time both sides of the piston will be pressurised, the larger force being exerted on the full bore side as it has the larger area, depending upon cylinder load, the piston will try to extend. Figures 3-3 and 3-4 show the features of both valves when operated together. The used air in this case is exhausted as the incoming air pushes the cylinder forwards and backwards.

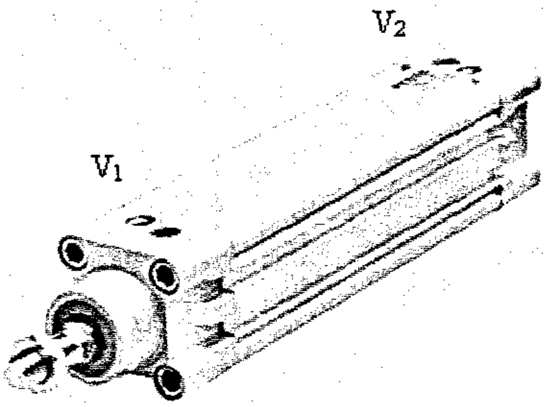


Figure 3-2: DNC-50-450-PPV-A double-acting cylinder

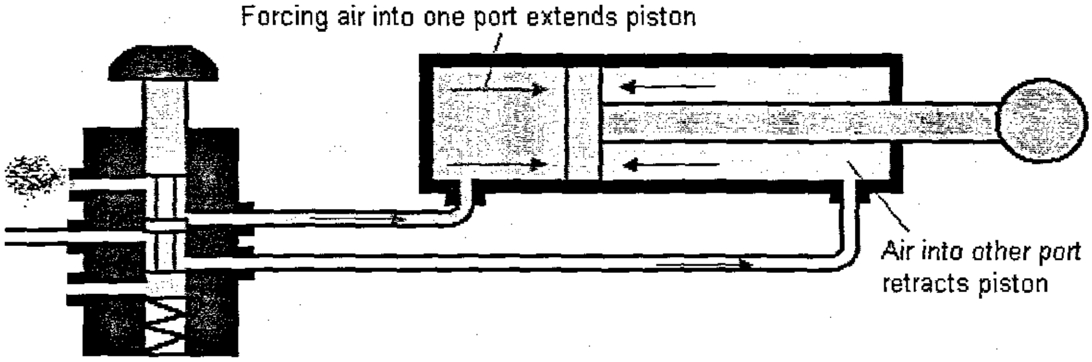

Forcing air into one port extends piston
Air into other port retracts piston

Figure 3-3: Double-acting pushes in action

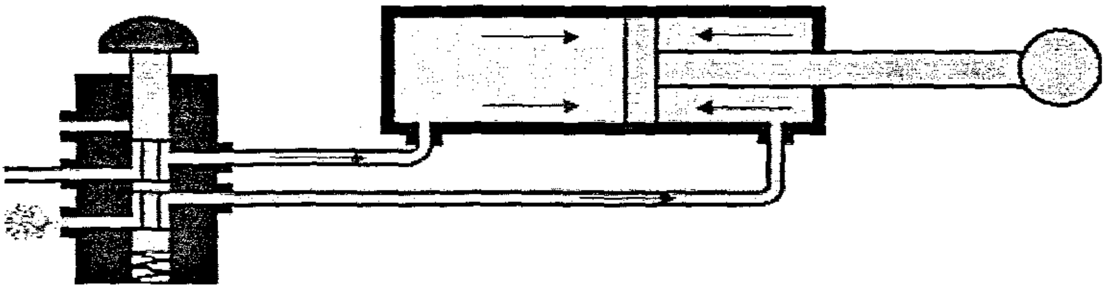


Figure 3-4: Double-acting pulls back action

3.1.2.2 MPZ setpoint module

The MPZ setpoint module has been designed for generating 6+1 analog nominal values for Festo proportional valves. Figure 3-5 features the MPZ setpoint module. The MPZ is a setpont value generator. Six reference or setpoint voltages can be preset by means of rotary potentiometers. The output of the MPZ provides constantly the voltage which is actuated via a digital controller. The nominal values SP1, SP2, SP3, SP4, SP5, and SP6 have priority (Figure 3-6). SP1 has the highest priority, and SP6 the lowest priority. If none of the six nominal value voltages is activated, the output will supply the voltage which is specified by the external input (FESTO, 2007).

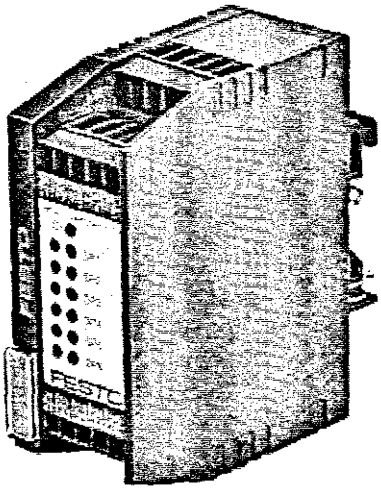


Figure 3-5: MPZ setpoint module

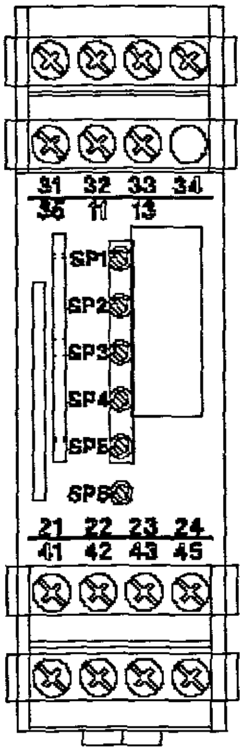
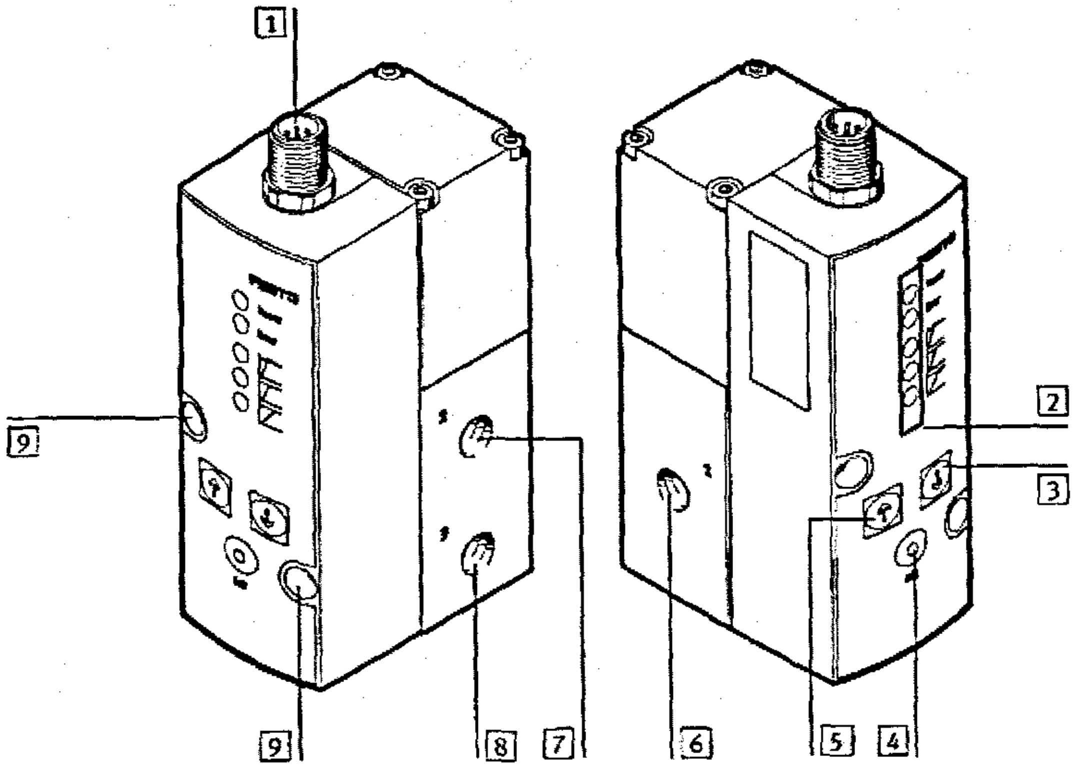

31
32
33
34
35
11
13
SP1
SP2
SP3
SP4
SP5
SP6
21
22
23
24
41
42
43
45

Figure 3-6: MPZ display and operating elements

3.1.2.3 Proportional pressure regulator valves

The pneumatic system has four proportional pressure regulator valves, named VPPM. The VPPM has been designed to regulate a pressure proportional to a specified setpoint value which is defined by MPZ setpoint module. An integrated pressure sensor records the pressure at the working line and compares this value to the setpoint value. In the case of deviations between the setpoint and actual value, the regulator is activated until the output pressure has reached the setpoint value (FESTO, 2007). The features of the VPPM are shown in Figure 3-7.



1 Plug for electrical connection (8-pin)
2 LED for operational and status displays
3 DOWN button
4 EDIT button
5 UP button
6 Supply port 1 (pressure input)
7 Air port 2 (pressure output)
8 Valve exhaust port 3
9 Through holes for fastening

Figure 3-7: Operating elements and connections of VPPM

3.1.2.4 Displacement transducer

A displacement transducer is defined as a transducer that physically moves in response to a change in condition, often used for precision measurement of small distances (Intota, n.d.). A MLO-POT-450-LWG (MLO...) displacement transducer is to be used in combination with cylinder for positioning measures. The features of the MLO... displacement transducer are shown in Figure 3-8.

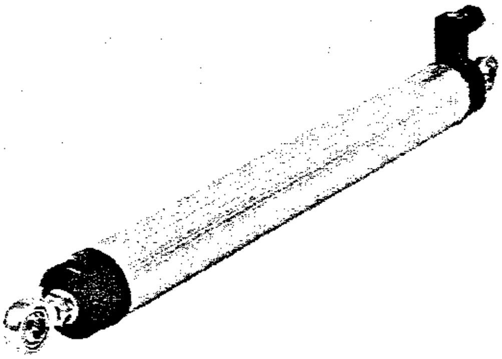


Figure 3-8: MLO-POT-450-LWG displacement transducer

3.1.2.5 Force transducer

A force transducer is defined as a device that senses the magnitude of a load upon it, such as a tension load, and sends a corresponding signal out (Google Glossary Definition, n.d.). The U2B force transducer (Figure 3-9) is to be used exclusively for force measurement tasks and directly-related control tasks. The U2B force transducer is also suitable for measuring tensile forces and pressures. It measures static and dynamic forces with great accuracy (HBM, 2007).

The U2B force transducer is manufactured from stainless steel and is suitable for use under harsh environmental conditions and severe operating constraints. Its measuring signals can be transmitted to remote measuring equipment (HBM, 2007).

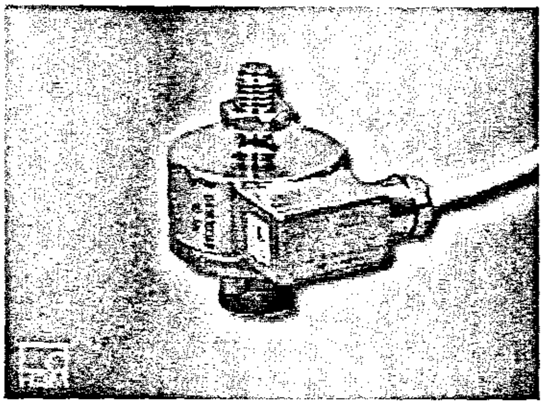


Figure 3-9: U2B force transducer

3.1.2.6 Air treatment

Drying of compressed air is probably the most important form of air treatment because water contamination results in inefficiency and can cause serious damage to equipment (Stacey, 1998). The additional air treatment and other components are normally positioned at the point of use, these are:

- An isolation valve – an on-off valve for the plant served at this point.
- A filter – similar to the filter already described with very probably a higher filtration rating.
- A pressure regulator and pressure gauge. The regulator is an adjustable component which allows mains pressure downstream of the plant only up to the pressure to which it has been adjusted. It therefore imposes a limit on the plant pressure. A secondary function of most regulators is to vent pressure from downstream when that pressure exceeds the regulator setting – a situation which can arise if the regulator setting is reduced or if actuator loads cause back – pressures.
- A soft – start / dump valve
- A lubricator

Stacey (1998)

The MS..-LFR-/LR(B)-..., MS-LF(M)-/LFX-... air treatment is used in pneumatic system (Figure 3-10). The MS..-LFR-..., MS..-LR-... has been designed to regulate compressed air in the following string to the set work pressure. The MS..-LFR-..., MS..-LR-... thereby smoothes out fluctuations in pressure. The MS..-LF-..., MS..-LFR-... with water separator frees compressed air blown through from dust particles and condensed water (FESTO, 2007).

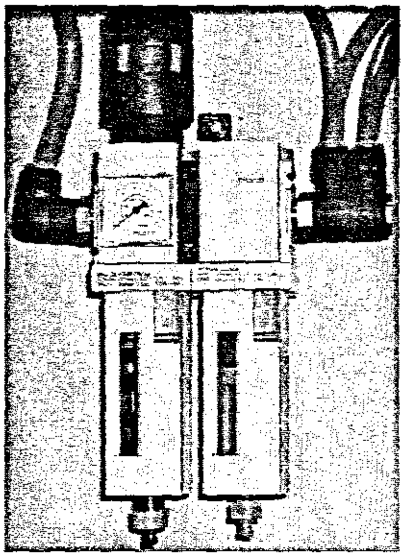


Figure 3-10: MS..-LFR-/LR(B)-..., MS-LF(M)-/LFX-... air treatment

3.1.3 Design overview of the pneumatic system

The design process criteria are focused on research with the algorithm to support the optimum control of the pneumatic cylinders. The best initial pressures are provided to prime cylinder. Chambers are considered as well. On the other hand, the STEP function is used for validating the responses of the pneumatic system. For estimating any industrial system, the response time always is the important consideration. In order to get the best condition, the PID control circuit is concerned in the pneumatic system with specific reference to the manifestation of P-control for responsiveness, I-control for accuracy, and D-control for stability.

3.1.3.1 Simulate exerciser

The simulate exerciser contains a DNC... double-acting cylinder in combination with a MLO... displacement transducer. In Figure 3-11, two VPPM proportional valves are giving pressures to make the cylinder piston move. A measured value is gained by MLO... displacement transducer to opposite each of position of cylinder.

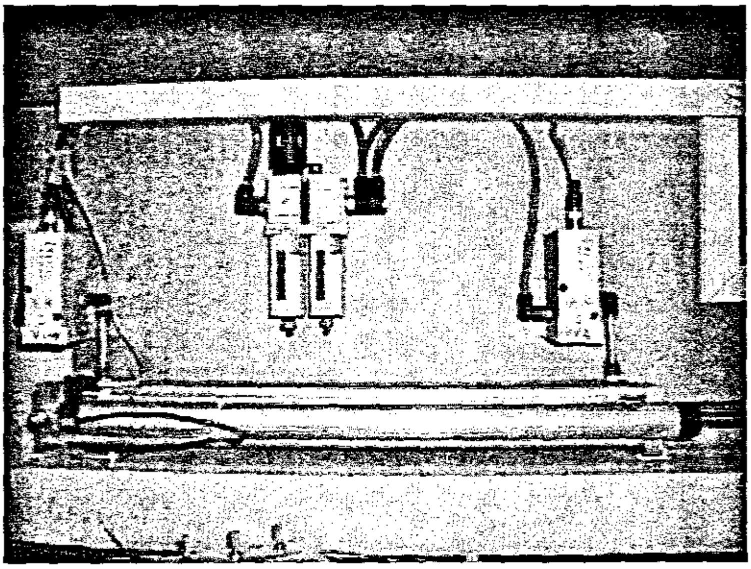


Figure 3-11: Simulate exerciser

3.1.3.2 Simulate exercise equipment

The simulate exercise equipment presents a counter force against the exerciser's effort. The functioning of the simulate exercise equipment is based on a force-displacement (FX) relationship.

The principle of FX control relies on differential pressure control as represented in Figure 3-12. FX control can be described as follows:

> A bi-directional pneumatic cylinder has each chamber connected via an electronically controlled pressure control valve to a high pressure

reservoir; by reducing or increasing pressure force can be controlled through differential pressure (Alexander, 2006).

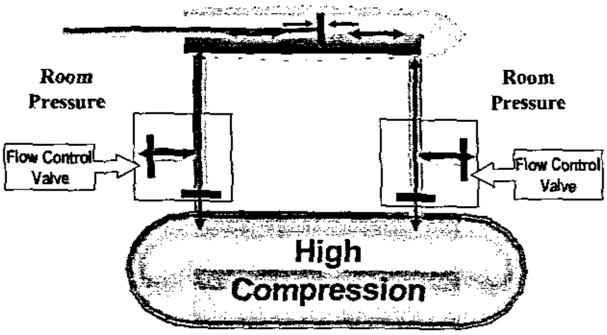

Room
Pressure
Room
Pressure
Flow Control Valve
Flow Control Valve
High
Compression

Figure 3-12: Differential pressure control principle

***Source:* Alexander (2006)**

In FX technology, exercise trajectory is specifically controlled using a computer-based profile that determines the differential pressure in the cylinder relative to the spatial position of the mechanical linkage (Figure 3-13). An exercise trajectory control system uses mathematical algorithms to deliver the required pressure to achieve the desired force trajectories. This is dealt with in more detail in the section dealing with the exposition of the control software.

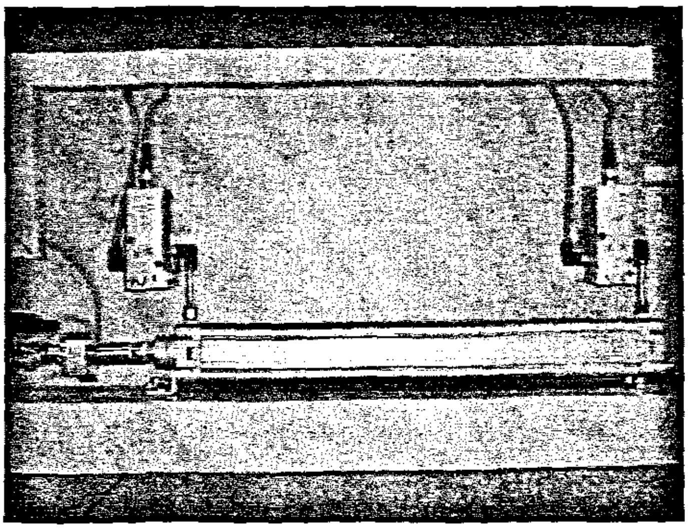


Figure 3-13: Simulate exercise equipment

3.1.3.3 Pressure

All fluids can convey force from one place to another. Fluid can be liquid or a gas such as air. A force applied to the surface of fluid in a container will cause a force to occur at every point where the fluid is contained. These forces result from the fluid trying to escape in all directions.

Pressure is the measure of how much force is present on an area of the fluid. It is created by applying a force to an area. A force applied to a small area will give a high pressure, while the same force applied to a large area will give a low pressure. When the pressure in the fluid has conveyed the force through the fluid to another location, the force is available for use. A high pressure in the fluid acting on an area will create a large force, or a low pressure acting on the same area will create a small force. Also, a low pressure applied over a large area results in a large force, and a high pressure applied over a small area will create a small force.

Stacey (1998) defined "pressure" for pneumatic purposes:

> *Pressure is the force in air due to compression, per unit of surface area.*

Focusing on the above definition, the pressure created in a fluid by the application of a force can be presented as Equation 3-1:

$$\text{Pressure} = \text{Force} / \text{Area} \qquad \textbf{Equation 3-1}$$

Consequently, the force exerted by pressure acting on an area will be presented as Equation 3-2:

$$\text{Force} = \text{Pressure} \times \text{Area} \qquad \textbf{Equation 3-2}$$

The units of the above formulas are given as follows:

- Force – newton (N)
- Area – mm^2
- Pressure – bar

3.1.3.4 Initial pressures to prime cylinder

From Equation 1 and Equation 2, suppose a force applied to an unchangeable area, area will be seem as a constant, that is to say, high pressure will produce great force. Conversely, small pressure will produce low force. Therefore, a direct proportion has been created between force and pressure. Another important factor is response time, which is the waiting time needed for increasing or decreasing enough pressure to produce the target force.

In Figure 3-14, a STEP input is applied in (a), and the relative force output is shown in (b). The actual force output in (b) does not reach the target force immediately, but gradually increased till the target force is produced. The time used during this process is called response time or time delay. The shortest response time is desired.

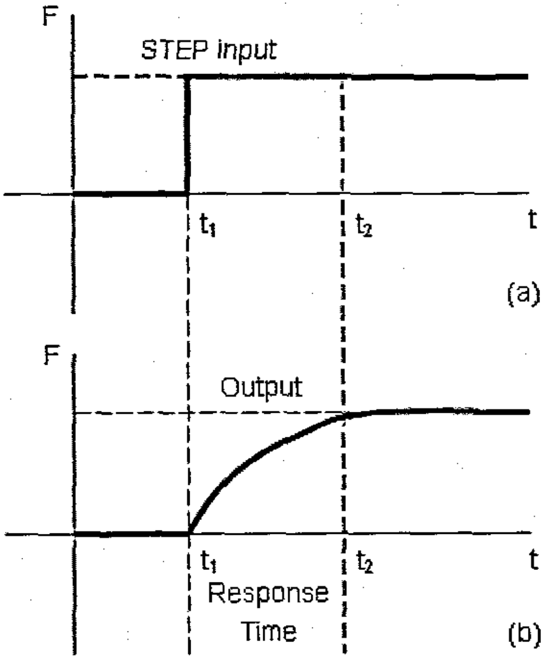


Figure 3-14: Response time

The fastest response is all the system desired, depending on the above description, the criteria that defines response time is focused on how soon can generate enough pressure to produce a setting STEP input, and pressure is decided by STEP input. In this research, the STEP input can be implemented in two ways:

1. Increase pressure on one side of cylinder.
2. Increase pressure on one side, and decrease on other side of cylinder.

In the first implementation, the cylinders will open one valve and close another. Initial pressure is empty on both sides, for example, V_1 opens and closes V_2, initial pressure is 0 bar (Figure 3-15).

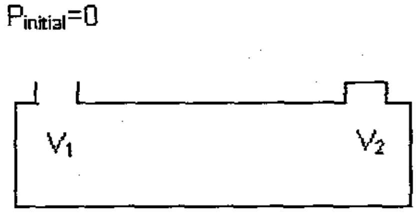


Figure 3-15: Increase pressure on one side

Response is getting soon if V_1 pressure is increased at the beginning, but with increased pressure, the response decreases, because the more pressure in the cylinder, the more difficult it is to put pressure into it. The trend is shown in Figure 3-16. For example, with a balloon, at the beginning the pressure in it would be 0. As soon as inflating starts, the more pressure added the harder it would be to add more. As soon as the opening of the balloon is released, it would deflate, the amount of pressure would decrease dramatically, and the balloon will be deflated.

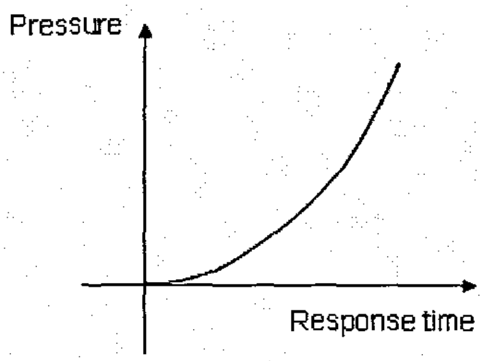


Figure 3-16: Pressure vs. response time

In the second implementation, both side valves are opened, and the initial pressure is set to half of the maximum pressure of the cylinder. If pressure is increased on V_1 valve, and decreased on V_2 valve, the maximum pressure of the cylinder is 200 bars, so $P_{initial}$ will be 100 bars for each of side (Figure 3-17).

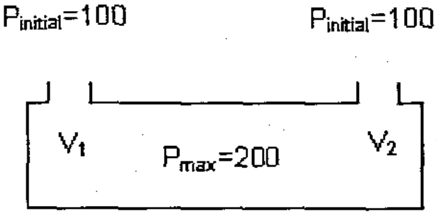

$P_{initial}$=100
$P_{initial}$=100
V_1
P_{max}=200
V_2

Figure 3-17: Increase on one side and decrease on other side

If produce 40 bars force on the second implementation, the V_1 valve needs an increase of 20 bars pressure, and V_2 valve needs a decrease of 20 bars pressure in order to generate 40 bars pressure. Therefore, P_{v1} will be 120 bars, and P_{v2} change to 80 bars. P_{V1} (120) minus P_{v2} (80), 40 bars pressure created (Figure 3-18).

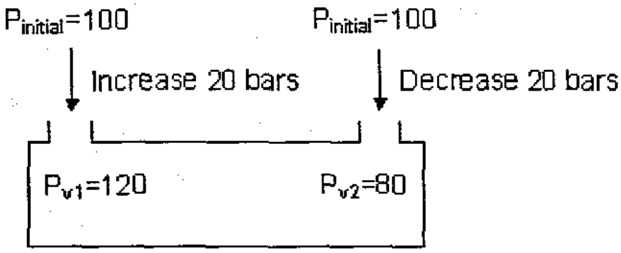

$P_{initial}$=100
$P_{initial}$=100
Increase 20 bars
Decrease 20 bars
P_{v1}=120
P_{v2}=80

Figure 3-18: 40 bars force applied on both side working cylinder

To calculate the response time for the second implementation, it will be calculated on both side valves at the same time, increases half pressure of first implementation on one side valve, and exhaust another half pressure on other valve. As we know, exhaust pressure is a very quick action. Therefore, the second implementation response seems quicker than the first implementation, but that is not exactly the case; it is quicker when applying a small pressure force. However, for a big pressure force, nobody knows the response time because it depends on the maximum pressure of the cylinder. The trend line of the intake and exhaust valves are shown in Figure 3-19 and Figure 3-20, respectively. Therefore, the two implementations are used in different considerations.

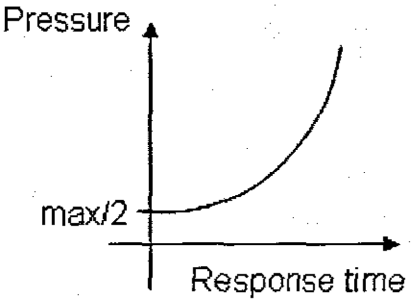


Figure 3-19: Intake valve

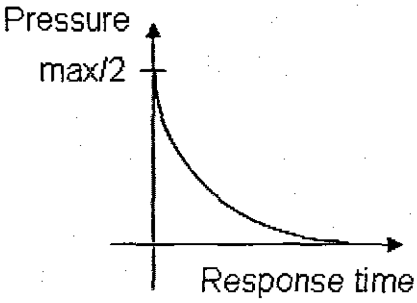


Figure 3-20: Exhaust valve

3.1.4 Process control pneumatics

In some industrial process is to be automatically controlled, there will be many process variables, e.g. temperature, flow, pressure, level, which need to be measured and kept at the correct value to ensure safe and economic operation (Parr, 1998). In this research, displacement and force are measured. In Figure 3-21, the force is measured to give the current value (usually termed PV – for process variable) which is generated by F(X) that in order to against exerciser action by moving the position of the cylinder. This is compared with the required force (called SP – for set point) to give an error signal, which is passed to the control system. This adjusts the actuator drive signal to move the valve in the direction to give the required force. The arrangement of Figure 3-21 is called closed loop control.

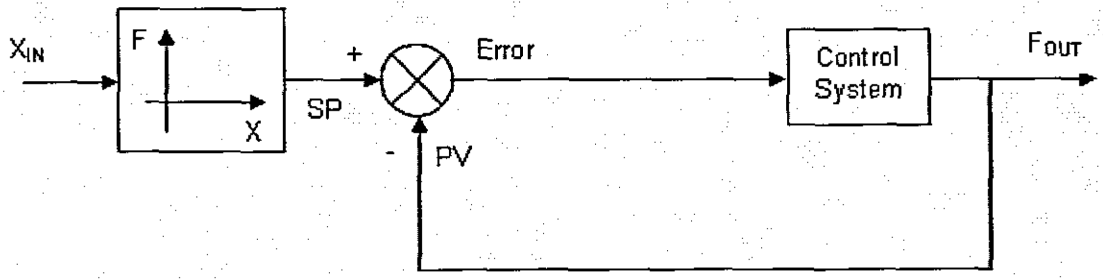


Figure 3-21: Closed loop control

3.1.4.1 Closed loop control

Closed-loop control is the type most commonly used in process control system because it responds to control quicker and with greater accuracy. A closed-loop control system is called a feedback control system, and uses feedback to control states or outputs of a dynamic system. Its name comes from the information path in the system: process inputs (e.g. *voltage applied to a motor) have an effect on the* process outputs (e.g. velocity or position of the motor), which is measured with sensors and processed by the control, the result (the control signal) is used as input to the process, and closing the loop (Wikipedia, n.d.).

In a closed-loop control system, input and output quantities are compared to produce an error signal which actually operates the forward path, which is the whole of the system between the error signal and the final output.

The great advantage of a *closed-loop control system is that since it is error-operated it* contains the facility to compensate for any departure of the output from the required condition set by the input because this departure changes the error, causing a correcting signal to be applied to the forward path. The disadvantage of feedback system is that due to give an oscillatory response to any change of input which may take some time to die away, or that the system may even become unstable and maintain self-oscillation, this is shown in Figure 3-22.

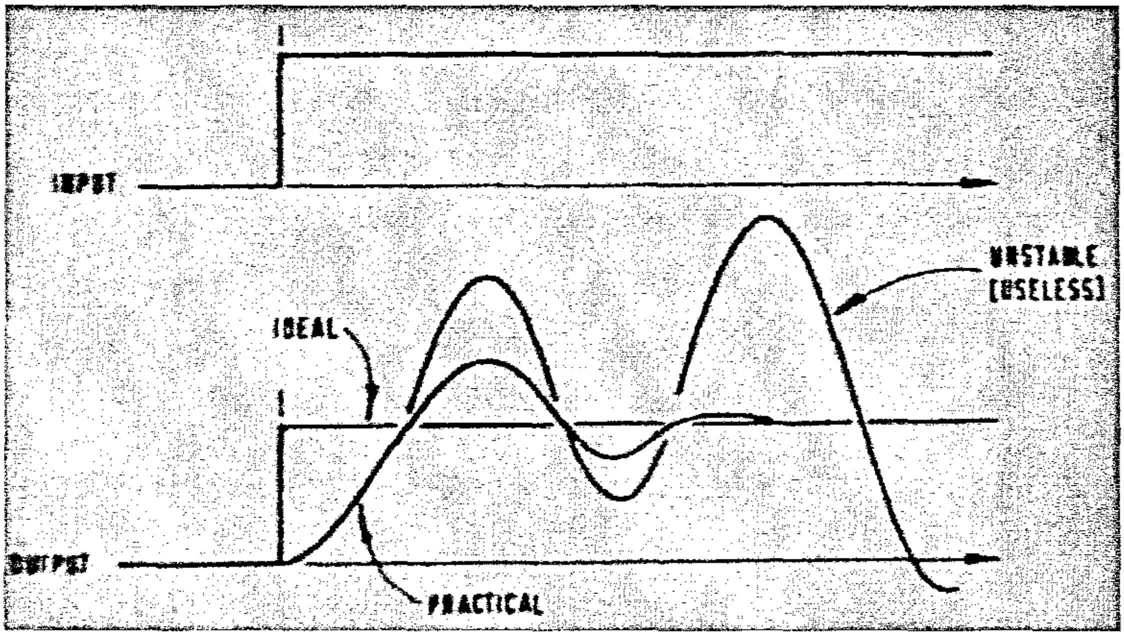


Figure 3-22: System responses

In order to avoid oscillatory and unstable feedback system, a PID controller is used. It has the specific reference to the manifestation of P-control for responsiveness, I-control for accuracy, and D-control for stability.

3.1.4.2 PID controller

A proportional-integral-derivative controller (PID controller) is a generic control loop feedback mechanism widely used in industrial control systems (Wikipedia, n.d.). A PID controller attempts to correct the error between a measured process variable and a desired setpoint by calculating and then outputting a corrective action that can adjust the process accordingly, based on three parameters (Parr, 1998).

The PID controller algorithm involves three separate parameters: proportional, integral, and derivative. The proportional determines the reaction to the current error, the integral determines the reaction based on recent errors and the derivative determines the reaction based on the rate by which the error has been changing (Wikipedia, n.d.). The weighted sum of these three actions is outputted to control elements such as the position of control valves.

By tuning the three constants in the PID controller algorithm, the PID can provide individualised control specific to process requirements including error responsiveness, overshoot of setpoint and system oscillation. Figure 3-23 shows a block diagram of a PID controller.

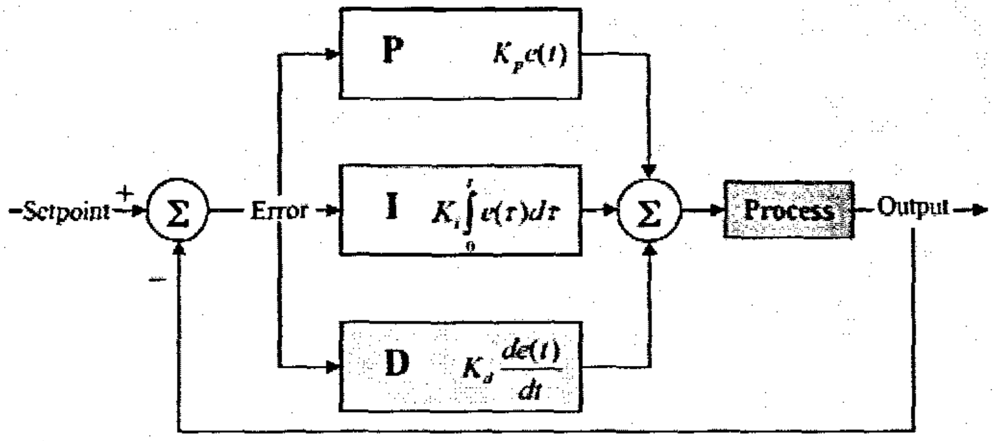


Figure 3-23: Block diagram of a PID controller

Proportional term

The proportional term responds to a change in the process variable proportional to the current measured error value. The proportional response can be adjusted by multiplying the error by a constant K_p, called the proportional gain. The proportional term is given by Equation 3-3:

$$P_{out} = K_p e(t) \qquad \textbf{Equation 3-3}$$

where

- P_{out}: Proportional output
- K_p: Proportional gain
- e: Error = SP – PV

- t: Time

From Equation 3-3, a high proportional gain results in a large change in the output for a given change in the error. If the proportional gain is too high, the system can become unstable (Scrcek, Mahoney, & Young, 2000). In contrast, a small gain results in a small output response to a large input error, and a less responsive controller. If the proportional gain is too low, the control action may be too small when responding to system disturbances (Wikipedia, n.d.).

In the absence of disturbances pure proportional control will not settle at its target value, but will retain a steady state error that is a function of the proportional gain and the process gain. Despite the steady-state offset, both tuning theory and industrial practice indicate that it is the proportional term that should contribute the bulk of the output change (Wikipedia, n.d.).

Integral term

The contribution from integral term is proportional to both the magnitude of the error and its duration. Summing the instantaneous error over time gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain and added to the controller output (Wikipedia, n.d.). The magnitude of the contribution of the integral term to the overall control action is determined by the integral gain, K_i. The integral term is given by Equation 3-4:

$$I_{out} = K_i$$ **Equation 3-4**

where

- I_{out}: Integral output
- K_i: Integral gain
- e: Error = SP – PV
- t: Time in the past contributing to the integral response

The integral term accelerates the movement of the process towards setpoint and eliminates the residual steady-state error that occurs with proportional only controller. However, since the integral term is responding to accumulated errors from the past, it can cause the present value to overshoot the setpoint value (Wikipedia, n.d.).

Derivative term

The derivative term provides a braking action to the controller response as the process variable approaches the setpoint. To accomplish this, the process error is predicted by the derivative gain K_d, calculated by analysing the slope of error vs. time (i.e. the rate of change of error, which is its first derivative with respect to time) (Wikipedia, n.d.). The magnitude of the contribution of the derivative term to the overall control action is determined the derivative gain, K_d. The derivative term is given by Equation 3-5:

$$D_{out} = K_d \, de/dt \qquad \textbf{Equation 3-5}$$

where

- D_{out}: Derivative output
- K_d: Derivative gain
- e: Error = SP – PV
- t: Time

The derivative term slows the rate of change of the controller output and this effect is most noticeable close to the controller setpoint. Hence, derivative control is used to reduce the magnitude of the overshoot produced by the integral component and improve the combined controller process stability (Wikipedia, n.d.).

The output from the three terms, the proportional, the integral and the derivative are summed to calculate the output of the PID controller.

Loop tuning

If the PID controller parameters (the gains of proportional, integral and derivative terms) are chosen incorrectly, the controlled process input can be unstable. Tuning a control loop involves the adjustment of its control parameters to the optimum values for the desired control response. Generally, stability of response is required and the process must not oscillate for any combination of process conditions and setpoints. Tuning of loops is made more complicated by the response time of the process. It may take minutes or hours for a setpoint change to produce a stable effect. In order to have the shortest response time with stable effect, this section describes a method – PID tuning software-which is widely used for loop tuning.

PID tuning software will gather the data, develop process models, and suggest optimal tuning. The National Instrument LabVIEW PID Model is one of the software package, used in this research.

Therefore, Figure 3-21 will be modified to Figure 3-24.

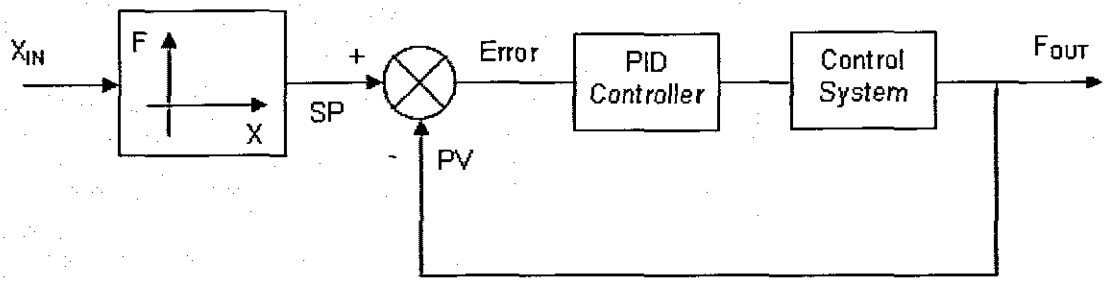


Figure 3-24: Modified closed loop control

3.2 Monitoring and control software

Another important feature of this research is developing *a monitoring and control* software. The purpose of the software is to control a FX mechanical linkage via the accompanying electro-pneumatic components in a manner that fulfils the objectives of the exercise routine designer. The control software is developed to demonstrate F(X) control using the following functions:

1. Step inputs
2. Ramp inputs
3. Step cycles
4. Ramp cycles
5. Sinusoidal

Details of F(X) control functions will be presented in Chapter 4.

Furthermore, the friendly GUI is designed in order to simulate the physical environment into computer. The physical components are simulated and shown as controllers in to GUI.

On the other hand, the software is implemented Data Acquisition and Control (DAQAC) capacity that collects control signals and converts to analog input or output signals between physical environment and software. With this DAQAC capacity, the exercise data can be saved in the software control system, the fitness consultant can then review the data, ensuring that the user meets the required fitness objectives.

The monitoring and control software will be implemented on a "National Instruments PXI" computer, and developed using "LabVIEW 7.0" based-on Object-Oriented (OO) software design methodology.

3.2.1 National Instruments LabVIEW

LabVIEW is a graphical programming language and uses icons instead of lines of text to create applications; in contrast to text-based programming languages, where instructions determine program execution, LabVIEW uses dataflow programming, where the flow of data determines execution (National Instruments, 2003).

In LabVIEW, we build a user interface with a set of tools and objects. The user interface is known as the front panel, and then, add a code using graphical representations of functions to control the front panel objects; the block diagram contains this code, resembles a flowchart (National Instruments, 2003).

LabVIEW is designed for use in the laboratory. The features that make LabVIEW stand out as a research tool are the ease of controlling data flow between computers and instruments, the large number of algorithms that come with the software as premade VIs that can be easily incorporated into other VIs (i.e. PID controller which concerned in 3.1.4.2), the ability to incorporate code from other programs into LabVIEW VIs, and the ability to make VIs that may be used in place of physical instrumentation (Jehander, 2003).

Working with LabVIEW is very different from working with languages like Basic, FORTRAN, and C, which are text-based and procedural. LabVIEW uses a graphic, OO computer language. This type of language takes advantage of the Macintosh or Windows-type operating system, and every variable, function, or subroutine is represented as an object (Gulotta, 1995).

In LabVIEW, instead of writing programs, it creates VIs. VIs have front panels just like any other instrument on your bench; the input variables are set the same way as the settings on a "real" instrument; output is displayed using LEDs, charts, graphs, and digital indicators (Guotta, 1995). VIs may be run as autonomous programs or may be incorporated into other programs. A VI that is called from within another VI is a subVI, it is look like a subroutine in a text-based program (Gulotta, 1995). Therefore, the object-oriented design methodology is also used to develop VI and subVI in LabVIEW.

3.2.2 Object-oriented design methodology

Object-oriented (OO) offers a new and powerful model for developing computer software. The OO methodology speeds the development of new programs, and if properly used, improves the maintenance, reusability, and modifiability of software (Baudoin & Hollowell, 1996). According to Baudoin and Hollowell (1996), by providing first class support for the objects and classes of objects of an application domain, the OO paradigm precepts offer better modeling and implementation of systems.

3.2.2.1 Object-oriented methodology

Object-Oriented (OO) methodology is a system development approach encouraging and facilitating re-use of software components. With this methodology, a computer system can be developed on a component basis which enables the effective re-use of existing components and facilitates the sharing of its components by other systems (HKSAR, 2005).

OO methodology applies a single object model that evolves from the analysis and design stage and carries all the way down to the programming level. An object contains both the data and the functions that operate upon that data. An object can only be accessed via the functions it makes publicly available, so that all details of its implementation are hidden from all other objects. This strong encapsulation provides the basis for the improvements in traceability, quality, maintainability and extensibility that are key features of well-designed object-oriented systems (HKSAR, 2005).

Many benefits are cited for OOD, some of these potential benefis are:

- **Faster development:** OOD has long been touted as leading to faster development. Many of the claims of potentially reduced development time are correct in principle, if a bit overstated.

- **Reuse of previous work:** This is the benefit cited most commonly in literature, particularly in business periodicals. OOD produces software modules that can be plugged into one another, which allows creation of new programs. However, such reuse does not come easily. It takes planning and investment.

- **Increased quality:** Increases in quality are largely a by-product of this program reuse. If 90% of a new application consists of proven, existing components, then only the remaining 10% of the code has to be tested from scratch. That observation implies an order-of-magnitude reduction in defects.

- **Modular architecture:** Object-oriented systems have a natural structure for modular design: objects, subsystems, framework, and so on. Thus, OOD systems are easier to modify. OOD systems can be altered in fundamental ways without ever breaking up since changes are neatly encapsulated. However, nothing in OOD guarantees or requires that the code produced will be modular. The same level of care in design and implementation is required to produce a modular structure in OOD, as it is for any form of software development.

- **Client/server applications:** By their very nature, client/server applications involve transmission of message back and forth over a network, and the object-message paradigm of OOD meshes well with the physical and conceptual architecture of client/server applications.

- **Better mapping to the problem domain:** This is a clear winner for OOD, particularity when the project maps to the real world. Whether objects represent customers, machinery, banks, sensors or pieces of paper, they can provide a clean, self-contained implication which fits naturally into human thought processes.

Adhikari (1995); Taylor (1995); Shah, Sivitanides & Martin (1997)

3.2.2.2 Object-oriented design theory

The aim of OO design is to design the product in terms of objects, that is, instantiations of the classes and subclasses that were extracted during OO analysis.

An object like a "black box" which receives and sends messages, provides a canonical focus throughout analysis, design, and implementation by emphasising the state, behaviour, and interaction of objects in its models, providing the desirable property of seamlessness between activities (objectfaq, n.d.).

OO design can be thought of in two phases. The first, called high-level design, deals with the decomposition of the system into large, and complex objects. The second phase is called low-level design. In this phase, attributes and methods are specified at the level of individual objects. This is also where a project can realise most of the reuse of object-oriented products, since it is possible to guide the design so that lower-level objects correspond exactly to those in existing object libraries or to develop objects with reuse potential (objectfaq, n.d.).

OO methodology emphasises the following concepts:

- **Class** – the unit of definition of data and behaviour for some kind-of-thing. A class is the basis of modularity and structure in an object-oriented computer program. A class should typically be recognisable to a non-programmer familiar with the problem domain, and the code for a class should be self-contained and independent. With such modularity, the structure of a program will correspond to the aspects of the problem that the program is intended to solve. This simplifies the mapping to and from the problem and program.

- **Object** – an instance of a class, an object is the run-time manifestation of a particular exemplar of a class. Each object has its own data, though the code within a class (or a subclass or an object) may be shared for economy.

- **Method** – also known as message. It is refers to how code can use an object of some class. A method is a form of subroutine operating on a single object. Methods may be divided into queries returning the current state and commands changing it.

- **Inheritance** – a mechanism for creating subclasses, inheritance provides a way to define a (sub)class as a specialisation or subtype or extension of a more general class. A subclass inherits all the members of its superclass(es), but it can extend their behaviour and add new members.

- **Encapsulation** – refers to ensuring that code outside a class sees only functional details of that class, but not implementation details. The latter are liable to change, and could allow a user to put an object in an inappropriate state. Encapsulation is achieved by specifying which classes may use the members of an object. The result is that each object exposes to any class a certain interface – those members accessible to that class. Members are often specified as public, protected and private, determining whether they are available to all classes, sub-classes or only the defining class.

- **Abstraction** – the ability of a program to ignore the details of an object's (sub)class and work at a more generic level when appropriate.

- **Polymorphism** – polymorphism is behaviour that varies depending on the class in which the behavior is invoked, that is, two or more classes can react differently to the same message.

Wikipedia (n.d.)

OO programming is a computer program that may be seen as comprising a collection of individual units or objects that act on each other, as opposed to a traditional view in which a program may be seen as a collection of functions, or simply as a list of instructions to the computer. Each object is capable of receiving messages, processing data, and sending messages to other objects. Each object can be viewed as an independent little machine or actor with a distinct role or responsibility (Wikipedia, n.d.).

Three major steps are involved in object-oriented approach to systems analysis and design (van Vliet, 2001):

1. Identifying the objects;
2. determining their attributes and services; and
3. determining the relationships between objects.

Object-oriented analysis and design methods use a variety of graphical notations to depict the models developed. In particular, there is an overwhelming agreement that at least the following types of diagram are required:

- A **class diagram** to depict the static decomposition of the system. A class diagram is a graph in which the nodes are objects (classes) and the edges are relationships between objects.

- A **state diagram** to model the dynamic behaviour of single objects. The nodes in a state diagram represent possible states of an object. The edges denote possible transitions between states.

- An **interaction diagram** to model the sequence of messages of which a typical interaction is composed.

van Vliet (2001)

3.3 Summary

This chapter has presented the methods use a computer-controlled pneumatic rig to replace traditional deadweight in standard exercise equipment. The pneumatic system has two double-acting electro-pneumatic cylinders that are used to simulate exerciser and exercise equipment. The core of this research is based on force-displacement relationship. FX control relies on different pressure control. It has been defined as a bi-directional pneumatic cylinder that has each chamber connected via an electronically controlled pressure control valve to a high pressure reservoir. By reducing or increasing pressure, force can be controlled through different pressure. In FX this is specifically controlled using a computer-based profile that determines the differential pressure in the cylinder relative to the spatial position of the mechanical linkage.

Closed-loop control has been represented as feedback to control outputs of a dynamical system with great accuracy. In closed-loop control, input and output quantities are compared to produce an error signal which actually operated. In order to avoid oscillatory and unstable from occurring in feedback system, a PID controller is used, with specific reference to the manifestation of P-control for responsiveness, I-control for accuracy, and D-control for stability.

Finally, a monitoring and control software is developed with a friendly GUI design. The objective of the software is to control FX mechanical linkage via the accompanying electro-pneumatic components. On the other hand, the software is implemented on a "National Instruments PXI" computer featuring Data Acquisition and Control (DAQAC) capacity, and developed using "LabVIEW 7.0" based on object-oriented software design methodology.

CHAPTER 4

COMPUTER-CONTROLLED PNEUMATIC EXERCISE EQUIPMENT

Current exercise equipment impose fixed-trajectory exercise on users with the dominance of static equipment designs. These exercise equipment are normally called deadweight-based exercise equipment. In standard deadweight-based exercise equipment, the weights generally can be changed only when the equipment is inactive. This chapter, will present a dynamic resistance exercise equipment with onboard data management. The functioning of this exercise equipment is based on a force-displacement (FX) relationship. A counter force (F) is presented by the equipment against the exercisers effort. In deadweight-based equipment, the weight (force) at which the exercise is performed can be set. For a given setting, the weight will remain constant with respect to displacement (X) of the point of application of the exercise, i.e. $F(X) = constant$.

In this equipment, the FX control unit will replace the weight stacks of standard deadweight-based exercise equipment thereby greatly enhancing its functionality in respect of exercise optimisation and exercise data gathering. The actuation unit will feature a single pneumatic cylinder actuation based on FX control technology.

The software implementation will feature fail-safe design approaches to safeguard both human and machine. The software will also feature performance monitoring of both the human and machine.

The software design will be based on object-oriented methodology. Each function will be developed as an independent unit. Each unit can be called by one or more units. The integrated software is combined with all independent units, and has all functionalities.

With integrated software, the exerciser can perform a comprehensive set of exercise routines on exercise equipment without manually having to effect any adjustments. This new technology optimises exercise effectiveness for exercisers.

4.1 Design environment

The design environment consists of hardware environment which provides the real-world entities for applications, and software environment which supports how to execute applications. A software environment for a particular application includes the operating system, the database system, and specific development tools. Considering the whole system, the design environment is depicted in Figure 4-1.

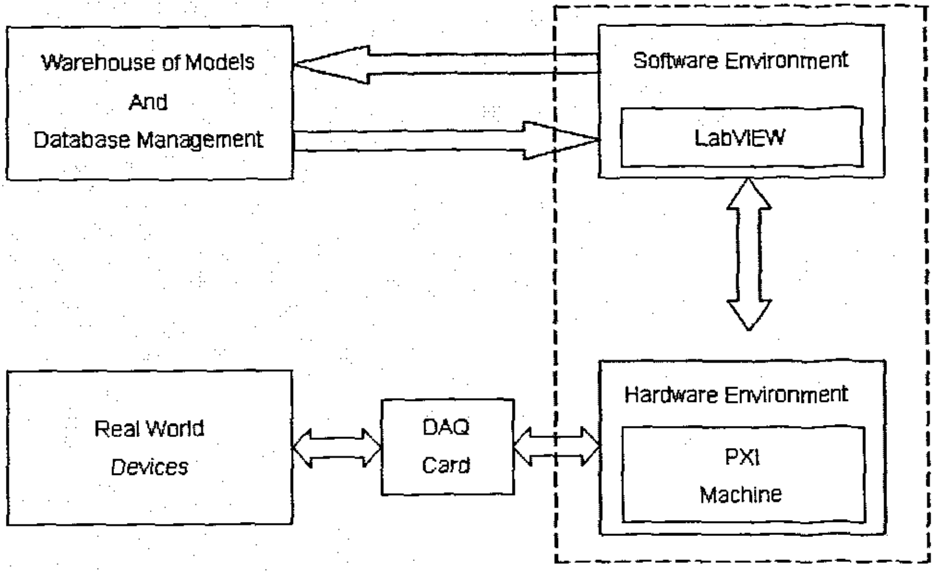

Warehouse of Models
And
Database Management
Software Environment
LabVIEW
Real World
Devices
DAQ
Card
Hardware Environment
PXI
Machine

Figure 4-1: Diagram of design the environment

4.1.1 Hardware environment

In this research, hardware environment is made up of a pneumatic rig connected with data acquisition card in order to communicate with a National Instruments PXI machine.

-

4.1.1.1 National Instruments PXI machine

With PXI modular instrumentation, we automatically benefit from the low cost, ease of use, and flexibility of PC technology. PXI also delivers significant performance improvements over older architecture by combining the high-speed, industry-standard PCI bus with a modular chassis-based architecture; PXI adds timing and synchronisation to provide a high-level of integration between modules designed specifically for measurement and automation applications (National Instruments, 2005). The PC-based architecture and advanced synchronisation features, are the heart of PXI modular instrumentation (National Instruments, 2005). Figure 4-2 shows the interface of PXI modular instrumentation.

National Instruments PXI offers a wide variety of PXI controllers, such as PXI embedded controller, PXI real-time controller, and PXI network system controller.

National Instruments PXI embedded controllers provide a high-performance compact embedded computer solution for our PXI measurement system. NI PXI embedded controllers come with standard features such as integrated CPU, hard drive, RAM, Ethernet, video, keyboard / mouse, serial, USB, and other peripherals, as well as Microsoft windows and all device drivers already installed (National Instruments, 2005).

National Instruments PXI real-time controllers deliver real-time, deterministic, and reliable I/O for measurement, automation, and control (National Instruments, 2005). We develop our LabVIEW application with the NI LabVIEW real-time module on Windows, and then download the program to our embedded controller via Ethernet. The embedded code executes on a real-time operation system. Thus, we use all of the powerful, flexible development tools of LabVIEW to build reliable real-time solutions.

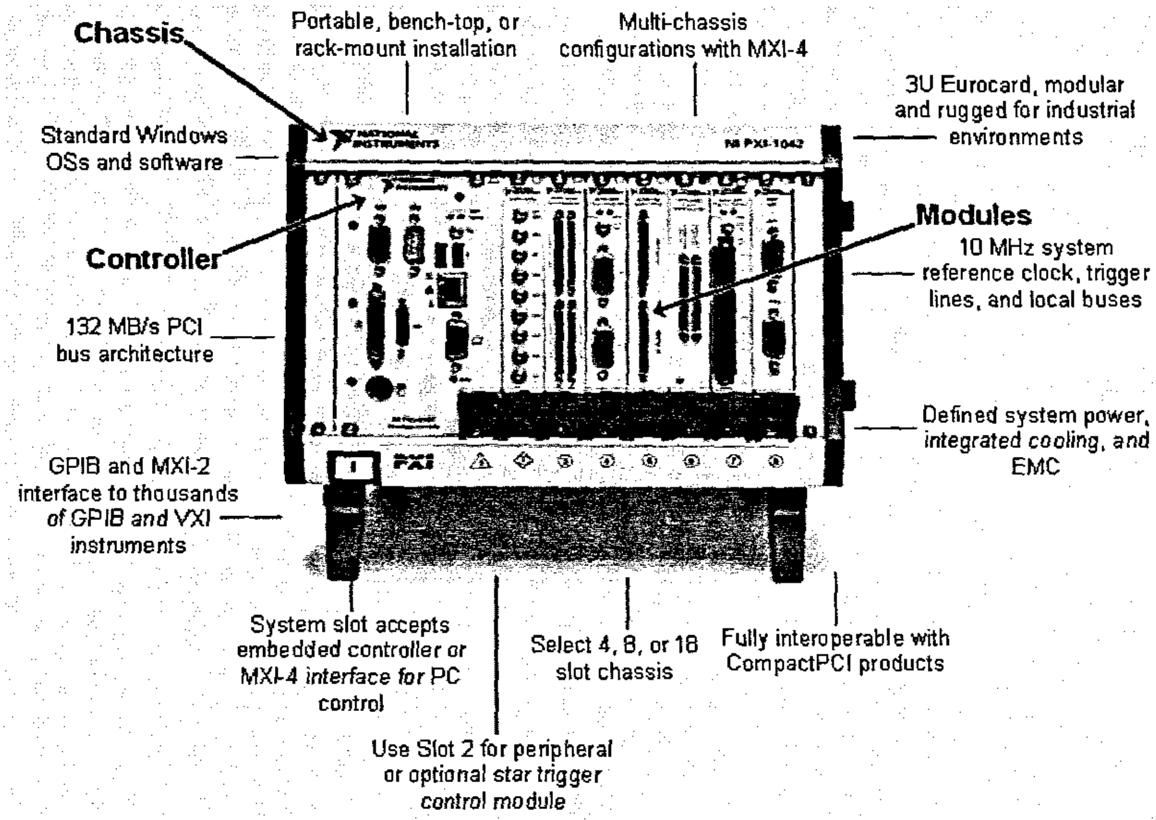

Chassis
Portable, bench-top, or rack-mount installation
Multi-chassis configurations with MXI-4
3U Eurocard, modular and rugged for industrial environments
Standard Windows OSs and software
Controller
Modules
10 MHz system reference clock, trigger lines, and local buses
132 MB/s PCI bus architecture
Defined system power, integrated cooling, and EMC
GPIB and MXI-2 interface to thousands of GPIB and VXI instruments
System slot accepts embedded controller or MXI-4 interface for PC control
Select 4, 8, or 18 slot chassis
Fully interoperable with CompactPCI products
Use Slot 2 for peripheral or optional star trigger control module

Figure 4-2: Interface of PXI modular instrumentation

National Instruments PXI network system controllers are ideal for Ethernet-based measurement systems that are controlled remotely, publish data, or are accessed over a network from one or more desktop or laptop PCs (National Instruments, 2005). With National Instruments PXI network system controllers, we can use standard Ethernet-based network technology to easily create simple point-to-point measurement applications or distributed measurement applications requiring multiple measurement and control nodes. The PXI network system controllers consist of PXI embedded controllers with LabVIEW or LabVIEW real-time software. LabVIEW and LabVIEW real-time have built-in functionality for easily building and deploying networked measurement applications (National Instruments, 2005).

4.1.1.2 Pneumatic rig

A pneumatic system has been described in Chapter 3. The exercise equipment is controlled by software through electro-pneumatic direct control to accomplish high-speed and accurate positioning in repetitive movement. Figure 4-3 presents the configuration of the whole pneumatic rig. The DNC... double-acting pneumatic cylinder has two chambers, each connected via a VPPM proportional pressure control valve to a high pressure reservoir. In the middle of Figure 4-3, is a power supply and four MPZ setpoint modules controlling and providing voltages to each VPPM. The built-in pressure sensors are further provided for measuring the output pressure response provided to the load and for generating a corresponding feedback voltage signal provided to the control circuit.

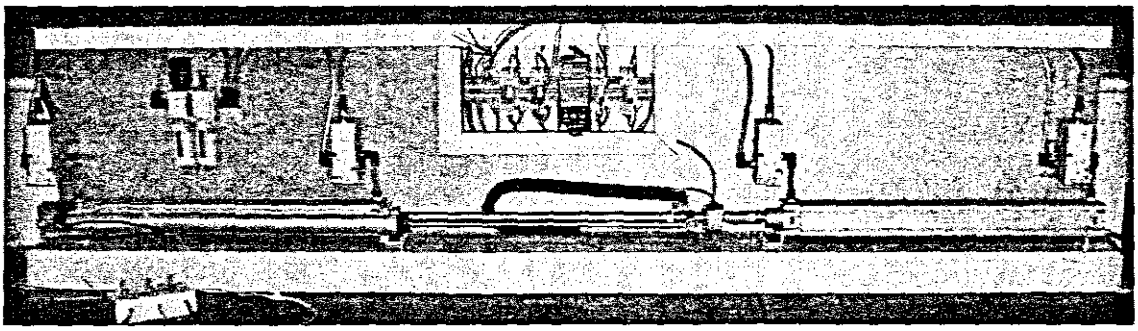


Figure 4-3: Pneumatic rig

Figure 4-3 depicts a simulated exerciser doing pushing or pulling action. In the simulated exercise equipment, increasing or reducing pressure force in the cylinder depends on the relative positions from simulated exerciser in order to get correct force to against exerciser effort. A closed cycle has been produced between position / displacement (X) and force (F) which has discussed in Chapter 3.

Finally, the pneumatic rig control signals are connected to a DAQ card as a bridge linking between the pneumatic rig and the control computer. In this section, four analog input signals will throughout DAQ card to connect each MPZ setpoint module to produce different voltages from the control computer in order to actuate each of the

VPPM. Two analog output signals which are produced by the displacement and force transducer are sent back to control computer as the feedback signals through the DAQ card.

4.1.1.3 Instrument amplifier

In order to increase the weak voltage signals detected from the force transducer, an amplifier has been designed to convert a small amount of energy to a larger amount of energy. The designed amplifier is shown in Figure 4-4. It includes two main components – INA 128 and OPA 2132. The block diagram of the amplifier is depicted in Figure 4-5. The signals from force transducer have been signed to a sin() signal – V_1. Positive signals are transferred to INA 128 port 3, and negative signals to port 2 of INA 128. Signals will be amplified once they arrive at INA 128 which is the main amplifier in the functioning. According to the gain Equation 4-1, in INA 128

$$G = 1 + \frac{50k\Omega}{R_G} \quad (R_G = 50)$$ **Equation 4-1**

Therefore, to calculate gain equal to $1 + \frac{50k}{50} = 1001$, which means signals will be amplified 1001 times by INA 128, then the out signals transferred by INA 128 port 6 to OPA 2132. The main function of OPA 2132 is to drive signals to DAQ card. In addition, OPA 2132 will amplify signals, depending on OPA 2132 gain Equation 4-2:

$$G = \frac{20k\Omega}{R_5} \quad (R_5 = 10k)$$ **Equation 4-2**

to have gain 2 from OPA 2132. Therefore, the original signals of force transducer have been amplified $1001 \times 2 = 2002$ times. Details about INA 128 and OPA 2132 are presented in the following sections.

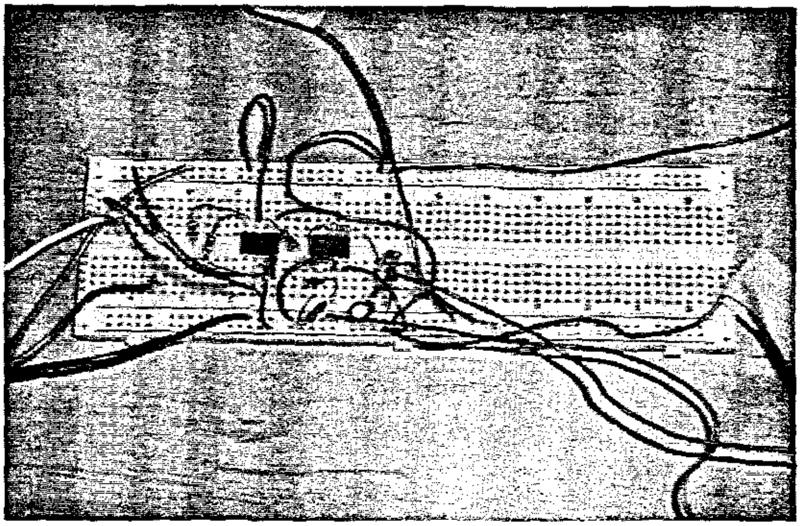


Figure 4-4: Instrument amplifier

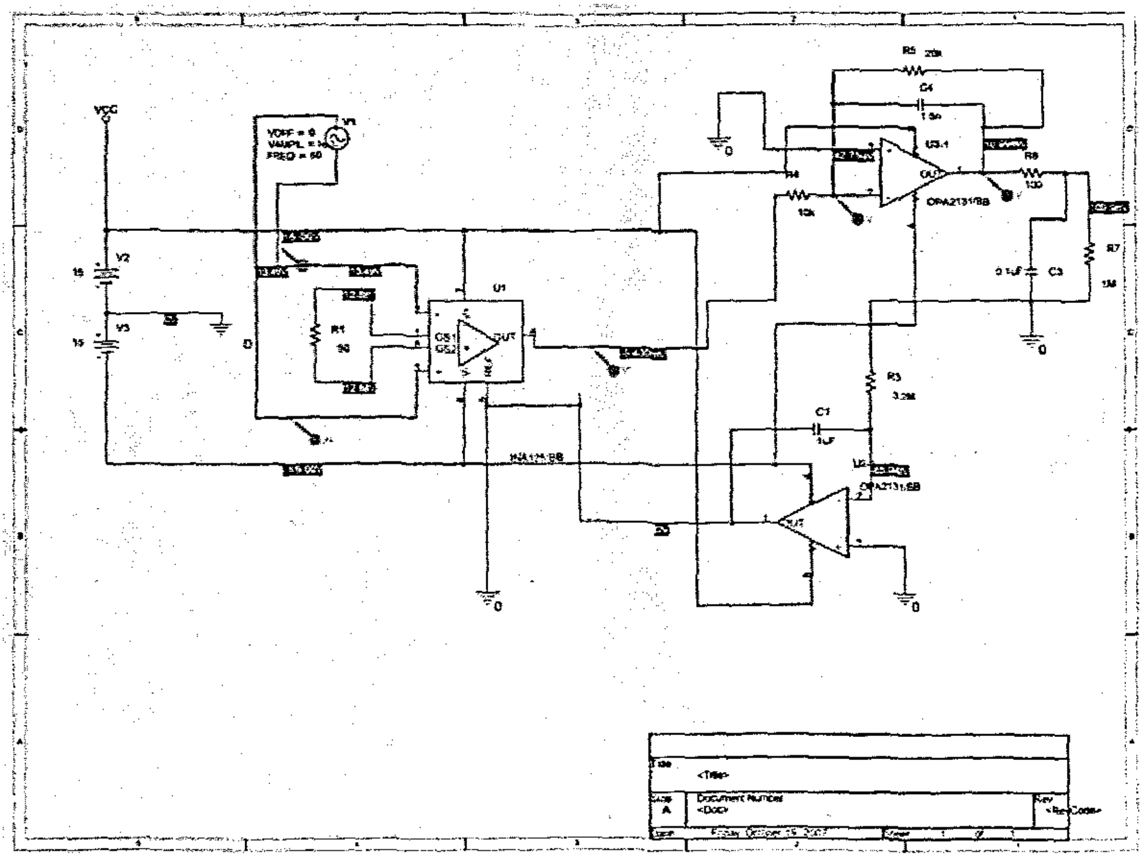

VCC
V1
VOFF = 0
FREQ = 60
V2
15
V3
15
0
R1
50
U1
CS1
CS2
OUT
INA128/BB
R5 20k
C4
U3A
OPA2131/BB
R4
10k
R6
100
R7
1M
0.1uF
C3
0
R3
3.3M
C1
1uF
U2
OPA2131/BB
OUT
0
0
Title
<Title>
Size
A
Document Number
<Doc>
Rev
<RevCode>

Figure 4-5: Block diagram of instrument amplifier

INA 128

The INA 128 is a low power, general purpose instrumentation amplifier offering excellent accuracy; its versatile 3-op amp design and small size makes it ideal for a wide range of applications. Current feedback input circuitry provides wide bandwidth even at high gain; a single external resistor sets any gain from 1 to 10,000, and provides an industry standard gain equation (Burr-Brown, 2007).

INA 128 is laser trimmed for very low offset voltage (50 μV), drift (0.5 $\mu V/°C$) and high common-mode rejection (120dB at G>=100). It operates with power supplies as low as ±2.25V, and quiescent current is only 700 μA - ideal for battery operated systems; internal input protection can withstand up to ±40V without damage. It is available in 8-pin plastic DIP, and SO-8 surface-mount packages, specified for the -40 $°C$ to +85 $°C$ temperature range (Burr-Brown, 2007). The block diagram of INA 128 is given in Figure 4-6.

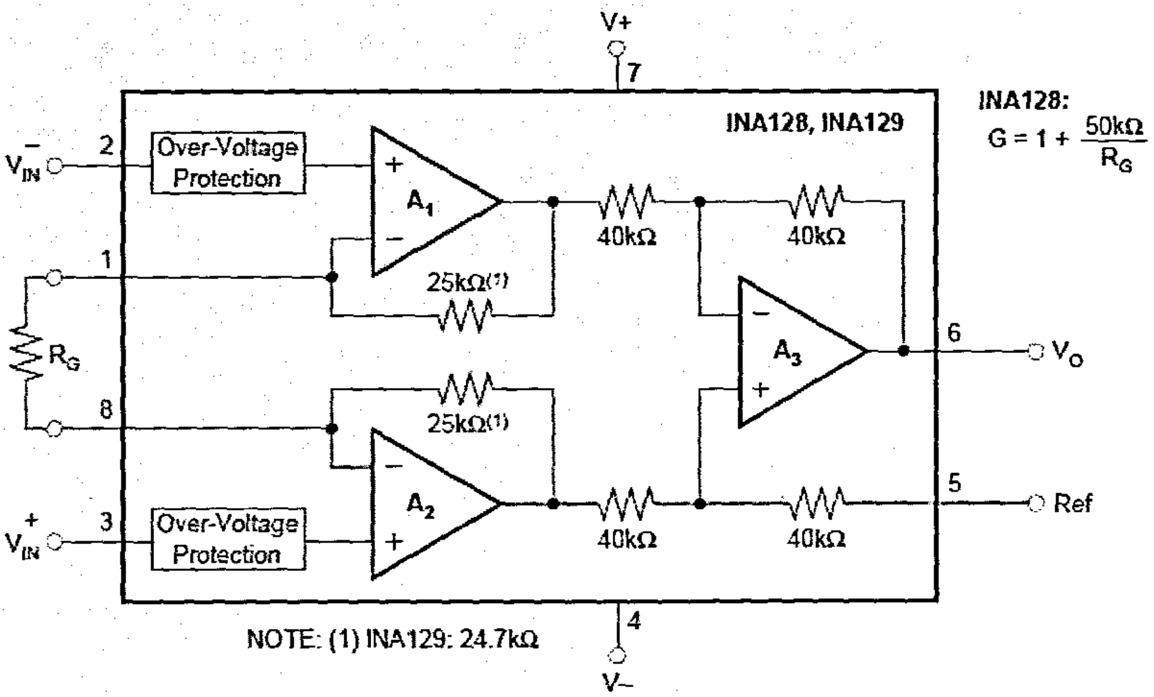

V+
7
INA128, INA129
INA128:
G = 1 + 50kΩ / R_G
V_{IN}^-
2
Over-Voltage Protection
A1
40kΩ
40kΩ
1
25kΩ(1)
R_G
A3
6
V_O
8
25kΩ(1)
A2
5
Ref
V_{IN}^+
3
Over-Voltage Protection
40kΩ
40kΩ
NOTE: (1) INA129: 24.7kΩ
4
V–

Figure 4-6: Block diagram of INA 128

OPA 2132

OPA 2132 FET-input op amp provides high-speed and excellent dc performance, the combination of high slew rate and wide bandwidth provide fast settling time. Single, dual, and quad versions have identical specifications for maximum design flexibility, all are ideal for general purpose, audio, data acquisition and communications applications, especially where high source impedance is encountered (Burr-Brown, 2007). The three versions of OPA 2132 are shown in Figure 4-7, in this research, uses dual version.

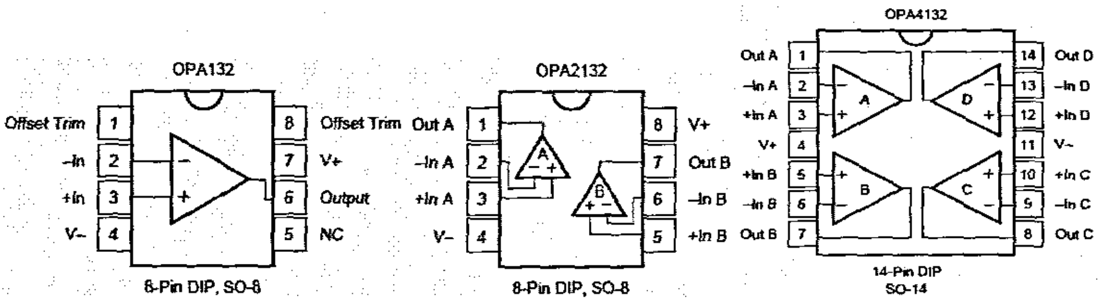

OPA132
Offset Trim
-In
+In
V-
1
2
3
4
8
7
6
5
Offset Trim
V+
Output
NC
8-Pin DIP, SO-8
OPA2132
Out A
-In A
+In A
V-
V+
Out B
-In B
+In B
A
B
8-Pin DIP, SO-8
OPA4132
Out A
-In A
+In A
V+
+In B
-In B
Out B
Out D
-In D
+In D
V-
+In C
-In C
Out C
A
B
C
D
14
13
12
11
10
9
8
14-Pin DIP
SO-14

Figure 4-7: Single, dual, and quad versions of OPA 2132

OPA 2132 is easy to use and free from phase inversion and overload problems often found in common FET-input op amps. Input cascode circuitry provides excellent common-mode rejection and maintains low input bias current over its wide input voltage range (Burr-Brown, 2007). OPA 2132 is stable in unity gain and provides excellent dynamic behaviour over a wide range of load conditions, including high load capacitance. The dual version features completely independent circuitry for lowest crosstalk and freedom from interaction, even when overdriven or overloaded (Burr-Brown, 2007).

A dual version is available in 8-pin DIP and SO-8 surface-mount packages, specified for -40 $^{\circ}C$ to +85 $^{\circ}C$ operation.

4.1.2 Software environment

The objective of the software is to control the FX mechanical linkages via the accompanying pneumatic components. The software applications design will be based on LabVIEW programming environment.

4.1.2.1 LabVIEW programming environment

As mentioned in Chapter 3, LabVIEW is a graphic object-oriented computer language developed to facilitate hardware / software communication. LabVIEW is a complete computer language that can be used like Basic, FORTAN, or C. In contrast to text-based programming languages, LabVIEW uses icons instead of lines of text to create applications, and uses dataflow programming, where the flow of data determines execution.

In LabVIEW, a VI is known as the front panel and block diagram. Which front panel is set tools and objects, then add code using graphical representations of functions to control the front panel objects. The block diagram which resembles a flowchart contains this code.

A simple LabVIEW VI will illustrate to show us the feature of front panel and flow data in block diagram. This example will create a VI that simulates an analog signal and plots it on a waveform graph. The VI will set the input values against a user-specified limit and light an LED if the input value exceeds that limit. Figure 4-8 shows the objects of front panel, and Figure 4-9 represents the flow data in block diagram.

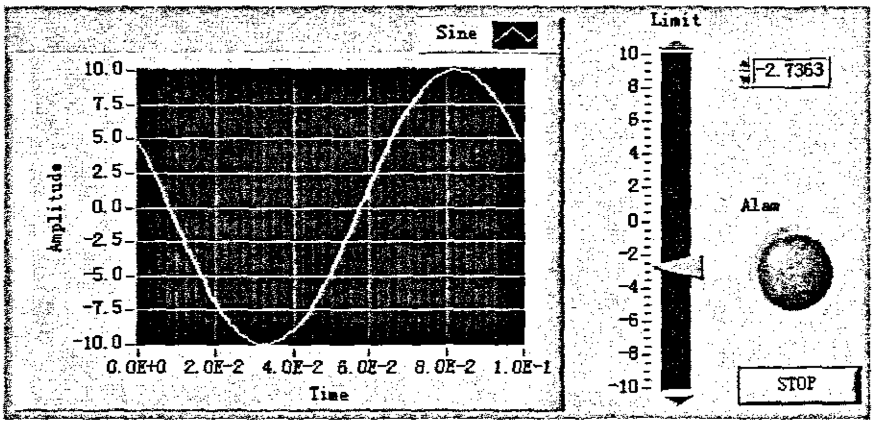
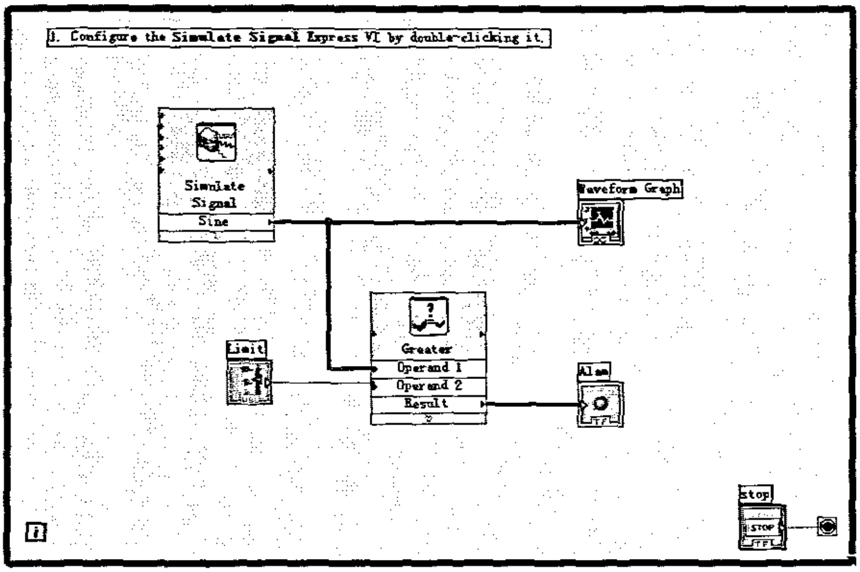


Figure 4-8: A simple LabVIEW VI example – front panel

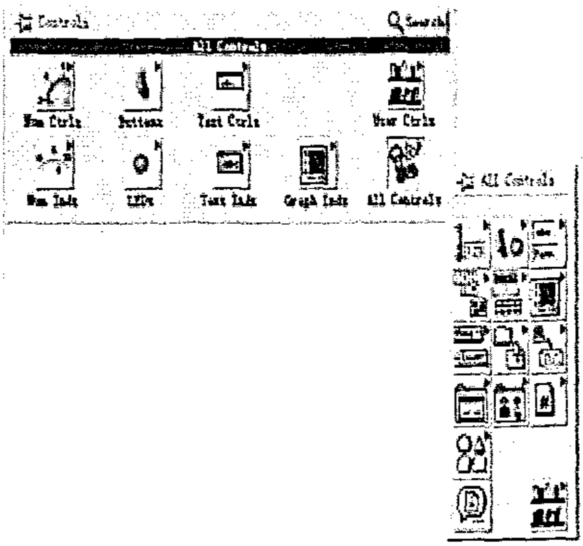


1. Configure the Simulate Signal Express VI by double-clicking it.

Simulate
Signal
Sine
Waveform Graph
Limit
Greater
Operand 1
Operand 2
Result
Alarm
Stop
STOP
TF

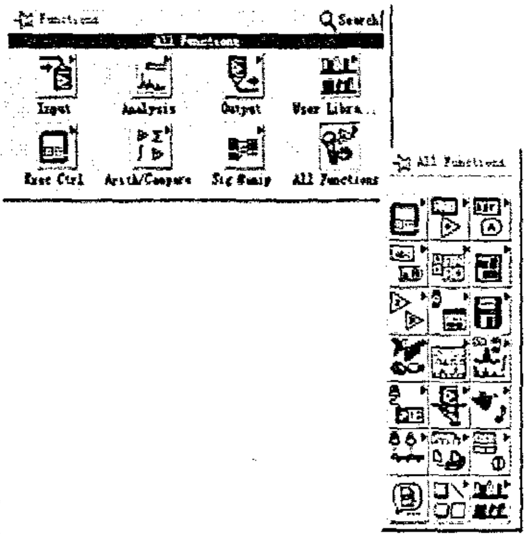
Figure 4-9: A simple LabVIEW VI example – block diagram

LabVIEW provides two palettes, named controls palette and function palette. The control palette that serves as the user interface provides all of the objects and tools such as a numeric box, slide, or LED, shown in Figure 4-10. The function palette which contains the graphical source code that defines the functionality of the VI such as structures, array, or comparison, shown in Figure 4-11.



Controls
Search
All Controls
Num Ctrls
Buttons
Text Ctrls
User Ctrls
Num Inds
LEDs
Text Inds
Graph Inds
All Controls
All Controls

Figure 4-10: Controls palette



Functions
Search
All Functions
Input
Analysis
Output
User Libra...
Exec Ctrl
Arith/Compare
Sig Manip
All Functions
All Functions

Figure 4-11: Functions palette

4.2 Pneumatic mechanical linkage

Chapter 3 discussed two assumptions that defined about the initial pressure of cylinders. This section will concentrate on discussing the processes of these two experiments. The experiments include electronic wires connection, and pneumatic rig set up under different situations. Furthermore, the software aspects will be presented based on those two experiments. The specific software design will be presented based on developing a computer-controlled exercise system in 4.4.

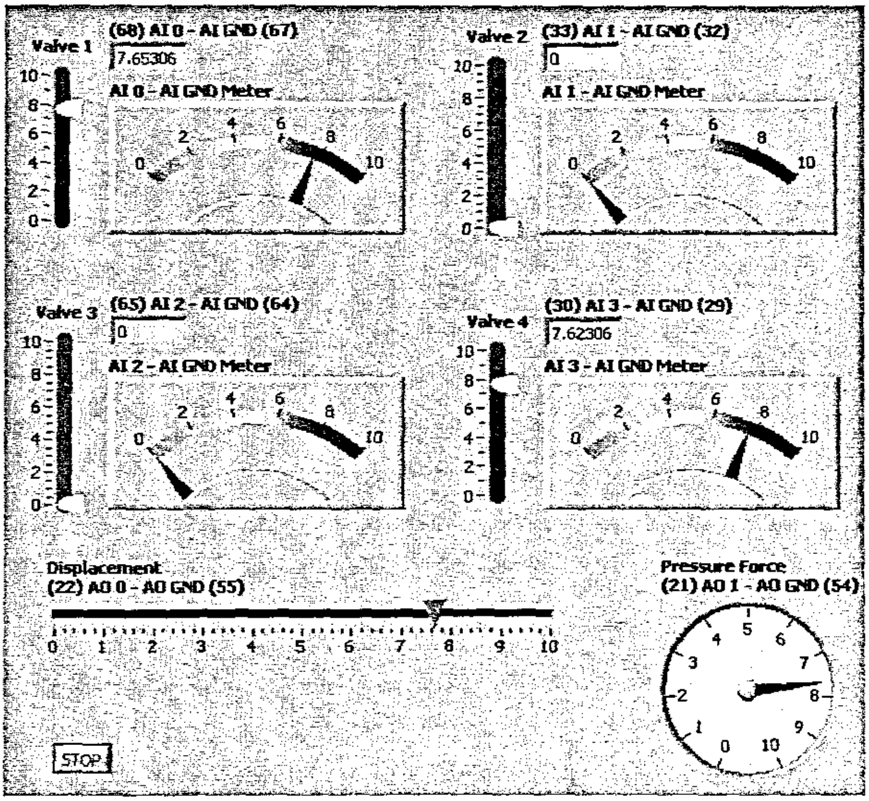
4.2.1 Experiment 1 – One valve open and close another valve

In experiment 1, each cylinder always keeps one valve open and one closed. Assume exerciser cylinder has valve 1 and valve 2, and exercise equipment cylinder has valve 3 and valve 4. That is, if valve 1 opens, valve 2 will be closed. At the same time, valve 3 is also closed and valve 4 open in order to against pressure force by valve 1. The same logic is used in the backward path. On the backward, valve 1 and valve 4 will release pressure immediately, and valve 2 increases pressure gradually, valve 3 supports to be changed to against valve 2.

Monitor and control software

The features of two descriptions in experiment 1 are shown in Figures 4-12 and 4-13. Figure 4-14 gives the block diagram. In the block diagram, four analog input channels are controlling each of valves. The displacement transducer and force transducer will detect current values of displacement and pressure force. Those are generated based on the pressure in the cylinders. The detected values will be sent back through two analog output channels to the system.

In the whole processing, all analog input signals and analog output signals are collected, converted, and sent by a National Instrument TBX-68 DAQ card. In Figure 4-12 and Figure 4-13 , each valve controller is signed by "*AI*" with "*Port Number*", such as valve 1 is signed *(68) AI0 – AI GND (67)* which AI means analog input, port number is the connect point on TBX-68 DAQ card. On the other hand, AO means analog output which signed for displacement controller and pressure force controller. For the data transfers between control software and pneumatic linkage, the following sections will present the specific wires connection, DAQ card set up, and pneumatic control panels set up.



(68) AI 0 - AI GND (67): 7.65306

(33) AI 1 - AI GND (32): 0

(65) AI 2 - AI GND (64): 0

(30) AI 3 - AI GND (29): 7.62306

Valve 1
AI 0 - AI GND Meter
Valve 2
AI 1 - AI GND Meter
Valve 3
AI 2 - AI GND Meter
Valve 4
AI 3 - AI GND Meter
Displacement
(22) AO 0 - AO GND (55)
Pressure Force
(21) AO 1 - AO GND (54)
STOP
0
2
4
6
8
10

Figure 4-12: Experiment 1 – valve 1 & valve 4 open

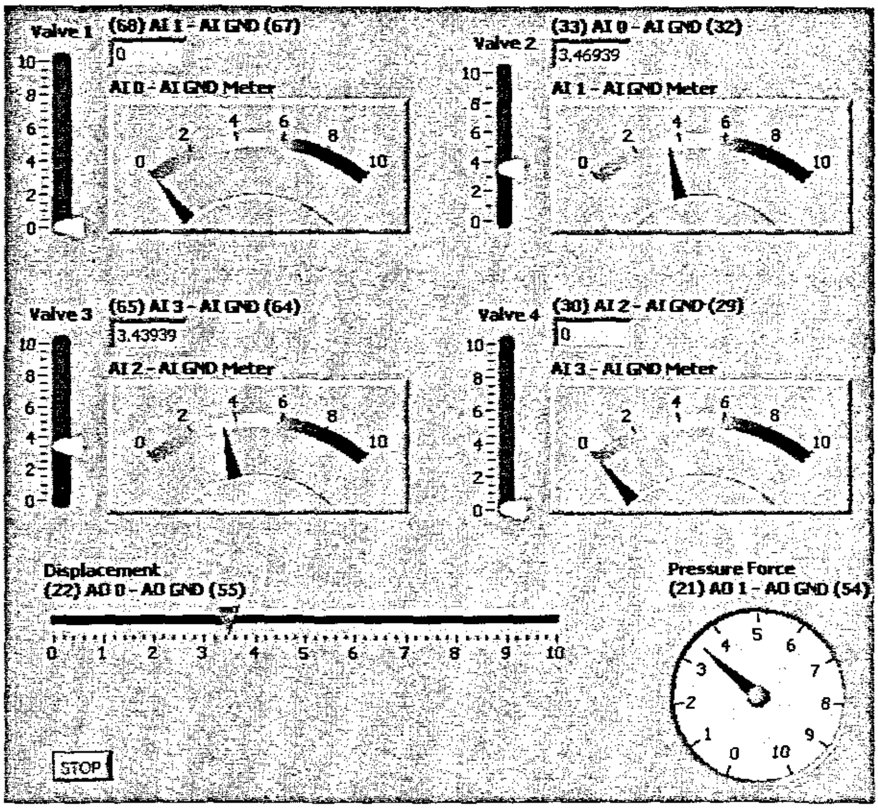

Valve 1
(68) AI 1 - AI GND (67)
0
AI 0 - AI GND Meter
Valve 2
(33) AI 0 - AI GND (32)
3.46939
AI 1 - AI GND Meter
Valve 3
(65) AI 3 - AI GND (64)
3.43939
AI 2 - AI GND Meter
Valve 4
(30) AI 2 - AI GND (29)
0
AI 3 - AI GND Meter
Displacement
(22) AO 0 - AO GND (55)
Pressure Force
(21) AO 1 - AO GND (54)
STOP

Figure 4-13: Experiment 1 – valve 2 & valve 3 open

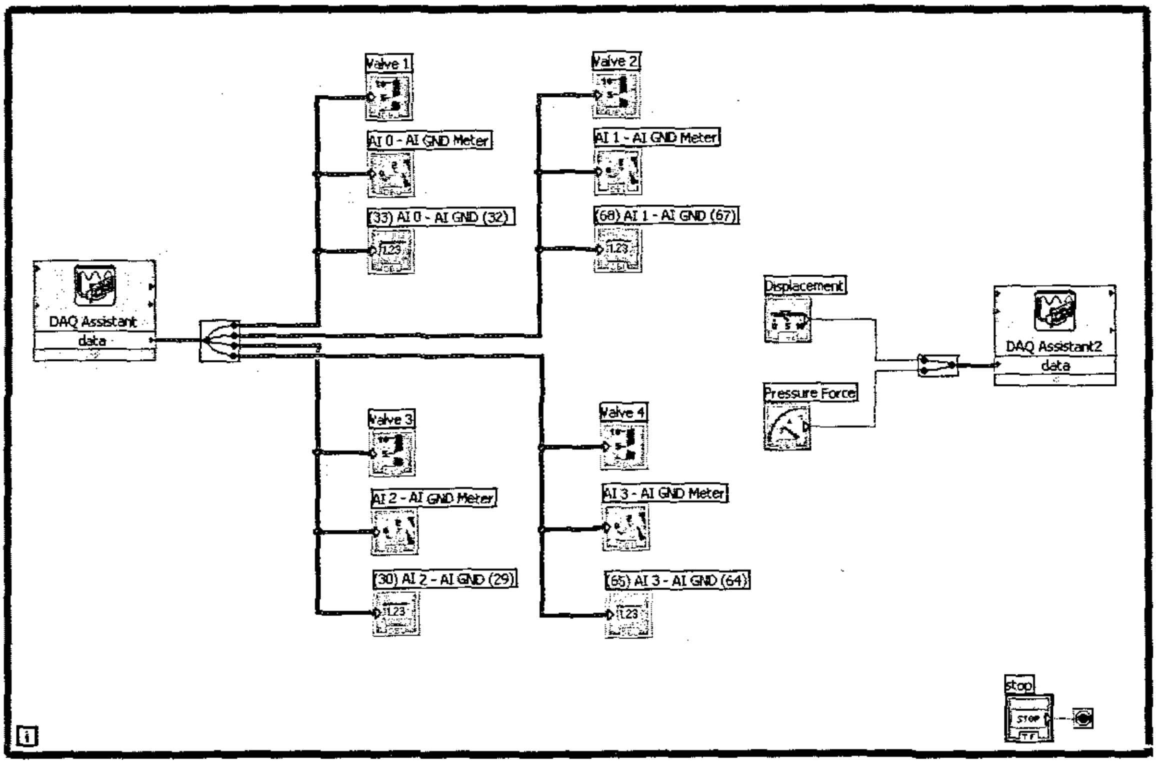

DAQ Assistant
data
Valve 1
AI 0 - AI GND Meter
(33) AI 0 - AI GND (32)
Valve 2
AI 1 - AI GND Meter
(68) AI 1 - AI GND (67)
Valve 3
AI 2 - AI GND Meter
(30) AI 2 - AI GND (29)
Valve 4
AI 3 - AI GND Meter
(65) AI 3 - AI GND (64)
Displacement
Pressure Force
DAQ Assistant2
data
stop

Figure 4-14: Experiment 1 – block diagram

Hardware connections

The TBX-68 DAQ card is one of the most important components used into the project as a data converter. Let us look at the features of TBX-68 in Figure 4-15. The top cable port is going to connect to the control machine, National Instrument PXI machine. The numbers on TBX-68 card are I/O port numbers which have been presented earlier. The I/O connector of TBX-68 card is shown in Figure 4-16. In Experiment 1, has four analog input signals used on AI0 (68), AI1 (33), AI2 (65), and AI3 (30) port; two analog output signals, used on port AO0 (22) and AO1 (21). Now, the connected TBX-68 card is shown in Figure 4-17.

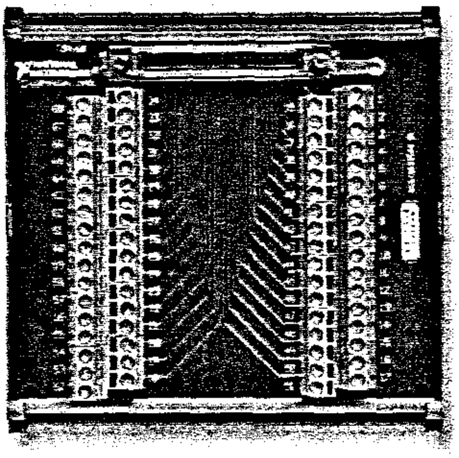


Figure 4-15: National Instrument TBX-68 DAQ Card

Secondly, how to actuate the pneumatic rig according to software commands? There have series wires connections have to present between pneumatic rig and TBX-68 DAQ card. A signal control unit (Figure 4-18) is used in the pneumatic rig in order to receive and reply signals accompany with TBX-68 DAQ card. The block diagram of signal control unit is shown in Figure 4-19, the signals control ports on TBX-68 DAQ card are configured as well in Figure 4-19.

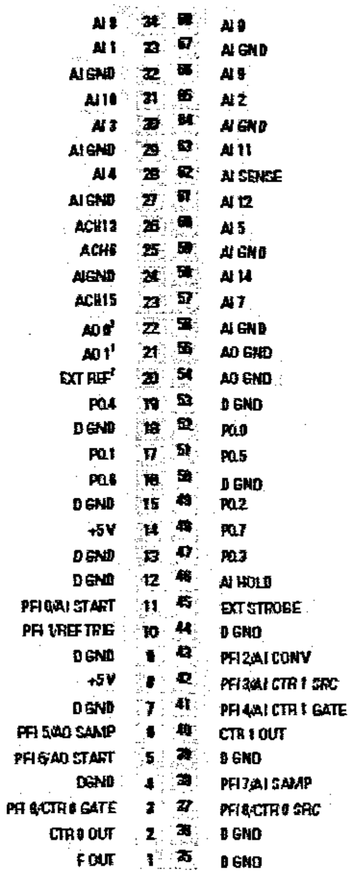

AI 8 34 68 AI 0
AI 1 33 67 AI GND
AI GND 32 66 AI 9
AI 10 31 65 AI 2
AI 3 30 64 AI GND
AI GND 29 63 AI 11
AI 4 28 62 AI SENSE
AI GND 27 61 AI 12
ACH13 26 60 AI 5
ACH6 25 59 AI GND
AIGND 24 58 AI 14
ACH15 23 57 AI 7
AO 0[1] 22 56 AI GND
AO 1[1] 21 55 AO GND
EXT REF[2] 20 54 AO GND
P0.4 19 53 D GND
D GND 18 52 P0.0
P0.1 17 51 P0.5
P0.6 16 50 D GND
D GND 15 49 P0.2
+5V 14 48 P0.7
D GND 13 47 P0.3
D GND 12 46 AI HOLD
PFI 0/AI START 11 45 EXT STROBE
PFI 1/REF TRIG 10 44 D GND
D GND 9 43 PFI 2/AI CONV
+5V 8 42 PFI 3/AI CTR 1 SRC
D GND 7 41 PFI 4/AI CTR 1 GATE
PFI 5/AO SAMP 6 40 CTR 1 OUT
PFI 6/AO START 5 39 D GND
DGND 4 38 PFI 7/AI SAMP
PFI 9/CTR 0 GATE 3 37 PFI 8/CTR 0 SRC
CTR 0 OUT 2 36 D GND
F OUT 1 35 D GND

Figure 4-16: TBX-68 – I/O connector

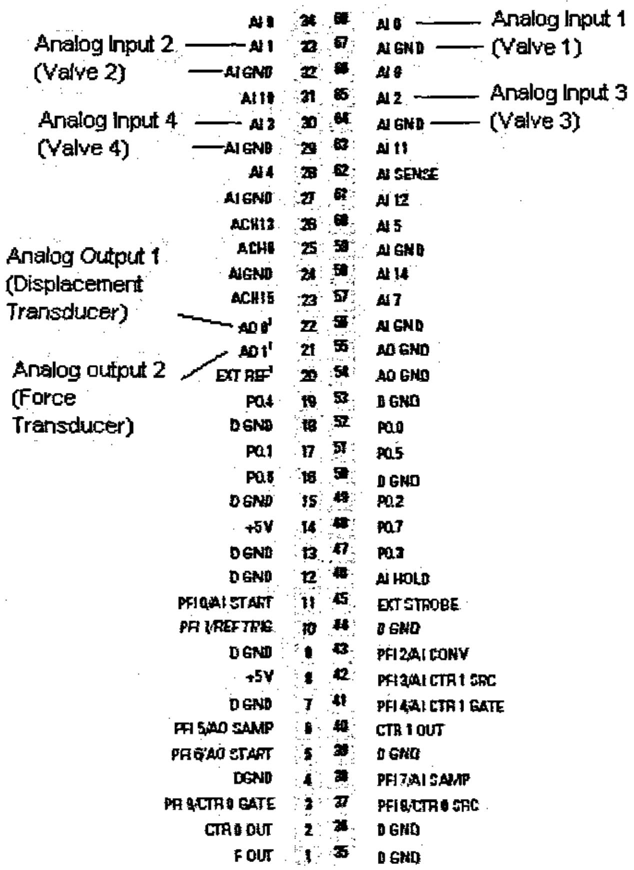

Analog Input 1 (Valve 1)
Analog Input 2 (Valve 2)
Analog Input 3 (Valve 3)
Analog Input 4 (Valve 4)
Analog Output 1 (Displacement Transducer)
Analog output 2 (Force Transducer)
AI 8 34 68 AI 0
AI 1 33 67 AI GND
AI GND 32 66 AI 9
AI 10 31 65 AI 2
AI 3 30 64 AI GND
AI GND 29 63 AI 11
AI 4 28 62 AI SENSE
AI GND 27 61 AI 12
ACH13 26 60 AI 5
ACH6 25 59 AI GND
AIGND 24 58 AI 14
ACH15 23 57 AI 7
AO 0[1] 22 56 AI GND
AO 1[1] 21 55 AO GND
EXT REF[2] 20 54 AO GND
P0.4 19 53 D GND
D GND 18 52 P0.0
P0.1 17 51 P0.5
P0.6 16 50 D GND
D GND 15 49 P0.2
+5V 14 48 P0.7
D GND 13 47 P0.3
D GND 12 46 AI HOLD
PFI 0/AI START 11 45 EXT STROBE
PFI 1/REF TRIG 10 44 D GND
D GND 9 43 PFI 2/AI CONV
+5V 8 42 PFI 3/AI CTR 1 SRC
D GND 7 41 PFI 4/AI CTR 1 GATE
PFI 5/AO SAMP 6 40 CTR 1 OUT
PFI 6/AO START 5 39 D GND
DGND 4 38 PFI 7/AI SAMP
PFI 9/CTR 0 GATE 3 37 PFI 8/CTR 0 SRC
CTR 0 OUT 2 36 D GND
F OUT 1 35 D GND

Figure 4-17: TBX-68 – I/O of experiment 1 & 2

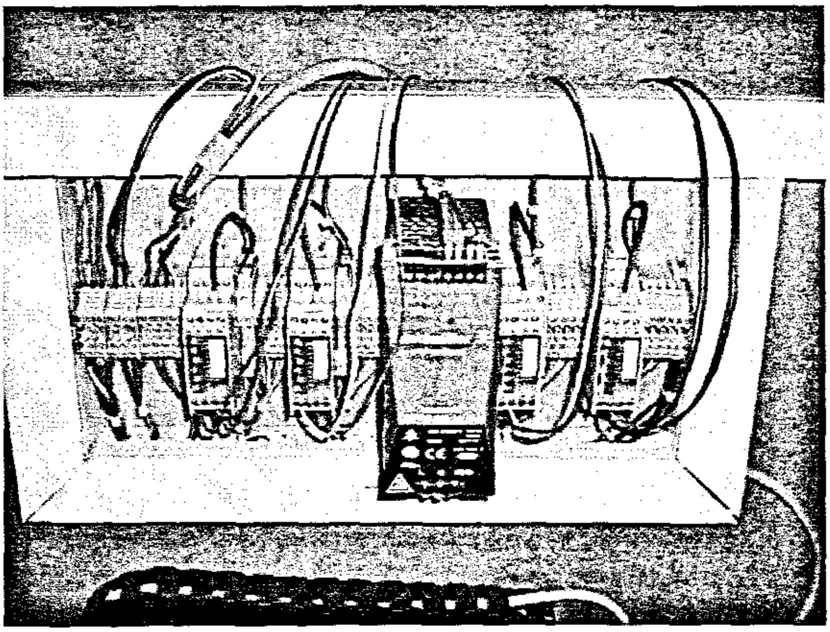


Figure 4-18: Pneumatic rig – signal control unit

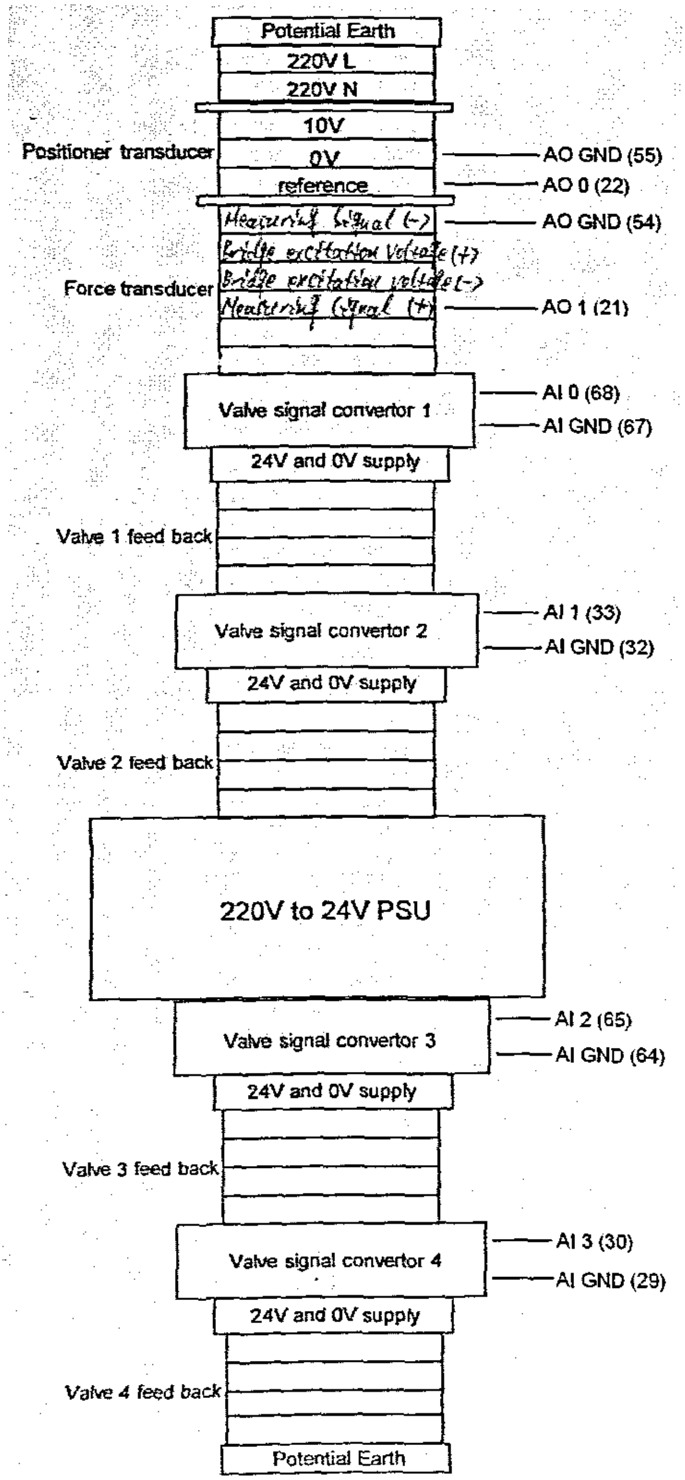

Potential Earth
220V L
220V N
10V
Positioner transducer
0V
reference
AO GND (55)
AO 0 (22)
Measuring signal (-)
AO GND (54)
Bridge excitation voltage (+)
Force transducer
Bridge excitation voltage (-)
Measuring signal (+)
AO 1 (21)
Valve signal convertor 1
AI 0 (68)
AI GND (67)
24V and 0V supply
Valve 1 feed back
Valve signal convertor 2
AI 1 (33)
AI GND (32)
24V and 0V supply
Valve 2 feed back
220V to 24V PSU
Valve signal convertor 3
AI 2 (65)
AI GND (64)
24V and 0V supply
Valve 3 feed back
Valve signal convertor 4
AI 3 (30)
AI GND (29)
24V and 0V supply
Valve 4 feed back
Potential Earth

Figure 4-19: Block diagram of signal control unit

According to the previous descriptions, the wires connection diagrams are shown in Figure 4-20.

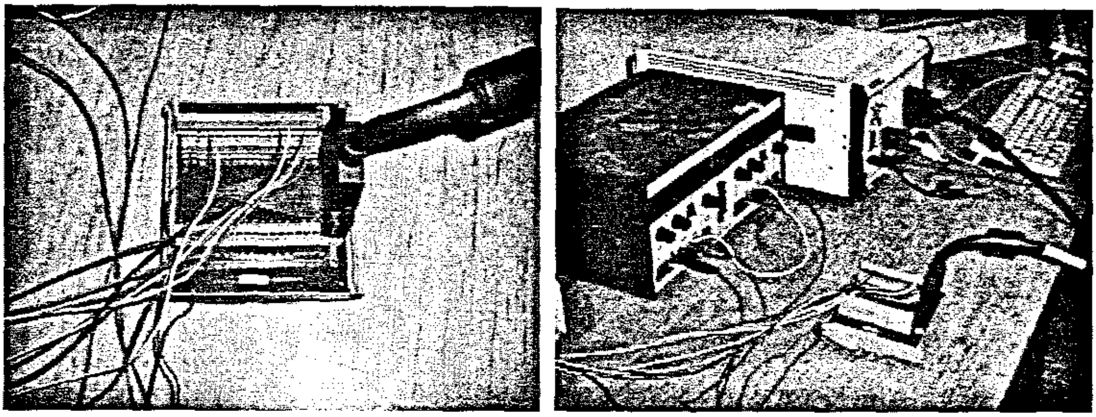


Figure 4-20: Wires connection diagrams

4.2.2 Experiment 2 – Two valves open

In this situation, each cylinder keeps two valves open. On the other hand, the initial pressure will be set to half of the maximum pressure of the cylinder. In order to obtain the intended force, pressure will be activated on both sides of the valve, that is, one side valve will increase half purposed pressure force, and the other side valve will decrease half purposed pressure force. Depending on the directional of the piston, on the forward path, the exerciser cylinder valve 1 pressure will be increased, while valve 2 pressure has to be decreased. Therefore, the equipment cylinder valve 3 pressure will be decreased, valve 4 pressure has to be increased, to against exerciser effort. The same logic is used in the backward path. For example, in Figure 4-21, the initial pressure was set in the middle (5 bars), if wants to produce 6 bars pressure force on the forward path, that is, valve 1 will increase 3 bars and valve 2 will decrease 3 bars at the same time. Therefore, valve 1 5 bars + 3 bars is 8 bars and valve 2 5 bars - 3 bars is 2 bars, then, valve 1 minus valve 2, 8 bars - 2 bars to have 6 bars purposed pressure force. To against exerciser effort, valve 3 will be decreased 3 bars and valve 4 will be increased 3 bars as well. The block diagram of this situation is shown in Figure 4-22. As in experiment 1, experiment 2 has four analog input signals and two analog output signals, the hardware connections set up are as the same as in experiment 1.

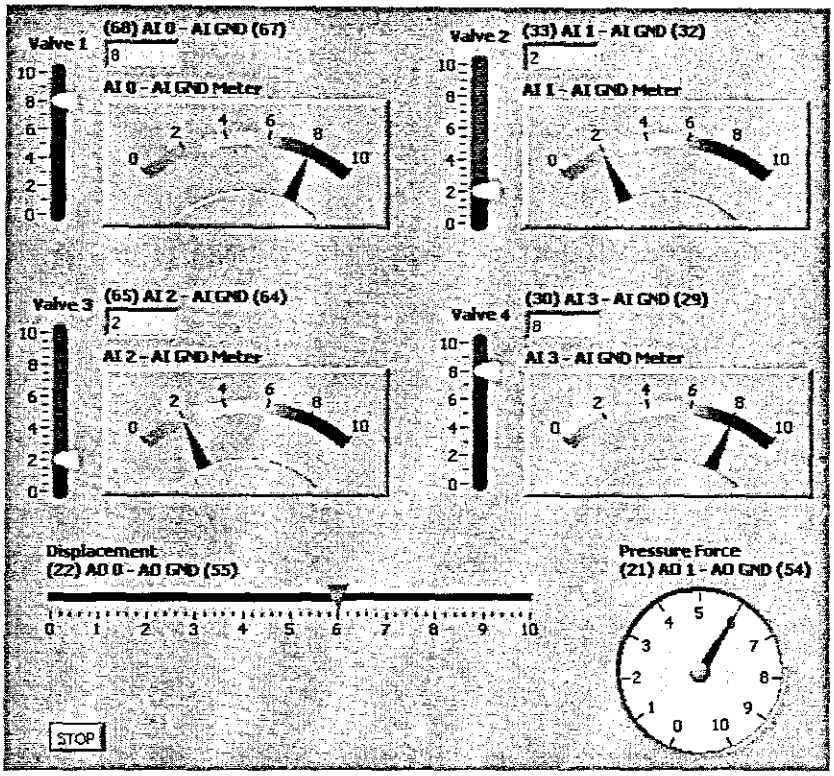

Valve 1
(68) AI 0 - AI GND (67)
8
AI 0 - AI GND Meter
Valve 2
(33) AI 1 - AI GND (32)
2
AI 1 - AI GND Meter
Valve 3
(65) AI 2 - AI GND (64)
2
AI 2 - AI GND Meter
Valve 4
(30) AI 3 - AI GND (29)
8
AI 3 - AI GND Meter
Displacement
(22) AO 0 - AO GND (55)
Pressure Force
(21) AO 1 - AO GND (54)
STOP

Figure 4-21: Experiment 2 – both sides valve open

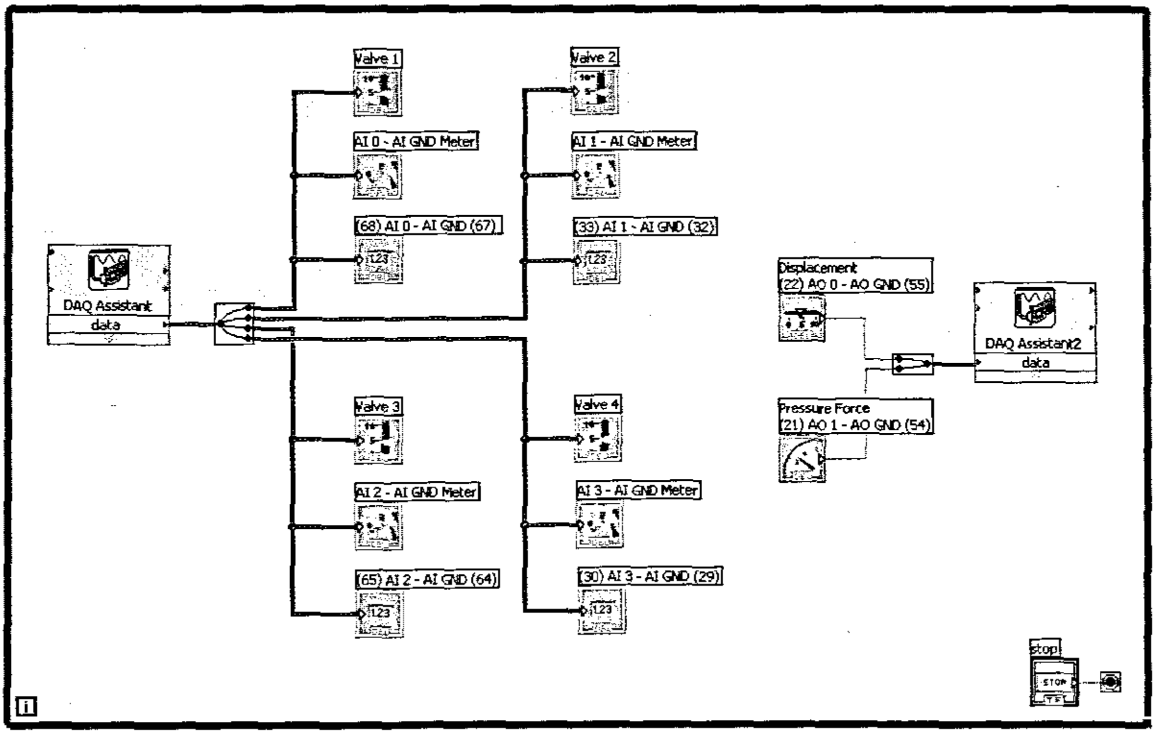

DAQ Assistant
data
Valve 1
AI 0 - AI GND Meter
(68) AI 0 - AI GND (67)
Valve 2
AI 1 - AI GND Meter
(33) AI 1 - AI GND (32)
Valve 3
AI 2 - AI GND Meter
(65) AI 2 - AI GND (64)
Valve 4
AI 3 - AI GND Meter
(30) AI 3 - AI GND (29)
Displacement
(22) AO 0 - AO GND (55)
Pressure Force
(21) AO 1 - AO GND (54)
DAQ Assistant2
data
stop
STOP
TF
i

Figure 4-22: Experiment 2 – block diagram

4.3 Computer-controlled exercise systems

This section focuses on presenting software development, deals with the design of computer-controlled exercise systems that are developed based on object-oriented approach. FX exerciser refers to the programmable resistance system which uses mathematical algorithms to define FX profiles. Smart card control technology for access control and exercise event recording. An exercise performance monitor is an integrated part that will be realised in four salient areas, namely – heart-rate monitoring, calculation of exercise workrate, exercise event recording, and electromyography (EMG) technology. The exercise motion status represents another major innovation in the field of exercise. The exercise motion status technology endeavours to capture the exercise status. Finally, the fail-safe mechanics is also an important part developed in order to safe both human and equipment.

4.3.1 Database design

The database design is based on relational database design. Four tables are included and related to each other by several fields. The four tables are named exerciser details, FX profile, exercise data record, and heart rate; defined and shown in Tables 1 – Table 4:

Table 4-1: Exerciser details

Field Name	**Data Type**	**Attribute**
Member_ID (KEY)	Number	Required: Yes
Name	Text	Required: Yes
Gender	Text	Required: Yes
Age	Number	Required: Yes
Profile_ID	Number	Required: Yes

Table 4-2: FX profile

Field Name	Data Type	Attribute
Profile_ID (KEY)	Number	Required: Yes
Slide 0	Number	Required: Yes
Slide 1	Number	Required: Yes
Slide 2	Number	Required: Yes
Slide 3	Number	Required: Yes
Slide 4	Number	Required: Yes
Slide 5	Number	Required: Yes
Slide 6	Number	Required: Yes
Slide 7	Number	Required: Yes
Slide 8	Number	Required: Yes
Slide 9	Number	Required: Yes
Slide 10	Number	Required: Yes
Slide 11	Number	Required: Yes
Slide 12	Number	Required: Yes
Slide 13	Number	Required: Yes
Slide 14	Number	Required: Yes
Slide 15	Number	Required: Yes
Slide 16	Number	Required: Yes
Slide 17	Number	Required: Yes
Slide 18	Number	Required: Yes
Slide 19	Number	Required: Yes
Slide 20	Number	Required: Yes

Table 4-3: Exercise data record

Field Name	Data Type	Attribute
Member_ID (KEY)	Number	Required: Yes
Interval	Number	Required: Yes

Data	Number	Required: Yes

Table 4-4: Heart-rate

Field Name	Data Type	Attribute
Auto_ID (KEY)	Number	Required: Yes
Gender	Text	Required: Yes
Age	Number	Required: Yes
MIN	Number	Required: Yes
MAX	Number	Required: Yes

Figure 4-23 shows the related fields and data transfers between tables.

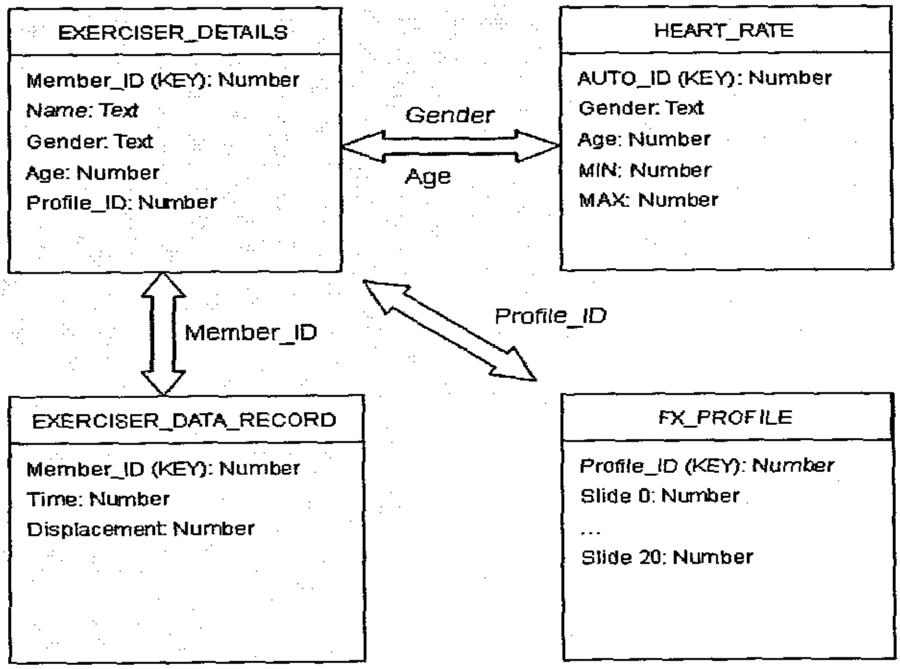

EXERCISER_DETAILS
Member_ID (KEY): Number
Name: Text
Gender: Text
Age: Number
Profile_ID: Number
HEART_RATE
AUTO_ID (KEY): Number
Gender: Text
Age: Number
MIN: Number
MAX: Number
Gender
Age
Member_ID
Profile_ID
EXERCISER_DATA_RECORD
Member_ID (KEY): Number
Time: Number
Displacement: Number
FX_PROFILE
Profile_ID (KEY): Number
Slide 0: Number
...
Slide 20: Number

Figure 4-23: Related data tables

4.3.2 System architecture design

The system consists of seven models, namely FX control, exercise motion control, smart card control, heart rate control, exercise data recording control, fail-safe control, and data warehouse control. Figure 4-24 shows the macro cross-functional diagram of this research. In Figure 4-24, a central control hub controls other phases, and communicates with other local control hubs. For example, a server-based machine will link the individual FX exercisers which conform to standard LAN protocols. In addition, the central control hub also operates the several control units which are depicted in the control phase. Control phase is the core of the whole project, providing the specific works and functionalities. A performance monitor uses to monitor exercise in performance phase; in this phase, if performance monitor detects any danger data, such as any damage for human or equipment, a warning signal will be sent to fail-safe mechanics, and active fail-safe function. Storage phase, deals with all data transactions. Input / output phase, a Central Control Hub GUI Module, sends all requirements for data reports, especially exercise / health reports.

The more interaction of each of parts is shown in Figure 4-25, the data flow diagram depicts the processes and internal relationships of all controls units. The particular contents of functionalities will be presented in 4.4.4.

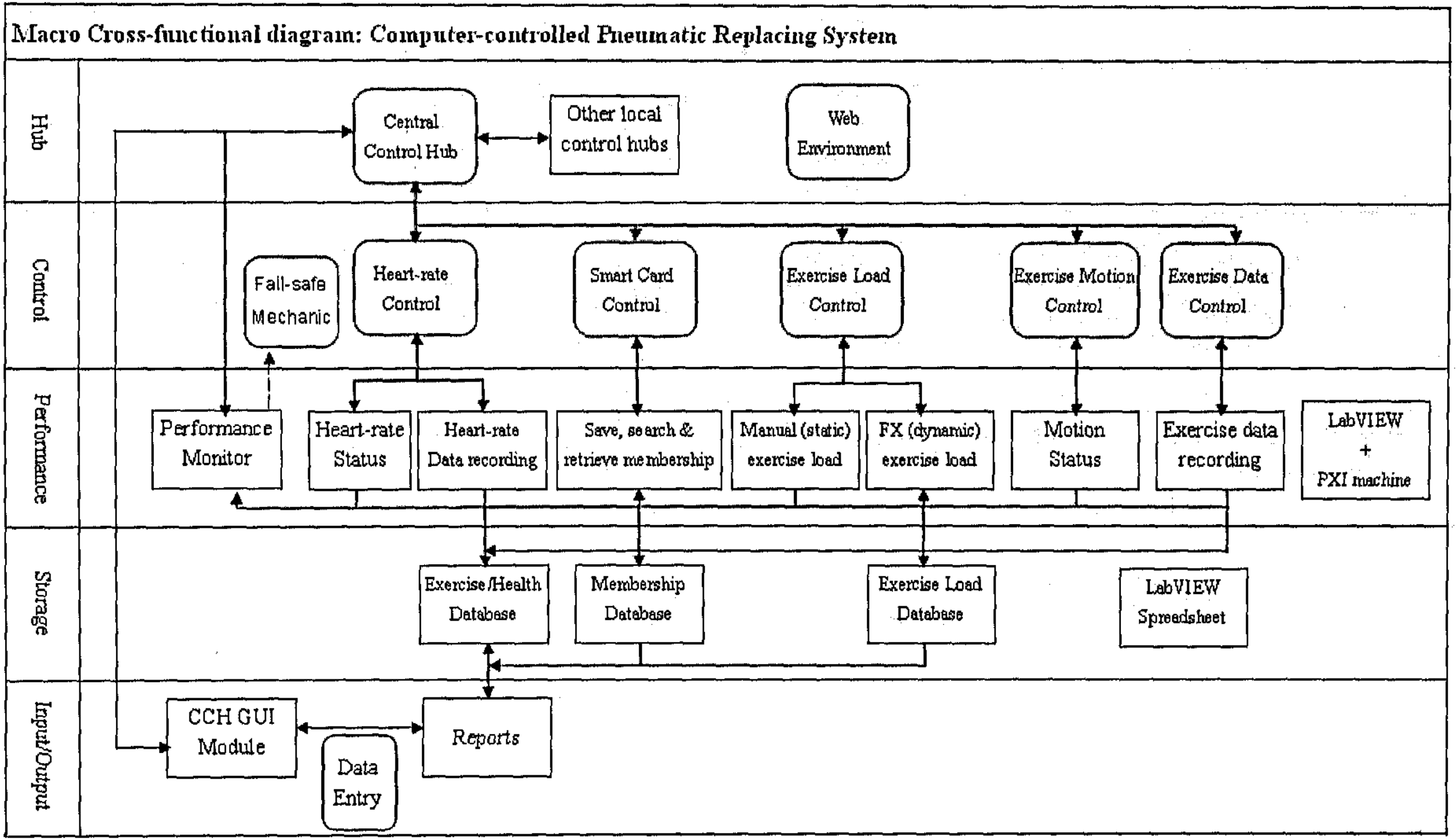

Macro Cross-functional diagram: Computer-controlled Pneumatic Replacing System
Hub
Control
Performance
Storage
Input/Output
Central Control Hub
Other local control hubs
Web Environment
Fail-safe Mechanic
Heart-rate Control
Smart Card Control
Exercise Load Control
Exercise Motion Control
Exercise Data Control
Performance Monitor
Heart-rate Status
Heart-rate Data recording
Save, search & retrieve membership
Manual (static) exercise load
FX (dynamic) exercise load
Motion Status
Exercise data recording
LabVIEW + PXI machine
Exercise/Health Database
Membership Database
Exercise Load Database
LabVIEW Spreadsheet
CCH GUI Module
Data Entry
Reports

Figure 4-24: Macro cross-functional diagram

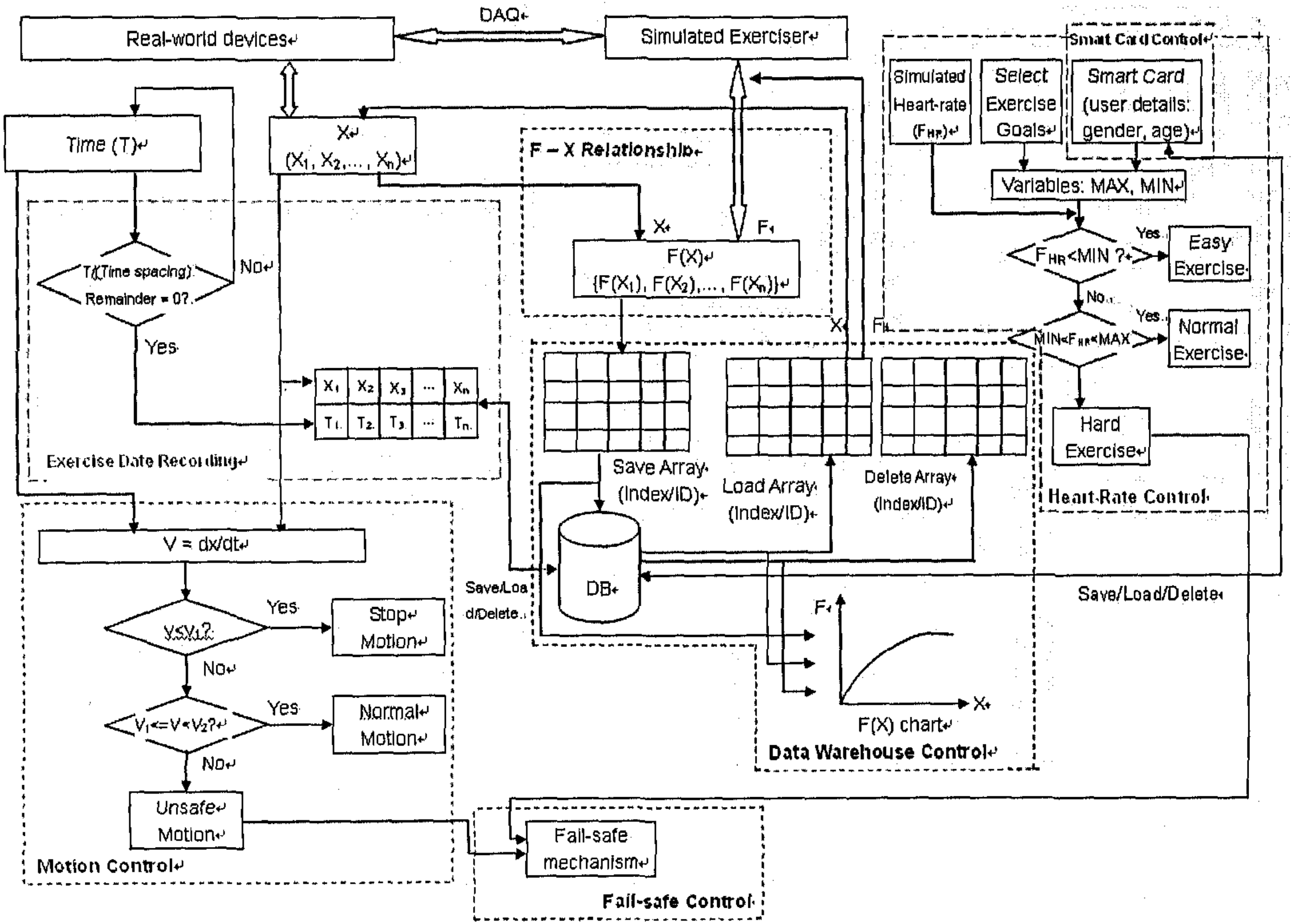

DAQ
Real-world devices
Simulated Exerciser
Time (T)
X
$(X_1, X_2, \ldots, X_n)$
T/(Time spacing) Remainder = 0?
No
Yes
X_1 X_2 X_3 ... X_n
T_1 T_2 T_3 ... T_n
Exercise Date Recording
F – X Relationship
X
F
F(X)
$\{F(X_1), F(X_2), \ldots, F(X_n)\}$
X
F
Save Array (Index/ID)
Load Array (Index/ID)
Delete Array (Index/ID)
DB
Save/Load/Delete
F
X
F(X) chart
Data Warehouse Control
Smart Card Control
Simulated Heart-rate (F_{HR})
Select Exercise Goals
Smart Card (user details: gender, age)
Variables: MAX, MIN
F_{HR}<MIN ?
Yes
Easy Exercise
No
MIN<F_{HR}<MAX
Yes
Normal Exercise
Hard Exercise
Heart-Rate Control
Save/Load/Delete
V = dx/dt
$V \le V_1$?
Yes
Stop Motion
No
$V_1 <= V < V_2$?
Yes
Normal Motion
No
Unsafe Motion
Motion Control
Fail-safe mechanism
Fail-safe Control

Figure 4-25: Diagram of system functionality

4.3.3 System analysis with object-oriented

The key concepts of object-oriented approach have been mentioned in Chapter 3. Object-oriented analysis and design methods use a variety of graphical notations to depict the models developed. In particular, there is an overwhelming agreement that at least three types of diagrams are required, namely class diagram, state diagram, and interaction diagram. The following sections will present the three types of diagrams used to design this computer-controlled exercise system.

4.3.3.1 Class diagram

Class diagrams depict the static structure of a system. The most common example of a class diagram is a diagram depicting the subclass-superclass hierarchy of objects. The objects are denoted by rectangles that have three compartments. These compartments contain:

- The name of the object;
- the list of attributes of the object; and
- the list of services of the object

van Vliet (2001)

In this application, specific design will be separated by seven modules that have been depicted earlier, namely FX control, exercise motion control, smart card control, heart rate control, exercise data recording control, fail-safe control, and data warehouse control. Each module will be designed and can be implemented as an independent unit. Figures 4-26 – 4-32 show the class diagrams of each control unit.

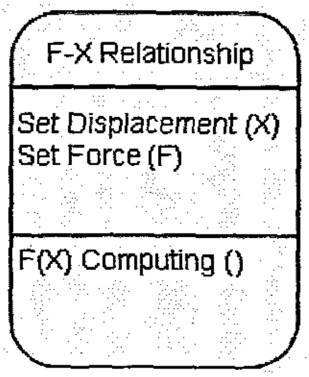

F-X Relationship
Set Displacement (X)
Set Force (F)
F(X) Computing ()

Figure 4-26: Class diagram – FX control

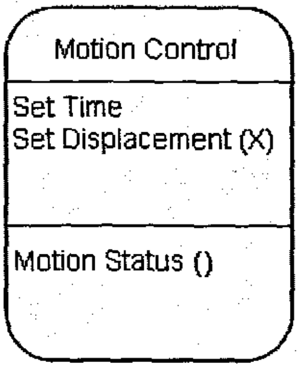

Motion Control
Set Time
Set Displacement (X)
Motion Status ()

Figure 4-27: Class diagram – exercise Motion control

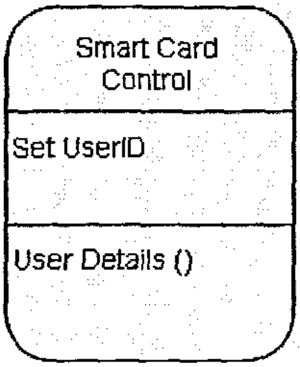

Smart Card Control
Set UserID
User Details ()

Figure 4-28: Class diagram – smart card control

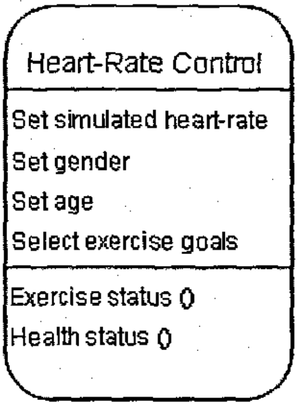

Heart-Rate Control
Set simulated heart-rate
Set gender
Set age
Select exercise goals
Exercise status ()
Health status ()

Figure 4-29: Class diagram – heart-rate control

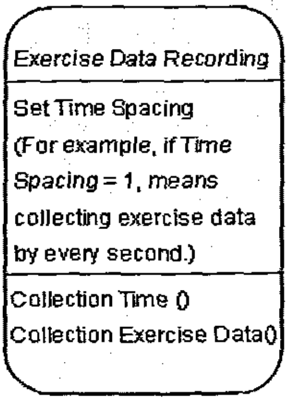

Exercise Data Recording
Set Time Spacing
(For example, if Time Spacing = 1, means collecting exercise data by every second.)
Collection Time ()
Collection Exercise Data()

Figure 4-30: Class diagram – exercise data recording control

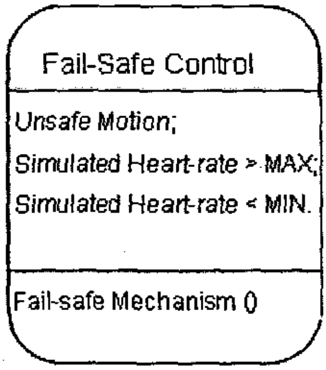

Fail-Safe Control
Unsafe Motion;
Simulated Heart-rate > MAX;
Simulated Heart-rate < MIN.
Fail-safe Mechanism ()

Figure 4-31: Class diagram – fail-safe control

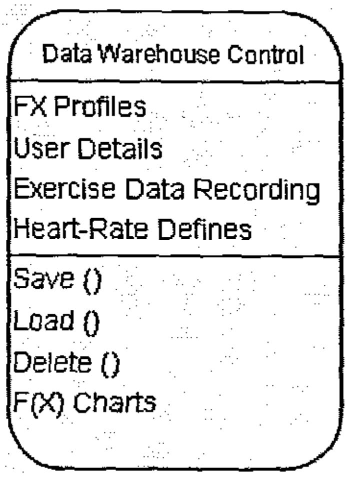

Data Warehouse Control
FX Profiles
User Details
Exercise Data Recording
Heart-Rate Defines
Save ()
Load ()
Delete ()
F(X) Charts

Figure 4-32: Class diagram – data warehouse control

4.3.3.2 State diagram

A major class of services provided by an object relates to the object's life cycle. An object, for instance, is created, updated zero or more times, and finally destroyed. *State transition diagrams*, which depict the possible states of an object and the transitions between those states, are a good help in modeling this life cycle (van Vliet, 2001).

There have *input events* and *output actions*. Input events trigger transitions. For instance, in motion control, time (t) and displacement (x) will trigger the transition; when speed (v = dx/dt) is *calculated, it triggers a transition from a state*, such as from stop motion to a state normal motion, or unsafe motion. Figure 4-33 shows the input events which are denoted as strings that *label state transitions*. The particular details of state diagrams of other control units will be presented in 4.4.4, which overview presents the system features and functionalities.

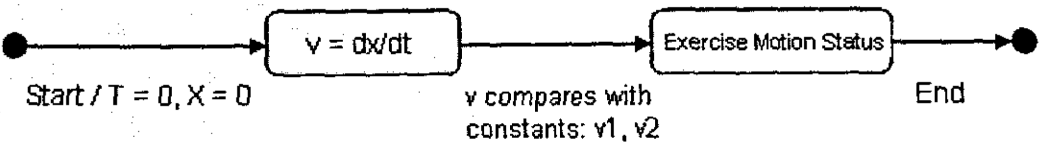

v = dx/dt
Exercise Motion Status
Start / T = 0, X = 0
v compares with
constants: v1, v2
End

Figure 4-33: State diagram – *exercise motion control*

4.3.3.3 Interaction diagram

There are two types of interaction diagram: sequence diagram and collaboration diagram. A sequence diagram emphasises the time ordering of events within an interaction, whereas a collaboration diagram emphasises the objects and their relationships relevant to a particular interaction (van Vliet, 2001).

In a sequence diagram, objects communicate by sending messages. To carry out a certain task, a particular sequence of messages may have to be exchanged between two or more objects. The horizontal dimension in a sequence diagram shows the various objects that participate in the interaction. An object is shown as a vertical line. The period in which the object is active is shown as a thin rectangle. The vertical dimension denotes the time sequencing of messages. Only the order in which messages are displayed carries meaning. Figure 4-34 depicts a possible sequence of interactions between user, data warehouse, and heart-rate status in Heart-Rate control. At first, the user sends "UserID", then the database will search and react by sending the related data to the user. Concurrently, two variables of consulting heart-rate range – "MAX" and "MIN" will be generated according to different users' group (gender and age), and compared with a simulated heart-rate that will be created from user. The comparison results indicate the current heart-rate status.

The collaboration diagram is another way to show one possible scenario for the interaction between a number of related objects. A collaboration diagram is a directed graph where the nodes denote entities and the edges denote communication between those entities. Figure 4-35 depicts the same sequence of interactions as depicted in the sequence diagram in Figure 4-34. A collaboration diagram emphasises the objects and their relationships relevant to a particular interaction. To provide more detail about the interaction, relevant attributes may be shown inside the nodes and these attributes may be incorporated in the labels of the edges as well. More details about sequence diagrams and collaboration diagrams will be presented in 4.4.4.

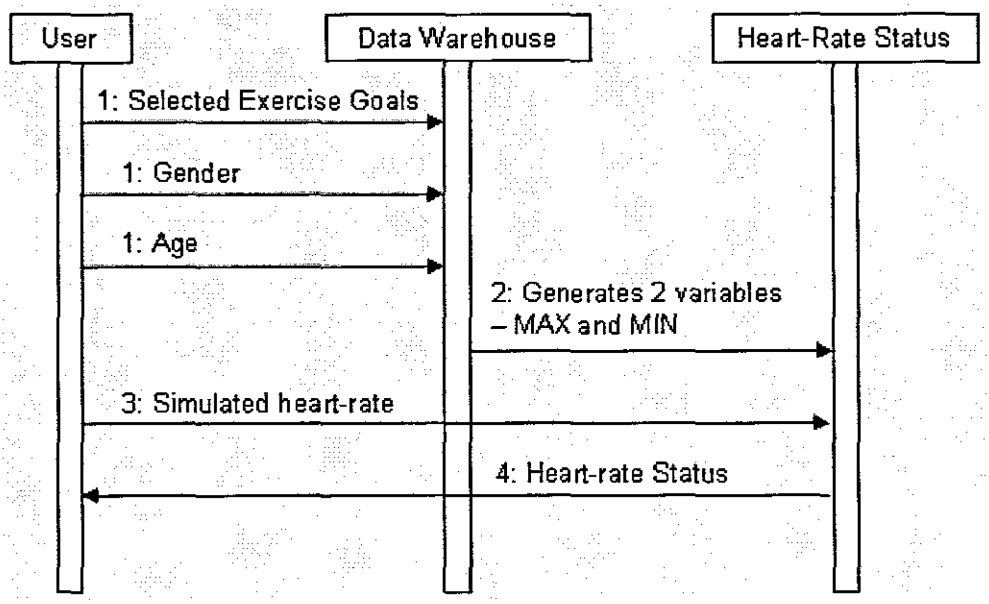

User
Data Warehouse
Heart-Rate Status
1: Selected Exercise Goals
1: Gender
1: Age
2: Generates 2 variables – MAX and MIN
3: Simulated heart-rate
4: Heart-rate Status

Figure 4-34: Sequence diagrams – heart-rate control

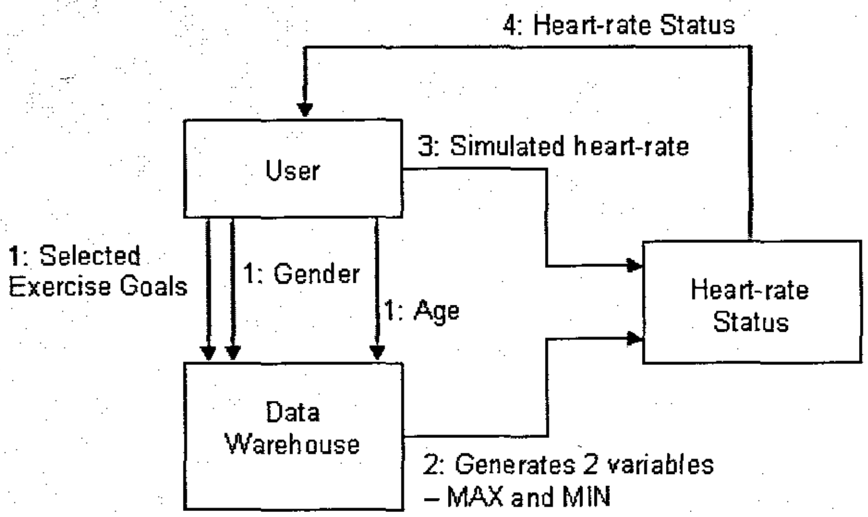

4: Heart-rate Status
User
3: Simulated heart-rate
1: Selected Exercise Goals
1: Gender
1: Age
Heart-rate Status
Data Warehouse
2: Generates 2 variables – MAX and MIN

Figure 4-35: Collaboration diagrams – heart-rate control

4.3.4 Software features and functionalities

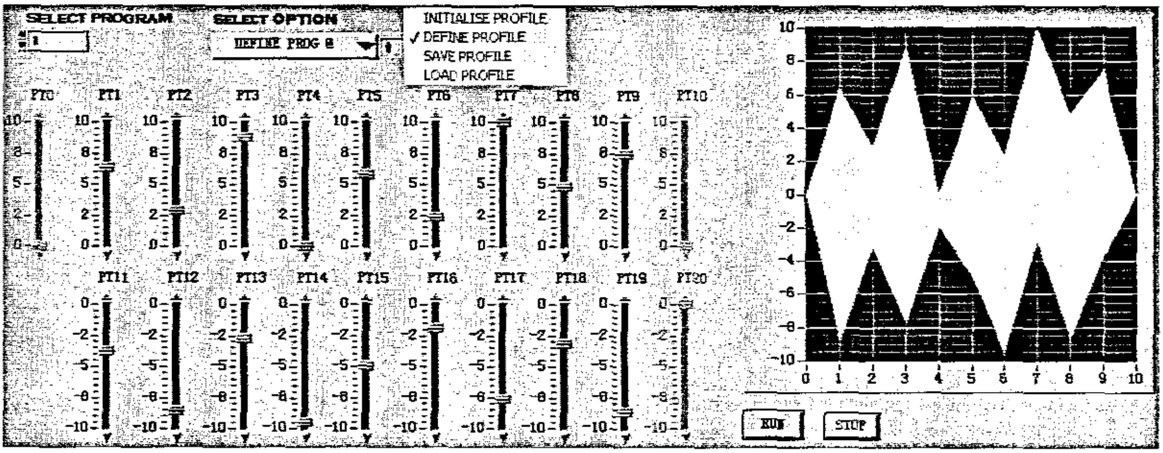
This section presents the specific work on system design. The system basically consists of FX control, exercise motion control, smart card control, heart rate control, exercise data recording, fail-safe mechanics, and data warehouse control. Each control unit will be designed and developed independently as a subsystem. The above control units / subsystems are presented in the following sections.

4.3.4.1 FX control

The FX control is the most important control unit of the whole system. FX control achieve, the complex trajectories required for exercise together with delivering the various force components required. In this application, the FX control unit will replace the weight stacks of standard deadweight-based exercise equipment, thereby greatly enhancing its functionality in respect of exercise optimisation. The concept of FX control technology on a pneumatic platform has been successfully prototyped in Chapter 3.

FX control is a specific control using a computer-based profile which determines the differential pressure in the cylinder in terms of the spatial position of the mechanical linkage. A simulated exercise trajectory control unit uses mathematical algorithms to deliver the required pressure to achieve the desired force trajectories.

A feature of FX control is shown in Figure 4-36. It has a numeric controller (left top) used to define / select a program. And will also be the profile ID once the profile is saved; a combo box controller (middle top) implements different operations, including initialize FX profile, define FX profile, save FX profile, and load FX profile; the series of slide controllers determine the desired force on each of integer point of the spatial positions which are plotted out by 10 pieces between 0 to 10. Controller PT0 sets the desired force at the start position, controller PT1 gives the desired force at integer position 1, and so on. In additional, the spatial positions are set as two parts – forward path (push action, the areas of spatial positions from 0 to 10) and backward path (pull action, the areas of spatial positions from 10 back to 0), each part includes 10 slide controllers. The selected area is displayed in graph controller (right) after the profile is set up. To assume push or pull action in this application, positive force is defined push action, and negative force is indicated pull action.



SELECT PROGRAM 1

SELECT OPTION DEFINE PROG 8

✓ DEFINE PROFILE

INITIALISE PROFILE
SAVE PROFILE
LOAD PROFILE
PT0
PT1
PT2
PT3
PT4
PT5
PT6
PT7
PT8
PT9
PT10
PT11
PT12
PT13
PT14
PT15
PT16
PT17
PT18
PT19
PT20
10
8
5
2
0
-2
-5
-8
-10
0 1 2 3 4 5 6 7 8 9 10
RUN
STOP

Figure 4-36: FX control – define FX profiles

According to FX control technology, the FX profile can be set up by many modes exercise actions, including lift and spring modes exercises. In lift motion exercise, the exerciser always keeps push action. Figures 4-37 and 4-38 show forward and backward lift exercises. Because of centrifugal force, the exerciser has to push against the weights not only in forward path, but also in backward path. Therefore, one of the FX profile for lift exercise can be defined in Figure 4-39. Many exercise trainings belong to lift motion exercise, such as free weights, smith machine, lat pull down, leg press, pec deck, shoulder press (Damon, 2007; Leroux, 2007).

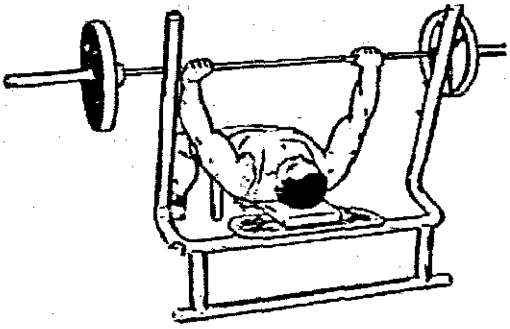


Figure 4-37: Lift exercise – forward

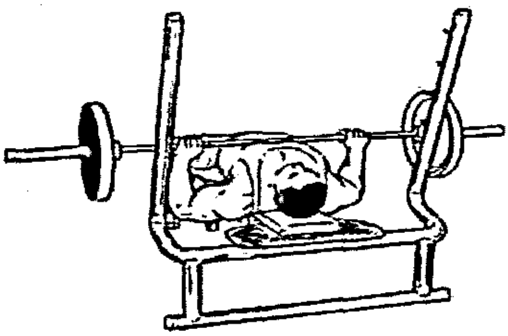
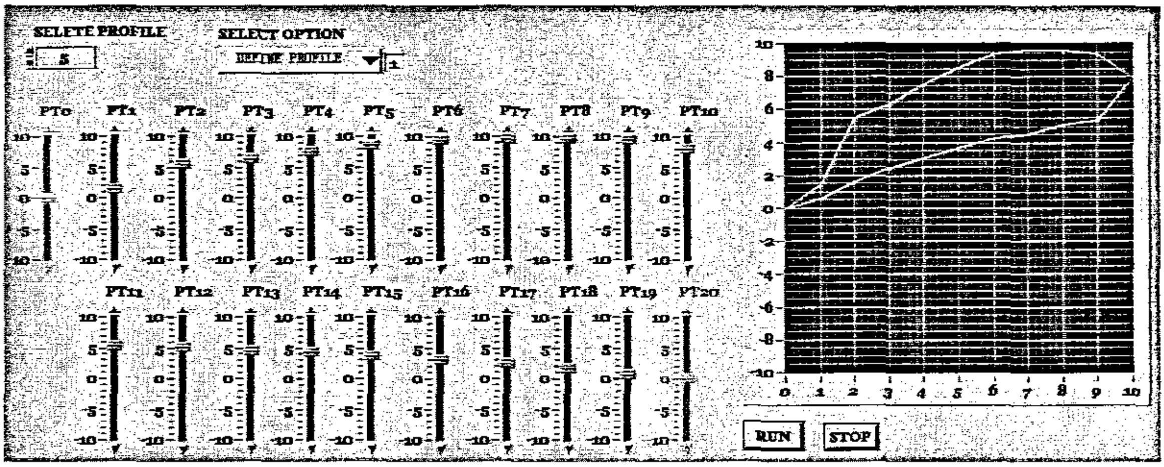


Figure 4-38: Lift exercise – backward



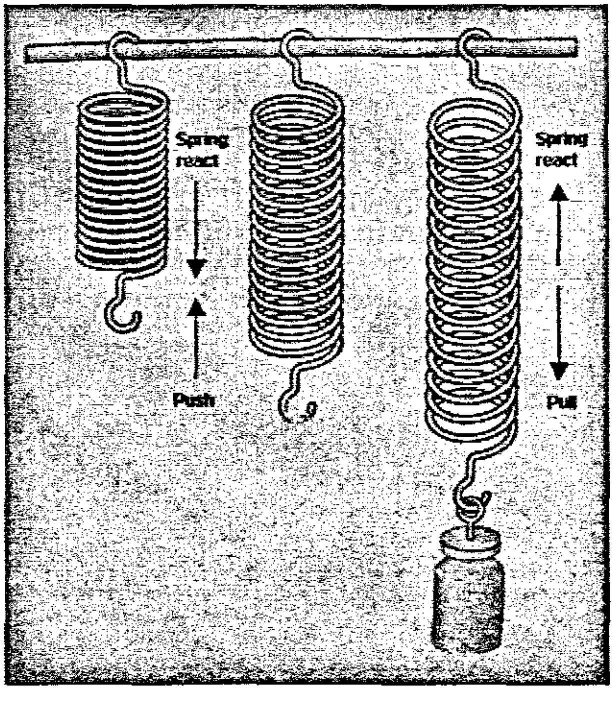
SELETE PROFILE: 5

SELECT OPTION: DEFINE PROFILE 1

PT0
PT1
PT2
PT3
PT4
PT5
PT6
PT7
PT8
PT9
PT10
PT11
PT12
PT13
PT14
PT15
PT16
PT17
PT18
PT19
PT20
10
5
0
-5
-10
10
8
6
4
2
0
-2
-4
-6
-8
-10
0
1
2
3
4
5
6
7
8
9
10
RUN
STOP

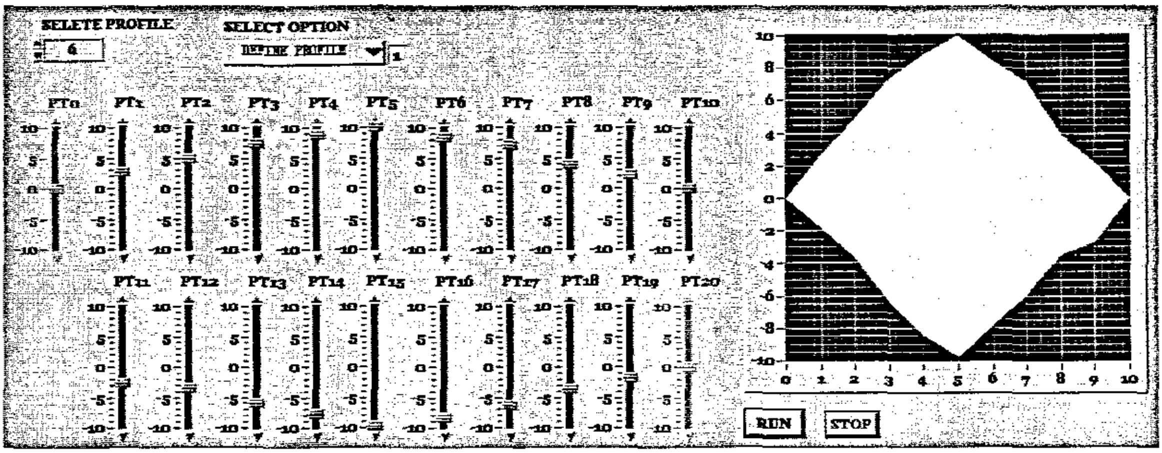
Figure 4-39: One of lift exercise FX profiles

In spring motion exercise, push and pull actions alternate. When one tries to push a spring, it will react to you, if you try to pull a spring, it will react in the other side as well. Figure 4-40 shows the direction of a spring to push and pull actions. According to the pervious description. Push action is, thus defined by positive direction, and pull action is defined by negative direction. Therefore, one of the FX profile for spring exercise can be defined in Figure 4-41.



Spring react
Push
Spring react
Pull

Figure 4-40: Spring exercise

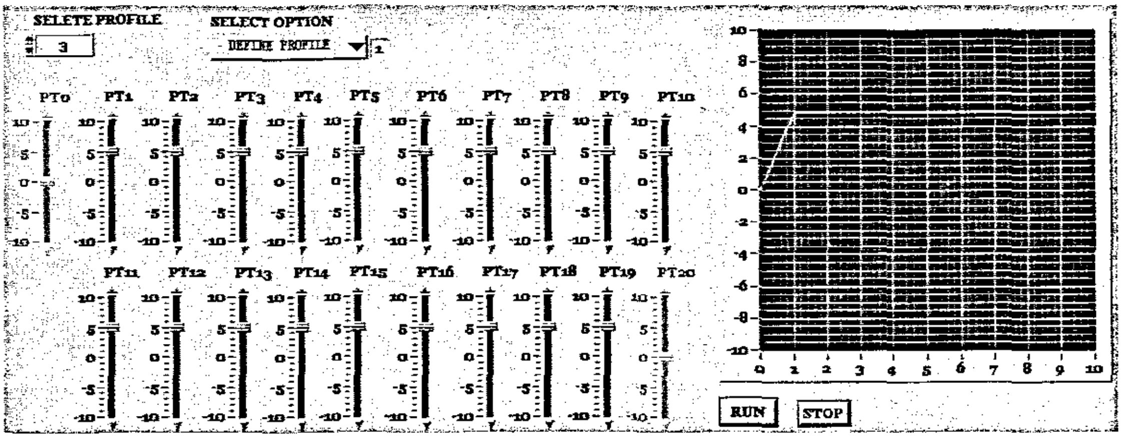

SELETE PROFILE 6

SELECT OPTION DEFINE PROFILE

PT0 PT1 PT2 PT3 PT4 PT5 PT6 PT7 PT8 PT9 PT10
PT11 PT12 PT13 PT14 PT15 PT16 PT17 PT18 PT19 PT20
10 5 0 -5 -10
10 8 6 4 2 0 -2 -4 -6 -8 -10
0 1 2 3 4 5 6 7 8 9 10
RUN
STOP

Figure 4-41: One of spring exercise FX profiles

In addition, with the FX control technology, both types of aerobic and anaerobic exercises are becoming available in one single exercise equipment with different FX profiles. Basic information about aerobic and anaerobic exercises has been discussed in Chapter 2. Aerobic exercise is training heart fitness in a lower intensity and longer time; and anaerobic exercise is building muscles at high intensity and a high rate of work for a short period of time. Anaerobic exercise profiles have been depicted in the last two graphs (Figure 4-40 and Figure 4-41). Figure 4-42 shows a FX profile set for aerobic exercise. A lower intensity is selected for the unique weight input, here it is set at 5. Therefore, exerciser keeps this lower intensity action for minutes until heart fitness is trained, the actual force outputs are depicted in Figure 4-43.


SELETE PROFILE 3

SELECT OPTION DEFINE PROFILE

PT0 PT1 PT2 PT3 PT4 PT5 PT6 PT7 PT8 PT9 PT10
PT11 PT12 PT13 PT14 PT15 PT16 PT17 PT18 PT19 PT20
10 5 0 -5 -10
10 8 6 4 2 0 -2 -4 -6 -8 -10
0 1 2 3 4 5 6 7 8 9 10
RUN
STOP

Figure 4-42 FX profile for aerobic exercise

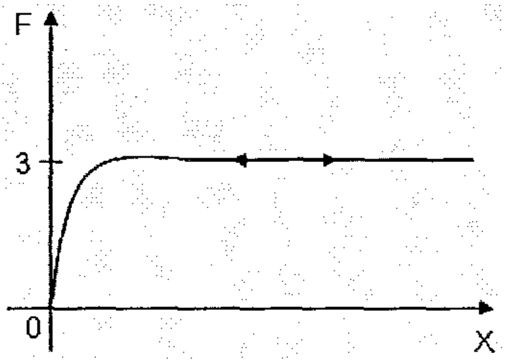


Figure 4-43: Actual force outputs

A state diagram is shown in Figure 4-44, which includes two inputs, F (force) and X (displacement) in order to create the F-X profile (output) which will be a norm to determine exercise routine for exercisers. Figures 4-45 and 4-46 show the sequence diagram and collaboration diagram of this application, respectively.

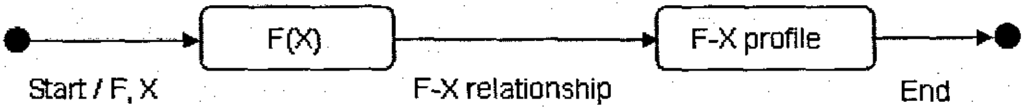

F(X)
F-X profile
Start / F, X
F-X relationship
End

Figure 4-44:State diagram – FX control

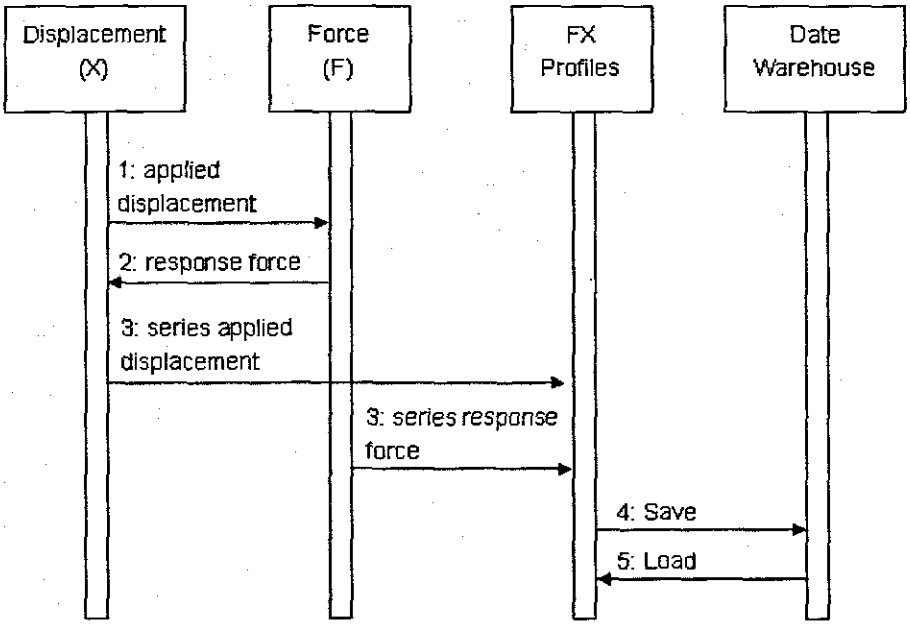

Displacement (X)
Force (F)
FX Profiles
Date Warehouse
1: applied displacement
2: response force
3: series applied displacement
3: series response force
4: Save
5: Load

Figure 4-45: Sequence diagram – FX control

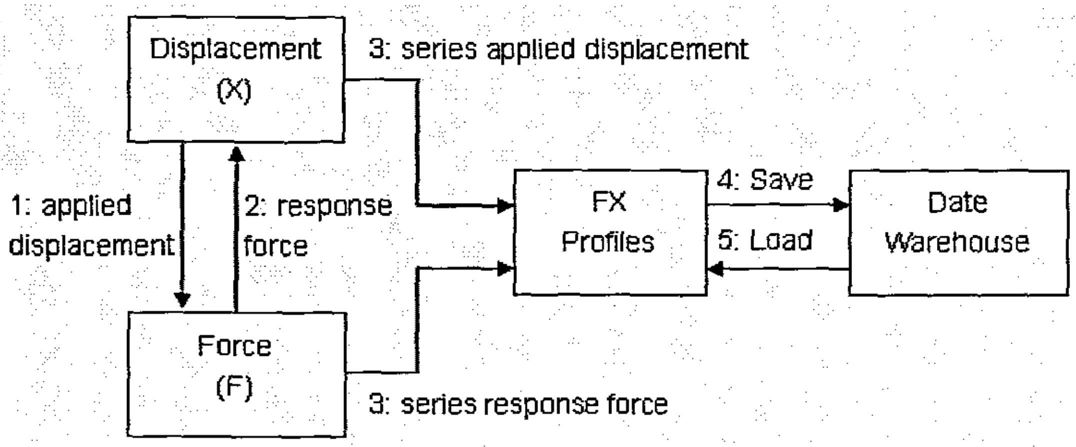
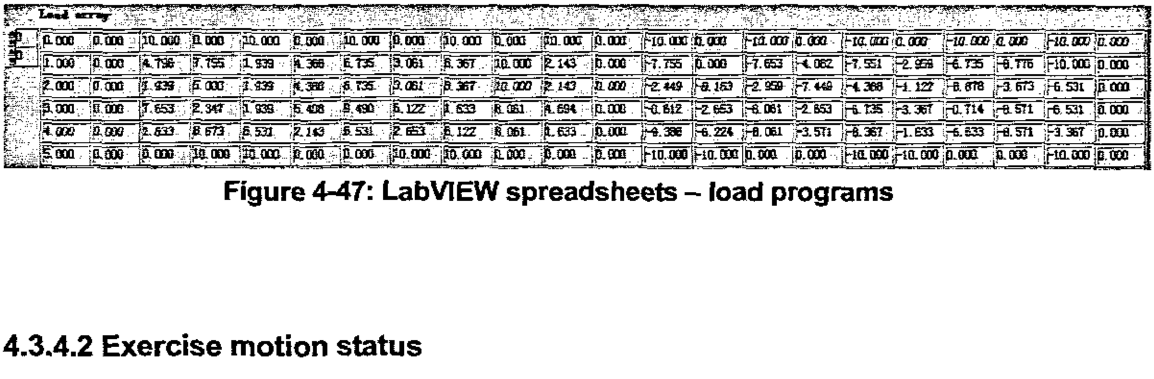


Figure 4-46: Collaboration diagram – FX control

Defined FX profiles will be saved in LabVIEW spreadsheet (Figure 4-47). In addition, the load function will retrieve programs in order to modify existing ones.



Load array

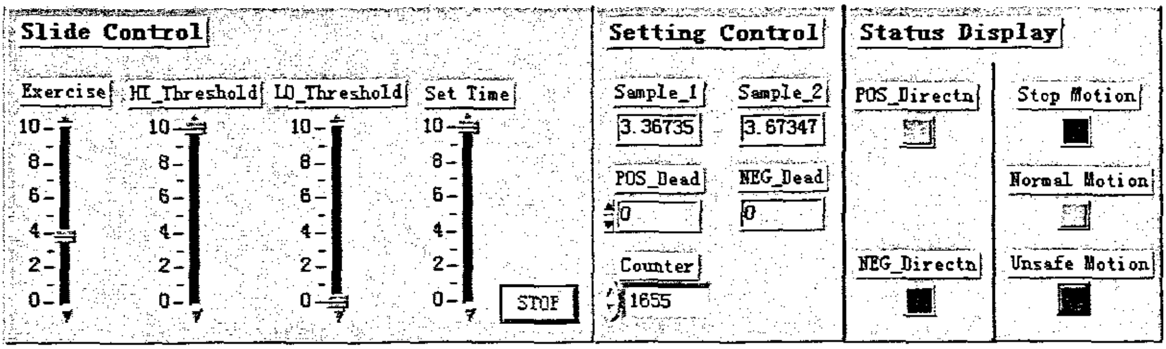
0.000	0.000	10.000	0.000	10.000	0.000	10.000	0.000	10.000	0.000	10.000	0.000	-10.000	0.000	-10.000	0.000	-10.000	0.000	-10.000	0.000	-10.000	0.000
1.000	0.000	4.796	7.755	1.939	4.388	6.735	3.061	8.367	10.000	2.143	0.000	-7.755	0.000	-7.653	-4.082	-7.551	-2.959	-6.735	-8.776	-10.000	0.000
2.000	0.000	1.939	5.000	1.939	4.388	6.735	3.061	8.367	10.000	2.143	0.000	-2.449	-8.163	-2.959	-7.449	-4.388	-1.122	-8.878	-3.673	-6.531	0.000
3.000	0.000	7.653	2.347	1.939	5.408	9.490	6.122	1.633	8.061	4.694	0.000	-0.612	-2.653	-8.061	-2.653	-6.735	-3.367	-0.714	-8.571	-6.531	0.000
4.000	0.000	2.633	8.673	6.531	2.143	6.531	2.653	6.122	8.061	1.633	0.000	-4.388	-6.224	-8.061	-3.571	-8.367	-1.633	-6.633	-8.571	-3.367	0.000
5.000	0.000	0.000	10.000	10.000	0.000	0.000	10.000	10.000	0.000	0.000	0.000	-10.000	-10.000	0.000	0.000	-10.000	-10.000	0.000	0.000	-10.000	0.000

Figure 4-47: LabVIEW spreadsheets – load programs

4.3.4.2 Exercise motion status

Exercise motion status represents the velocity of displacement state of the pneumatic cylinder in a variation time. This section focuses on the changed spatial positions only, provides three motion status, namely stop motion, normal motion, and unsafe motion. Motion status depicts the exercise status and changes with the velocity of displacement of an exerciser's push or pull cylinder. This is defined by dynamic change displacement (X) and a variation time (T), normally is known as v = dx / dt.

Figure 4-48 shows the features of this application. In slide control column, the exercise slide controller simulated the actual positions of a cylinder. The *HI_Threshold* and *LO_Threshold* slide controllers are used define the range values of the exercise slide controller. For example, in Figure 4-48, the defined range is from 0 to 10. In the setting control column, controller *Sample_2* shows the current position, and a previous position is shown in controller *Sample_1*. Use *Sample_2* subtracts *Sample_1* after sampling two of them. Nowadays, observes the result, if a positive result, means exerciser is pushing cylinder, and the *POS_Directn* LED controller will be lit. Otherwise, exerciser is pulling the cylinder, and *NEG_Directn* LED controller will be lit. For example, in Figure 4-46, used *Sample_2* (3.67347) minus *Smple_1* (3.36735), obtained a positive result, therefore, *POS_Directn* LED controller is lighting. Except *POS_Directn* and *NEG_Directn*, another three LED controllers are included in status display column yet. They respectively indicate three exercise motion statuses: stop motion, normal motion, and unsafe motion. These three motion status controllers will be distinguished by the constants – v_1, v_2, which are compared with current velocity. If the current velocity smaller than constant v_1, the motion status will be represented as stop motion; if the current velocity is between constant v_1 and constant v_2, the motion status will be represented as normal motion, which indicates the current exercise under a safety condition. Otherwise, the motion status will be represented as unsafe motion, meaning the current velocity is too fast to machine work, the fail-safe mechanics will be triggered under this motion status in order to safeguard the equipment. On the other hand, if the stop motion keeps on for a certain time, and the position is not standing at 0, the fail-safe mechanics will be triggered as well in order to safeguard the user. Because of in this condition, people usually persist in a higher intensity. Following the exercise motion status system, the exerciser can determine if he or she meets the required FX profile or not. In addition, it gives full protection to both the user and the equipment.



Sample_1: 3.36735
Sample_2: 3.67347
POS_Dead: 0
NEG_Dead: 0
Counter: 1655

Figure 4-48: Exercise motion status

Figure 4-49 gives the state diagram of this application. The continuous time and dynamic change displacement are the inputs. The current velocity (output) is generated by the formulation v = dx / dt, and indicates the corresponding motion status. More internal transactions are shown in Figure 4-50 sequence diagram and Figure 4-51 collaboration diagram.

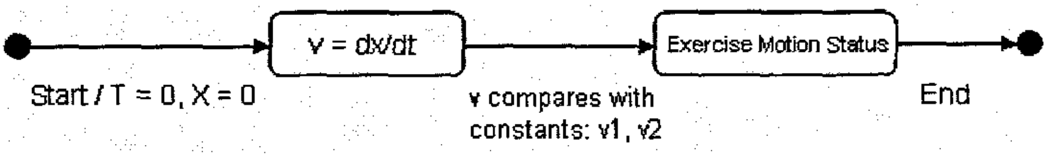

v = dx/dt
Exercise Motion Status
Start / T = 0, X = 0
v compares with constants: v1 , v2
End

Figure 4-49: State diagram – exercise motion status

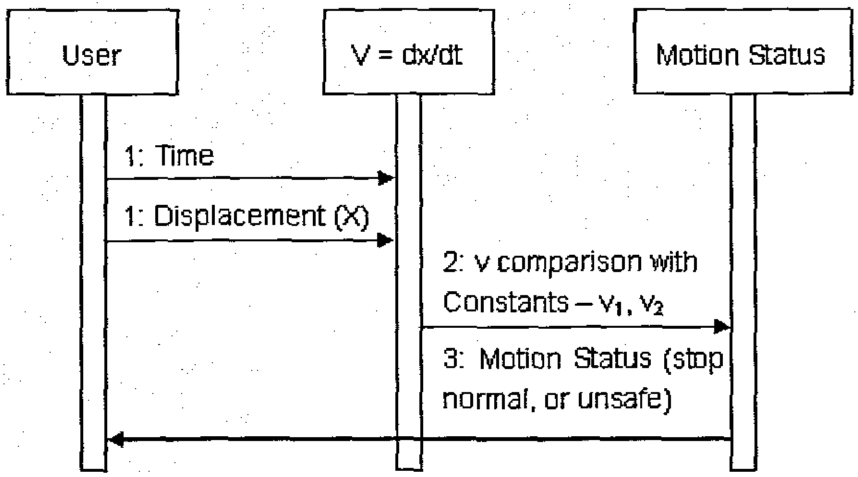

User
V = dx/dt
Motion Status
1: Time
1: Displacement (X)
2: v comparison with Constants – v1, v2
3: Motion Status (stop normal, or unsafe)

Figure 4-50: Sequence diagram – exercise motion status

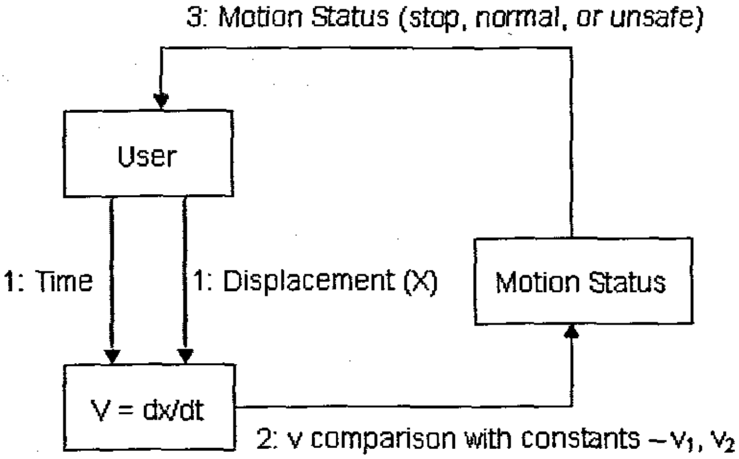

3: Motion Status (stop, normal, or unsafe)
User
1: Time
1: Displacement (X)
Motion Status
V = dx/dt
2: v comparison with constants – v1, v2

Figure 4-51: Collaboration diagram – exercise motion status

4.3.4.3 Smart card technology

Smart card technology is used to access control and exercise event recording. Each exerciser will be provided with a smart card, which is used to save the exerciser's details, especially for the optimum FX profile. Before an exerciser uses the equipment, he / she will be requested to swipe card in order to load the relevant user details and the set up FX profile. The exercise data records of the exerciser can also be retrieved.

The state diagram of this application is shown in Figure 4-52. UserID as the unique input, requests relevant user details. Figures 4-53 and 4-54 show the sequence diagram and collaboration diagram of smart card control, respectively.

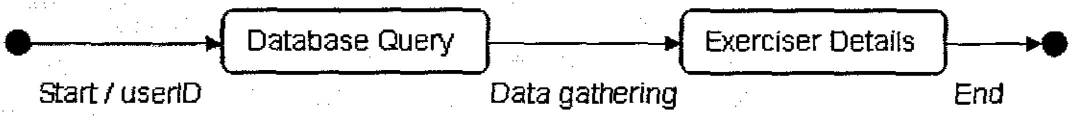

Database Query
Exerciser Details
Start / userID
Data gathering
End

Figure 4-52: State diagram – smart card control

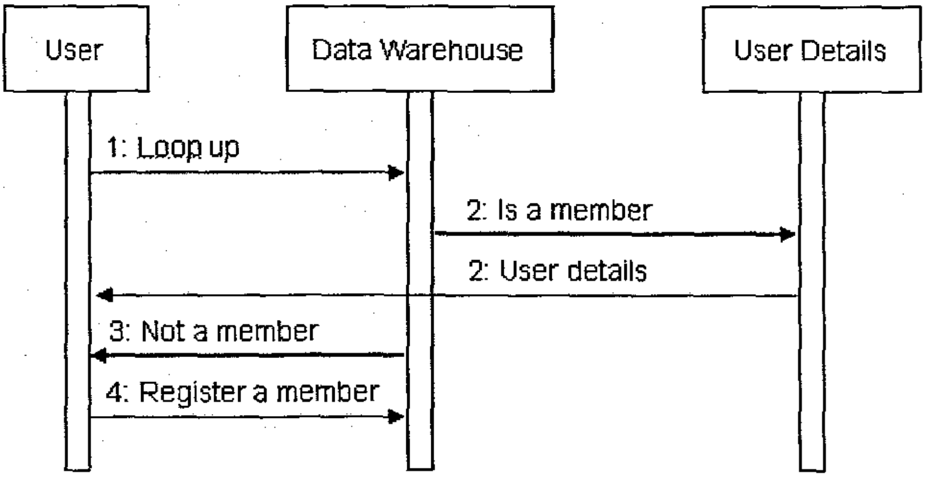

User
Data Warehouse
User Details
1: Loop up
2: Is a member
2: User details
3: Not a member
4: Register a member

Figure 4-53: Sequence diagram – smart card control

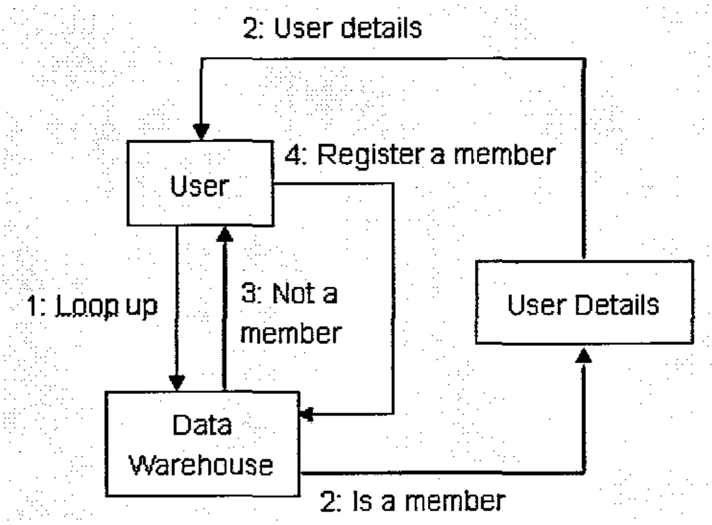
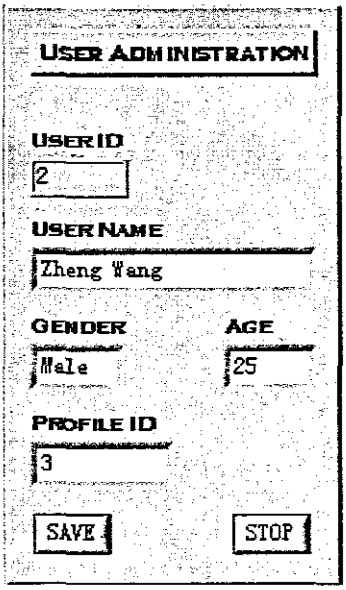

2: User details
User
4: Register a member
1: Loop up
3: Not a member
User Details
Data Warehouse
2: Is a member

Figure 4-54: Collaboration diagram – smart card control

Figure 4-55 describes the feature of user administration. The numeric control user ID shows the identity number of a user. Three string controllers present the user name, gender, and user's age. The profile ID numeric controller is used to select the existing FX profile.



USER ADMINISTRATION

USER ID: 2

USER NAME: Zheng Wang

GENDER: Male

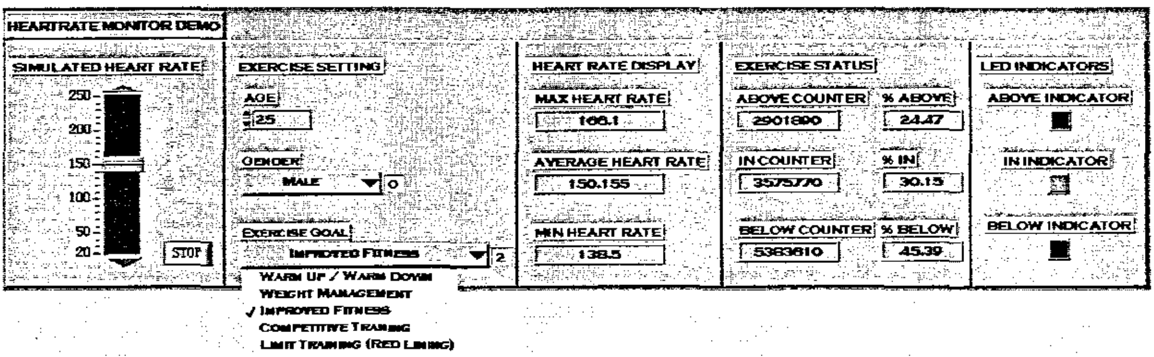
AGE: 25

PROFILE ID: 3

Figure 4-55: Smart card control – user administration

4.3.4.4 Heart-rate control

Heart-rate control is used to display the status of heart rate under the different selected exercise goals. In this application, the whole function will be decomposed to five parts, namely: simulated heart rate controller, heart rate display, exercise setting, *exercise status, and LED indicators display as shown in Figure 4-56.*


HEARTRATE MONITOR DEMO
SIMULATED HEART RATE
250
200
150
100
50
20
STOP
EXERCISE SETTING
EXERCISE GOAL
WARM UP / WARM DOWN
WEIGHT MANAGEMENT
✓ IMPROVED FITNESS
COMPETITIVE TRAINING
LIMIT TRAINING (RED LINING)
HEART RATE DISPLAY
EXERCISE STATUS
LED INDICATORS
ABOVE INDICATOR
IN INDICATOR
BELOW INDICATOR

AGE: 25

GENDER: MALE 0

EXERCISE GOAL: IMPROVED FITNESS 2

MAX HEART RATE: 166.1

AVERAGE HEART RATE: 150.155

MIN HEART RATE: 138.5

ABOVE COUNTER: 2901890

% ABOVE: 24.47

IN COUNTER: 3575770

% IN: 30.15

BELOW COUNTER: 5383810

% BELOW: 45.39

Figure 4-56: Heart-rate control

A simulated heart rate controller (left column) will generate assumptive heart rates and display in third column. In exercise setting (second column), selectable age and gender will be selected by different groups of exercisers. In addition, exercise goal represents the purpose of exercisers. For example, the exerciser will select warm up, weight management, improved fitness, competitive training, or limit training. After that, the built-in algorithms will calculate two variables (maximum heart rate, and minimum heart rate) in order to have a referenced range of heart rate depending on the deployed settings (exerciser's age, gender, and goal).

LED indicators reflect heart rates under the selected exercise mode. Three LED indicators are provided in this application. The first, "above indicator", indicates a dangerous status that the current heart rate is higher than suggested maximum heart rate. That is to say, the current exercise mode is not fit anymore; it warns the exerciser to change or reduce current exercise intensity. "In indicator" indicates a normal status that the current heart rate is standing in a safe range. Therefore, the exerciser can increase or reduce heart rate in order to make harder exercise training or relax exercise training. "Below indicator" indicates an inefficient exercise status, that the current heart rate is lower than suggested minimum heart rate, and recommends increasing current exercise intensity.

The state diagram of this application is shown in Figure 4-57, three inputs – simulated heart rate, exerciser's age, and gender will be set before any exercise.

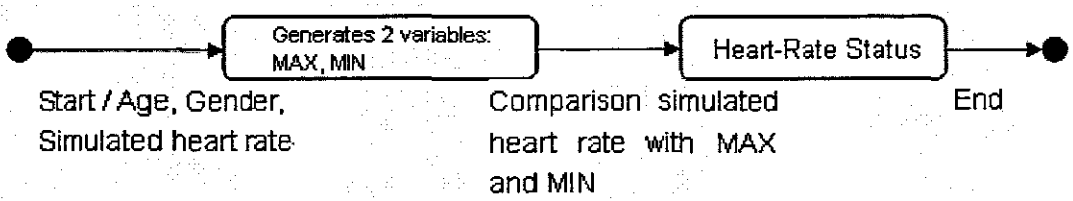
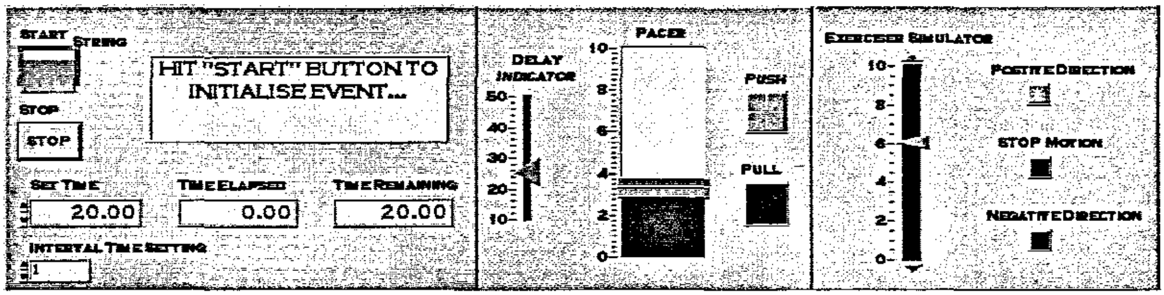

Generates 2 variables: MAX, MIN
Heart-Rate Status
Start / Age, Gender, Simulated heart rate
Comparison simulated heart rate with MAX and MIN
End

Figure 4-57: State diagram – heart-rate control

4.3.4.5 Exercise data recording control

The purpose of this control unit is to capture exercise data which will be manipulated into meaningful information for use. With this application, a number of peripheral stakeholders will be allowed access to previously inaccessible exerciser data.

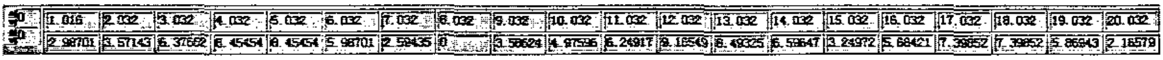
The features of this application are shown in Figure 4-58, which includes three columns. The middle and right columns have been presented earlier. The focus at present is on the left column – time setting. *Set Time*, *Time Elapsed*, and *Time Remaining* are easy to understand. The most important element is *Interval Time Setting* controller which is used to decide that every how many seconds will sample a value. For example, in Figure 4-58, setting value 1 to this controller means capturing exercise data every 1 second. Figure 4-59 shows the results in 20 seconds of exercising.


START
STRING
STOP
STOP
PACER
DELAY INDICATOR
PUSH
PULL
EXERCISER SIMULATOR
POSITIVE DIRECTION
STOP MOTION
NEGATIVE DIRECTION
50
40
30
20
10
10
8
6
4
2
0
10
8
6
4
2
0

HIT "START" BUTTON TO INITIALISE EVENT...

SET TIME: 20.00
TIME ELAPSED: 0.00
TIME REMAINING: 20.00
INTERVAL TIME SETTING: 1

Figure 4-58: Exercise data recording control



0	1.016	2.032	3.032	4.032	5.032	6.032	7.032	8.032	9.032	10.032	11.032	12.032	13.032	14.032	15.032	16.032	17.032	18.032	19.032	20.032
0	2.98701	3.57143	6.37662	6.45454	8.45454	5.98701	2.59435	0	3.58624	4.97596	6.24917	9.16549	8.49325	6.59647	3.24972	5.68421	7.39852	7.39852	5.86943	2.16579

Figure 4-59: Exercise data sampling

The state diagram of this application is shown in Figure 4-60. Time as the unique input and cycle qualification judge whether the current time is satisfied or not. If satisfied, then the current time and exercise data will be sampled and saved. Otherwise, the cycle will be carried on. Figures 4-61 and 4-62 shows sequence diagram and collaboration diagram, respectively.

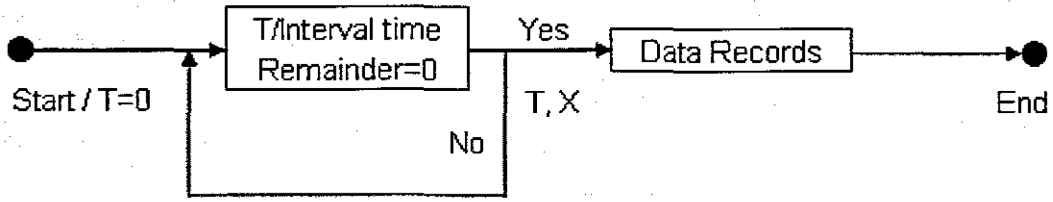

T/Interval time
Remainder=0
Yes
Data Records
Start / T=0
T, X
End
No

Figure 4-60: State diagram – exercise data recording control

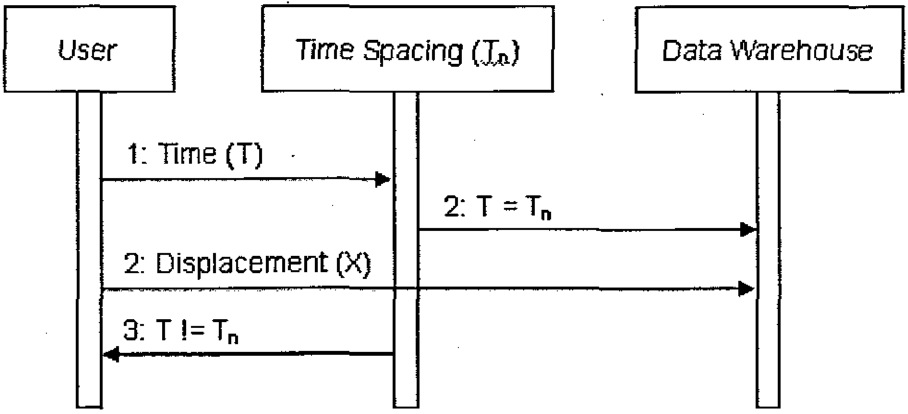

User
Time Spacing (T_n)
Data Warehouse
1: Time (T)
2: T = T_n
2: Displacement (X)
3: T != T_n

Figure 4-61: Sequence diagram – exercise data recording control

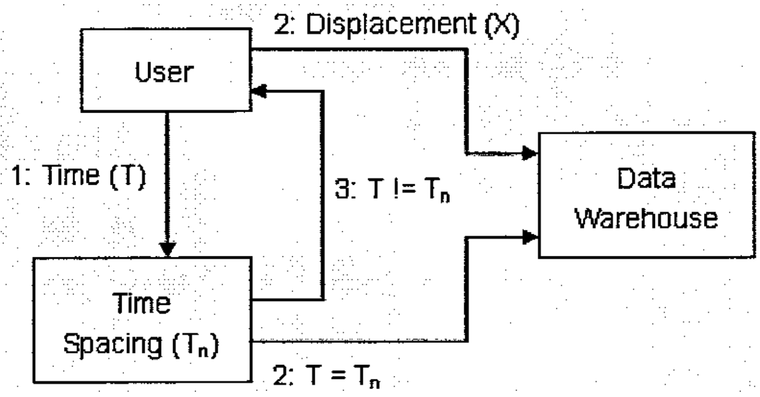

2: Displacement (X)
User
1: Time (T)
3: T != T_n
Data Warehouse
Time Spacing (T_n)
2: T = T_n

Figure 4-62: Collaboration diagram – exercise data recording control

4.3.4.6 Fail-safe mechanics

This computer-controlled exercise equipment enables high efficiency and fine operation without any adjustments. However, accidents such as over-weights appended to exercisers may happen when sensors and controllers checking pressure fail. Many accidents are caused by the failure of sensors for machine controls. In order to solve this safety problem, fail-safe mechanics for protecting exercisers and equipment are presented in this section.

Figure 4-63 shows a general method of fail-safe design. The guard block is implemented by hardware or software parts and validates the output data. The output information of the guard block is a valid / error property for the output data.

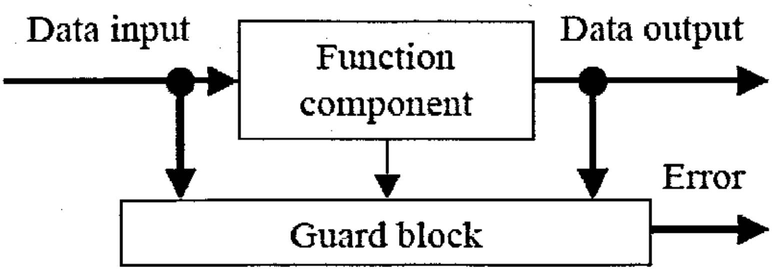

Data input
Function component
Data output
Error
Guard block

Figure 4-63: The general scheme for fail-safe systems

Source: Dobiáš (2005)

In this application, the fail-safe design is analysed by two aspects. The first aspect is analysed as the use of a "positive" fail-safe philosophy throughout the software design. The positive philosophy is a method of processing good signals only. Any type of reject or failure would result in an absence of signals indicating failures. In this way, an overall system failure or aberration that would result in an absence of signals would lead the machine to treat the occurrence as a failure by default. For example, if a shift register tracks bad signal through a machine, the "eject station" will automatic reject this bad signal. How does it work in practice? The machine will be designed with a sensor to detect any pressure present just prior to the "reject station". If the control system sends a positive signal associated with the pressure (data input), then the "reject station" (guard block) is signaled to hold back and allow the pressure (data output) to pass. But if the "reject station" receives no positive signal as a result of a problem (for example, pressure is too high), then it will automatically reject the pressure (error), in addition, error light is triggered.

Sometimes, even good signals are received, but accidents may still happen because of the incorrect intensity selected by inexperienced exercisers, such as selection of too high intensity. Therefore, the second aspect of fail-safe design is analyzed and focused on developing a software program in order to avoid hidden troubles in exercising. In this application, if stop motion is displayed, and exercise weights are not equal to 0, the time recorder controller will start to count, shut down function will be triggered till time recorder controller counts to 5, and unsafe LED indicator is displayed as well see Figure 4-64. Otherwise, the time recorder will be reset, and kept at "on" function. It has to be emphasised that "shut down" function will not release pressure immediately, but gradually, and thus, exercise weights will reduce gradually as well.

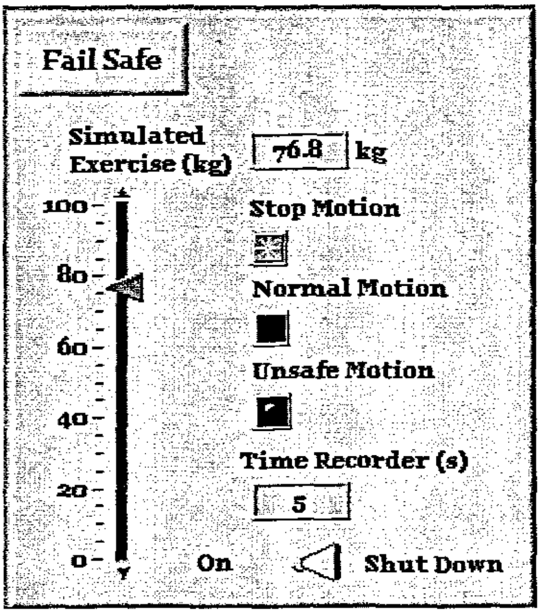

Fail Safe
Simulated Exercise (kg)
76.8
kg
100
80
60
40
20
0
Stop Motion
Normal Motion
Unsafe Motion
Time Recorder (s)
5
On
Shut Down

Figure 4-64: Fail-safe design

4.3.4.7 Data warehouse control

This control unit deals with all data transactions, and the implementation will be web-based, featuring hierarchical access control on a secure database and information systems platform. Figure 4-65 shows the state diagram of this application.

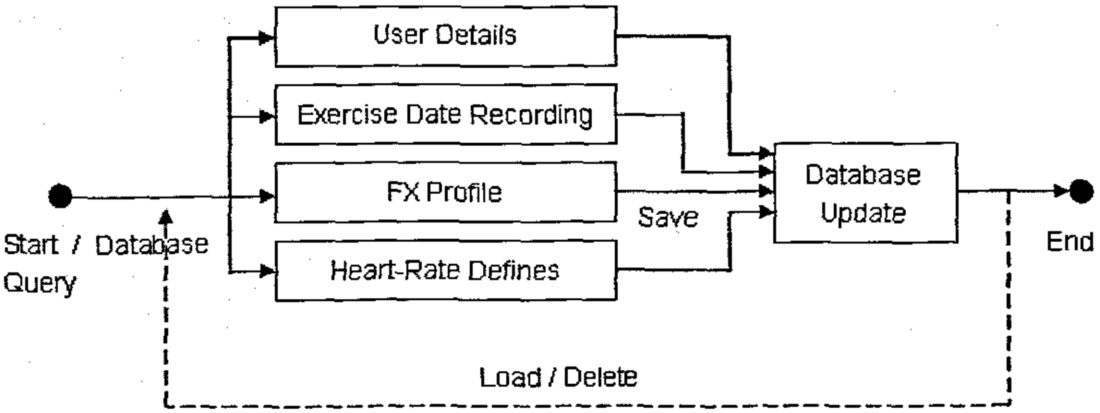

User Details
Exercise Date Recording
FX Profile
Heart-Rate Defines
Save
Database Update
Start / Database Query
End
Load / Delete

Figure 4-65: State diagram – array updates and database control

4.3.5 System integration

System integration is the bringing together of the component subsystems into one system and ensuring that the subsystems function together as a system (Wikipedia, n.d.). In information technology, system integration is the process of linking together different computing systems and software applications physically or functionally (Georgia State University, n.d.).

While it may sound like the final assembly of the parts of a system, successful system integration involves almost every aspect of the project and reaches from the very beginning into and through the maintenance phase of a system's life cycle, Figure 4-66 shows the actual integration, where the system comes together, many of the results of successful integration, and several of the activities that are required for successful integration (GSAM handbook, 2003).

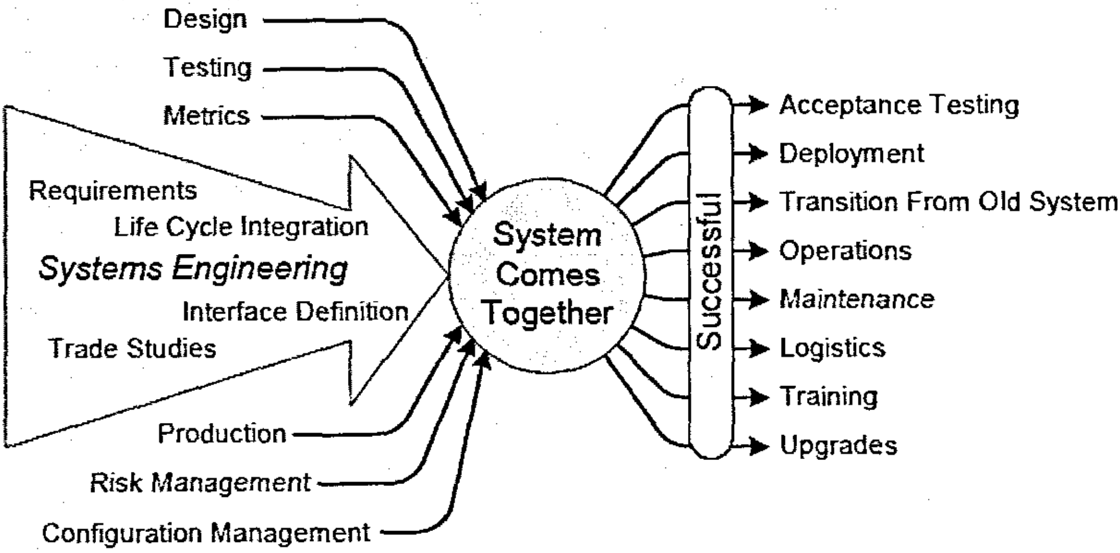

Design
Testing
Metrics
Requirements
Life Cycle Integration
Systems Engineering
Interface Definition
Trade Studies
Production
Risk Management
Configuration Management
System Comes Together
Successful
Acceptance Testing
Deployment
Transition From Old System
Operations
Maintenance
Logistics
Training
Upgrades

Figure 4-66: System integration inputs and results

Source: GSAM (2003)

Successful system integration results from the proper implementation of project activities shown on the left side of Figure 4-66. The primary requirement and driver is systems engineering; when systems engineering is employed throughout the project, successful system integration is one of the primary outcomes. This includes requirements definition, functional analysis, synthesis, trade studies, careful interface definition, true life cycle integration. In addition to the activities associated with systems engineering, correct employment of other activities such as configuration management, design, risk management, and testing are essential to ensuring all the pieces fit together during integration (GSAM handbook, 2003).

4.3.5.1 Process description

System integration begins with planning because system integration is the logical consequence of systems engineering and other activities. The integration plan is usually a composite of those portions of other plans which pertain to it, as shown in Figure 4-67 (GSAM handbook, 2003).

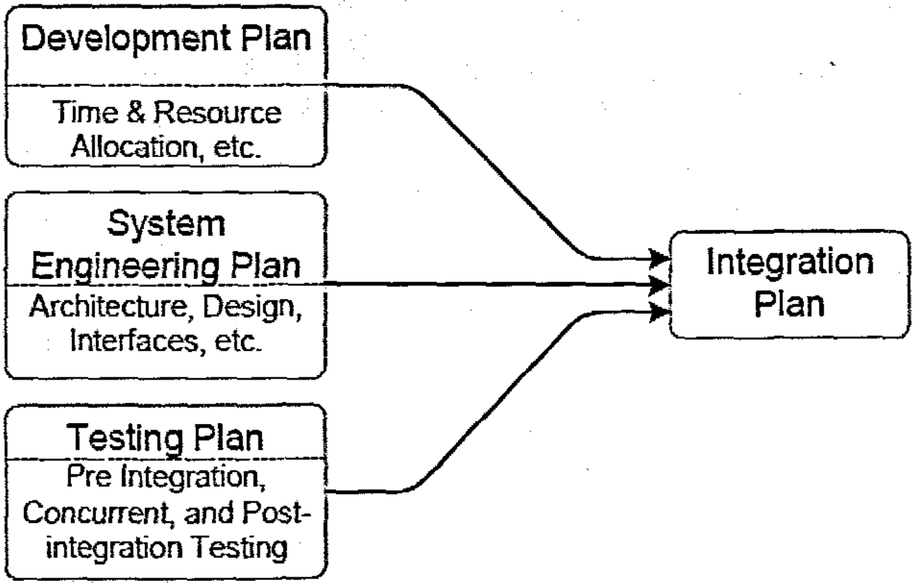

Development Plan
Time & Resource Allocation, etc.
System Engineering Plan
Architecture, Design, Interfaces, etc.
Testing Plan
Pre Integration, Concurrent, and Post-integration Testing
Integration Plan

Figure 4-67: System integration planning

Source: GSAM (2003)

The integration process is shown Figure 4-68 to depict integration and testing more realistically as a series of integrations and tests. Testing is used to assure developers that the integrated product is properly functional. Integrated modules that fail testing are sent back for debugging and rework (GSAM handbook, 2003).

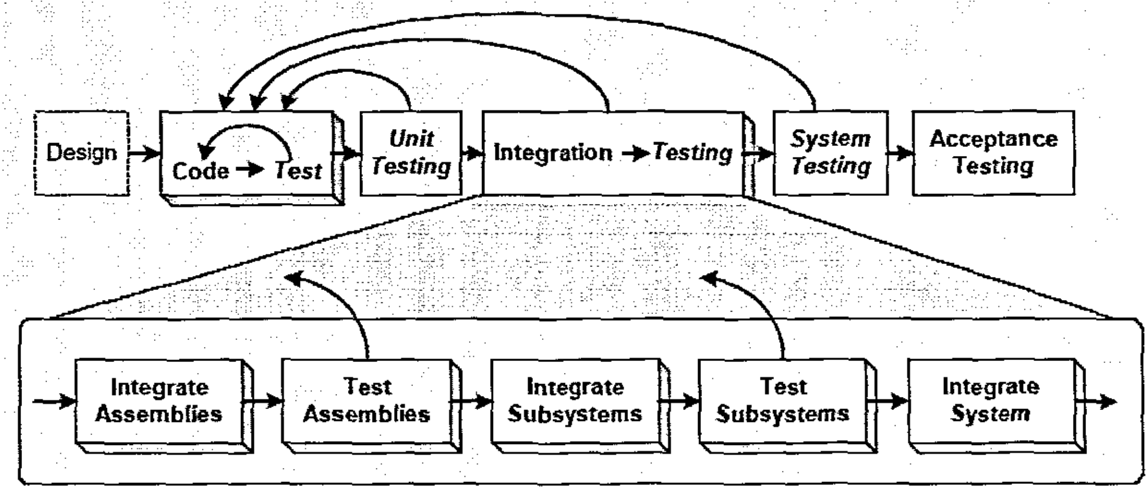

Design
Code → Test
Unit Testing
Integration → Testing
System Testing
Acceptance Testing
Integrate Assemblies
Test Assemblies
Integrate Subsystems
Test Subsystems
Integrate System

Figure 4-68: System integration process

***Source:* GSAM (2003)**

When tests fail, the test results are analysed to determine the cause of failure. The components that make up the module being tested are then sent back for debugging and recoding. If there appears to be a problem with the design, and not with the coding, the module is sent back to design for resolution. When the problem appears to be solved, the integration is repeated and the module is tested again.

Integration is iterative and progressive, with each level of integration building from and on top of the previous level of integration. This iterative, progressive nature is shown in Figure 4-69. Components are integrated into assemblies, and the assemblies are tested for functionality (GSAM handbook, 2003). Successful testing is followed by the integration of subsystems, which are also tested for correct functionality. Finally, the subsystems are integrated into the complete system, which is then tested for functionality (GSAM handbook, 2003).

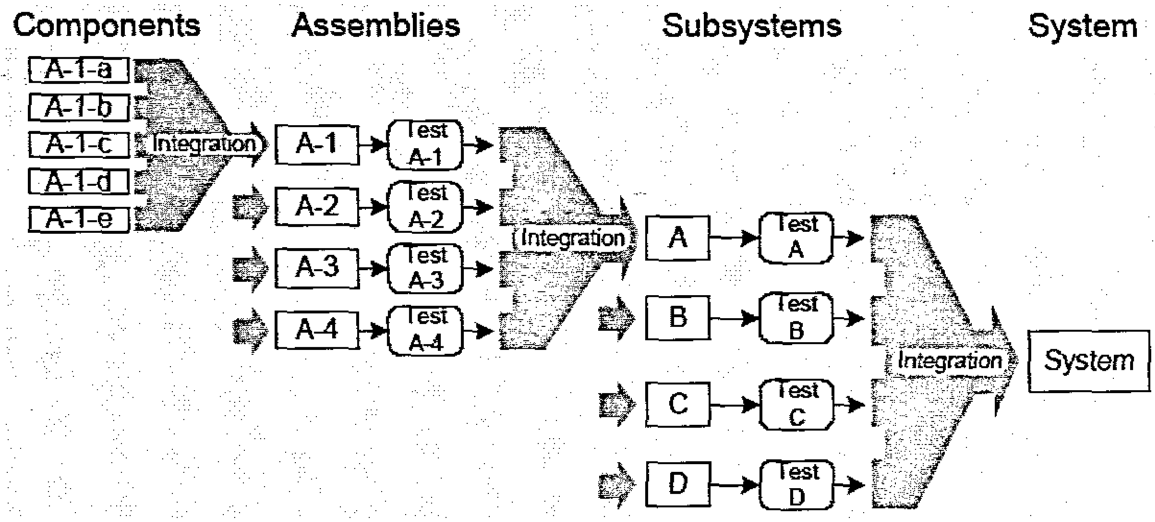

Components
Assemblies
Subsystems
System
A-1-a
A-1-b
A-1-c
A-1-d
A-1-e
Integration
A-1
A-2
A-3
A-4
Test A-1
Test A-2
Test A-3
Test A-4
Integration
A
B
C
D
Test A
Test B
Test C
Test D
Integration
System

Figure 4-69: Iterative, progressive nature of integration

Source: GSAM (2003)

In this application, the iterative, progressive nature of integration is shown in Figure 4-70.

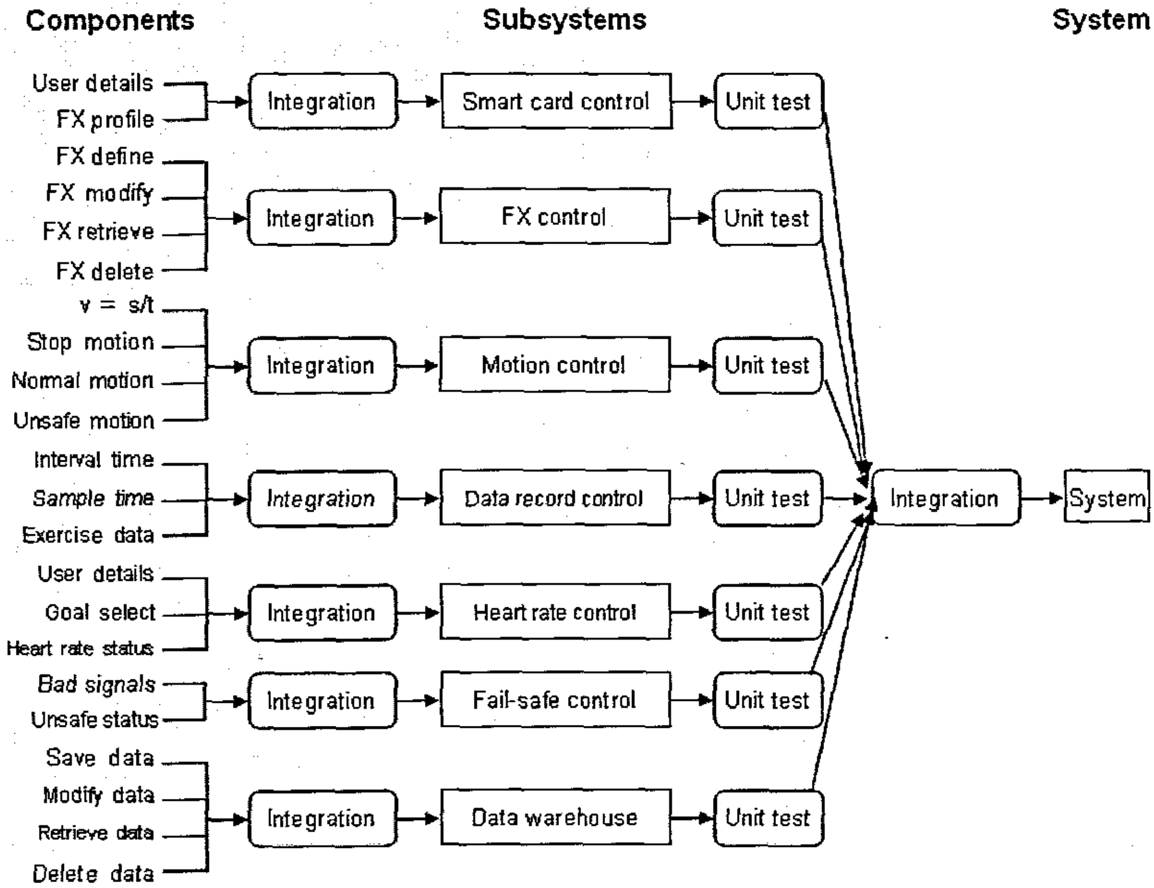

Components
Subsystems
System
User details
FX profile
FX define
FX modify
FX retrieve
FX delete
v = s/t
Stop motion
Normal motion
Unsafe motion
Interval time
Sample time
Exercise data
User details
Goal select
Heart rate status
Bad signals
Unsafe status
Save data
Modify data
Retrieve data
Delete data
Integration
Smart card control
FX control
Motion control
Data record control
Heart rate control
Fail-safe control
Data warehouse
Unit test
Integration
System

Figure 4-70: Iterative, progressive nature of integration in application

4.3.5.2 Interfaces

An absolute essential to any integration effort is complete knowledge of all interfaces. This includes interfaces between components, assemblies, subsystems and between the system and other systems it will need to work with (GSAM handbook, 2003). This is depicted in Figure 4-71.

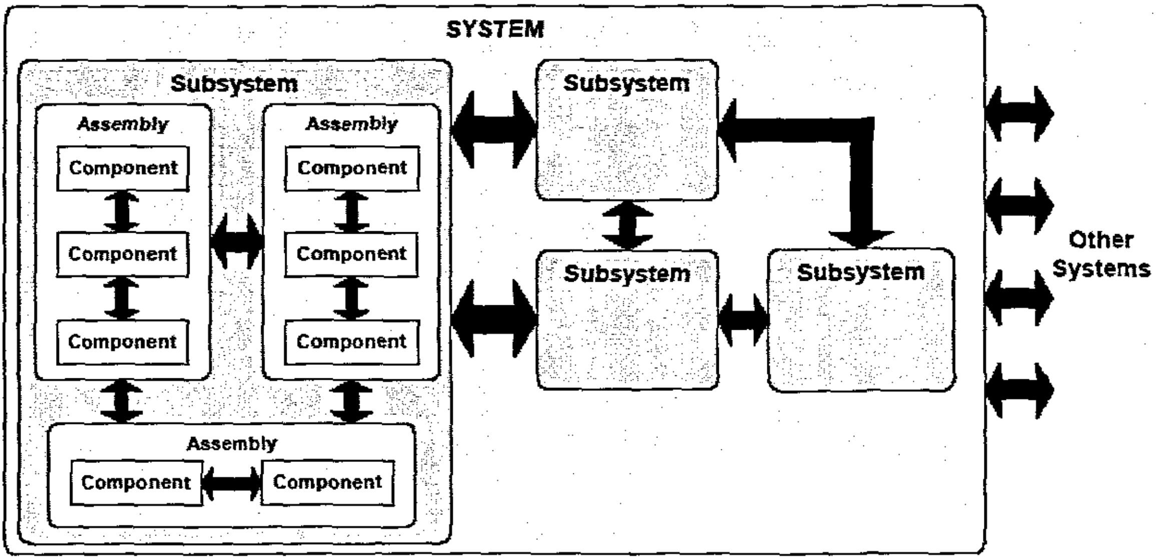

SYSTEM
Subsystem
Assembly
Assembly
Component
Component
Component
Component
Component
Component
Assembly
Component
Component
Subsystem
Subsystem
Subsystem
Other Systems

Figure 4-71: Interfaces between system parts and between systems

Source: GSAM (2003)

In this application, control system comprises seven subsystems those presented in 4.4.4. Based on Figure 4-71, the integrated system interface between subsystems is shown in Figure 4-72. The software UGI is given in Figure 4-73.

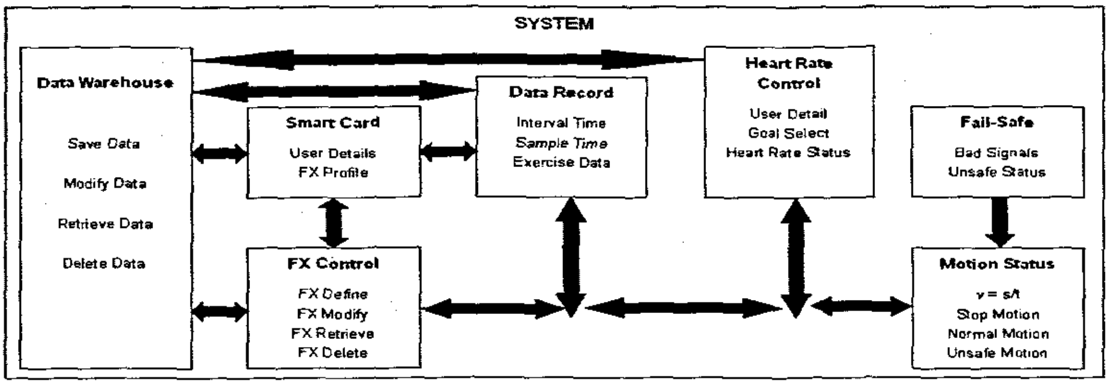
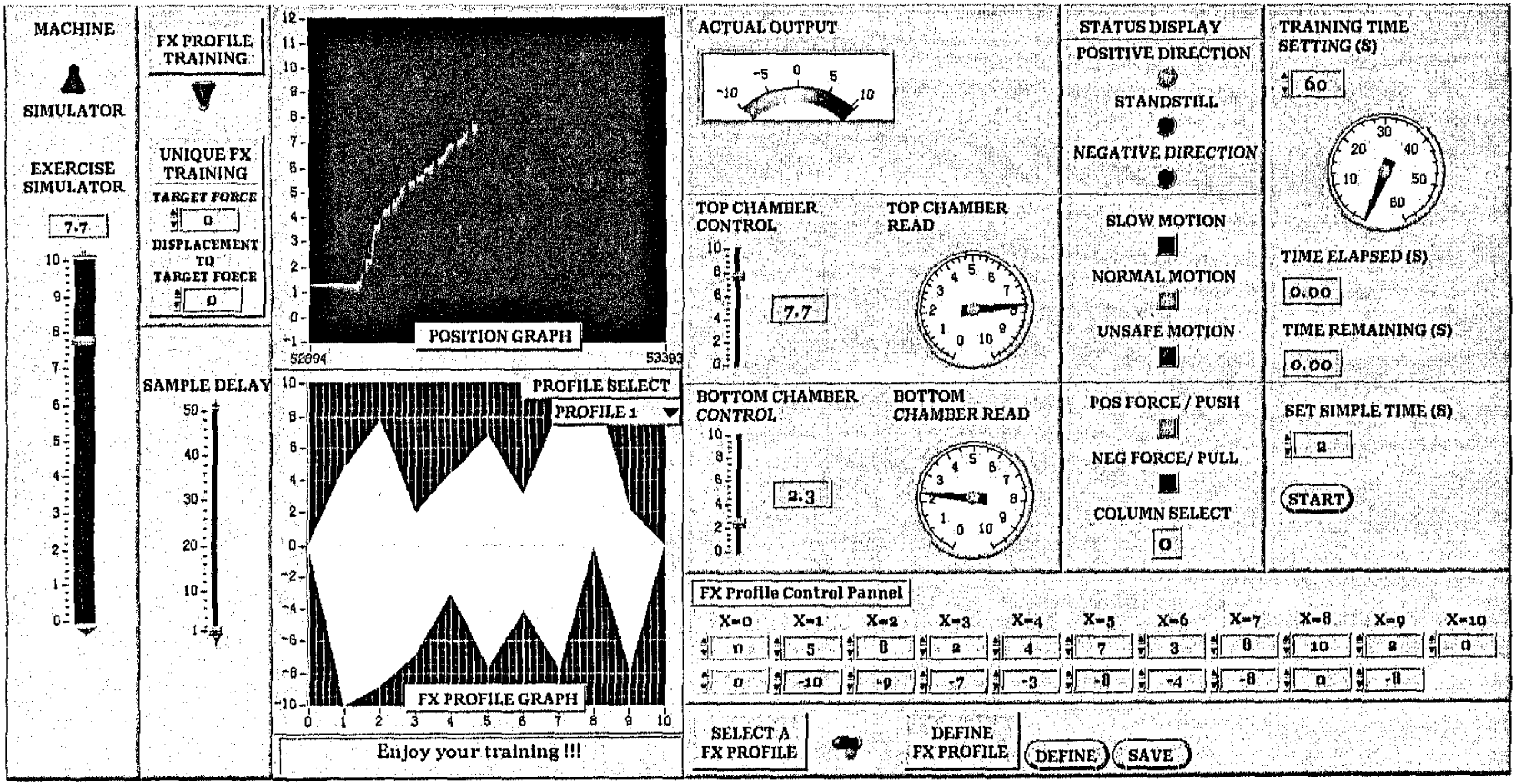

SYSTEM
Data Warehouse
Save Data
Modify Data
Retrieve Data
Delete Data
Smart Card
User Details
FX Profile
FX Control
FX Define
FX Modify
FX Retrieve
FX Delete
Data Record
Interval Time
Sample Time
Exercise Data
Heart Rate Control
User Detail
Goal Select
Heart Rate Status
Fail-Safe
Bad Signals
Unsafe Status
Motion Status
v = s/t
Stop Motion
Normal Motion
Unsafe Motion

Figure 4-72: Integrated system interface between subsystems


MACHINE
SIMULATOR
EXERCISE SIMULATOR
FX PROFILE TRAINING
UNIQUE FX TRAINING
SAMPLE DELAY
POSITION GRAPH
PROFILE SELECT
FX PROFILE GRAPH
ACTUAL OUTPUT
STATUS DISPLAY
POSITIVE DIRECTION
STANDSTILL
NEGATIVE DIRECTION
SLOW MOTION
NORMAL MOTION
UNSAFE MOTION
POS FORCE / PUSH
NEG FORCE/ PULL
TOP CHAMBER CONTROL
TOP CHAMBER READ
BOTTOM CHAMBER CONTROL
BOTTOM CHAMBER READ
START
SELECT A FX PROFILE
DEFINE FX PROFILE
DEFINE
SAVE

EXERCISE SIMULATOR: 7.7

TARGET FORCE: 0

DISPLACEMENT TO TARGET FORCE: 0

PROFILE SELECT: PROFILE 1

TOP CHAMBER CONTROL: 7.7

BOTTOM CHAMBER CONTROL: 2.3

COLUMN SELECT: 0

TRAINING TIME SETTING (S): 60

TIME ELAPSED (S): 0.00

TIME REMAINING (S): 0.00

SET SIMPLE TIME (S): 2

Enjoy your training !!!

FX Profile Control Pannel

X=0	X=1	X=2	X=3	X=4	X=5	X=6	X=7	X=8	X=9	X=10
0	5	8	2	4	7	3	8	10	2	0
0	-10	-9	-7	-3	-8	-4	-8	0	-8	

Figure 4-73: Integrated system GUI

4.3.6 Software testing

Software testing is the process used to help identify the correctness, completeness, security, and quality of developed computer software (Wikipedia, n.d.). It involves any activity aimed at evaluating an attribute or capability of a program or system and determining that it meets its required results (Hetzel, 1988).

In order to appreciate the testing, it is important to make a careful distinction between the terms "error", "fault" and "failure". As discussed in the earlier chapter, an error is a human action that products an incorrect result. The consequence of an error is software containing a fault. A fault, thus, is the manifestation of an error. If encountered, a fault may result in a failure. These failures are caused by faults, which are, in turn, the result of human errors. A failure may be caused by more than one fault, and a fault may cause different failures. Similarly, the relation between errors and *faults need not be one-to-one.*

Another distinction is often made between verification and validation. The IEEE Glossary defines "verification" as the process of evaluating a system or component to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase (IEEE, 1986). Verification, thus, tries to answer the question: Have we built the system right? The term "validation" is defined in the IEEE Glossary as the process of evaluating a system or component during or at the end of the development process to determine whether it satisfies specified requirements (IEEE, 1986). Validation, then, boils down to the question: Have we built the right system?

-

4.3.6.1 The testing process

Systems are built out of units which may themselves be built out of procedures. The testing process, like the programming process, must proceed in stages where each stage is a logical continuation of the previous stage. Basically, three distinct stages can be identified in the testing process as shown in Figure 4-74 (van Vliet, 2001).

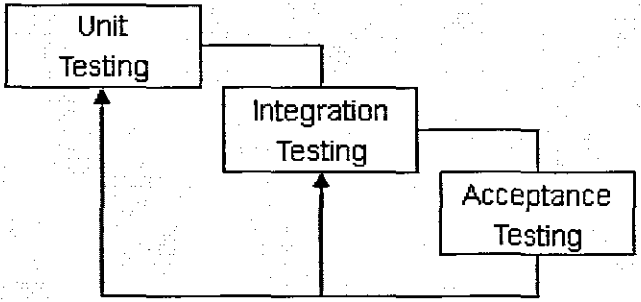


Figure 4-74: Testing process

Unit testing is the basic level of testing where individual components are tested to ensure that they operate correctly. It is the execution of a program with the intent of finding functional problems in the logic as well as technical problems in the code. Unit testing considers each component to be a stand-alone entity which does not require other system components to be present during the testing process.

Integration is carried out when the units are put together to make up the entire system. At this stage, the testing process is concerned with finding errors which normally result from unanticipated in unit testing stage. It is also concerned with validating that the overall system provides the functions specified in the requirements and that the dynamic characteristics of the system match those required by the system procurer.

Acceptance testing is the process of testing the system with real data. It involves testing the system as a whole to ensure that it meets the stated business requirements and that it works within the defined constraints.

In whole system testing, the testing will depend on the result of each of unit / module testing. The bottom-up testing philosophy is better to use in testing this system. In bottom-up testing the components making up a module are tested individually. Then they are integrated to form a module and this is tested. After each module has been tested, the modules are integrated, and the system is tested. For this research, the whole system is made up of several modules, namely smart card control module, exercise load control module, exercise motion control module, exercise data management control module, heart-rate control module, fail-safe control module, and data warehouse control module. Each module testing will be divided into three categories. Data input will test the edits and controls for entering data such as validations, cross references, and check digits. The second category is data processing which tests to ensure that the programs are working properly, and that data tables are accurately updated and internal calculations are correct. Finally, data output tests to ensure that the reports being generated are in the proper format and provide the proper information.

4.3.6.2 Test planning and scheduling

A test plan is a document that describes the objectives, scope, approach, and focus of a software testing effort. The process of preparing a test plan is a useful way to think through the efforts needed to validate the acceptability of a software product. The completed document will help people outside the test group understand the why and how of product validation.

A test plan states what the items to be tested are, at what level they will be tested, what sequence they are to be tested in, how the test strategy will be applied to the testing of each item, and describes the test environment. The major components of a test plan are:

- A description of the major phases of the testing process (unit testing and integration testing).
- A description of how traceability of testing to requirements is to be demonstrated.
- An overall testing schedule and resource allocation for this schedule.
- A description of the relationship between the test plan and other project plans.
- A description of the way in which tests are to be recorded. It is not enough simply to run tests. It must be possible to audit the testing process to check that it been carried out correctly.

Sommerville (1989)

Many test cases are used during the testing when a test plan is made. A test case is a document that describes an input, action, or event and an expected response, to determine if a feature of an application is working correctly. A test case should contain particulars such as test case identifier, test case name, objective, test conditions, input data requirements, and expected results.

The test case specifications should also be developed from the test plan. The test specification should explain how to implement the test cases described in the test plan.

Each test specification should contain the following items:

Case No.: The test case number.

Title: The title of the test.

ProgName: is the program name containing the test.

Author: is the person who wrote the test specification.

Date: is the date of the last revision to the test case.

Background: Describes in words how to conduct the test.

Expected error: Describes any errors expected.

Reference: Lists reference documentation used to design the specification.

Data: Describes the data flows between the implementation under test and the test engine.

The following sections describe the test cases used in this research to test each module.

Case No.: 1

Title: Membership

ProgName: Smart card control

Author: Wang

Date: 10/10/2006

Background: Save, query, retrieve, modify, and delete series of user details.

Expected error: Saving error, querying error, retrieving error, and deleting error.

Reference: None

Data: MemberID = 001, Name = "Wang", Gender = "Male", Age = 25, (FXProfileID = 1).

Case No.: 2.1

Title: Exercise load (static)

ProgName: Exercise load control (static)

Author: Wang

Date: 10/10/2006

Background: User sets the maximum and minimum weight manually.

Expected error: System does not accept or follow the user set weights.

Reference: None

Data: max weight = 8, min weight = 3

Case No.: 2.2

Title: Exercise load (FX dynamic)

ProgName: Exercise load control (FX dynamic)

Author: Wang

Date: 10/10/2006

Background: Save, retrieve, modify, and delete FX profiles.

Expected error: Saving error, retrieving error, and deleting error.

Reference: None

Data: $X_0=0$, $F_0=0$; $X_1=1$, $F_1=5$; $X_2=2$, $F_2=8$; $X_3=3$, $F_3=2$; $X_4=4$, $F_4=9$; $X_5=5$, $F_5=6$; $X_6=6$, $F_6=7$; $X_7=7$, $F_7=1$; $X_8=8$, $F_8=3$; $X_9=9$, $F_9=10$; $X_{10}=10$, $F_{10}=0$; $X_{11}=11$, $F_{11}=-2$; $X_{12}=12$, $F_{12}=-1$; $X_{13}=13$, $F_{13}=-8$; $X_{14}=14$, $F_{14}=-6$; $X_{15}=15$, $F_{15}=-9$; $X_{16}=16$, $F_{16}=-5$; $X_{17}=17$, $F_{17}=-7$; $X_{18}=18$, $F_{18}=-3$; $X_{19}=19$, $F_{19}=-8$; $X_{20}=20$, $F_{20}=0$.

Case No.: 3

Title: Exercise motion status

ProgName: Exercise motion control

Author: Wang

Date: 10/10/2006

Background: Exercise motion status responses by v=dx/dt with constants v_1, v_2.

Expected error: Read x error, read t error, exercise motion status displays error.

Reference: None

Data: $\Delta x = 0.2, \Delta t = 0.1$

Case No.: 4

Title: Data recording

ProgName: Exercise data management control

Author: Wang

Date: 10/10/2006

Background: Exercise data recording in every given time spacing.

Expected error: Data record error.

Reference: None

Data: time set = 30, time spacing = 1

Case No.: 5

Title: Heart-rate status

ProgName: Heart-rate control

Author: Wang

Date: 10/10/2006

Background: System depends on user's gender and age, and selected exercise goal to generate two variables, MAX and MIN, which are used as a measurement of heart-rate status under the current exercise goal. A simulated heart-rate will be loaded and compared with MAX and MIN to indicate which level of heart-rate status is standing, easy exercise, normal exercise, or hard exercise.

Expected error: Error values generated for two variables MAX and MIN. Error result of comparison simulated heart-rate with variables MAX and MIN. Heart-rate status result / display error.

Reference: None

Data: user's gender="male", user's age=25, exercise goal="warming up", simulated heart-rate=50

Case No.: 6

Title: Fail-safe

ProgName: Fail-safe control

Author: Wang

Date: 10/10/2006

Background: A mechanism used to deal with insecure data and safeguard both human and machine.

Expected error: Catastrophic events happen.

Reference: None

Data: Insecure data

Case No.: 7

Title: Database

ProgName: Data warehouse control

Author: Wang

Date: 10/10/2006

Background: Validation of database tables content.

Expected error: Character input error, numeric value error, digit error, and so on.

Reference: None

Data: Depends on each table field.

4.4 Summary

In this chapter, we fully illustrated the design and implementation of a computer-controlled pneumatic device to replace the deadweight in standard exercise equipment as a specific practical IT application. The design processes of the application successfully applied the object-oriented modeling method from system analysis to functional analysis, from software features to flow logic, from testing to evaluation. With the new technology, it is possible that the fitness industry will incorporate IT into its operations. The new pneumatic exercise equipment will greatly enhance the current deadweight-based exercise environment.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter summarises the previous chapters that discussed various aspects of the design and implementation of a computer-controlled pneumatic device to replace the deadweight in standard exercise equipment. On the one hand this thesis shows the benefits of usability design method but, on the other hand, it shows that many improvements can still be made. We first summarise the work and state the main contributions of this thesis.

As we indicated, this work involves the development of a practical IT application. We have focused on a computer-controlled pneumatic device that is more efficient and reliable in use, easy to operate, and will provide greater user satisfaction in exercise than deadweight-based exercise equipment.

During this research, we have learnt how to develop a practical application system, which includes preparing the literature, customising a suitable methodology and framework as a guide, and merging the method and framework into the design process.

5.1 Conclusions

This research set out to develop a novel dynamic resistance exercise equipment. The primary purpose of the project is to replicate and enhance the functionality, performance, and sensation of deadweight-based equipment. A further purpose of the project is to investigate the feasibility of designing a compact retrofit-able pneumatic unit to replace the deadweights of existing standard exercise equipment.

Chapter 2 described the key features of physical fitness, the relationships between physical activity, health-related fitness, and health. It indicated that physical activity can influence fitness, and also that fitness is related to health in a reciprocal manner. Fitness not only influences health, but health status also influences both physical activity level and fitness level. The health-related equipment which are used to maintain and promote fitness ability are presented as well. Following the fast developed IT areas, not only the traditional exercise equipment are required and used, but intelligent exercise equipment are also developed and devoted to provide appropriate responses in order to optimally exercise with a built-in computer system. The key concepts and technologies that use developing intelligent exercise equipment are discussed as well in this chapter.

Chapter 3 concentrated on the design methodologies presented by hardware features and software development. The hardware phase, focused on configuring a computer-controlled pneumatic rig in order to replace traditional deadweight in standard exercise equipment by FX (force-displacement) concept. In addition, closed-loop control method is concerned with using feedback to control outputs of dynamic system with great accuracy. In order to avoid oscillatory and unstable happened in feedback system, a PID controller with the specific reference of proportional, integral, and derivative capabilities is used. In the software phase, a monitoring and control software that used object-oriented as a guide under LabVIEW programming environment was presented. In the past decades, usability engineering was consistently neglected in software development. However, we are rapidly moving away from a technology-centred foundation to a user-centred maturity. In the beginning computing technology could not meet all the needs of customers, and software developers could take advantage of the relative stability of the object-oriented programming paradigm.

Chapter 4 explored a computer-controlled exercise system. The design environment includes hardware environment which involves NI PXI machine, NI TBX-68 data acquisition card, and a pneumatic rig; and software environment uses LabVIEW programming environment. The design processes of the application successfully applied the object-oriented modeling method from system analysis to functional analysis, from software features to flow logic, from testing to evaluation. With the new technology, it is possible that the fitness industry will incorporate IT into its operations. The new pneumatic exercise equipment will greatly enhance the current deadweight-based exercise environment.

5.2 Recommendations

Current exercise equipment imposes fixed-trajectory exercise on users with the dominance of static equipment designs. The weights generally can be changed only when the equipment is inactive, without any exercise data and body status feedback. Because current exercise equipment is mostly manually controlled, without any IT technologies, capturing and gathering of exercise data is difficult to achieve. Some basic physical protections are available on deadweight-based exercise equipment, but safety is still the problem for inexperienced exercisers. Fortunately, with the new exercise equipment, exercisers will concentrate on exercise without any inconvenience and danger.

The new exercise equipment is developed based on dynamic resistance with onboard data management. This new technology optimises exercise effectiveness for exercisers. Exercisers will have advanced diagnostic capacity, and will capture exerciser data which can be manipulated into meaningful information for use by health and fitness industry stakeholders.

In addition, exercisers will meet their fitness objectives more seamlessly. Medical specialists and fitness consultants will, via technology inputs, define the dynamics of exercise and the data statistics of equipment users will be remotely stored for manipulation by various third parties.

The novelty of the new exercise equipment lies in the exercises configured for individuals, using virtual trajectories that will allow for seamless exercise routines, without the need for physically adjusting weights. Data exercise management is an additional novelty offering useful empirical information on exercise status to interested third parties. In addition, new technology for fitness will open which uses pneumatic device to replace conventional deadweights in the traditional sports gym environment.

To summarise, compared with deadweight-based exercise equipment, new exercise equipment have some value propositions. That is why they need to be researched.

- First of all, the **adjust-abilities**.
  - Ease of adjustment
    - Re/setting weight

      In current standard deadweight exercise equipment, the exerciser has to adjust fitted weight after other users. Furthermore, each exerciser has to readjust the desired weights uninterrupted in-exercise.
    - Remember settings

      In the new exercise equipment, exercisers do not need to manually readjust weights. The system will remember each exerciser's settings and dynamical weight change by different exerciser's selection in-exercise.

- Secondly, the new exercise equipment provides more **safety** configurations for exercisers' use.
  - Protection of user in-exercise

    In current standard deadweight exercise equipment, the equipment cannot estimate exercisers' status, that is, whether the current weights still fit the exerciser when he puts in more intensity.
  - Fail-safe mechanics

The new exercise equipment provides fail-safe mechanics for catastrophic events, such as heart-rate monitoring that depicts exerciser's status, if any insecure situation happens, the equipment will send warning to the exerciser. Furthermore, if any calamities occur the exercise equipment will shut down immediately.

- Thirdly, the new exercise equipment has higher **performance**.
  - Integrated monitoring of user
    - Comprehensive exercise/health status

      In the new exercise equipment, the monitoring of exercise will be realised in four salient areas, namely – heart-rate monitoring, calculation of exercise work-rate, exercise event recording, and electromyography technology.
  - Dynamic adjustment of exercise parameters to exercise/health status.

    In current standard deadweight exercise equipment, exercisers have to manually readjust to the desired weights continually during the exercise. In the new exercise equipment, there is a bi-directional pneumatic cylinder actuation based on FX control technology to allow dynamically varied under computer control. With this new equipment, the exerciser can perform a comprehensive set of exercise routines without manually having to effect any adjustments.

- In addition, the new exercise equipment allows **data communication**.
  - Manuscript data recording

    Current standard deadweight exercise equipment do not include electronic data recording. If the exerciser wants to review the previous exercise data for a future exercise plan, they have to make a hand-written copy for every exercise recording.
  - Recording/archiving/retrieval electronic data transfer
    - Access control

    A smart card technology is used for access control and exercise event recording.

  - Distributed network environment

    A server controlled array of FX exercisers is included in the new exercise equipment. The server-based supervisory software will link the individual FX exercisers, enabling enhanced event recording, exercise optimisation, and management of the exercise circuit facility.

- Furthermore, **the enhanced machine dynamics**
  - FX control vs. Static

    In current standard deadweight exercise equipment, the weights generally can be changed only when the equipment is inactive. The new exercise equipment will use virtual trajectories that are based on FX technology to allow for seamless exercise routines without any physical adjustment.
  - Enhanced machine control dynamic

    In current standard deadweight exercise equipment, when weights are lifted an inertia of movement is created which tends to provide unevenness in the operating resistance during the exercise process. Sometimes, we describe it as vibration effect. In order to avoid this, the new exercise equipment uses carrier frequency technology to simulate vibration effects.
  - Improved exercise circuit

    In current standard deadweight exercise equipment, each equipment only provides single exercise motion. That is to say, the exerciser has to use different equipment in order to train arms and legs or other parts of the body. The new equipment provides an improved exercise circuit that performs a comprehensive set of exercise circuit on a single equipment with different exercise simulators.

- **On business features**

On business features, the new equipment has highly considerable Return on

Investment (ROI). As ROI described earlier, this equipment provides a series of exercise motions on a single equipment. That is much cheaper than purchasing different motions of deadweight equipment. The new equipment is targeted at medical insurers, medical specialists, fitness consultants and individuals seeking active management of their personal fitness data. In addition, the new equipment will be placed in new locations away from the traditional sports gym environment. From state-of-the-art perspective, the new equipment will primarily incorporate information technology into its operations.

- **Environment for exercise health**

A networked environment for exercise health is used in the new exercise equipment. Current standard deadweight exercise equipment only provide a training environment to exercisers. It does not have any description of exercise health. In the new equipment, a networked environment is used to link to each FX exerciser, and electronic capturing, managing and monitoring of exercise data is drawn from the machine user.

5.3 The future of intelligent exercise machine

Referring to the previous discussion, the main aspects of the development involved the building a pneumatic test rig which was successfully concluded. The rig itself has been designed and manufactured to the highest industry specifications using mainly FESTO components; the control aspects of the rig was implement using a National Instrument PXI unit.

In order to explore the future of Intelligent Exercise Machine (IEM), Newton Fortuin and John van Niekerk were interviewed and asked to reflect on IEM. Newton Fortuin and John van Niekerk is the original concept and product designer.

To explore the future of IEM, the following aspects should be considered. Firstly, the physical appearance of IEM which concerns a couple of elements includes what actuation approach to be used; which components to be used; the reliability of the machine and control technology; and the user environment communication feedback between machine and human.

According to Fortuin (2007), standard exercise equipment particularly deadweight-based equipment uses standard weight stack technology to ensure resistance to exercise against. The limitation of the weight stacks is that though the exercise only has one constant weight. It is not dynamically controllable and difficult to build in, but in exercise requirements should be variation displacement from actual weight. Oppositely, with pneumatic actuation approach, the weight can be controlled by spatial position of cylinders. On the other hand, Fortuin (2007) reflected that IEM would replicate the functionality of existing equipment, and then enhance and extend standard functionality in order to optimise the exercise experience to a particular user. To explore the further possibility of IEM, Fortuin (2007) pointed out that IEM should give user information feedback on how they perform in the exercise environment. He reflected we are obviously within information age, looking at the weight stack scenario it gives no information and it is difficult to obtain, for example, to automate a weight stack system, one needs to have a solenoid gun, and that is a mechanical unit shoot solenoid right into the system which costs R50, 000 per machine. In the future, new approaches to IEM will be raised and explored to set up standing wave patterns within pneumatics, which IEM needs to learn about users' exercise patterns and growth in muscle mass thus excite muscle regeneration during exercise.

In addition, van Niekerk made a vital comment on the size of components to be used in the future which will change the appearance of IEM drastically. According to van Niekerk (2007), the current physical size of IEM gives a clear display of the level of complexity of both the physical combined with the control system of the machine. In his view, he would not have to change the machine in design, Fortuin agreed as well.

But from the physical machine perspective, van Niekerk (2007) suggested the IEM needs to change in the size of components. The smallest viable unit which is available on the market is the retrofit unit which will replace the weight stacks.

Furthermore, two major issues are raised by van Niekerk (2007) to be considered. One is the reliability and control technology of the machine. The other important thing is the user environment or interface communication feedback between machine and human. For example, IEM needs to have some understanding and logic of the users exercise needs and patterns so that the interface with the users follows a logic accessible pattern in terms of settings onto the IEM and feedback from it to output the kind of data which the users are expecting.

The second issue, a very important one to the future of IEM is the market. Who will be prepared to buy the IEM? (Alexander (2007), reflecting on states in this industry in particular pointing out exports from China which almost proves that this industry is saturated. Chinese exports increase with 42% the exports by volume was 30% deadweight systems, 20% home gym, 14% treadmills and other fitness equipment 18%. On the other hand, Fortuin (2007) pointed out that the Chinese market is mainly exporting standard weight stack exercise equipment and for this reason the opportunity to sell IEM is great. Alexander feels that the 18% other fitness equipment is where IEM can conveniently be positioned. Fortuin and Alexander agreed that the 18% plus the 30% of the deadweight system is the market where IEM could possibly take over or share.

Van Niekerk (2007) agreed that with the minor changes in size and appearance of the machine the perfect market can be pursued and nurtured. He also admitted that it would take some exploring and research to find the diminutive component to replace the current ones but he is really excited that industry specifications were used in the actual building of the rig, thus, the IEM, which would assist the search greatly. Van Niekerk (2007) said it is just a matter of finding the niche market for the IEM then researching that market to see if it has been served and to what level and then finding the best way to enter. In his opinion, the best option in market strategy would be penetrative strategy, charging premium prices to a small segment of the market. From this, in my opinion, as soon as the market is informed and excited about the product, some advances can be introduced to the produce and the old version can to introduce to production. To keep the product life cycle going, new and improved version of the product or a complementary product can be designed and marketed with or separately from IEM.

The niche market I have in mind would be that of sport clubs (South African Rugby or Soccer) as well as other sport facilities such as athletics clubs, hospital heart units, and muscular dystrophy units, etc, can form part of this particular need. Advertising and marketing of the product should take place in health, PC, Gadget magazines. Conferences and other demonstrative media can be used to show and inform prospective users about the IEM.

REFERENCES

Adhikari, R. 1995. *Adopting OO Languages? Check Your Mindset at the Door.*

Alexander, B. 2006. *Technology Advancement Programme: Full Proposal-Innovation Fund Project.*

Alexander, B. 2007. *Personal Interview.* Cape Peninsula University of Technology, Head of Department – Information Technology. Contact number: 0822006763 (Cell), 021 959 6460.

American College of Sports Medicine (ACSM). 1990. *The Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness in Healthy Adults.*

American Diabetes Association. n.d. *What is Exercise?* http://www.diabetes.org/weightloss-and-exercise/exercise/what-is-exercise.jsp [20 November 2006].

American Psychological Association.1995. *Intelligence: Knowns and Unknowns.*

Andrews, R. B. 1971. *The Heart Rate as a Substitute for Respiratory Calorimetry,* American Journal of Clinical Nutrition. pp. 34-36, April.

Answer. n.d. *Anaerobic Exercise,* http://www.answers.com/topic/anaerobic-exercise-1 [19 April 2007].

Antsaklis, P. J. & Passino, K. M. 1992. *Introduction to Intelligent Control Systems with High Degrees of Autonomy.* Antsaklis, P. J. Dept. of Electrical Engineering, University of Notre Dame, Notre Dame. Passino, K. M. Dept. of Electrical Engineering, the Ohio State University, Neil Ave, Columbus.

Ariel, G. B. 1983. *Symposium on Olympic Sports Medicine – Clinics in Sports Medicine Vol. 2, No. 1, pp. 55-69.* President, Coto Research Centre, Trabuco Canyon, California; Chairman, Biomechanics Committee, Sport Medicine Council, United States Olympic Committee.

Armstrong, N., Balding, J., Gentle, P., & Kirby, B. 1990. *Estimation of Coronary Risk Factors in British Schoolchildren: A Preliminary Report.* British Journal of Sports Medicine. pp. 2-8, November.

Armstrong, N., Welsman, J. R., & Kirby, B. J. 2000. *Longitudinal changes in 11-13 Year Olds' Physical Activity.*

Armstrong, T., Bauman, A., Joanne, D. 2000. *Physical Activity Patterns of Australian Adults - Results of the 1999 National Physical Activity Survey*, Australian Institute of Health and Welfare, Canberra, August 2000.

Åström, K. J. & Wittenmark, B. 1997. *Computer-Controlled Systems – Theory and Design*, 3rd Edition.

Baudoin, C., & Hollowell, G. 1996. *Realizing the Object-Oriented Lifecycle*, Upper Saddle River, NJ: Prentice Hail.

Berggren, G., & Christensen, E. H. 1950. *Heart Rate as a Means of Measuring Metabolic Rate in Man.*

Berntson, G. G., Bigger, J. T., Jr., Eckbert, D. L., Grossman, P., Kaufmann, P. G., Malik, M., Nagaraja, N., Porges, S. W., Saul, J. P., Stone, P. H., & van der Molen, M. W. 1997.

Heart Rate Variability: Origins, Methods, and Interpretive Caveats. Psychophysiology.

Betterhealth. n.d. *Aerobic Exercise.* http://www.betterhealth.vic.gov.au/bhcv2/bhcpdf.nsf/ByPDF/Aerobic_exercise/$File/Aerobic_exercise.pdf [19 April 2007].

Beyondmoseying. n.d. *Hydraulic Exercise Equipment.* http://www.beyondmoseying.com/articles_hydraulic-exercise-equipment.html [27 October 2006].

Bijnen, F. C. H., Feskens, E. J. M, Caspersen, C. J., Nagelkerke, N., Mosterd, W. & Kromhout, D. 1999. *Baseline and Previous Physical Activity in Relation to Mortality in Elderly Men – The Zutphen Elderly Study, American Journal of Epidemiology 150.*

Blair, S. N., Kampert, J. B., Kohl, H. W., Barlow, C. E., Macera, C. A., Paffenbarger, R. S. et al. 1996. *Influences of Cardiorespiratory Fitness and Other Precursors on Cardiovascular Disease and all-cause Mortality in Men and Women.* The Journal of the American Medical Association. pp. 43-46, December.

Bouchard, C., Shephard, R. J., Stephens, T., & McPherson, B. D. 1990. *Exercise, Fitness, and Health: A Consensus of Current Knowledge*. Champaign, IL: Human Kinetics.

Bouchard, C., & Shephard, R.J. 1993. *Physical Activity, Fitness, and Health: The Model and Key Concepts.* In C. Bouchard, R.J. Shephard, & T. Stephens (Eds.), Physical Activity, Fitness, and Health: Consensus Statement (pp. 11-20). Champaign, IL: Human Kinetics Publishers.

Bouchard, C., Shephard, R.J., & Stephens T. 1994. *Physical Activity, Fitness, and Health: International Proceedings and Consensus Statement.* Canada.

Brownson, R.C., Baker, E.A., Housemann, R.A., Brennan, L.K., Bacak, S.J. 2001. Environmental and Policy Determinants of Physical Activity in the United States. *American Journal of Public Health*. pp. 14-18. Novermber.

Burr-Brown. 2007. *INA 128, INA 129 User Manual – Precision, Low Power INSTRUMENTATION AMPLIFIERS.*

Burr-Brown. 2007. *OPA 132, OPA 2132, OPA 4132 User Manual – High Speed FET-INPUT OPERATIONAL AMPLIFIERS.*

Butler, R.N., Davis, R., Lewis, C.B. 1998. *Physical Fitness: Benefits of Exercising for the Older Patient.*

Leroux, C. 2007. *Personal Interview*, Fitness consultant of Zone Fitness, 2nd floor paraw centre, voortrekker and de la ray road, Contact number: 021-9305150 (Work).

Cook & Gerry. 1989. *Pneumatic Exercise Device*, Published on 14 November 1989, http://www.freepatentsonline.com/4880230.html [7 September 2006].

Corbin, C.B., Lindsey, R., & Welk, G.J. 2001. *Concepts of fitness and wellness: A comprehensive lifestyle approach*, 3rd edition. St. Louis: McGraw Hill Higher Education.

Department of Health. 2000. *Health Survey for England 1998*, London: Stationery Office.

Department of Health. 1996. *Strategy Statement on Physical Activity*, London: Department of Health.

Deril, J. 2006. *Personal Interview*, Instructor of Virgin Active, Value Centre, N1 City, Goodwood, 7640, Contact Number: 0822267079 (Cell), 021-5953030 (Work).

Dobiáš, R. 2005. *Fail-safe Systems Design and Dependability Prediction*. Postgraduate study report. pp. 11-12, May. Department of Computer Science and Engineering, Faulty of Electrical Engineering, Czech Technical University. Karlovo nám. 13. Czech Republic.

FESTO. 2007. *MPZ-...-6-SW Manual.*

FESTO. 2007. *MS..-LFR- / LR(B)-..., MS-LF(M)- / LFX-... Manual.*

FESTO. 2007. *Proportional Pressure Regulator Type VPPM-... Manual.*

Fortuin, N. 2007. *Personal Interview*, Intelligent Exercise Machine Concept Designer of the Project.

Georgia State University. n.d. *Systems Integration Course Syllabus*. http://www2.cis.gsu.edu/cis/program/syllabus/graduate/CIS8020.asp [30 September 2007].

Gledhill, N. 1990. *Discussion: Assessment of Fitness. In: Bouchard, C., Shephard, R. J., Stephens, T., Sutton, J. R., & McPherson, B. D. - Exercise, Fitness, and Health: A Consensus of Current Knowledge*. Champaign, IL: Human Kinetics.

Google Glossary Definition. n.d. *Force Transducer*, http://www.google.com/search?hl=zh-CN&lr=&defl=en&q=define:Force+transducer&sa=X&oi=glossary_definition&ct=title [26 July 2007].

Grondard, C. 2005. *Regular Exercise Prolongs Survival in a Type 2 Spinal Muscular*

Atrophy Model Mouse.

GSAM Handbook. 2003. *System Integration – Chapter 14.* http://www.stsc.hill.af.mil/resources/tech_docs/gsam4/chap14.pdf [02 October 2007].

Gulotta, M 1995. *Teaching Computer Interfacing with Virtual Instruments in an Object-Oriented Language*, Biophysical journal volume 69, pp. 43-45, November. Department of Biochemistry, University of Minnesota, USA.

HBM. 2007. *U2B Force Transducer Manual.*

Health Promotion International (HPI). 1988. *Physical Fitness and Health-Related Fitness as Indicators of a Positive Health State, Vol. 3*, Oxford University Press.

Hetzel, W. C. 1988. *The Complete Guide to Software Testing, 2nd ed.* Publication info: Wellesley, Mass.: QED Information Sciences.

HKSAR. 2005. *OOM Procedures Manual,* http://www.ogcio.gov.hk/eng/prodev/eg52.htm [05 August 2007].

Howley, E.T. 2001. *Type of Activity: Resistance, Aerobic and Leisure Versus Occupational Physical Activity.* Med Sci Sports Exerc 33 (6 Suppl): S364-S369.

Hydraulic-equipment-manufactures. n.d. *Hydraulic Exercise Equipment,* http://www.hydraulic-equipment-manufacturers.com/hydraulic-exercise-equipment.html [29 October 2006].

IEEE. 1986. *Standard for Software Verification and Validation Plans.* IEEE Std 983.

Intota. n.d. *Experts in Displacement Transducer,* *Atrophy Model Mouse.*

GSAM Handbook. 2003. *System Integration – Chapter 14.* http://www.stsc.hill.af.mil/resources/tech_docs/gsam4/chap14.pdf [02 October 2007].

Gulotta, M 1995. *Teaching Computer Interfacing with Virtual Instruments in an Object-Oriented Language*, Biophysical journal volume 69, pp. 43-45, November. Department of Biochemistry, University of Minnesota, USA.

HBM. 2007. *U2B Force Transducer Manual.*

Health Promotion International (HPI). 1988. *Physical Fitness and Health-Related Fitness as Indicators of a Positive Health State, Vol. 3*, Oxford University Press.

Hetzel, W. C. 1988. *The Complete Guide to Software Testing, 2nd ed.* Publication info: Wellesley, Mass.: QED Information Sciences.

HKSAR. 2005. *OOM Procedures Manual*, http://www.ogcio.gov.hk/eng/prodev/eg52.htm [05 August 2007].

Howley, E.T. 2001. *Type of Activity: Resistance, Aerobic and Leisure Versus Occupational Physical Activity.* Med Sci Sports Exerc 33 (6 Suppl): S364-S369.

Hydraulic-equipment-manufactures. n.d. *Hydraulic Exercise Equipment*, http://www.hydraulic-equipment-manufacturers.com/hydraulic-exercise-equipment.html [29 October 2006].

IEEE. 1986. *Standard for Software Verification and Validation Plans.* IEEE Std 983.

Intota. n.d. *Experts in Displacement Transducer*, http://www.intota.com/multisearch.asp?strSearchType=all&strQuery=displacement+transducer [26 July 2007].

Jacobson, I. 1992. *Object-Oriented Software Engineering: a use case driven approach*, ACM Press – Addison – Wesley.

Jehander, J. 2003. *Graphical Object-Oriented Programming in LabVIEW*, http://zone.ni.com/dezone/concepted.nsf/webmain/1A7B60096CE0CDA986256A9A0074E4EC [22 June 2007].

Karvonen, J., Chwalbinska-Moneta, J., & Saynajakangas, S. 1984. *Comparison of Heart Rates Measured by ECG and Microcomputer*. Physician and Sports Medicine.

Kelly, L. E. 2000. *Patterns of Physical Activity in 9-10 Year Old American Children as Measured by Heart Rate Monitoring*. Pediatric Exercise Science.

Lee, I. & Paffenbarger, R. 1997. *Physical Activity, Fitness and Longevity. Ageing 9:2-11.*

Leger, L., & Thivierge, M. 1988. *Heart Rate Monitors: Validity, Stability and Functionality*. Physician and Sports Medicine.

Lige, D. 2002, *Aerobic Exercise for Life*. http://www.alive.com/812a3a2.php?subject_bread_cramb=94 [19 April 2007].

Mainstream Science on Intelligence. 1994. *Intelligence*.

Martin Buss & Hideki Hashimoto. 1996. *Intelligent Control for Human-Machine Systems*. IEEE.

Mayhew, D. J. 1999. *The usability engineering lifecycle: a practitioner's handbook for user interface design*, Morgan Kaufmann Publishers, San Francisco, California.

McAuley, E., Kramer, A. F., & Colcombe, S. J. 2004. *Cardiovascular Fitness and Neurocognitive Function in Older Adults.*

McGinnis, J.M., & Foege, W.H. 1993. *Actual causes of death in the United States.* JAMA, 270, 2207-2212.

Micropaedia. 2005. *The New Encyclopedia Britannica – Volume 4*, Encyclopedia Britannica Inc., Chicago.

Montoye, H. J., Kemper, H. C. G., Saris, W. H. M., & Washburn, R. A. 1996. *Measuring Physical Activity and Energy Expenditure*, Champaign, IL: Human Kinetics.

National Instruments. 2003. *LabVIEW 7 Express – User Manual*, 2003 edition.

National Instruments. 2005. *Measurement and Automation – Catalog 2005.*

Newfitness. n.d. *The Benefits of Aerobic Exercises,* http://www.new-fitness.com/Aerobics/index.html [19 April 2007].

O'Connor, D., Crowe, M., & Spinks, W. 2006. *Effects of Static Stretching on Leg Power During Cycling.*

O'Toole, M. L., Douglas, P. S., & Hiller, W. D. B. 1998. *Use of Heart Rate Monitors by Endurance Athletes: Lessons from Triathletes.* Journal of Sports Medicine and Physical Fitness. pp. 4-7, October.

Objectfaq. n.d. *Basics of Object-Oriented,* http://www.objectfaq.com/oofaq2/body/basics.htm [31 July 2007].

Parr, A. 1998. *Hydraulics and Pneumatics – A Technician's and Engineer's Guide*, 2nd edition.

Pate, R. R. & Shephard, R. J. 1989. *Characteristics of physical fitness in youth. In: Gisolfi, C. V., Lamb, D. R. – Perspectives in Exercise Science and Sports Medicine, Vol 2, Youth, Exercise and Sport. Indianapolis*, IN: Benchmark Press.

Pate, R. R. 1988. *The Evolving Definition of Fitness.* Disease Control and Prevention and the American College of Sports Medicine.

Polar Fitness. n.d. *Own Workout Program*, http://www.polar.fi/polar/channels/eng/data/features/feature.html [13 April 2007].

Polar Fitness. n.d. *OwnCal Energy Expenditure*, http://www.polar.fi/polar/channels/eng/data/features/feature_43.html [13 April 2007].

Polar Fitness. n.d. *Polar OwnZone*, http://www.polar.fi/polar/channels/eng/data/features/feature_164.html [13 April 2007].

Polar Fitness. n.d. *Polar Sport Zones*, http://www.polar.fi/polar/channels/eng/data/features/feature_196.html [13 April 2007].

Polar Fitness. n.d. *Recording Rate*, http:// www.polar.fi/polar/channels/eng/glossary/RecordingRate.html [13 April 2007].

Powell, K.E., & Blair, S.N. 1994. *The public health burdens of sedentary living habits: Theoretical but realistic estimates. Medicine and Science in Sports and Exercise*, 26, 851-856.

Rebecca, J. 2005. *Health, The Basics*, 6th edition, San Francisco, USA.

Robergs, R. A. & Robers, S. O. 2000. *Fundamental Principles of Exercise Physiology for Fitness, Performance, and Health*, The McGraw-Hill Company, Inc., USA.

Damon, R. 2007. *Personal Interview*, Fitness consultant of Zone Fitness, 2nd floor paraw centre, voortrekker and de la ray road, Contact number: 021-9305150 (Work).

Rqriley. n.d. *Numo The System*, http://www.rqriley.com/numo.htm [13 September 2006].

Saris, W. H. M., Snel, P., & Binkhorst, R. A. 1977. *A Portable Heart Rate Distribution Recorder for Studying Daily Physical Activity*, pp. 6-7, December. European Journal of Applied Physiology.

Scrcek, W. Y., Mahoney, D. P., & Young, B. R. 2000. *A Real-Time Approach to Process Control*, John Wiley & Sons, Ltd. Baffins Lane, Chichester, West Sussex PO19 1UD, England.

Shah, V.; Sivitanides, M. & Martin, R. 1997, *Object Oriented Development*. Department of CIS & QM, School of Business, Southwest Texas State University San Marcos, Texas.

Shephard, R. J. 1977. *Endurance Fitness*, 2nd edition, Toronto: University of Toronto Press.

Singh, N., de Vos, N., Ross, D., & Stavrinos, T. 2005. *Optimal Load for Increasing Muscle Power During Explosive Resistance Training in Older Adults. The Journals of Gerontology*. pp. 13-17, October.

Skinner, J. & Oja, P. 1994. *Laboratory and Field Tests for Assessing Health-Related Fitness*. In: Bouchard C., Shephard R., Stephens T. (eds) Physical Activity, Fitness and Health. Human Kinetics Publishers, Champaign, IL, pp. 160-179.

Sommerville, I. 1989. *Software Engineering*, 4th edition, Addison-Wesley Publishers Ltd., Addison-Wesley Publishing Company Inc.

Sparkpeople. n.d. *Fitness Reference Guide Anaerobic Exercise*, http://sparkpeople.com/resource/reference_anaerobic.asp [19 April 2007].

Stacey, C. 1998. *Practical Pneumatics*, London.

Standhousehotel. n.d. *Different Types of Exercise Equipment*, http://www.standhousehotel.com/Leisure-Centre/Different-types-of-Exercise-Equipment.htm [26 August 2006].

Steptoe, A. 2000. *Stress, Social Support and Cardiovascular Activity over the Working Day*. pp. 3-6, July. International Journal of Psychophysiology.

Stessman, J., Maaravi, Y., Hammerman, R. R., & Cohen, A. 2000. *The Effects of Physical Activity on Mortality in the Jerusalem 70-year-olds Longitudinal Study*. pp. 17-20, August. Journal of the American Geriatrics Society.

Stratton, G. 1996. *Children's Heart Rates during Physical Education Lessons: A Review*. Pediatric Exercise Science.

Taylor, D. 1995. *Object-Oriented Technology: A Manager's Guide*, Addision-Wesely, Reading, MA.

Torun, B. 1984. *Physiological Measurements of Physical Activity Among Children Under Free-Living Conditions.* In Gregory J. Welk, *Physical Activity Assessments for Health-Related Research*, 2002.

U.S. Department of Health and Human Services (USDHHS) – National Institutes of Health. 1996. *Physical Activity and Health: a report of the Surgeon General.* Atlanta: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention National Center for Chronic Disease Prevention and Health Promotion.

U.S. Department of Health and Human Services (USDHHS) – National Institutes of Health. 2002. *Obesity, Physical Activity, and Weight-control Glossary.*

University of Iowa. n.d. *Anaerobic Exercise Energy without Oxygen*, University of Iowa Health Care, http://www.uihealthcare.com/topics/exercisefitness/exer3098.html [19 April 2007].

USDA. 2005. *Dietary Guidelines for Americans – Chapter 4 Physical Activity,* http://www.health.gov/DietaryGuidelines/dga2005/document/html/chapter4.htm [08 April 2007].

van Niekerk, J. 2007. *Personal Interview*, Intelligent Exercise Machine Product Designer of the Project.

van Praag H., Kempermann G., & Gage F. H. 1999. *Ontogeny Running Increases Cell Proliferation and Neurogenesis in the Adult Mouse Dentate Gyrus.*

van Vliet, H. 2001. *Software Engineering: Principles and Practice*, second edition, John Wiley & Sons Ltd, Baffins Lane, Chichester, West Sussex PO19 1UD, England.

Villeneuve, P. J., Morrison, H. I., Craig, C. L., & Schaubel, D. E. 1998. *Physical Activity,* *Physical Fitness and Risk of dying - Epidemiology 9.*

Vincent, I. n.d. *Daily Aerobic Exercise is Required for Optimal Health*, http://searchwarp.com/swa146164.htm [19 April 2007].

Vuori, I. 1998. *Experiences of Heart Rate Monitoring in Observational and Intervention Studies*. pp. 7-8, April. Journal of Sports Sciences.

Wang, Zheng 1. 2006. *Personal observation of the training equipment functionalities*, Virgin Active Gymnasium, Value Centre, N1 City, Goodwood, 7640, 14 November 2006.

Wang, Zheng 2. 2006. *Personal observation of the training equipment functionalities*, Fox Gymnasium, Bellville, 7530, 15 November 2006.

Websites. n.d. *What is Exercise and Why is it Important?*, http://websites.afar.org/site/PageServer?pagename=IA_I_exer_2_what [20 November 2006].

Webster's Ninth New Collegiate Dictionary. 1984. Merriam – Webster, Springfield, MA.

Welk, G. J. 2002. *Physical Activity Assessments for Health-Related Research*, Iowa State University.

World Health Organization. 2000. Fifty-fifth World Health Assembly. Resolution WHA55.23: Diet, Physical Activity and Health. Geneva, Switzerland.

Wikipedia. n.d. *Anaerobic Exercise*, http://en.wikipedia.org/wiki/Anaerobic_exercise [19 April 2007].

Wikipedia. n.d. *Closed Loop*, http://en.wikipedia.org/wiki/Closed_loop [01 August 2007].

Wikipedia. n.d. *Hydraulic Exercise Equipment*, http://en.wikipedia.org/wiki/Hydraulic_Exercise_Equipment [27 October 2006].

Wikipedia. n.d. *Intelligence*, http://en.wikipedia.org/wiki/Intelligence [10 April 2007].

Wikipedia. n.d. *Object-Oriented Programming.* http://en.wikipedia.org/wiki/Object-oriented_programming [22 June 2007].

Wikipedia. n.d. *PID Controller.* http://en.wikipedia.org/wiki/PID_controller [03 August 2007].

Wikipedia. n.d. *Physical Exercise.* http://en.wikipedia.org/wiki/Exercise [19 April 2007].

Wikipedia. n.d. *Software Testing.* http://en.wikipedia.org/wiki/Software_testing [07 November 2006].

Wikipedia. n.d. *System Integration.* http://en.wikipedia.org/wiki/System_integration [30 September 2007].

Wilmore, J., & Knuttgen, H. 2003. *Aerobic Exercise and Endurance Improving Fitness for Health Benefits. The Physician and Sports Medicine.*

Wisegeek. n.d. *What are the Different Types of Exercise Equipment?* http://www.wisegeek.com/what-are-the-different-types-of-exercise-equipment.htm [25 August 2006].

Wittenmark, B., Åström, K. J., & Årzén, K. E. 2002. *IFAC Professional Brief – Computer Control: An Overview*, Department of Automatic Control, Lund Institute of Technology, Lund, Sweden.

World Book. 2006. *The World Book Encyclopedia – A Volume 1*, World Book Inc., a Scott Fetzer Company, Chicago.

World Health Organization. 1968. *Meeting of Investigators on Exercise Tests in Relation to Cardiovascular Function. WHO Technical Report.*

APPENDICES

Appendix A: Interview questions

Interviews with fitness consultants from Fox Fitness, Virgin Active, and Zone Fitness in Cape Town, South Africa.

Question 1

What exercise equipment are available in market? And how many types are there?

Question 2

Which exercise equipment are based on lift-mode exercise?

Question 3

Which exercise equipment are based on spring-mode exercise?

Question 4

Is there any exercise equipment controlled based on build-in controller?

Question 5

What procedures are available to protect humans on the current weight type / deadweight-based exercise equipment?

Question 6

Is there any exercise equipment that provides data transfer capability, and health status feedback function?

Question 7

Do you think exercise data record capability will assist fitness consultant to arrange optimal exercise routine to their exercisers?

Question 8

Is there any single exercise equipment can provide aerobic exercise and anaerobic exercise?

Question 9

Do you prefer to use pneumatic technology to instead of conventional deadweight-based exercise environment?

Question 10

Do you think a new innovation will be opened for traditional sports gym environment with the new exercise equipment?

Appendix B-1: Personal observation of the training equipment functionalities

Personal observation of the training equipment functionalities at Virgin Active
Gymnasium, N1 City, Cape Town, South Africa, 2006.

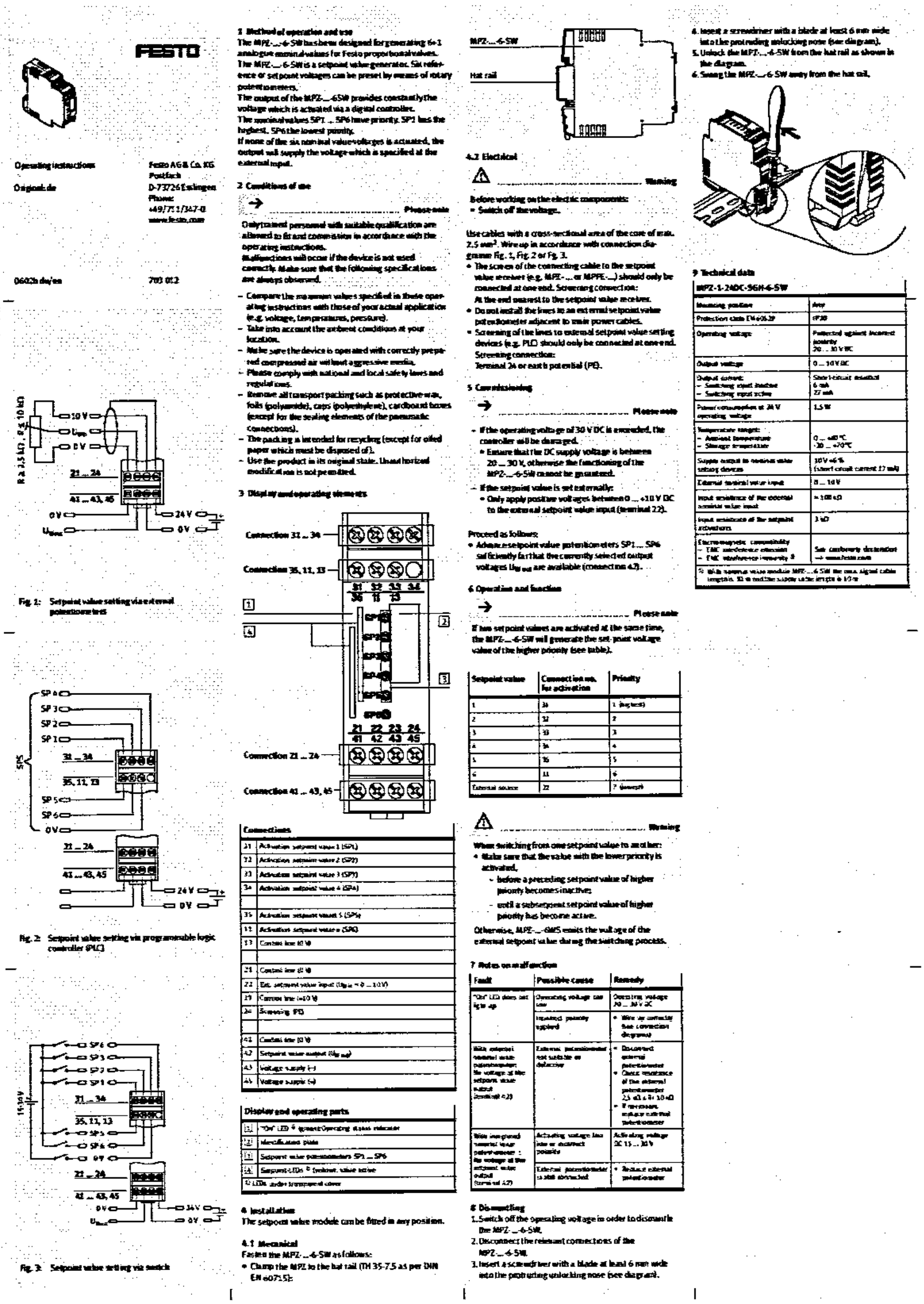
At Virgin Active Gymnasium, exercise equipment basically fall into muscle training equipment and cardio training equipment. The all muscle training equipment are deadweight-based equipment, completely manually controlled. Exercisers have to stop exercise to adjust weights physically after a phase. In addition, they do not have any muscle training equipment associated with IT technology to provide exercise data transfer in order to have advanced muscle training.

Appendix B-2: Personal observation of the training equipment functionalities

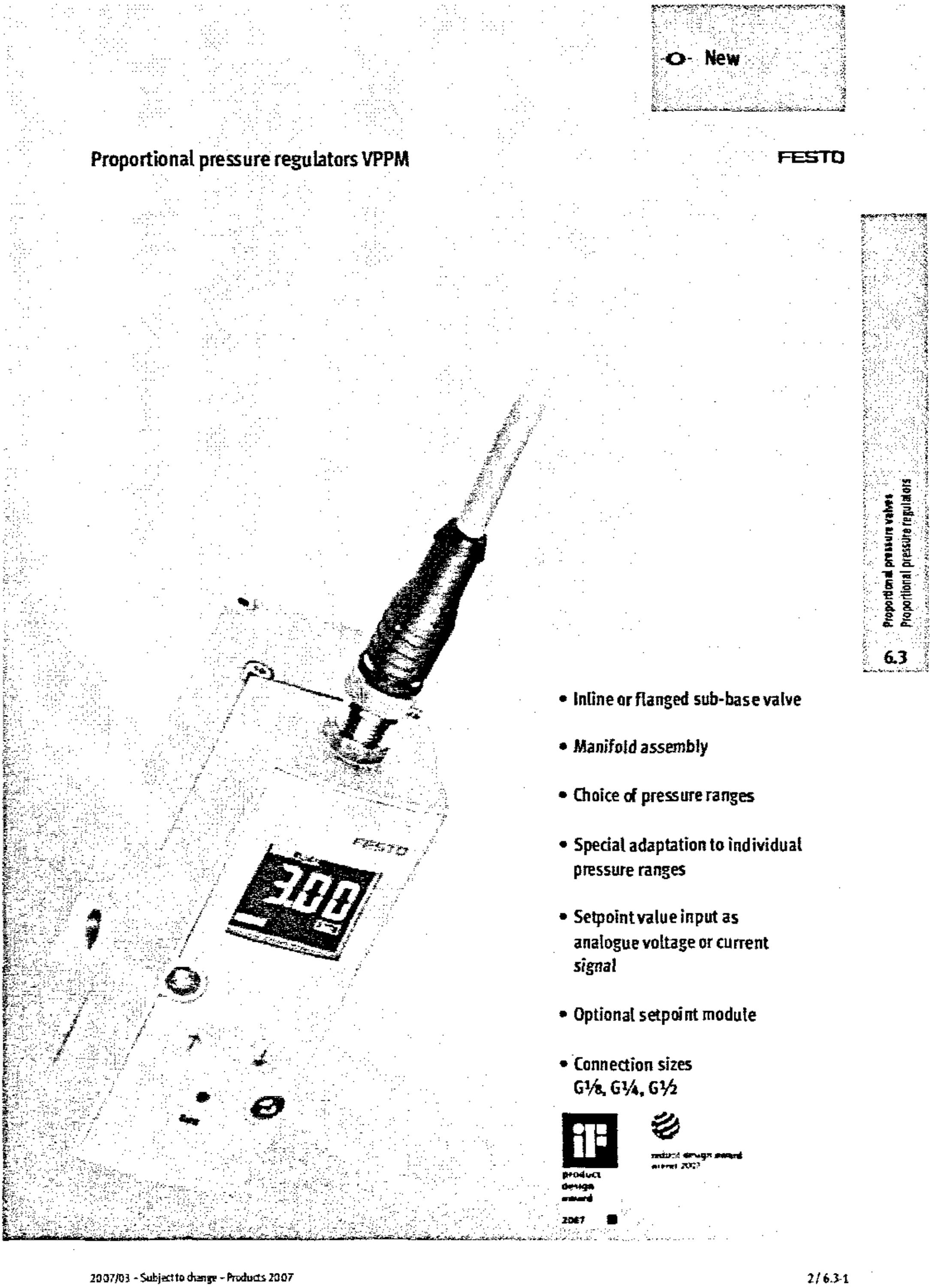
Personal observation of the training equipment functionalities at Fox Gymnasium,
Bellville, Cape Town, South Africa, 2006.

At Fox Gymnasium, the all muscle training equipment are not associated with IT technology. Therefore, the equipment cannot provide any capabilities related to IT, such as exercise data record and transfer, body status monitor, and so on. Only rowing machine has data record capability, but it is not used at that moment. The fitness consultant said that capability has to work accompanied with a data card for each exerciser, and only few exercisers are interested.

Appendix C: MPZ setpoint module user manual



Appendix D: Proportional pressure regulator type VPPM... user manual



New

Proportional pressure regulators VPPM

FESTO

Proportional pressure valves
Proportional pressure regulators
6.3

- Inline or flanged sub-base valve
- Manifold assembly
- Choice of pressure ranges
- Special adaptation to individual pressure ranges
- Setpoint value input as analogue voltage or current signal
- Optional setpoint module
- Connection sizes G⅛, G¼, G½

product
design
award
2007

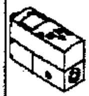
2007/03 - Subject to change - Products 2007 2 / 6.3-1

New

Proportional pressure regulators VPPM

FESTO

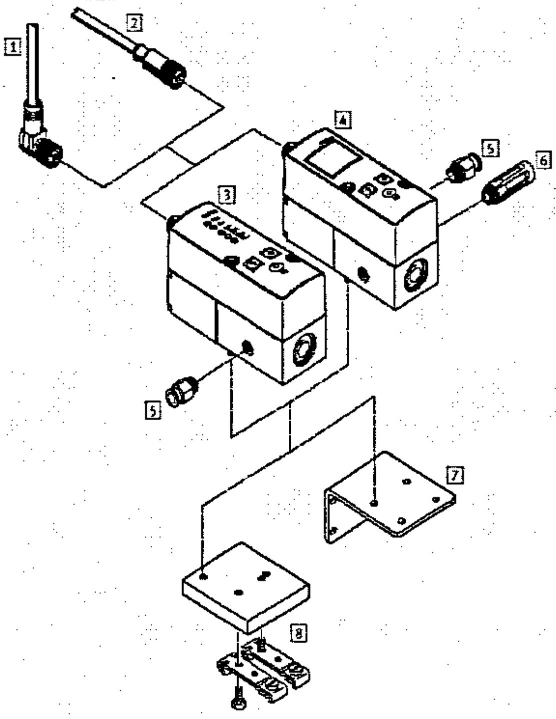
Product range overview

Function	Version	Constructional design	Pneumatic connection 1, 2, 3	Nominal diameter, pressurise/ exhaust [mm]	Pressure regulation range [bar]	Setpoint value input		→ Page
						Voltage type 0 … 10 V	Current type 4 … 20 mA	
Pressure regulators	With LED							
		Piloted diaphragm valve	G⅛	6/4.5	0.02 … 2 0.06 … 6 0.1 … 10	■	■	2 / 6.3-6
			Sub-base	6/4.5	0.02 … 2 0.06 … 6 0.1 … 10	■	■	
	With LCD							
		Piloted diaphragm valve	G⅛	6/4.5	0.02 … 2 0.06 … 6 0.1 … 10	■	■	2 / 6.3-6
			Sub-base	6/4.5	0.02 … 2 0.06 … 6 0.1 … 10	■	■	

Proportional pressure regulators VPPM

Peripherals overview

Individual valve



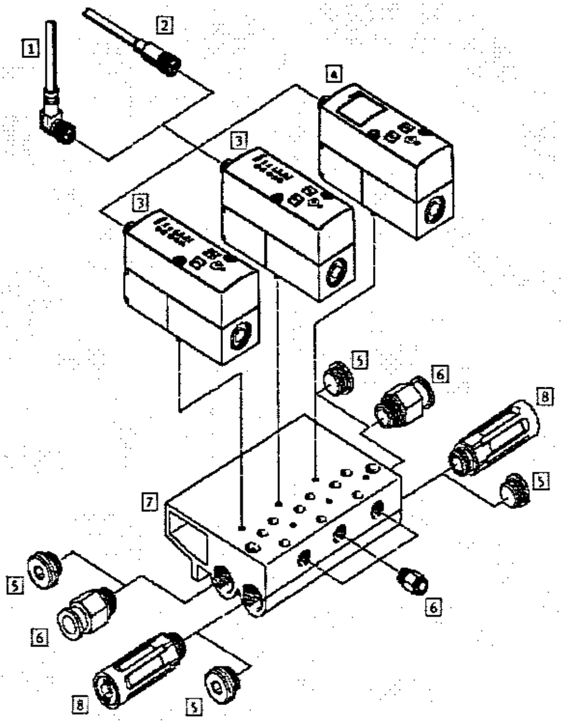
Accessories

		Brief description	→ Page
1	Plug socket with cable, angled NEBU-M12W8-...	–	2 / 6.3-16
2	Plug socket with cable, straight SIM-M12-8GD-...	–	2 / 6.3-16
3	Proportional pressure regulator VPPM	Operator unit with LED	2 / 6.3-6
4	Proportional pressure regulator VPPM	Operator unit with LCD	2 / 6.3-6
5	Push-in fitting QS	For connecting compressed air tubing with standard external diameters	Volume 3
6	Silencer	For fitting in exhaust ports	Volume 3
7	Mounting bracket VAME-P1-A	For attaching the valve	2 / 6.3-15
8	DIN H-rail mounting VAME-P1-T	For mounting on a DIN H-rail	2 / 6.3-14

Proportional pressure regulators VPPM

Peripherals overview

Valve manifold



Accessories	Brief description	→ Page
1 Plug socket with cable, angled NEBU-M12W8-...	–	2 / 6.3-16
2 Plug socket with cable, straight SIM-M12-8GD-...	–	2 / 6.3-16
3 Proportional pressure regulator VPPM	Operator unit with LED	2 / 6.3-6
4 Proportional pressure regulator VPPM	Operator unit with LCD	2 / 6.3-6
5 Blanking plug B	–	Volume 3
6 Push-in fitting QS	For connecting compressed air tubing with standard external diameters	Volume 3
7 Manifold block VABM	–	2 / 6.3-14
8 Silencer	For fitting in exhaust ports	Volume 3

Proportional pressure regulators VPPM

Type codes

VPPM – 6 L – L – 1 – G18 – 0L 6H – V1 N – S1 –

Type	
VPPM	Modular proportional pressure regulator

Nominal diameter	
6	6 mm

Design	
L	In-line valve
F	Flanged valve

Mounting method	
	Freely mountable

Dynamic response class	
L	Low

Valve function	
1	3/2-way valve, normally closed

Pneumatic connection	
G18	G⅛ thread
F	Flange/sub-base

Lower pressure value of regulation range	
0L	0 bar

Upper pressure value of regulation range	
2H	2 bar
6H	6 bar
10H	10 bar

Setpoint specification for individual valve	
V1	0 … 10 V
A4	4 … 20 mA

Switch output	
N	Negative switching

Accuracy	
	2% (standard)
S1	1%

Operator unit	
	LED (standard)
C1	With LCD, pressure unit variable

Proportional pressure regulators VPPM

Technical data

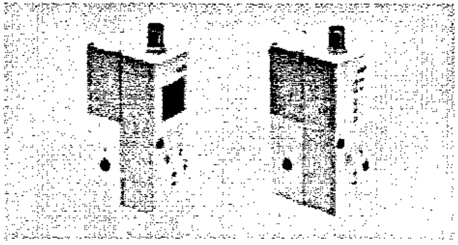
Flow rate
380 … 1,200 l/min

Voltage
21.6 … 26.4 V DC

Pressure regulation range
0.02 … 10 bar

Variants

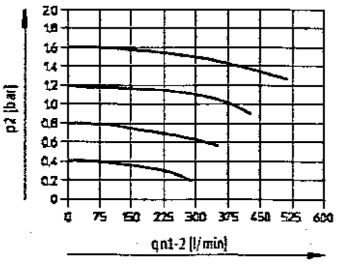
- Setpoint input as analogue voltage signal 0 … 10 V
- Setpoint input as analogue current signal 4 … 20 mA



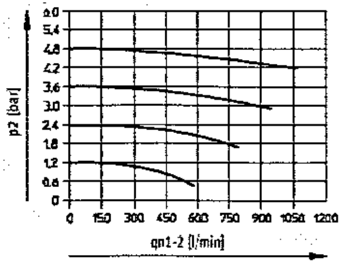
General technical data				
Pneumatic connection 1 and 2			G¼	Connecting plate
Constructional design			Pilot-actuated diaphragm regulator	
Sealing principle			Soft	
Actuation type			Electrical	
Control type			Pilot actuated via 2/2-way valves	
Type of mounting			Via through-hole, via accessories	
Mounting position			Any	
Nominal diameter	Pressurising	[mm]	6	
	Exhaust	[mm]	4.5	
Standard nominal flow rate		[l/min]	→ Graphs	
Product weight		[g]	400	

Flow rate qn as a function of the output pressure p2

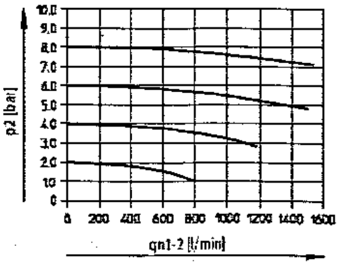
VPPM-6L-…-0L2H-… (2 bar)



VPPM-6L-…-0L6H-… (6 bar)



VPPM-6L-…-0L10H-… (10 bar)



Proportional pressure regulators VPPM

Technical data

Electrical data			
Electrical connection			Plug, round design, 8-pin, M12
Operating voltage range		[V DC]	24±10% = 21.6 … 26.4
Residual ripple			10%
Max. electrical power consumption		[W]	7
Signal setpoint input	Voltage	[V DC]	0 … 10
	Current	[mA]	4 … 20
Protection against short circuit			For all electrical connections
Protection against polarity reversal			For all electrical connections
Protection class			IP65
CE mark			EU conformity in accordance with the directive 89/336/EEC (EMC)

Operating and environmental conditions				
Pressure regulation range	[bar]	0.02 … 2	0.06 … 6	0.1 … 10
Operating medium		Compressed air, filtered, unlubricated, grade of filtration 40µm Neutral gases		
Input pressure 1	[bar]	0 … 4[2]	0 … 8[2]	0 … 11[2]
Max. hysteresis	[mbar]	10	30	50
Linearity error FS	[%]	1		
Repetition accuracy FS	[%]	0.5		
Temperature coefficient	[%]	0.04		
Ambient temperature	[°C]	0 … 60		
Temperature of medium	[°C]	10 … 50		
Corrosion resistance class	[CRC]	2[1]		

[1] Corrosion resistance class 2 to Festo standard 940 070
Components subject to moderate corrosion stress. Externally visible parts with primarily decorative surface requirements which are in direct contact with a normal industrial environment or media such as coolants or lubricating agents.

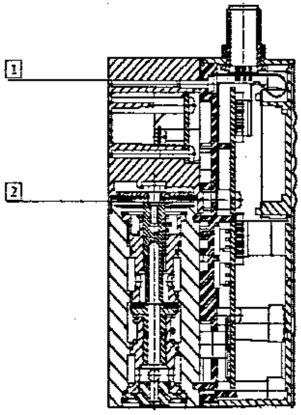
[2] Input pressure 1 should always be 1 bar greater than the maximum regulated output pressure.

Note

If the power supply cable is interrupted, output pressure is maintained unregulated.

Materials

Sectional view



1	Housing	Wrought aluminium alloy
2	Diaphragm	Nitrile rubber

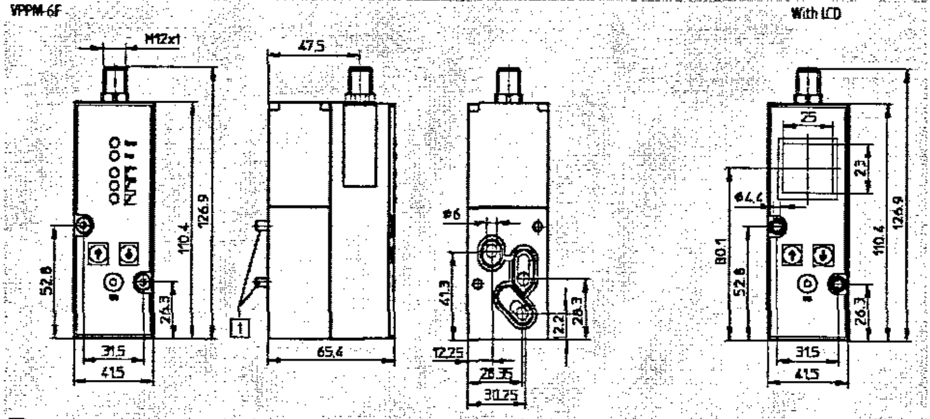
Proportional pressure regulators VPPM

Technical data

Dimensions

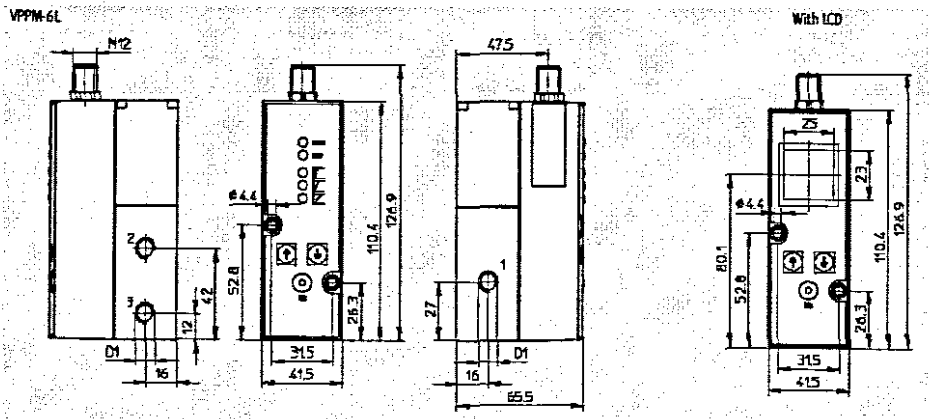
Download CAD data → www.festo.com/en/engineering

VPPM-6F


With LCD
M12x1
47.5
126.9
110.4
52.8
26.3
31.5
41.5
65.4
1
ø6
41.3
12.25
28.35
30.25
2.2
28.3
25
23
ø4.4
80.1

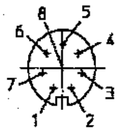
1 Socket head screw M5x65

VPPM-6L


With LCD
M12
47.5
2
3
1
42
12
D1
16
ø4.4
52.8
110.4
126.9
26.3
31.5
41.5
27
65.5
25
23
80.1

D1 = G¼

M12 – Pin allocation



1	Digital In S1
2	24 V DC
3	Nom. Value –
4	Nom. Value +
5	Digital In S2
6	Analogue Out
7	Ground
8	Digital Out

Proportional pressure regulators VPPM

Technical data

Ordering data

Pneumatic connection	Pressure regulation range [bar]	Voltage type 0 … 10 V Part No.	Voltage type 0 … 10 V Type	Current type 4 … 20 mA Part No.	Current type 4 … 20 mA Type
Overall accuracy 2%					
G⅛	0.02 … 2	542 233	VPPM-6L-L-1-G18-0L2H-V1N	542 236	VPPM-6L-L-1-G18-0L2H-A4N
	0.06 … 6	542 234	VPPM-6L-L-1-G18-0L6H-V1N	542 237	VPPM-6L-L-1-G18-0L6H-A4N
	0.1 … 10	542 235	VPPM-6L-L-1-G18-0L10H-V1N	542 238	VPPM-6L-L-1-G18-0L10H-A4N
Sub-base	0.02 … 2	542 245	VPPM-6L-L-1-F-0L2H-V1N	542 248	VPPM-6L-L-1-F-0L2H-A4N
	0.06 … 6	542 246	VPPM-6L-L-1-F-0L6H-V1N	542 249	VPPM-6L-L-1-F-0L6H-A4N
	0.1 … 10	542 247	VPPM-6L-L-1-F-0L10H-V1N	542 250	VPPM-6L-L-1-F-0L10H-A4N
Overall accuracy 1%					
G⅛	0.02 … 2	542 227	VPPM-6L-L-1-G18-0L2H-V1N-S1	542 230	VPPM-6L-L-1-G18-0L2H-A4N-S1
	0.06 … 6	542 228	VPPM-6L-L-1-G18-0L6H-V1N-S1	542 231	VPPM-6L-L-1-G18-0L6H-A4N-S1
	0.1 … 10	542 229	VPPM-6L-L-1-G18-0L10H-V1N-S1	542 232	VPPM-6L-L-1-G18-0L10H-A4N-S1
Sub-base	0.02 … 2	542 239	VPPM-6L-L-1-F-0L2H-V1N-S1	542 242	VPPM-6L-L-1-F-0L2H-A4N-S1
	0.06 … 6	542 240	VPPM-6L-L-1-F-0L6H-V1N-S1	542 243	VPPM-6L-L-1-F-0L6H-A4N-S1
	0.1 … 10	542 241	VPPM-6L-L-1-F-0L10H-V1N-S1	542 244	VPPM-6L-L-1-F-0L10H-A4N-S1

Note

Further variants can be ordered using the modular system.

→ 2 / 6.3-10

-O- New

Proportional pressure regulators VPPM

Ordering data – Modular products

[M] **Mandatory data** →

Module No.	Design	Nominal diameter	Valve type	Dynamic response	Valve mode	Connection type
543 432	VPPM	6	L F	L	1	G18 F
Order example						
543 432	VPPM	- 6	F	- L	- 1	- F

Ordering table

Size		6	Condi-tions	Code	Enter code
[M]	Module No.	543 432			
	Design	Modular pressure regulator		VPPM	VPPM
	Nominal diameter	6		-6	-6
	Valve type	In-line	[1]	L	
		Flanged valve	[2]	F	
	Dynamic response	Low dynamic response (pilot-actuated, soft-sealing)		-L	-L
	Valve mode	3/2-way valve, normally closed		-1	-1
	Connection type	G⅛ thread		-G18	
↓		Flange/connecting plate		-F	

[1] L Only with connection type G18 (G⅛ thread)

[2] F Only with connection type F (flange/sub-base)

Transfer order code

543 432	VPPM	- 6		- L	- 1	-

Proportional pressure regulators VPPM

Ordering data – Modular products

→ **M Mandatory data** | **O Options**

	Pressure regulation range	Alternative lower pressure regulation range	Alternative upper pressure regulation range		Setpoint specification	Switch output		Overall accuracy	Operator unit
	0L2H 0L6H 0L10H	0.1 ... 10L	0.1 ... 10H		V1 A4	P N		S1	C1
-		6.5L	7.1H	-	A4	P	-	S1	C1

Ordering table

	Size	6	Condi-tions	Code	Enter code
M	Pressure regulation range	0 ... 2 bar		-0L2H	
		0 ... 6 bar		-0L6H	
		0 ... 10 bar		-0L10H	
	Alternative lower pressure regulation range	0.1 ... 10 bar	[3]	-...L	
	Alternative upper pressure regulation range	0.1 ... 10 bar	[4]	...H	
	Setpoint specification	Voltage (standard 0 ... 10 V)		-V1	
		Current (standard 4 ... 20 mA)		-A4	
	Switch output	Positive switching		P	
		Negative switching		N	
O	Overall accuracy	1%		-S1	
	Operator unit	With LCD, pressure unit variable		C1	

[3] ...L Not with pressure regulation range (0L2H, 0L6H, 0L10H). Must always be less than alternative upper pressure regulation range H

[4] ...H Not with pressure regulation range (0L2H, 0L6H, 0L10H). Must always be greater than alternative lower pressure regulation range L.

Transfer order code

-				-			-		

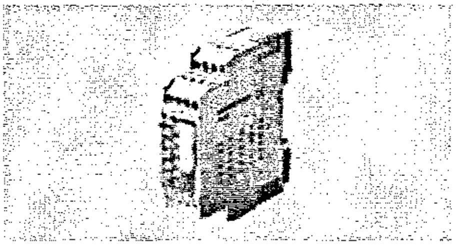
Proportional pressure regulators MPPE/VPPE/MPPES

Accessories

Setpoint module MPZ

Voltage
20 … 30 V DC

Function
- Generation of 6+1 analogue setpoint values for the proportional pressure regulators MPPE, MPPES and MPYE
- Digital controller
- Output voltage adjustable via spindle potentiometer



General technical data			
Mode of operation			Digital-analogue circuit with analogue output
Electrical connection			Screw terminal
Connection cross section		[mm²]	2.5
Operating voltage range		[V DC]	20 … 30
Adjustable output voltage		[V DC]	0 … 10
Max. output current		[mA]	27
Power consumption at 24 V DC		[W]	1.5
Supply setpoint value adjustment	Voltage	[V]	10 … 10.6
	Current	[mA]	6 … 6.36
External setpoint input	Voltage	[V DC]	0 … 10
	Potentiometer	[kΩ]	2.5 … 10
Setpoint controller	Input resistance	[kΩ]	3
Residual ripple		[%]	Max. 10
Display	Ready		Green LED
	Setpoint active		Yellow LED
Type of mounting			On H-rail
Assembly position			Any
Product weight		[g]	80

Operating and environmental conditions		
Ambient temperature	[°C]	0 … 60
Protection class		IP20
CE symbol (declaration of conformity)		In accordance with EU EMC directive
Corrosion resistance class CRC[1]		2

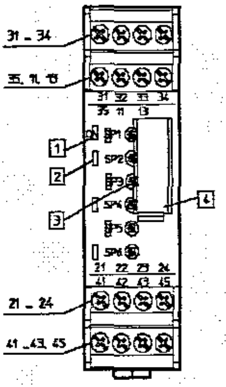
[1] Corrosion resistance class 2 according to Festo standard 940 070
Components requiring moderate corrosion resistance. Externally visible parts with primarily decorative surface requirements which are in direct contact with a normal industrial environment or media such as coolants or lubricating agents

Proportional pressure regulators MPPE/VPPE/MPPES

Accessories

Connections and control elements

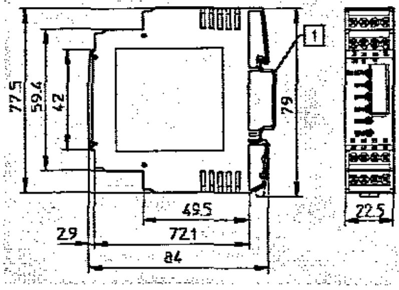
Connections			Priority
31	Activate setpoint 1	SP1	1 (highest)
32	Activate setpoint 2	SP2	2
33	Activate setpoint 3	SP3	3
34	Activate setpoint 4	SP4	4
35	Activate setpoint 5	SP5	5
11	Activate setpoint 6	SP6	6
13	Control line	0 V	–
21	Control line	0 V	–
22	External setpoint input	$U_{w, in}$ = 0 … 10 V DC	7 (lowest)
23	Control line	10 V DC	–
24	Screening	PE	–
41	Control line	0 V DC	–
42	Setpoint output	$U_{w, out}$	–
43	Power supply	–	–
45	Power supply	+	–


31 … 34
35, 11, 13
31 32 33 34
35 11 13
1
2
3
4
SP1
SP2
SP3
SP4
SP5
SP6
21 22 23 24
41 42 43 45
21 … 24
41 … 43, 45

[1] Operational status display, green LED
[2] Setpoint display active (SP1 … SP6), yellow LED
[3] Setpoint potentiometer SP1 … SP6
[4] Inscription label

Dimensions

Download CAD data → www.festo.com/en/engineering


1
77.5
59.4
42
79
49.5
72.1
2.9
84
22.5

[1] H-rail to DIN EN 60715

Ordering data

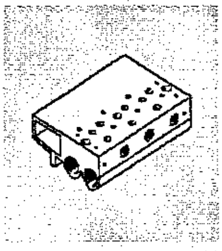
	Description	Part No.	Type
	Setpoint module for generating 6 + 1 analogue voltage signals	546 224	MPZ-1-24DC-SGH-6-SW

Proportional pressure regulators VPPM

Accessories

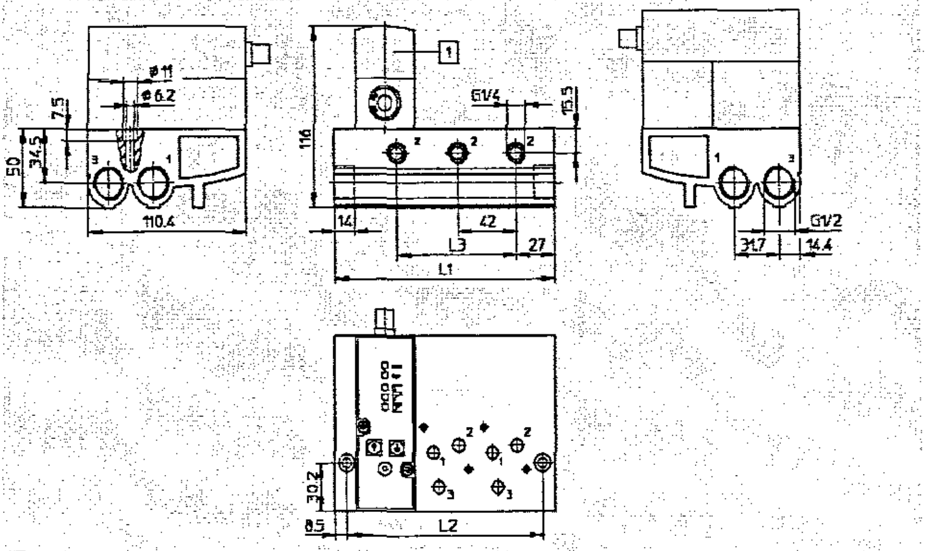
Manifold block VABM-P1

Material:
Wrought aluminium alloy



Dimensions

Download CAD data → www.festo.com/en/engineering



1 Proportional pressure regulator VPPM

Dimensions and ordering data							
Valve positions	L1	L2	L3	Weight [g]	CRC[1]	Part No.	Type
2	113	96	42	900	2	542 252	VABM-P1-SF-G18-2-P3
3	155	138	84	1,230	2	542 253	VABM-P1-SF-G18-3-P3
4	197	180	126	1,565	2	542 254	VABM-P1-SF-G18-4-P3

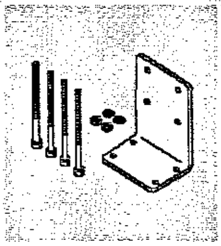
[1] Corrosion resistance class 2 to Festo standard 940 070
Components subject to moderate corrosion stress. Externally visible parts with primarily decorative surface requirements which are in direct contact with a normal industrial environment or media such as coolants or lubricating agents.

Proportional pressure regulators VPPM

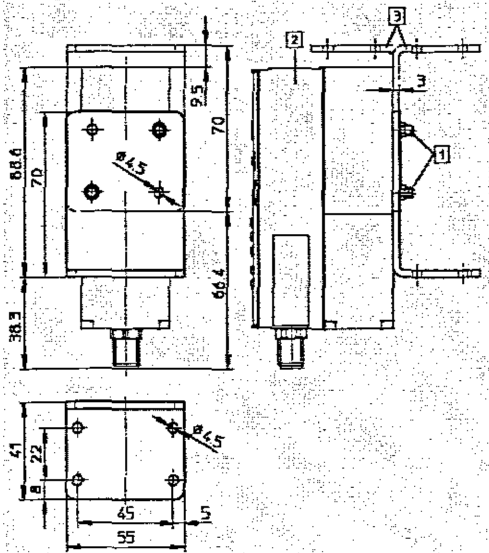
Accessories

Mounting bracket VAME-P1-A

Material:
Wrought aluminium alloy, steel



Dimensions Download CAD data → **www.festo.com/en/engineering**



1 Socket head screw M4

2 Proportional pressure regulator VPPM

3 Mounting bracket can optionally be turned

Ordering data			
Weight [g]	CRC[1]	Part No.	Type
71	1	542 251	VAME-P1-A

[1] Corrosion resistance class 1 to Festo standard 940 070
Components requiring low corrosion resistance. Transport and storage protection. Parts that do not have primarily decorative surface requirements, e.g. in internal areas that are not visible or behind covers.

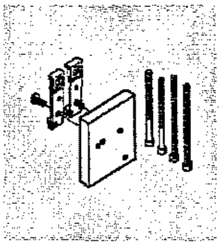
New

Proportional pressure regulators VPPM

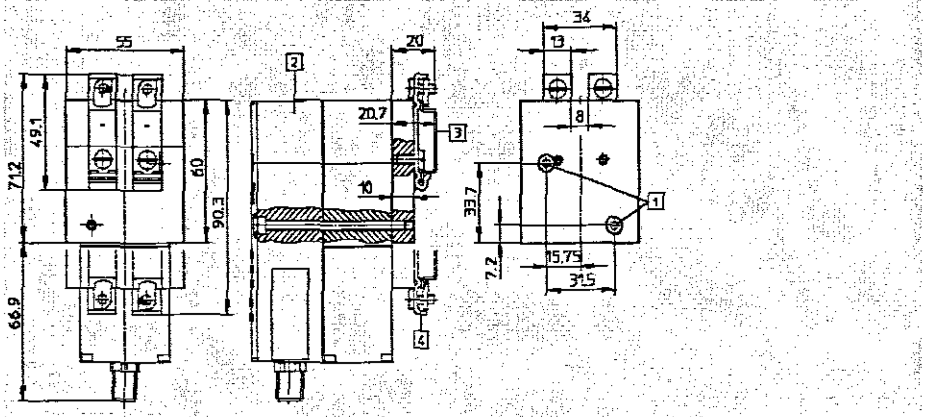
Accessories

H-rail mounting VAME-P1-T

Material:
Wrought aluminium alloy, steel



Dimensions Download CAD data → www.festo.com/en/engineering



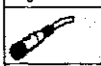
[1] Socket head screw M4 [2] Proportional pressure regulator VPPM [3] Mounting rail NRH [4] Mounting rail NRH

Ordering data

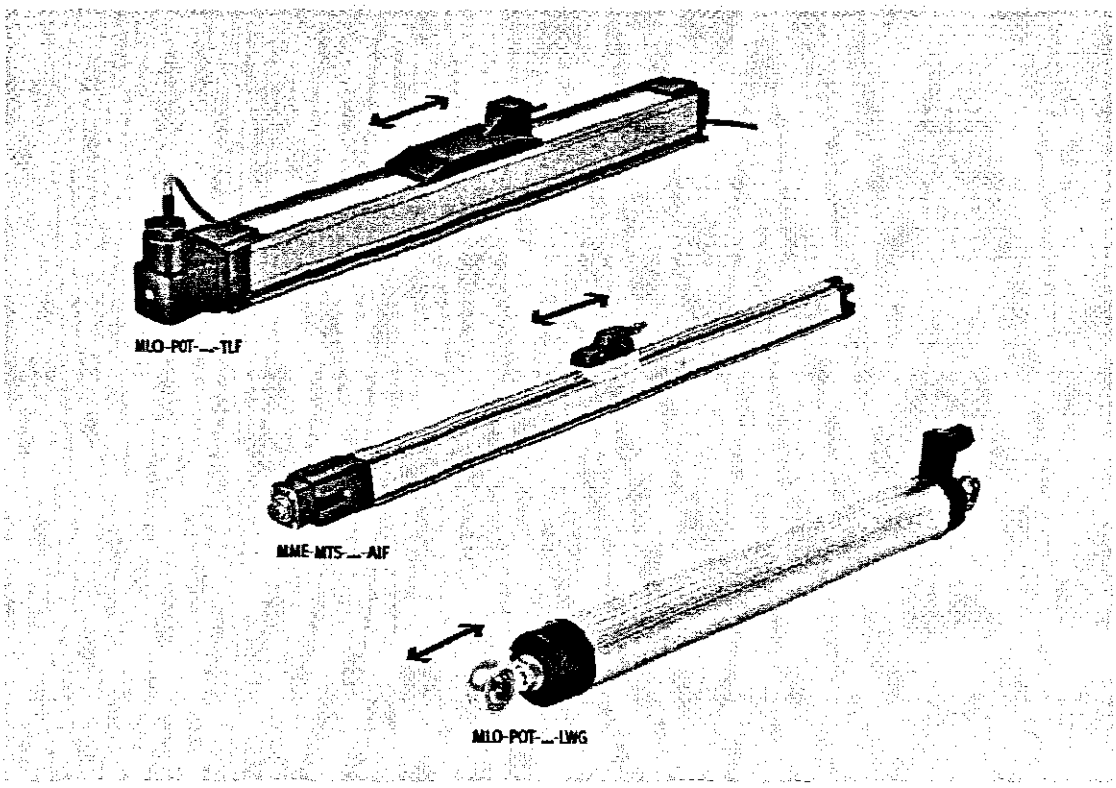
Weight [g]	CRC[1]	Part No.	Type
150	1	542 255	VAME-P1-T

[1] Corrosion resistance class 1 to Festo standard 940 070
Components requiring low corrosion resistance. Transport and storage protection. Parts that do not have primarily decorative surface requirements, e.g. in internal areas that are not visible or behind covers.

Ordering data

	Description	Cable length [m]	Part No.	Type
Plug socket with cable				Technical data → Volume 4
	Straight, 8-pin, M12	2	525 616	SIM-M12-8GD-2-PU
		5	525 618	SIM-M12-8GD-5-PU
	Angled, 8-pin, M12	2	542 256	NEBU-M12W8-2-N-LE8
		5	542 257	NEBU-M12W8-5-N-LE8

Appendix E: MLO-POT-450-LWG displacement transducer data sheet


MLO-POT-...-TLF
MME-MTS-...-AIF
MLO-POT-...-LWG

위치 측정 엔코더 MLO/MME

개요 및 주문자료

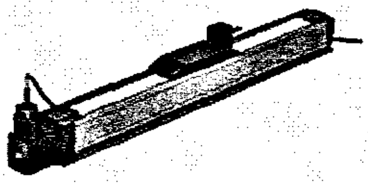
위치 측정 엔코더		MLO-POT-...-TLF (아날로그)		MME-MTS-...-AIF (디지털)		MLO-POT-...-LWG (아날로그)	
		Part No.	Type	Part No.	Type	Part No.	Type
행정거리 [mm]	100	–		–		192 213	MLO-POT-100-LWG ○
	150	–		–		192 214	MLO-POT-150-LWG ○
	225	152 625	MLO-POT-225-TLF	178 310	MME-MTS-225-AIF	152 645	MLO-POT-225-LWG ○
	300	152 626	MLO-POT-300-TLF	178 309	MME-MTS-300-AIF	152 646	MLO-POT-300-LWG ○
	360	152 627	MLO-POT-360-TLF	178 308	MME-MTS-360-AIF	152 647	MLO-POT-360-LWG ○
	450	152 628	MLO-POT-450-TLF	178 307	MME-MTS-450-AIF	152 648	MLO-POT-450-LWG ○
	500	152 629	MLO-POT-500-TLF	178 306	MME-MTS-500-AIF	152 649	MLO-POT-500-LWG ○
	600	152 630	MLO-POT-600-TLF	178 305	MME-MTS-600-AIF	152 650	MLO-POT-600-LWG ○
	750	152 631	MLO-POT-750-TLF	178 304	MME-MTS-750-AIF	152 651	MLO-POT-750-LWG ○
	1000	152 632	MLO-POT-1000-TLF	178 303	MME-MTS-1000-AIF	–	
	1250	152 633	MLO-POT-1250-TLF	178 302	MME-MTS-1250-AIF	–	
	1500	152 634	MLO-POT-1500-TLF	178 301	MME-MTS-1500-AIF	–	
	1750	152 635	MLO-POT-1750-TLF	178 300	MME-MTS-1750-AIF	–	
	2000	152 636	MLO-POT-2000-TLF	178 299	MME-MTS-2000-AIF	–	

시스템 액세서리

	위치 측정 엔코더		
	MLO-POT-...-TLF (아날로그)	MME-MTS-...-AIF (디지털)	MLO-POT-...-LWG (아날로그)
공압선형 드라이브 DGP... 	Soft Stop 적용		–
표준 실린더 DNC 	–	–	Soft Stop 적용
Soft Stop 컨트롤러 SPC10 	Soft Stop 적용	–	Soft Stop 적용
Soft Stop 컨트롤러 SPC11 	Soft Stop 적용		
공압선형 드라이브 DGP... 	위치제어 적용		–
Smart 위치제어 컨트롤러 SPC200 	위치제어 적용		–

위치 측정 엔코더 MLO/MME

기술 자료



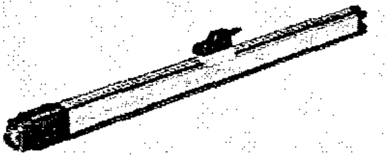
위치 측정 엔코더			Type	MLO-POT-...-TLF (아날로그)											
		행정거리	[mm]	225	300	360	450	500	600	750	1000	1250	1500	1750	2000
전기 자료	연결 저항		[kΩ]	5	5	5	5	5	5	10	10	10	10	20	20
기계 자료	유효 경로	기계적	[mm]	234	310	372	463	514	616	768	1022	1276	1526	1776	2026
		전기적	[mm]	228	304	366	457	508	610	762	1016	1270	1520	1770	2020
수명				>100 x 10^6 행정											
볼 커플링의 유격	각도 상쇄		[°]	±1											
	수평 상쇄		[mm]	±1.5											
진동	주기		[Hz]	5 ... 2000											
	진폭 (최대)		[mm]	0.75											
	가속 (최대)		[g]	20											
충격	가속		[g]	50											
	지속		[ms]	11											
조정 자료	조정 속도		[m/s]	최대 10											
	조정 가속		[m/s²]	최대 200											
			[g]	20											
마운팅 위치				수평/수직											
중량	기본 중량		[kg]	0.9	1	1.1	1.2	1.3	1.5	1.8	2.2	2.5	3	3.5	3.9
주변 조건	온도*		[°C]	-30 ... +100											
	보호 등급	윗면	[IP]	40 (DIN 40 050에 따름)											
		밑면	[IP]	42**											
	CE 인증			EMC 규정 89/336/EWG에 따름											

* 완제품 시스템 솔루션에 사용된 각 개별 부품의 온도 범위에 주의

** 반전 마운팅 위치: 포텐시오미터 슬라이드 지붕 밑면

위치 측정 엔코더 MLO/MME

기술 자료



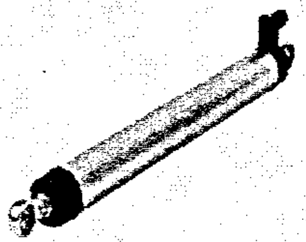
위치 측정 엔코더			Type	MME-MTS-...-AIF (디지털)											
		행정 거리	[mm]	225	300	360	450	500	600	750	1000	1250	1500	1750	2000
전기 자료	연결 저항		[kΩ]	–	–	–	–	–	–	–	–	–	–	–	–
기계 자료	유효 경로	기계적	[mm]	–	–	–	–	–	–	–	–	–	–	–	–
		전기적	[mm]	225	300	360	450	500	600	750	1000	1250	1500	1750	2000
수명				광섬유 시스템 용 4백만 시간 MTBF											
볼 커플링의 유격	각도 상쇄		[°]	±1											
	수평 상쇄		[mm]	±1.5											
진동	주기		[Hz]	충격 저항100g (단일 충격) ICE 표준68-2-27에따름											
	진폭 (최대.)		[mm]	진동 저항 5 g/ 10 – 150 Hz ICE 표준 68-2-6에 따름											
	가속 (최대.)		[g]	–											
충격	가속		[g]	–											
	지속		[ms]	–											
조정 자료	조정 속도		[m/s]	임의											
	조정 가속		[m/s²]	임의											
			[g]	–											
마운팅 위치				수평/수직											
중량	기본 중량		[kg]	0.62	0.71	0.78	0.89	0.95	1.07	1.25	1.55	1.85	2.15	2.45	2.75
	온도*		[°C]	–40 ... +75											
	보호 등급	윗면	[IP]	67											
		밑면	[IP]	67											
	CE기호			DIN IEC 801-4 / 시험 강도 4 / CE테스트 (EMC 규정89/336/EWG에 따름)											

* 완제품 시스템 솔루션에 사용된 각 개별 부품의 온도 범위에 주의

** 안전 마운팅 위치: 포텐시오미터 슬라이드 지점 밑면

위치 측정 엔코더 MLO/MME

기술 자료



위치 측정 엔코더			Type	MLO-POT-...-LWG (아날로그)								
		행정 거리	[mm]	100	150	225	300	360	450	500	600	750
전기 자료	연결 저항		[kΩ]	3	3	5	5	5	5	5	5	10
기계 자료	유효 경로	기계적	[mm]	105	155	231	307	368	460	510	612	764
		전기적	[mm]	100	150	225	300	360	450	500	600	750
반복 정확도			[mm]	0.01								
수명				>50 x 10^6 행정								
볼 커플링의 유격	각도 상쇄		[°]	±30								
	수평 상쇄		[mm]	–								
진동	주기		[Hz]	5 ... 2000								
	진폭 (최대)		[mm]	0.75								
	가속 (최대)		[g]	20								
충격	가속		[g]	50								
	지속		[ms]	11								
조정 자료	조정 속도		[m/s]	최대 5								
	조정 가속		[m/s^2]	최대 200								
			[g]	20								
마운팅 위치				수평								
주변 조건	온도*		[°C]	–30 ... +100								
	보호 등급	윗면	[IP]	65 (DIN 40 050에 따름)								
		밑면	[IP]	–								
	CE 인증			EMC 규정 89/336/EWG 에 따름								

Note

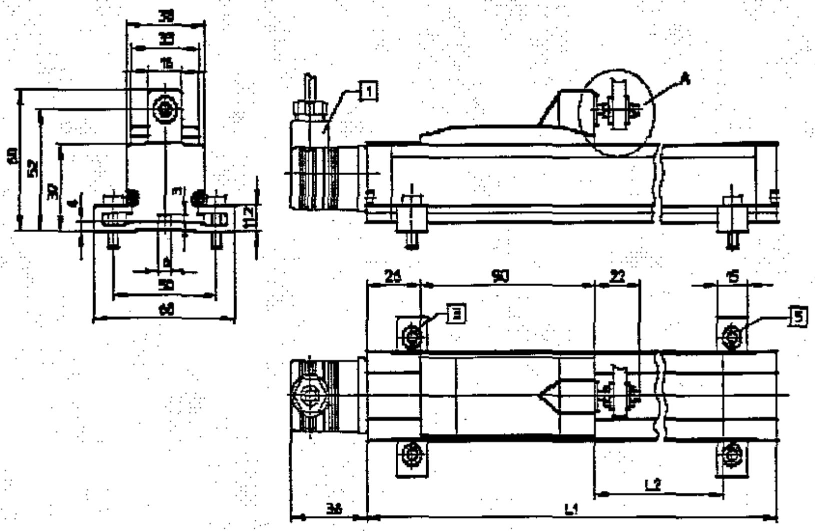
포텐시오미터 MLO-POT-...-LWG:
포텐시오미터는 기계장비와 절연된 상태로 설치해야만 합니다.
로드 Eye를 통해 기계적 커플링이 영향을 받는다면 필요에 따라 추가적 전기 절연을 지원해 주도록 보장해 줍니다.
피스톤 로드의 기계적 진동이 위치 측정 엔코더에 전달되지 않도록 해야만 합니다.
케이블 고리나 접지대를 사용하여 엔드캡에 볼트 체결하여 접지된 포텐시오미터는 SPC10-...-LWG 하우징의 접지 볼트에 연결해 주어야합니다.
접지 케이블이 SPC10-...-LWG의 포텐시오미터 케이블보다 길어서는 안됩니다. 연결부는 낮은 저항값으로 설계해야만 합니다.
도체 단면이 적어도 1.5 mm^{2}는 되어야 합니다. 접지 밴드 (꼬임)가 간섭을 발산하는데 현저한 효과가 있다면 원형 케이블 대신 접지 밴드를 사용해야 합니다.

위치 측정 엔코더 MLO/MME

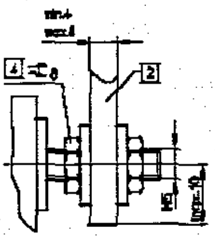
Dimensions

아날로그 위치 측정 엔코더

MLO-POT-...-TLF


38
33
15
60
52
37
4
11.2
8
50
68
1
A
24
90
22
15
3
5
36
L1
L2

세부 도면 지수 A


min.4
max.8
4
8
2
M5
max. 10

- 1 플러그 소켓 DIN 43 650에 따른 4 핀 90° 회전 삽입 가능
- 2 드라이버 (별도 주문 품목)
- 3 마운팅 볼트 M5x18
- 4 육각 너트 M5
- 5 공급 마운팅 키트

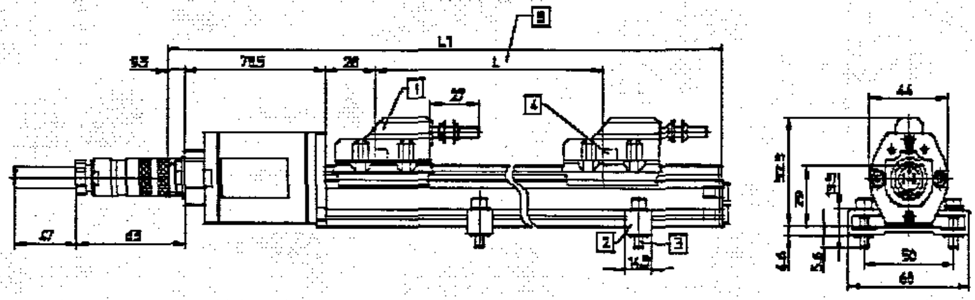
Type	L1	L2 (유효 기계적 위치 측정)
MLO-POT-225-TLF	376	234
MLO-POT-300-TLF	452	310
MLO-POT-360-TLF	514	372
MLO-POT-450-TLF	605	463
MLO-POT-500-TLF	656	514
MLO-POT-600-TLF	758	616
MLO-POT-750-TLF	910	768
MLO-POT-1000-TLF	1164	1022
MLO-POT-1250-TLF	1418	1276
MLO-POT-1500-TLF	1668	1526
MLO-POT-1750-TLF	1918	1776
MLO-POT-2000-TLF	2168	2026

위치 측정 엔코더 MLO/MME

Dimensions

디지털 위치 측정 엔코더

MME-MTS-...-AIF



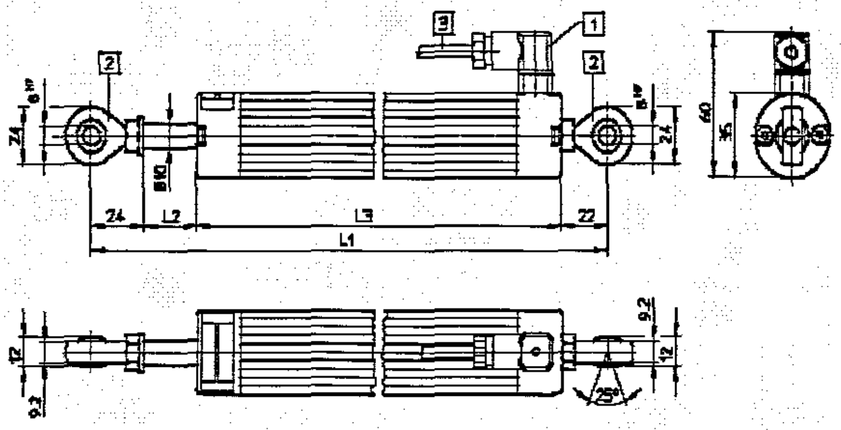
1 슬라이드 위치
2 조절가능 마운팅 클램
3 소켓 헤드 볼트 M5x20
4 자석
5 유효 전기 위치 측정

Type	L (유효 전기적 위치 측정)	L1
MME-MTS-225-AIF	225	407
MME-MTS-300-AIF	300	482
MME-MTS-360-AIF	360	542
MME-MTS-450-AIF	450	632
MME-MTS-500-AIF	500	682
MME-MTS-600-AIF	600	782
MME-MTS-750-AIF	750	932
MME-MTS-1000-AIF	1000	1182
MME-MTS-1250-AIF	1250	1432
MME-MTS-1500-AIF	1500	1682
MME-MTS-1750-AIF	1750	1932
MME-MTS-2000-AIF	2000	2182

위치 측정 엔코더 MLO/MME

Dimensions

아날로그 위치 측정 엔코더
MLO-POT-...-LWG

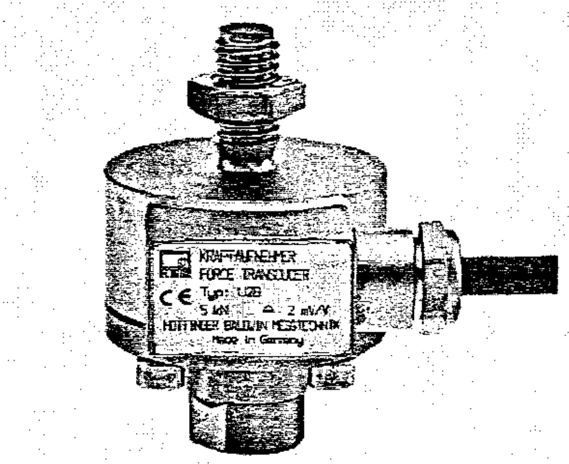


1. 플러그 소켓 DIN 43 650에 따른 3 핀 90° 회전 삽입 가능 (별도 주문 품목)
2. 로드 Eye, backlash 없음
3. 위치 측정 엔코더 케이블 KPGT-LWG-... (별도 주문 품목)

Type	L1	L2	L3
MLO-POT-100-LWG	273	105	227
MLO-POT-150-LWG	323	155	277
MLO-POT-225-LWG	400	231	354
MLO-POT-300-LWG	476	307	430
MLO-POT-360-LWG	534	368	492
MLO-POT-450-LWG	665	460	519
MLO-POT-500-LWG	730	510	684
MLO-POT-600-LWG	856	612	810
MLO-POT-750-LWG	1040	764	994

Appendix F: U2B force transducer data sheet

Data Sheet



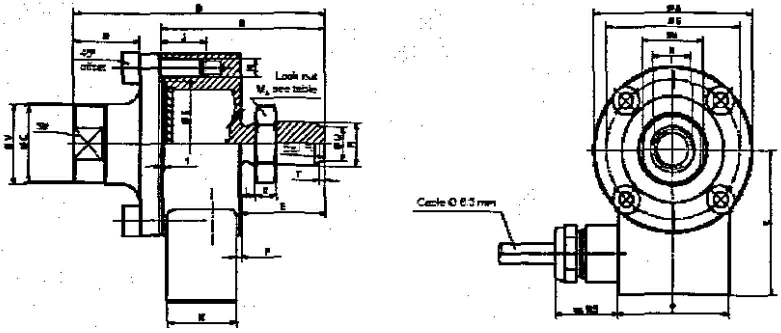
U2B

Force Transducer

Special features

- Tensile / compressive force transducer made from stainless materials
- Nominal forces 500 N ... 200 kN
- Integrated lateral force compensation
- Low overall height

Dimensions (in mm; 1 mm= 0.03937 inches)



Rated force	ØA-0.2	B	ØC	D	E	F	ØG	H	J	K	L	M	N	O	ØS	SW	T	ØU	ØV	X	Y	M_A (N·m)	Ball R
0.5-5 kN	50	72	21	47	24	1.5	42	4xM5	13	43.5	4.2	M12	10	6	34	18	1.6	8.5	22	20	30	60	60
10 kN											7.6												
20 kN	90	112	35	72	38	2	70	4xM10	20.5	63.5	10.6	M20x1.5	15	10	50	30		17	34	30	50	500	100
50 kN	100	141	40	66	47	6	78	4xM12	19	68	13.2	M24x2	20	12	61	36	2	22	42			300	
100 kN	135	167	66	122	57	17	100	8xM12	16	83.5	19	M36x2	26	16	79	60		35	70			2500	160
250 kN	155	232	82	142	85	19	123	8xM16	26	93.5	24.2	M45x2	30	22	87	70	2.2	43	54			4500	

B0482-2.5 en

HBM

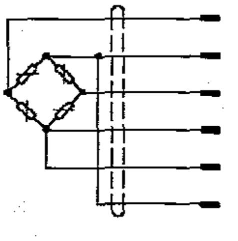
Specifications

Force transducer type			U2B								
Rated force	F_{nom}	kN	0.5	1	2	5	10	20	50	100	200
Class of accuracy			0.2	0.1							
Rated sensitivity	C_{nom}	mV/V	2								
rel. tensile/compressive sensitivity variance	d_c	%	<0.2/1.5	<0.2/0.5							
rel. zero signal variance	$d_{s,o}$	%	<1								
Hysteresis error (0.5F_{nom})	u	%	<0.2	<0.15							
Linearity variation	d_{lin}	%	<0.2	<0.1							
Influence of temperature on sensitivity/10 K relative to nominal sensitivity	TK_c	%	0.1								
Influence of temperature on the zero signal/10 K relative to nominal sensitivity	TK_0	%	0.05								
Influence of eccentricity (1 mm)	d_E	%	0.05								
Influence of lateral force (lateral force 10 % F_{nom})[1]	d_Q	%	0.1								
Rel. creep over 30 min	d_{crF+E}	%	<± 0.06								
Input resistance	R_i	Ω	>345								
Output resistance	R_o	Ω	300...400								
Insulation resistance	R_{is}	Ω	$>2 \cdot 10^9$								
Reference excitation voltage	U_{ref}	V	5								
Service range of excitation voltage	$B_{U,G}T$	V	0.5...12								
Rated temperature range	$B_{t,nom}$	°C	–10...+70								
Service temperature range	$B_{t,G}$	°C	–30...+85 (120)[3]								
Storage temperature range	$B_{t,S}$	°C	–50...+85								
Reference temperature	t_{ref}	°C	+23								
Max. operating force	(F_G)	%	130	150							
Breaking force	(F_B)	%	>300								
Static lateral force limit[1]	(F_Q)	%	25								
Nominal displacement	S_{nom}	mm	<0.1					<0.07		<0.09	
Fundamental resonance frequency	f_G	kHz	4	6	6.7	14	17.5	8	8.5	6	5.6
Weight		kg	0.8					2.9	4.3	10.7	15.9
Rel. permissible vibration loading	F_{rb}	%	100	160							
Protection system according to DIN EN 60529	–	–	IP67								
Length of cable, 6-wire connection	–	–	3 m					6 m		12 m	

[1] relative to a force introduction 20 mm over the membrane

[3] Class 120 °C version optional. The technical data in the extenden service temperature range may differ from the data mentioned above. The 120 °C version cannot be used for zero–related long–term measurements.

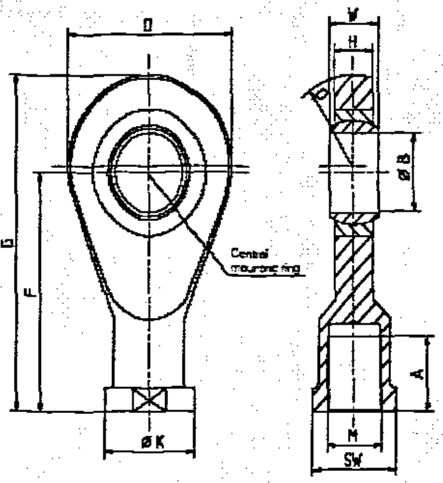
Cable wiring assignment (six wire connection)



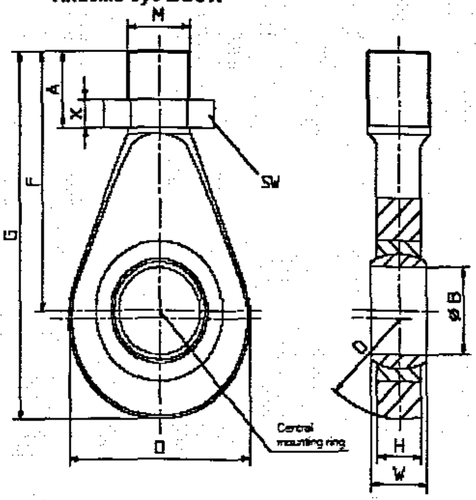
WH (white)	Measuring signal (+) U_A
BK (black)	Bridge excitation voltage (–) U_B
RD (red)	Measuring signal (–) U_A
BU (blue)	Bridge excitation voltage (+) U_B
GN (green)	Sense lead (+)
GY (grey)	Sense lead (–)

Aid to installation (dimensions in mm)

Knuckle eye ZGOW



Knuckle eye ZGUW



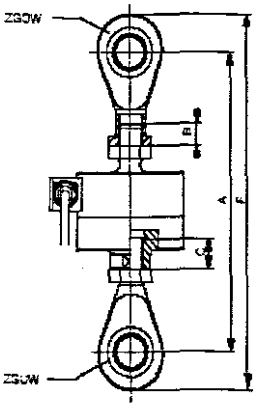
Material: tempered steel, galvanized; rolled steel and Teflon/bronze fabric foil

Rated force in kN	Order No. Knuckle eye ZGOW	Weight in kg	A	∅B	D	F	G	H	∅K	M	SW	W
0.5...10	1-U2A/1t/ZGOW	0.2	22	12^{H7}	32	50	66	12	22	M12	19	16
20	1-U2A/2t/ZGOW	0.5	33	20^{H7}	50	77	102	18	34	M20x1.5	32	25
50	1-U2A/5t/ZGOW	0.8	42	25^{H7}	60	94	124	22	42	M24x2	36	31
100	1-U2A/10t/ZGOW	3.2	50	$50^{+0.002}_{-0.014}$	115	151	212.5	28	65	M39x2	60	35
200	1-U2A/20t/ZGOW	4.8	60	$60^{+0.003}_{-0.016}$	126	167	235	36	82	M48x2	70	44

Rated force in kN	Order No. Knuckle eye ZGOW	Weight in kg	A	∅B	D	F	G	H	M	SW	W	X
0.5...10	1-U2A/1t/ZGUW	0.1	33.5	12^{H7}	32	54.5	70.5	12	M12	19	16	7
20	1-U2A/2t/ZGUW	0.2	46.8	20^{H7}	50	79.8	104.8	18	M20x1.5	30	25	9
50	1-U2A/5t/ZGUW	0.4	57.5	25^{H7}	60	94.5	124.5	22	M24x2	36	31	10
100	1-U2A/10t/ZGUW	1.1	65.5	$50^{+0.002}_{-0.014}$	115	148.5	210	28	M39x2	60	35	16
200	1-U2A/20t/ZGUW	3.2	80	$60^{+0.003}_{-0.016}$	126	168	236	36	M48x2	75	44	18

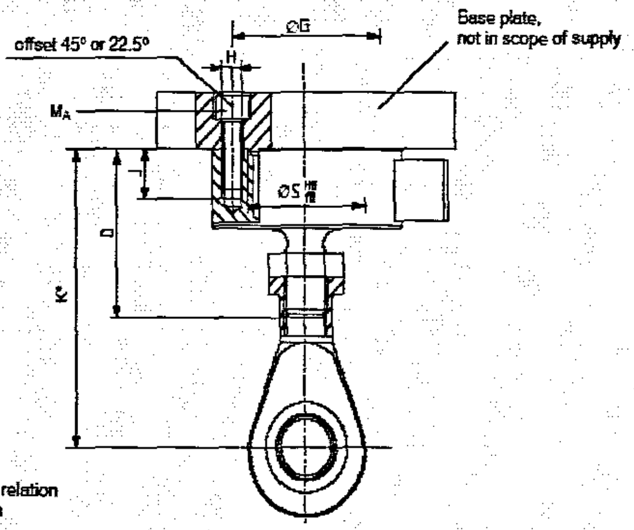
U2B force transducer complete with knuckle eyes ZGOW, ZGUW

Rated force in [kN]	A_{min}	A_{max}	F_{min}	F_{max}	Minimum screwed-in depth		Maximum screwed-in depth
					b	c	
0.5...10	139	156	171	188	9.6	9.6	25
20	212	234	252	264	16	16	40
50	260	288	320	348	19.2	19.2	55
100	416	436	541	559	27	31.2	75
200	466	489	602	625	36.6	38.4	90



Mounting accessories, continued (dimensions in mm)

U2B with ZGOW,
without adapter



* Recommended dimension in relation to minimum screwed-in depth

Rated force in kN	D	∅G	H	J	K	∅S	MA$^{1)}$ [N·m]
0.5...10	47	42	4xM5	13	84...86.4	34	5
20	72	70	4xM10	20.5	131.6	55	35
50	86	78	4xM12	19	158.2	61	60
100	122	105	8xM12	16	244	79	60
200	142	125	8xM16	26	270.2	97	150

$^{1)}$ Recommended values when using a torque wrench on dry thread

Options

- Service temperature range uprated to 120 °C

Accessories, additional:

- Knuckle eye U2B, upper, U2A/.../ZGOW
- Knuckle eye U2B, lower, U2A/.../ZGUW

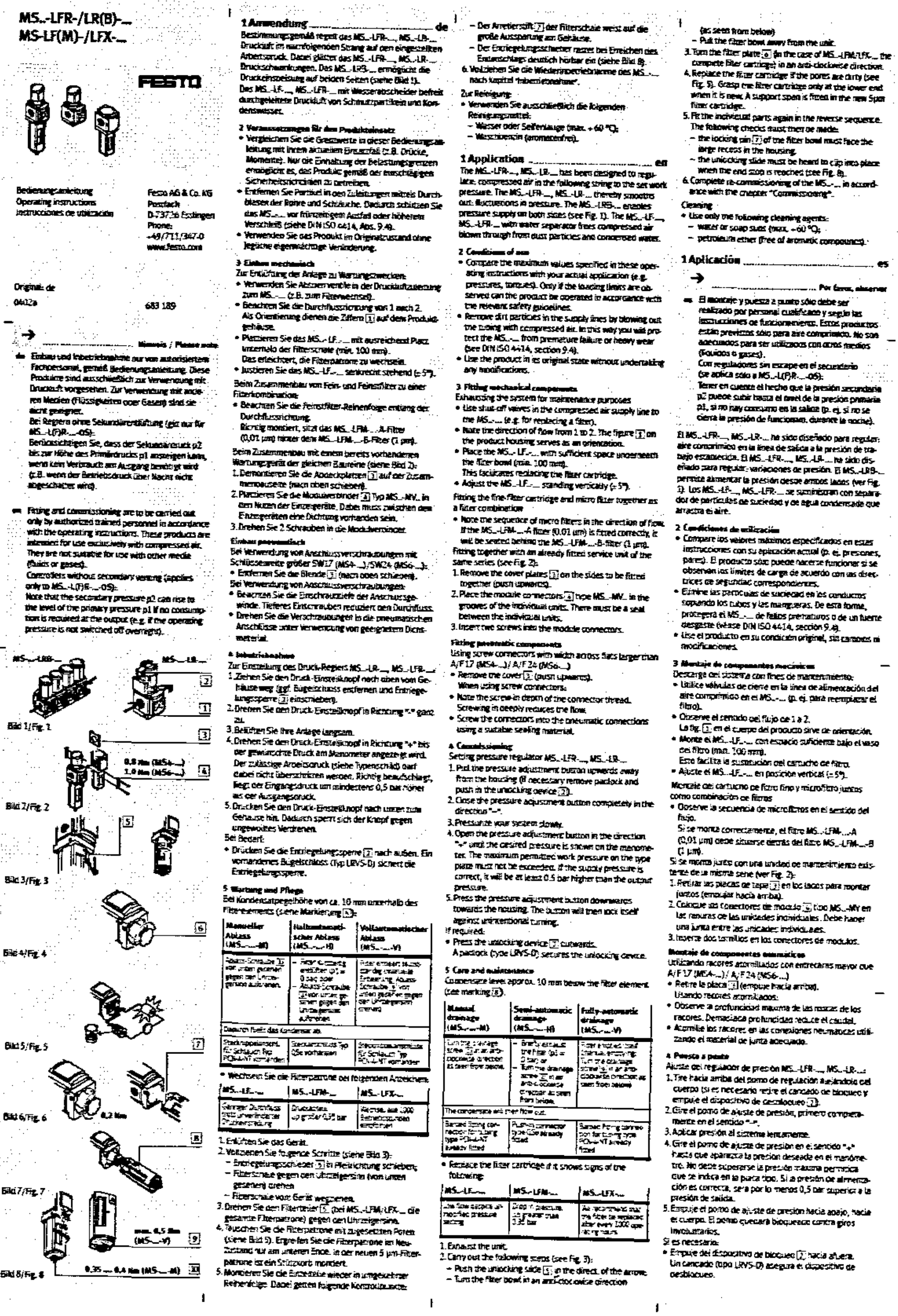
Modifications reserved.
All details describe our products in general form only. They are not to be understood as express warranty and do not constitute any liability whatsoever.

Hottinger Baldwin Messtechnik GmbH

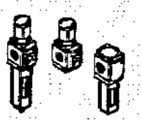
Im Tiefen See 45, D-64293 Darmstadt, Germany
Tel.: +49 6151 803-0 Fax: +49 6151 803 9100
Email: support@hbm.com Internet: www.hbm.com

HBM
measurement with confidence

Appendix G: Air treatment use manual



MS...-LFR-/LR(B)-...
MS-LF(M)-/LFX-...



FESTO

Instrucciones de utilización
Noticе d'utilisation
Istruzioni d'uso

Festo AG & Co. KG
Postfach
D-73726 Esslingen
Phone:
+49/711/347-0
www.festo.com

Original: de

0402a

683 189

→ Note / Nota

fr Montage et mise en service uniquement par du personnel agréé, conformément à la notice d'utilisation. Ces produits sont conçus pour être exclusivement utilisés avec de l'air comprimé. Ils ne se prêtent pas aux applications avec d'autres fluides tels que les liquides ou les gaz.
Sur les régulateurs sans échappement secondaire (valable uniquement pour MS...-L(F)R-...-OS) :
Tenir compte du fait que la pression secondaire p2 peut croître jusqu'à atteindre la pression primaire p1 si aucune consommation a lieu à la sortie (p. ex. lorsque la pression de travail n'est pas coupée pendant la nuit).

it Montaggio e messa in funzione devono essere effettuati da personale qualificato e autorizzato, in conformità alle istruzioni d'uso. Questi prodotti sono predisposti solo per il funzionamento con aria compressa. Non sono adatti all'impiego con altri mezzi (liquidi o gassosi).
In caso di impiego di riduttori non dotati di scarico secondario (vale solo per MS...-L(F)R-...-OS):
Tenere presente che la pressione secondaria p2 può raggiungere il valore della pressione primaria p1 in assenza di consumo nell'uscita (ad es. nel caso in cui la pressione d'esercizio non venga disinserita durante la notte).

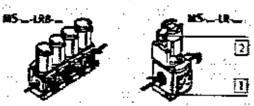


Fig. 1

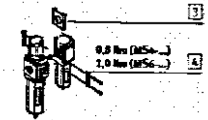


Fig. 2

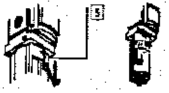


Fig. 3

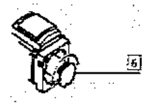


Fig. 4

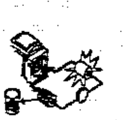


Fig. 5

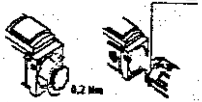


Fig. 6

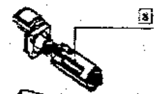


Fig. 7

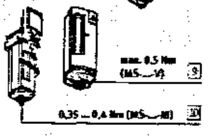


Fig. 8

5 Cuidados y mantenimiento

Nivel de condensados aprox. 10 mm por debajo del elemento filtrante (ver marca [8]).

Purga manual (MS...-...-M)	Purga semi-automática (MS...-...-H)	Purga totalmente automática (MS...-...-V)
Gire el tornillo de purga [9] en sentido antihorario (visto desde abajo).	– Descargue brevemente el filtro (p1 = 0 bar) o – Gire el tornillo de purga [9] en sentido antihorario visto desde abajo	El filtro se vacía. Vaciado manual: Gire el tornillo de purga [9] en sentido antihorario visto desde abajo.
El condensado escapará hacia el exterior.		
Racor de boquilla para tubo del tipo PCN-4-AT ya montado	Racor rápido tipo QS ya montado	Racor de boquilla para tubo del tipo PCN-4-AT ya montado

- Reemplace el cartucho de filtro si muestra alguno de estos signos:

MS...-LF-...-...	MS...-LFM-...	MS...-LFX-...
Poco caudal sin haber modificado el ajuste de la presión	Caída de presión: es mayor de 0,35 bar	Recomendamos sustituir el filtro cada 1000 horas de funcionamiento

1. Descargue el aire del dispositivo.
2. Realice los siguientes pasos (ver Fig. 3):
   - Deslice la pieza de desbl. [5] en el sentido de la flecha.
   - Gire el vaso del filtro en sentido antihorario (visto desde abajo).
   - Saque el vaso del filtro de la unidad.
3. Gire la placa del filtro [6] (en el caso del MS...-LFM/LFX-... todo el elemento filtrante) en sentido antihorario.
4. Reemplace el elemento filtrante si está sucio (ver Fig. 5). Sujete el filtro por su extremo inferior cuando es nuevo. Un soporte distanciador se monta en el nuevo cartucho de filtro de 5 µm.
5. Monte las piezas individuales de nuevo en orden inverso al de desmontaje. Hay que realizar las siguientes verificaciones:
   - El pasador de bloqueo [7] del vaso, debe apuntar hacia el rebaje grande en el cuerpo.
   - La corredera de desbloqueo debe engatillarse cuando se alcanza el tope final (ver Fig. 8).
6. Volver a poner a punto el MS...-... de acuerdo con el capítulo "Puesta a punto".

Limpieza
- Use solamente los siguientes agentes de limpieza.
  - agua o soluciones jabonosas (temp. máx. +60 °C);
  - éter de petróleo (libre de compuestos aromáticos).

1 Utilisation fr

Conformément à l'usage prévu, le MS...-LFR-..., MS...-LR-... maintient constante à la valeur réglée la pression de travail de l'air comprimé dans la branche aval. Le MS...-LFR-..., MS...-LR-... compense les variations de pression. Le MS...-LRB-... permet l'alimentation en air comprimé des deux côtés (voir fig. 1). Le MS...-LF-..., MS...-LFR-... muni d'un purgeur élimine les saletés et l'eau de condensation présentes dans l'air comprimé amené.

2 Conditions de mise en œuvre du produit

- Comparer au cas réel les valeurs limites indiquées dans cette notice d'utilisation (p. ex. pressions, couples). Seul le respect des limites de charge permet un fonctionnement du produit conforme aux directives de sécurité en vigueur.
- Éliminer les particules dans les conduites d'alimentation en soufflant de l'air comprimé dans les tubes et les tuyaux. Ceci permet de protéger le MS...-... contre une panne prématurée ou une usure importante (voir DIN ISO 4414, § 9.4).
- Utiliser le produit dans son état d'origine, sans apporter de modification.

3 Montage mécanique

Lors de la purge de l'installation pour des travaux d'entretien :
- Utiliser des vannes d'arrêt sur la conduite d'alimentation d'air comprimé du MS...-... (p. ex. pour remplacer le filtre).
- Tenir compte du sens du débit, de 1 vers 2.
  Pour ce faire, s'orienter par rapport au chiffre [1] situé sur le corps du produit.
- Placer le MS...-LF-... de sorte qu'il y ait suffisamment de place sous la cuve du filtre (100 mm min.).
  Cela facilite le remplacement de la cartouche filtrante.
- Monter le MS...-LF-... en position verticale (± 5°).

Lors de l'assemblage du filtre et du filtre fin pour obtenir une combinaison de filtres :
- Respecter l'ordre des filtres fins dans le sens du débit. Lorsqu'il est monté correctement, le filtre MS...-LFM-...-A (0,01 µm) se trouve derrière le filtre MS...-LFM-...-B (1 µm).

Lors de l'assemblage avec un appareil de conditionnement de l'air déjà présent et de la même série (voir Fig. 2) :
1. Démonter les plaques d'obturation [3] du côté assemblage (les pousser vers le haut).
2. Placer les brides d'assemblage [4] de type MS...-MV... dans les rainures des différents appareils. Un joint doit se trouver entre les différents appareils.
3. Visser les 2 vis dans les brides d'assemblage.

Montage pneumatique

Lors de l'utilisation de raccords avec un surplat supérieur à 17 (MS4-...)/24 (MS6-...) :
- Retirer le cache [3] (le pousser vers le haut).
  Lors de l'utilisation de raccords :
- Respecter la profondeur de vissage du filetage de raccordement. Un vissage plus profond a pour effet de réduire le débit.
- Visser les raccords dans les orifices pneumatiques en utilisant un joint d'étanchéité adéquat.

4 Mise en service

Réglage du régulateur de pression MS...-LR-..., MS...-LFR-... :
1. Tirer le bouton de réglage de la pression vers le haut dans le sens opposé au boîtier (si nécessaire retirer l'étrier de raccordement et enfoncer l'arrêt du dispositif de déverrouillage [2]).
2. Tourner le bouton de réglage de la pression d'abord à fond vers "–".
3. Mettre l'installation progressivement sous pression.
4. Tourner le bouton de réglage de la pression vers "+" jusqu'à atteindre la pression souhaitée.
   La pression de travail admissible indiquée sur la plaque signalétique ne doit pas être dépassée. Si la pression d'entrée est appliquée correctement, elle est au moins supérieure de 0,5 bar à la pression de sortie.
5. Enfoncer le bouton de réglage de la pression vers le bas (vers le boîtier). De cette manière, le bouton ne peut pas être manipulé involontairement.

Si nécessaire :
- Éjecter le dispositif de déverrouillage [2].
  L'étrier de raccordement (type LRVS-D) bloque l'arrêt du dispositif de déverrouillage.

5 Maintenance et entretien

Lorsque le niveau du condensat se situe à env. 10 mm au-dessous de la cartouche filtrante (voir marquage [8]) :

Purge manuelle (MS...-...-M)	Purge semi-automatique (MS...-...-H)	Purge automatique (MS...-...-V)
Dévisser la vis de purge [9] en la tournant dans le sens inverse des aiguilles d'une montre (vue de dessous).	– Purger brièvement le filtre (p1 = 0 bar) ou – Dévisser la vis de purge [9] en la tournant dans le sens inverse des aiguilles d'une montre (vue de dessous).	Le filtre est purgé automatiquement. Purge manuelle : Dévisser la vis de purge [9] en la tournant dans le sens inverse des aiguilles d'une montre (vue de dessous).
De cette manière, le condensat s'écoule.		
Raccord cannelé pour flexible de type PCN-4-AT disponible	Connecteur de type QS disponible	Raccord cannelé pour flexible de type PCN-4-AT disponible

- Remplacer la cartouche filtrante dans les cas suivants :

MS...-LF-...	MS...-LFM-...	MS...-LFX-...
Si le débit diminue alors que le réglage de la pression n'a pas été modifié.	Chute de pression : est supérieur à 0,35 bar	Remplacement recommandé après 1000 heures de service

1. Purger l'appareil.
2. Effectuer les étapes suivantes (voir Fig. 3) :
   - Pousser le taquet de déverrouillage [5] dans le sens de la flèche.
   - Tourner la cuve du filtre dans le sens inverse des aiguilles d'une montre (vue de dessous).
   - Retirer la cuve du filtre de l'appareil.
3. Tourner le fond du filtre [6] (sur le MS...-LFM/LFX-... toute la cartouche filtrante) en sens antihoraire.
4. Remplacer la cartouche filtrante dont les pores sont bouchés (voir Fig. 5). Ne saisir la cartouche filtrante neuve que par le dessous. Dans la nouvelle cartouche filtrante de 5 µm, un support est intégré.
5. Monter les différents éléments dans l'ordre inverse. Il faut alors tenir compte des points suivants :
   - La tige d'arrêt [7] de la cuve du filtre doit correspondre au grand évidement situé sur le boîtier.
   - Le taquet de déverrouillage doit s'enclencher avec un bruit clairement audible lorsqu'il atteint la butée (voir Fig. 8).
6. Procéder à la remise en service du MS...-... selon le chapitre "Mise en service".

Pour le nettoyage :
- Utiliser uniquement les produits de nettoyage suivants
  - eau ou eau savonneuse (+ 60 °C max.) ;
  - white spirit (non aromatique).

1 Impiego it

La funzione delle unità MS...-LFR-... e MS...-LR-... consiste nel regolare una determinata pressione di lavoro dell'aria compressa nel tratto dell'impianto posto a valle. MS...-LFR-... e MS...-LR-... sono in grado di compensare eventuali variazioni di pressione. L'unità MS...-LRB-... permette l'alimentazione di aria compressa su entrambi i lati (vedi Fig. 1). Le unità MS...-LF-... e MS...-LFR-... con separatore d'acqua depurano l'aria compressa da particelle di sporcizia e dalla condensa.

2 Condizioni di utilizzo

- Confrontare i valori limite indicati nelle presenti istruzioni d'uso (ad es. per pressioni e momenti) con il caso d'impiego specifico. Solamente mantenendo le sollecitazioni entro i limiti previsti, è possibile assicurare un funzionamento del prodotto conforme alle direttive di sicurezza del settore.
- Rimuovere le particelle presenti nelle linee soffiando aria compressa nei tubi rigidi e flessibili. In tal modo si protegge l'unità MS...-... impedendone la rottura e limitandone l'usura (vedi DIN ISO 4414, parte 9.4).
- Utilizzare il prodotto nel suo stato originale, senza apportare modifiche non autorizzate.

3 Montaggio delle parti meccaniche

Per scaricare la pressione dall'impianto per interventi di manutenzione.
- Installare valvole di intercettazione sulla linea di mandata dell'unità MS...-... (ad es. per sostituire il filtro).
- Tenere presente la direzione di flusso da 1 a 2.
  Le cifre [1] fungono da orientamento sul corpo del prodotto.
- Posizionare l'unità MS...-LF-... mantenendo uno spazio sufficiente sotto la tazza del filtro (min. 100 mm).
  Così facendo si agevola la sostituzione della cartuccia filtrante.
- Regolare l'unità MS...-LF-... in posizione verticale (± 5°).

Per l'assemblaggio del filtro fine e del filtro ad alta capacità
- Rispettare l'ordine di successione dei filtri ad alta capacità rispetto alla direzione del flusso.
  Se montato correttamente, il filtro MS...-LFM-...-A (0,01 µm) è situato a valle del filtro MS...-LFM-...-B (1 µm).

Per il collegamento a un gruppo di trattamento aria della stessa serie preesistente (vedi Fig. 2):
1. Smontare le piastre di copertura [3] dal lato di montaggio (spingendole verso l'alto).
2. Inserire i connettori per moduli [4] tipo MS...-MV... nelle scanalature delle singole unità. Verificare che fra unità e unità sia presente una guarnizione.
3. Fissare 2 viti nei connettori.

Montaggio delle parti pneumatiche

In caso di utilizzo di raccordi filettati di misura superiore a 17 (MS4-...) o 24 (MS6-...):
- Rimuovere il diaframma [3] (spingendolo verso l'alto).
  In caso di utilizzo di raccordi filettati:
- Rispettare la profondità di avvitamento dei raccordi filettati. Serrando i raccordi oltre misura, si riduce la portata.
- Avvitare i raccordi negli attacchi pneumatici utilizzando materiale di tenuta appropriato.

4 Messa in servizio

Per la taratura del riduttore di pressione MS...-LR-..., MS...-LFR-...:
1. Sollevare la manopola di regolazione della pressione, allontanandola dal corpo (rimuovere eventualmente la staffa di chiusura e inserire il dispositivo di bloccaggio [2]).
2. Ruotare la manopola di taratura della pressione in direzione "–" (chiuso).
3. Alimentare gradualmente l'impianto.
4. Ruotare la manopola di taratura della pressione in direzione "+" fino a raggiungere la pressione desiderata indicata sul manometro. Non superare la pressione di lavoro ammissibile riportata nella targhetta del tipo. Se la regolazione è stata eseguita correttamente, la pressione d'ingresso è superiore alla pressione d'uscita di ca. 0,5 bar.
5. Abbassare la manopola di regolazione della pressione. In tal modo si impedisce qualsiasi tentativo di manomissione.

All'occorrenza:
- Spingere all'esterno il dispositivo di bloccaggio [2].
  La staffa di chiusura (tipo LRVS-D) ferma il dispositivo di bloccaggio.

5 Manutenzione e cura

Quando la condensa si trova a ca. 10 mm dall'elemento filtrante (vedi segno di livello [8]):

Scarico manuale (MS...-...-M)	Scarico semiautomatico (MS...-...-H)	Scarico automatico (MS...-...-V)
Girare la vite di scarico [9] in senso antiorario (vista dal basso).	– Scaricare brevemente il filtro (p1 = 0 bar) oppure – Girare la vite di scarico [9] in senso antiorario (vista dal basso)	Il filtro si scarica automaticamente. Scarico manuale: girare la vite di scarico [9] in senso antiorario (vista dal basso)
La condensa defluisce dal filtro.		
Attacco a innesto sonato per tubo flessibile PCN-4-AT disponibile	Attacco sonrato QS disponibile	Attacco a innesto sonato per tubo flessibile PCN-4-AT disponibile

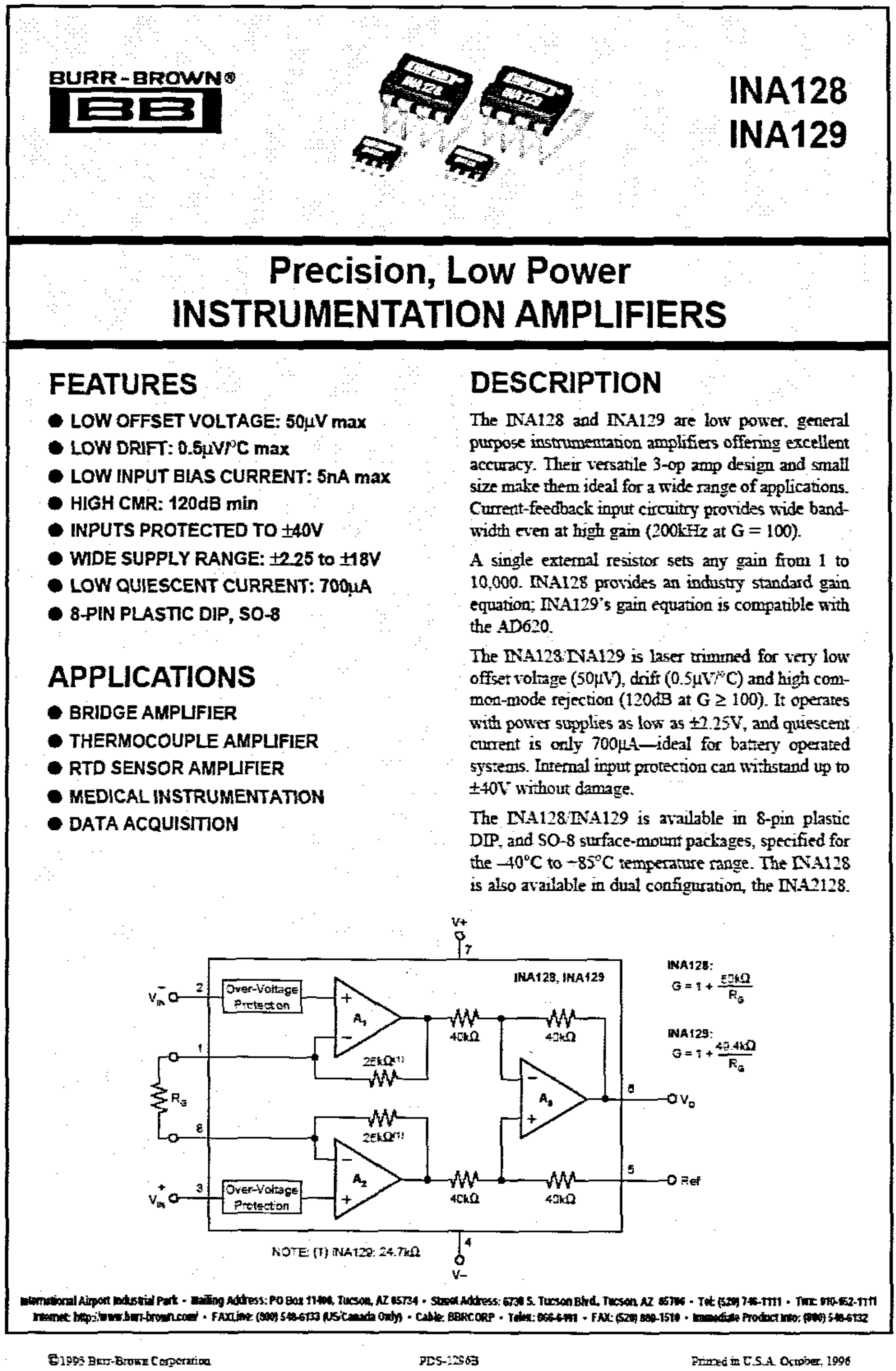
- Sostituire la cartuccia filtrante se si osservano le seguenti anomalie:

MS...-LF-...	MS...-LFM-...	MS...-LFX-...
Riduzione della portata a regolazione costante	Calo della pressione: è maggiore di 0,35 bar	Sostituzione raccomandata ogni 1000 ore di funzionamento

1. Scaricare la pressione dall'unità.
2. Effettuare le seguenti operazioni (vedi Fig. 3):
   - Spingere il cursore di sbloccaggio [5] in direzione della freccia.
   - Girare la tazza del filtro in senso antiorario (vista dal basso).
   - Rimuovere la tazza dall'unità.
3. Girare il piattello del filtro [6] (l'intera cartuccia filtrante nell'MS...-LFM/LFX-...) in senso antiorario.
4. Sostituire la cartuccia filtrante con i pori ostruiti (vedi Fig. 5). Toccare la cartuccia filtrante nuova solo nella parte inferiore. La nuova cartuccia filtrante 5 µm è dotata di un castello di supporto.
5. Montare i singoli componenti eseguendo le operazioni in ordine inverso. Effettuare i seguenti controlli:
   - Il perno d'arresto [7] della tazza del filtro indica la grande cavità sul corpo
   - Il cursore di sbloccaggio si innesta in modo percepibile quando raggiunge la battuta d'arresto (vedi Fig. 8).
6. Ripristinare il funzionamento dell'MS...-... secondo il cap. "Messa in servizio".

Pulizia
- Utilizzare solo i seguenti detergenti:
  - acqua pura o saponata (max. +60° C)
  - benzina solvente (senza aromi).

Appendix H: INA 128 amplifier data sheet



BURR-BROWN®

INA128
INA129

Precision, Low Power
INSTRUMENTATION AMPLIFIERS

FEATURES

- LOW OFFSET VOLTAGE: 50μV max
- LOW DRIFT: 0.5μV/°C max
- LOW INPUT BIAS CURRENT: 5nA max
- HIGH CMR: 120dB min
- INPUTS PROTECTED TO ±40V
- WIDE SUPPLY RANGE: ±2.25 to ±18V
- LOW QUIESCENT CURRENT: 700μA
- 8-PIN PLASTIC DIP, SO-8

APPLICATIONS

- BRIDGE AMPLIFIER
- THERMOCOUPLE AMPLIFIER
- RTD SENSOR AMPLIFIER
- MEDICAL INSTRUMENTATION
- DATA ACQUISITION

DESCRIPTION

The INA128 and INA129 are low power, general purpose instrumentation amplifiers offering excellent accuracy. Their versatile 3-op amp design and small size make them ideal for a wide range of applications. Current-feedback input circuitry provides wide bandwidth even at high gain (200kHz at G = 100).

A single external resistor sets any gain from 1 to 10,000. INA128 provides an industry standard gain equation; INA129's gain equation is compatible with the AD620.

The INA128/INA129 is laser trimmed for very low offset voltage (50μV), drift (0.5μV/°C) and high common-mode rejection (120dB at G ≥ 100). It operates with power supplies as low as ±2.25V, and quiescent current is only 700μA—ideal for battery operated systems. Internal input protection can withstand up to ±40V without damage.

The INA128/INA129 is available in 8-pin plastic DIP, and SO-8 surface-mount packages, specified for the –40°C to +85°C temperature range. The INA128 is also available in dual configuration, the INA2128.

INA128:
$G = 1 + \frac{50k\Omega}{R_G}$

INA129:
$G = 1 + \frac{49.4k\Omega}{R_G}$

NOTE: (1) INA129: 24.7kΩ

International Airport Industrial Park • Mailing Address: PO Box 11400, Tucson, AZ 85734 • Street Address: 6730 S. Tucson Blvd., Tucson, AZ 85706 • Tel: (520) 746-1111 • Twx: 910-952-1111
Internet: http://www.burr-brown.com/ • FAXLine: (800) 548-6133 (US/Canada Only) • Cable: BBRCORP • Telex: 066-6491 • FAX: (520) 889-1510 • Immediate Product Info: (800) 548-6132

©1995 Burr-Brown Corporation

PDS-1296B

Printed in U.S.A. October, 1996

SPECIFICATIONS

At T_A = +25°C, V_S = ±15V, R_L = 10kΩ, unless otherwise noted.

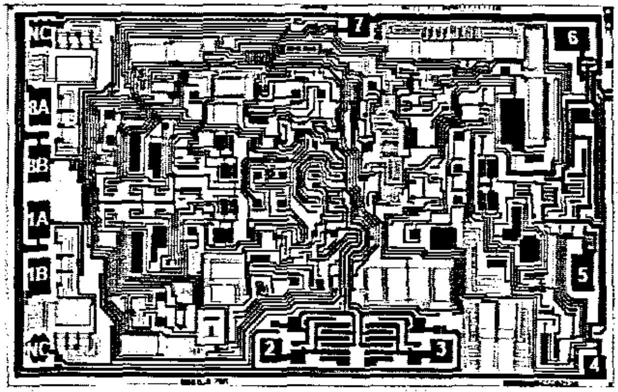
PARAMETER	CONDITIONS	INA128P, U INA129P, U			INA128PA, UA INA129PA, UA			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
INPUT								
Offset Voltage, RTI								
Initial	T_A = +25°C		±10 ±100/G	±50 ±500/G		±25 ±100/G	±125 ±1000/G	µV
vs Temperature	$T_A = T_{MIN}$ to T_{MAX}		±0.2 ± 2/G	±0.5 ± 20/G		±0.2 ± 5/G	±1 ± 20/G	µV/°C
vs Power Supply	V_S = ±2.25V to ±18V		±0.2 ±20/G	±1 ±100/G		*	±2 ±200/G	µV/V
Long-Term Stability			±0.1 ±3/G			*		µV/mo
Impedance, Differential			10^{10} ‖ 2			*		Ω ‖ pF
Common-Mode			10^{11} ‖ 9			*		Ω ‖ pF
Common-Mode Voltage Range(1)	V_O = 0V	(V+) – 2	(V+) – 1.4		*	*		V
		(V–) + 2	(V–) + 1.7		*	*		V
Safe Input Voltage				±40			*	V
Common-Mode Rejection	V_{CM} = ±13V, ΔR_S = 1kΩ							
	G=1	80	86		73	*		dB
	G=10	100	106		93	*		dB
	G=100	120	125		110	*		dB
	G=1000	120	130		110	*		dB
BIAS CURRENT			±2	±5		*	±10	nA
vs Temperature			±30			*		pA/°C
Offset Current			±1	±5		*	±10	nA
vs Temperature			±30			*		pA/°C
NOISE VOLTAGE, RTI	G = 1000, R_S = 0Ω							
f = 10Hz			10			*		$nV/\sqrt{Hz}$
f = 100Hz			8			*		$nV/\sqrt{Hz}$
f = 1kHz			8			*		$nV/\sqrt{Hz}$
f_B = 0.1Hz to 10Hz			0.2			*		µVp-p
Noise Current								
f=10Hz			0.9			*		$pA/\sqrt{Hz}$
f=1kHz			0.3			*		$pA/\sqrt{Hz}$
f_B = 0.1Hz to 10Hz			30			*		pAp-p
GAIN								
Gain Equation, INA128			1 + (50kΩ/R_G)			*		V/V
INA129			1 + (49.4kΩ/R_G)			*		V/V
Range of Gain		1		10000	*		*	V/V
Gain Error	G=1		±0.01	±0.024		*	±0.1	%
	G=10		±0.02	±0.4		*	±0.5	%
	G=100		±0.05	±0.5		*	±0.7	%
	G=1000		±0.5	±1		*	±2	%
Gain vs Temperature(2)	G=1		±1	±10		*	*	ppm/°C
50kΩ (or 49.4kΩ) Resistance(2, 3)			±25	±100		*	*	ppm/°C
Nonlinearity	V_O = ±13.6V, G=1		±0.0001	±0.001		*	±0.002	% of FSR
	G=10		±0.0003	±0.002		*	±0.004	% of FSR
	G=100		±0.0005	±0.002		*	±0.004	% of FSR
	G=1000		±0.001	(Note 4)		*	*	% of FSR
OUTPUT								
Voltage: Positive	R_L = 10kΩ	(V+) – 1.4	(V+) – 0.9		*	*		V
Negative	R_L = 10kΩ	(V–) + 1.4	(V–) + 0.8		*	*		V
Load Capacitance Stability			1000			*		pF
Short-Circuit Current			+6/–15			*		mA
FREQUENCY RESPONSE								
Bandwidth, –3dB	G=1		1.3			*		MHz
	G=10		700			*		kHz
	G=100		200			*		kHz
	G=1000		20			*		kHz
Slew Rate	V_O = ±10V, G=10		4			*		V/µs
Settling Time, 0.01%	G=1		7			*		µs
	G=10		7			*		µs
	G=100		9			*		µs
	G=1000		80			*		µs
Overload Recovery	50% Overdrive		4			*		µs
POWER SUPPLY								
Voltage Range		±2.25	±15	±18	*	*	*	V
Current, Total	V_{IN} = 0V		±700	±750		*	*	µA
TEMPERATURE RANGE								
Specification		–40		85	*		*	°C
Operating		–40		125	*		*	°C
θ_{JA} 8-Pin Dip			80			*		°C/W
SO-8 SOIC			150			*		°C/W

* Specification same as INA128P, U or INA129P, U.

NOTE: (1) Input common-mode range varies with output voltage—see typical curves. (2) Guaranteed by wafer test. (3) Temperature coefficient of the 50kΩ (or 49.4kΩ) term in the gain equation. (4) Nonlinearity measurements in G = 1000 are dominated by noise. Typical nonlinearity is ±0.001%.

The information provided herein is believed to be reliable; however, BURR-BROWN assumes no responsibility for inaccuracies or omissions. BURR-BROWN assumes no responsibility for the use of this information, and all use of such information shall be entirely at the user's own risk. Prices and specifications are subject to change without notice. No patent rights or licenses to any of the circuits described herein are implied or granted to any third party. BURR-BROWN does not authorize or warrant any BURR-BROWN product for use in life support devices and/or systems.

DICE INFORMATION



INA128, INA129 DIE TOPOGRAPHY

PAD	FUNCTION	PAD	FUNCTION
1A, 1B[1]	R_G	5	Ref
2	V^-_{IN}	6	V_O
3	V^+_{IN}	7	V+
4	V−	8A, 8B[1]	R_G

NC = No Connection.

NOTES: (1) Connect both indicated pads.

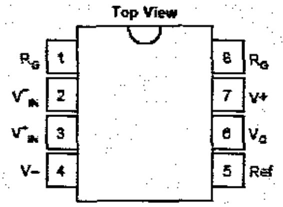
Substrate Bias: Internally connected to V− power supply.

MECHANICAL INFORMATION

	MILS (0.001")	MILLIMETERS
Die Size	123 x 76 ±5	3.05 x 1.76 ±0.13
Die Thickness	14 ±3	0.35 ±0.08
Min. Pad Size	4 x 4	0.1 x 0.1
Backing		Gold

PIN CONFIGURATION

8-Pin DIP and SO-8



ABSOLUTE MAXIMUM RATINGS

Supply Voltage	±18V
Analog Input Voltage Range	±40V
Output Short-Circuit (to ground)	Continuous
Operating Temperature	−40°C to +125°C
Storage Temperature	−40°C to +125°C
Junction Temperature	+150°C
Lead Temperature (soldering, 10s)	+300°C

ELECTROSTATIC DISCHARGE SENSITIVITY

This integrated circuit can be damaged by ESD. Burr-Brown recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

ORDERING INFORMATION

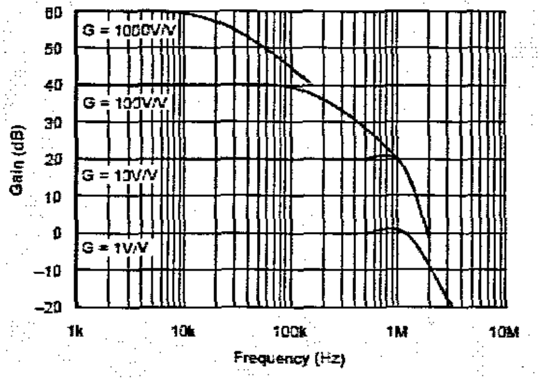
PRODUCT	PACKAGE	PACKAGE DRAWING NUMBER[1]	TEMPERATURE RANGE
INA128PA	8-Pin Plastic DIP	006	−40°C to +85°C
INA128P	8-Pin Plastic DIP	006	−40°C to +85°C
INA128UA	SO-8 Surface-Mount	182	−40°C to +85°C
INA128U	SO-8 Surface-Mount	182	−40°C to +85°C
INA129PA	8-Pin Plastic DIP	006	−40°C to +85°C
INA129P	8-Pin Plastic DIP	006	−40°C to +85°C
INA129UA	SO-8 Surface-Mount	182	−40°C to +85°C
INA129U	SO-8 Surface-Mount	182	−40°C to +85°C

NOTE: (1) For detailed drawing and dimension table, please see end of data sheet, or Appendix C of Burr-Brown IC Data Book.

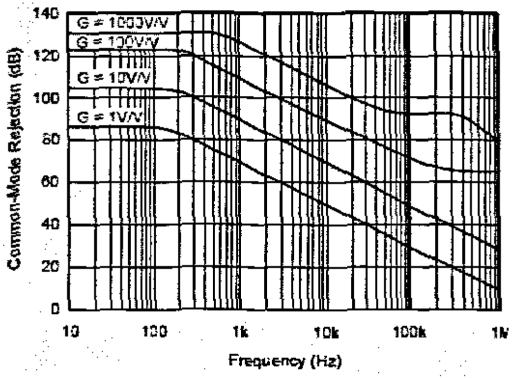
TYPICAL PERFORMANCE CURVES

At $T_A = +25°C$, $V_S = ±15V$, unless otherwise noted.

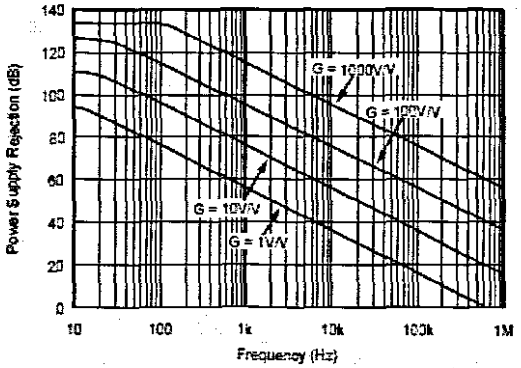
GAIN vs FREQUENCY



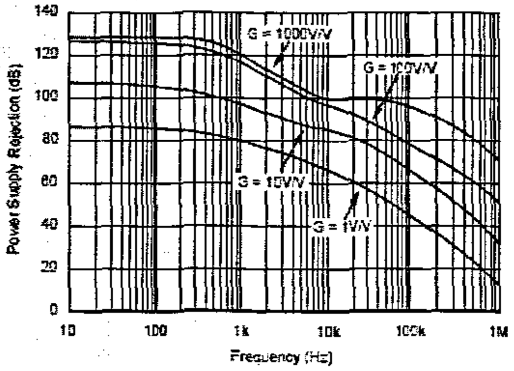
COMMON-MODE REJECTION vs FREQUENCY



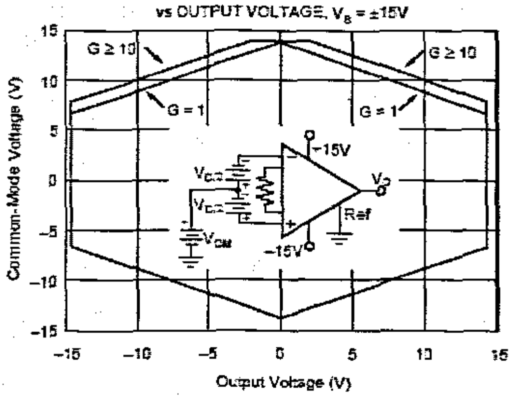
POSITIVE POWER SUPPLY REJECTION vs FREQUENCY



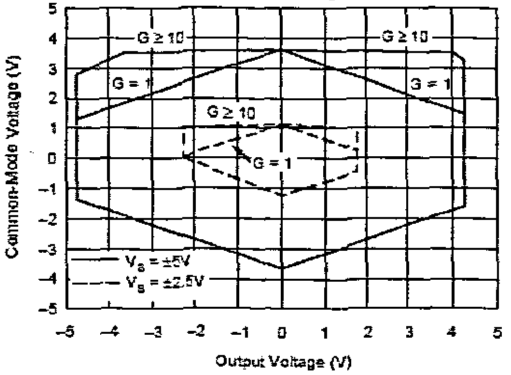
NEGATIVE POWER SUPPLY REJECTION vs FREQUENCY



INPUT COMMON-MODE RANGE vs OUTPUT VOLTAGE, $V_S = ±15V$



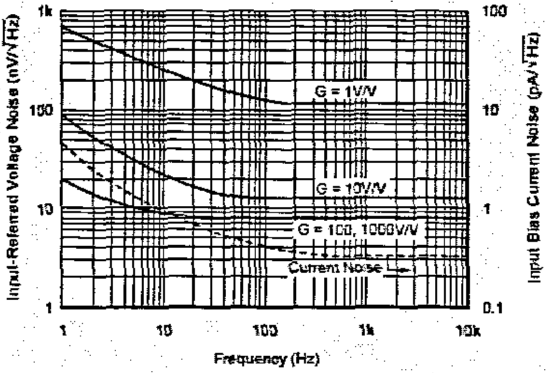
INPUT COMMON-MODE RANGE vs OUTPUT VOLTAGE, $V_S = ±5, ±2.5V$



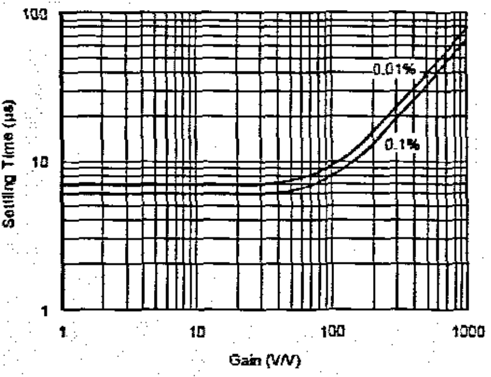
TYPICAL PERFORMANCE CURVES (CONT)

At T_A = +25°C, V_S = ±15V, unless otherwise noted.

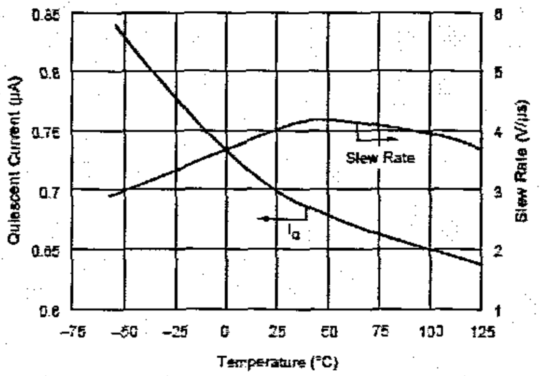
INPUT-REFERRED NOISE vs FREQUENCY



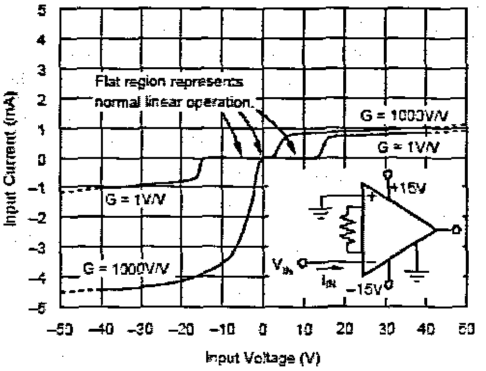
SETTLING TIME vs GAIN



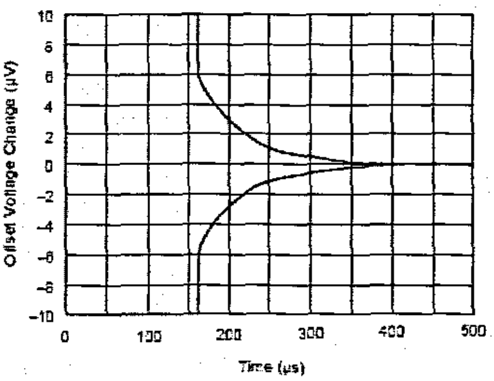
QUIESCENT CURRENT and SLEW RATE vs TEMPERATURE



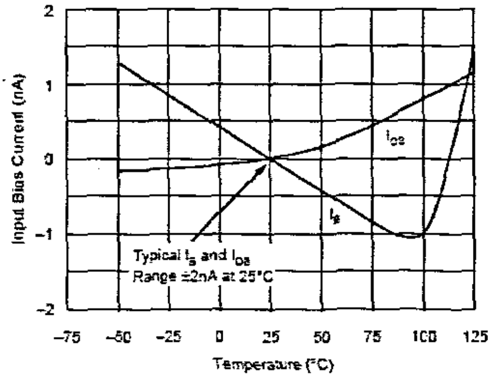
INPUT OVER-VOLTAGE V/I CHARACTERISTICS



INPUT OFFSET VOLTAGE WARM-UP

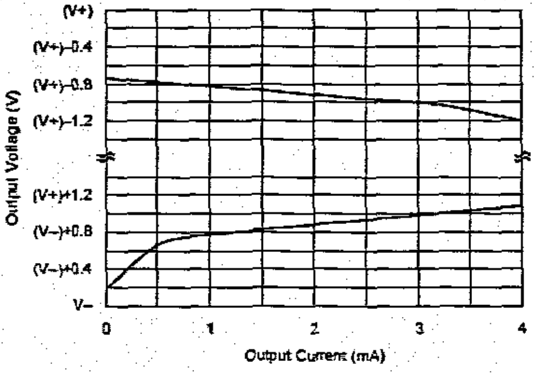


INPUT BIAS CURRENT vs TEMPERATURE

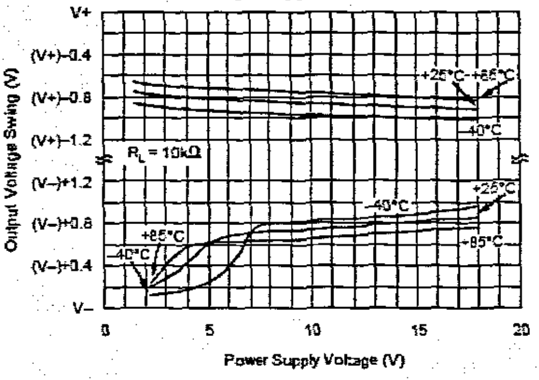


TYPICAL PERFORMANCE CURVES (CONT)

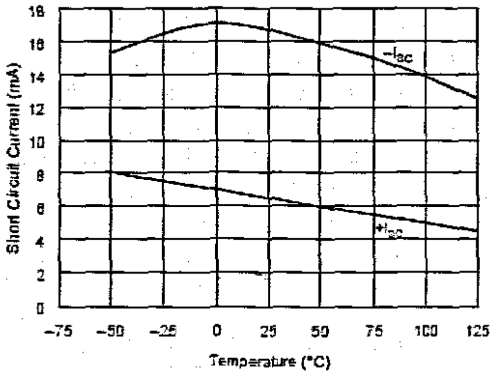
At $T_A = +25°C$, $V_S = ±15V$, unless otherwise noted.



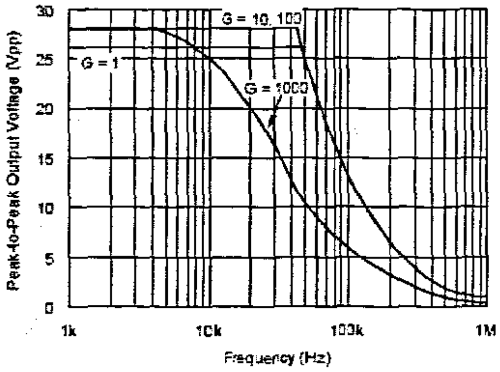
OUTPUT VOLTAGE SWING vs OUTPUT CURRENT



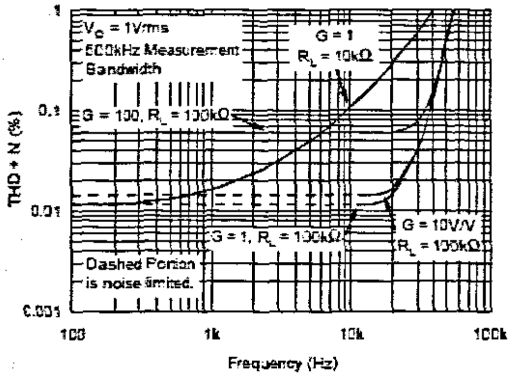
OUTPUT VOLTAGE SWING vs POWER SUPPLY VOLTAGE



SHORT-CIRCUIT OUTPUT CURRENT vs TEMPERATURE



MAXIMUM OUTPUT VOLTAGE vs FREQUENCY

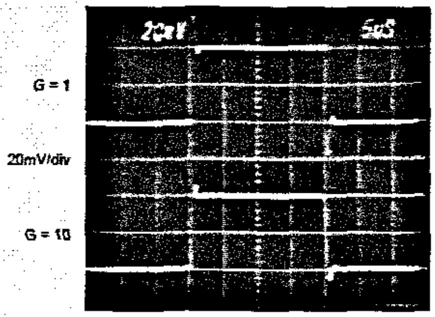


TOTAL HARMONIC DISTORTION + NOISE vs FREQUENCY

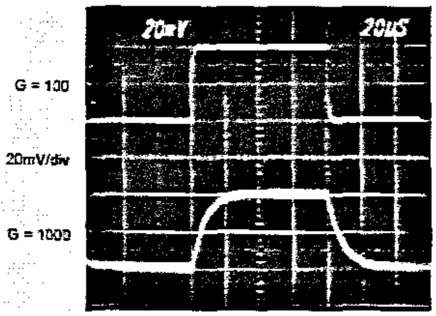
TYPICAL PERFORMANCE CURVES (CONT)

At $T_A = +25°C$, $V_S = ±15V$, unless otherwise noted.

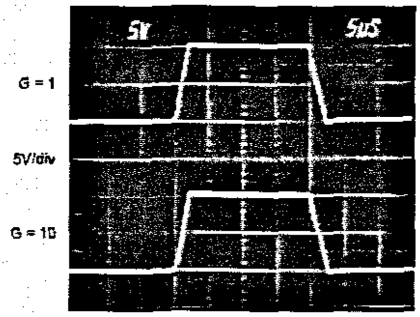
SMALL-SIGNAL
(G = 1, 10)



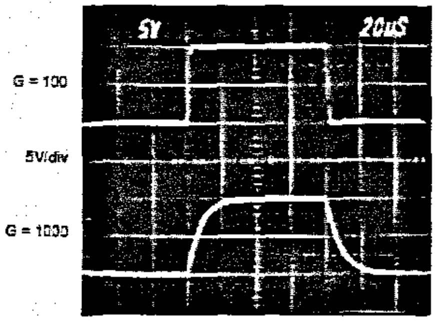
SMALL-SIGNAL
(G = 100, 1000)



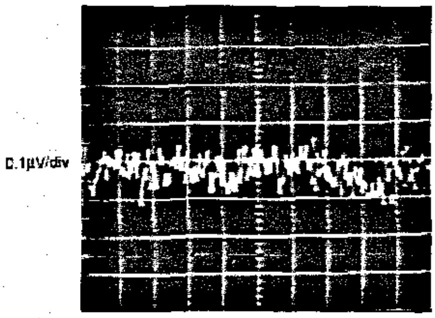
LARGE-SIGNAL
(G = 1, 10)



LARGE-SIGNAL
(G = 100, 1000)



VOLTAGE NOISE 0.1 to 10Hz
INPUT-REFERRED, G ≥ 100



APPLICATION INFORMATION

Figure 1 shows the basic connections required for operation of the INA128/INA129. Applications with noisy or high impedance power supplies may require decoupling capacitors close to the device pins as shown.

The output is referred to the output reference (Ref) terminal which is normally grounded. This must be a low-impedance connection to assure good common-mode rejection. A resistance of 8Ω in series with the Ref pin will cause a typical device to degrade to approximately 80dB CMR (G = 1).

SETTING THE GAIN

Gain is set by connecting a single external resistor, R_G, connected between pins 1 and 8:

INA128: $$G = 1 + \frac{50k\Omega}{R_G} \tag{1}$$

INA129: $$G = 1 + \frac{49.4k\Omega}{R_G} \tag{2}$$

Commonly used gains and resistor values are shown in Figure 1.

The 50kΩ term in Equation 1 (49.4kΩ in Equation 2) comes from the sum of the two internal feedback resistors of A_1 and A_2. These on-chip metal film resistors are laser trimmed to accurate absolute values. The accuracy and temperature coefficient of these internal resistors are included in the gain accuracy and drift specifications of the INA128/INA129.

The stability and temperature drift of the external gain setting resistor, R_G, also affects gain. R_G's contribution to gain accuracy and drift can be directly inferred from the gain equation (1). Low resistor values required for high gain can make wiring resistance important. Sockets add to the wiring resistance which will contribute additional gain error (possibly an unstable gain error) in gains of approximately 100 or greater.

DYNAMIC PERFORMANCE

The typical performance curve "Gain vs Frequency" shows that, despite its low quiescent current, the INA128/INA129 achieves wide bandwidth, even at high gain. This is due to the current-feedback topology of the input stage circuitry. Settling time also remains excellent at high gain.

NOISE PERFORMANCE

The INA128/INA129 provides very low noise in most applications. Low frequency noise is approximately 0.2μVp-p measured from 0.1 to 10Hz (G ≥ 100). This provides dramatically improved noise when compared to state-of-the-art chopper-stabilized amplifiers.

INA128: $G = 1 + \frac{50k\Omega}{R_G}$

INA129: $G = 1 + \frac{49.4k\Omega}{R_G}$

	INA128		INA129	
DESIRED GAIN (V/V)	R_G (Ω)	NEAREST 1% R_G (Ω)	R_G (Ω)	NEAREST 1% R_G (Ω)
1	NC	NC	NC	NC
2	50.00k	49.9k	49.4k	49.9k
5	12.50k	12.4k	12.35k	12.4k
10	5.556k	5.62k	5489	5.49k
20	2.632k	2.61k	2600	2.61k
50	1.02k	1.02k	1008	1k
100	505.1	511	499	499
200	251.3	249	248	249
500	100.2	100	99	100
1000	50.05	49.9	49.5	49.9
2000	25.01	24.9	24.7	24.9
5000	10.00	10	9.88	9.76
10000	5.001	4.99	4.94	4.87

NC: No Connection.

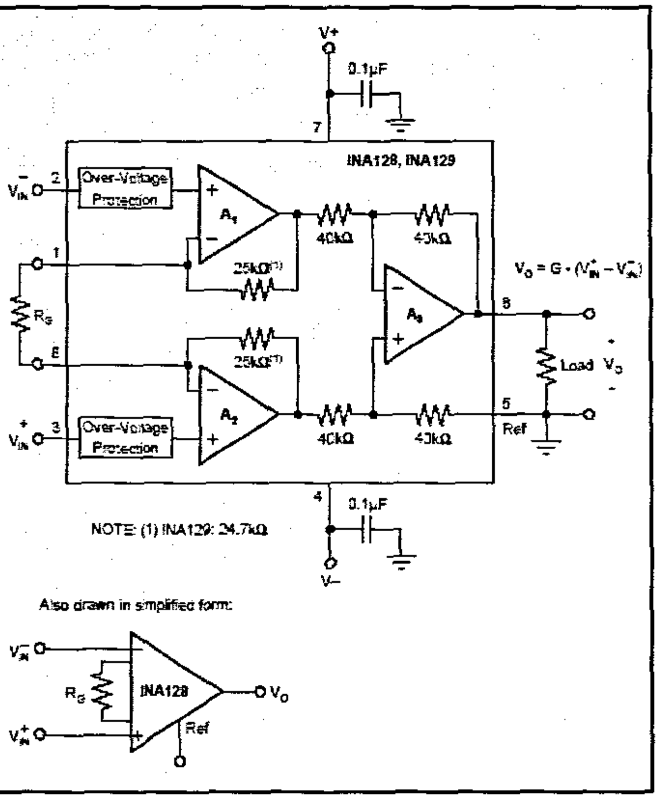


FIGURE 1. Basic Connections.

OFFSET TRIMMING

The INA128/INA129 is laser trimmed for low offset voltage and offset voltage drift. Most applications require no external offset adjustment. Figure 2 shows an optional circuit for trimming the output offset voltage. The voltage applied to Ref terminal is summed with the output. The op amp buffer provides low impedance at the Ref terminal to preserve good common-mode rejection.

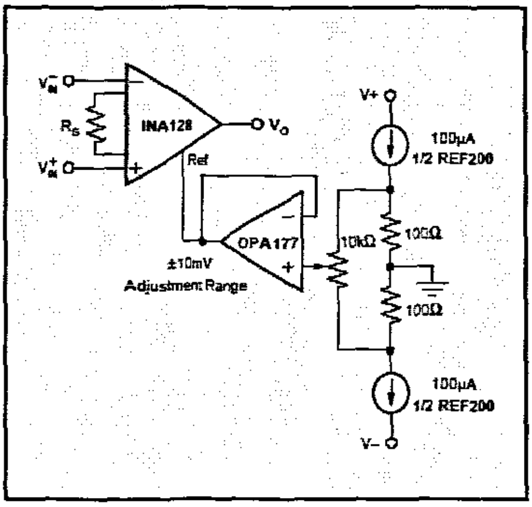


FIGURE 2. Optional Trimming of Output Offset Voltage.

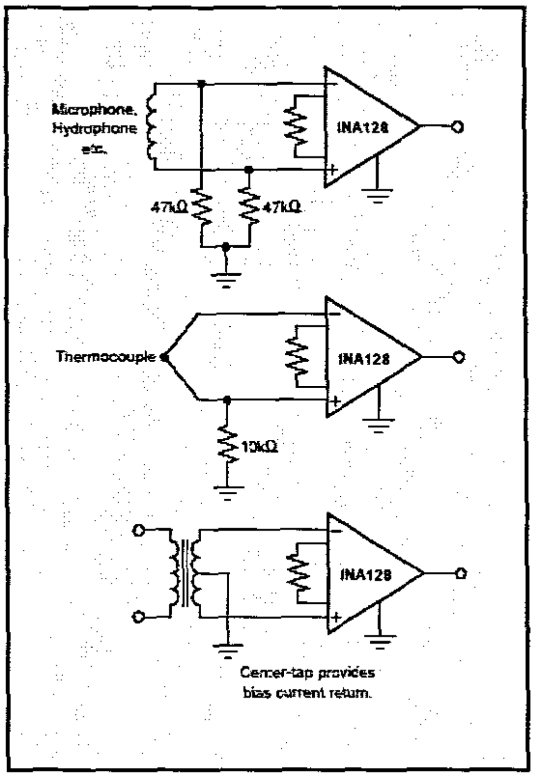


FIGURE 3. Providing an Input Common-Mode Current Path.

INPUT BIAS CURRENT RETURN PATH

The input impedance of the INA128/INA129 is extremely high—approximately $10^{10}\Omega$. However, a path must be provided for the input bias current of both inputs. This input bias current is approximately ±2nA. High input impedance means that this input bias current changes very little with varying input voltage.

Input circuitry must provide a path for this input bias current for proper operation. Figure 3 shows various provisions for an input bias current path. Without a bias current path, the inputs will float to a potential which exceeds the common-mode range, and the input amplifiers will saturate.

If the differential source resistance is low, the bias current return path can be connected to one input (see the thermocouple example in Figure 3). With higher source impedance, using two equal resistors provides a balanced input with possible advantages of lower input offset voltage due to bias current and better high-frequency common-mode rejection.

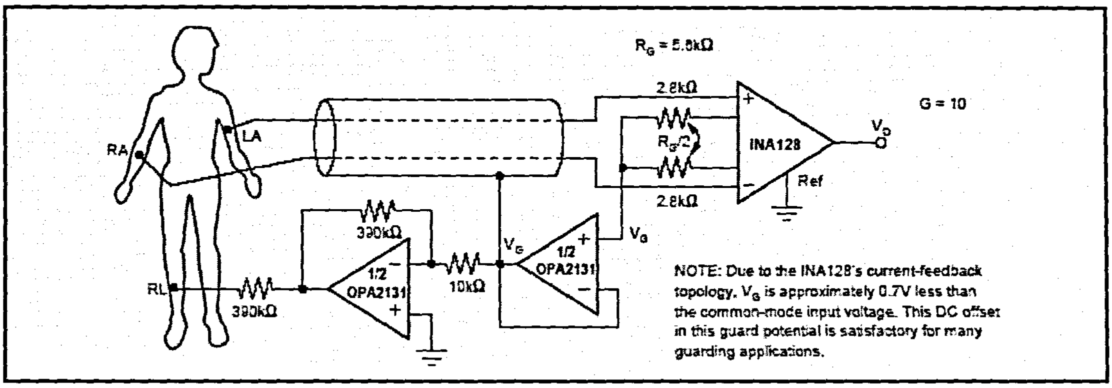
INPUT COMMON-MODE RANGE

The linear input voltage range of the input circuitry of the INA128/INA129 is from approximately 1.4V below the positive supply voltage to 1.7V above the negative supply. As a differential input voltage causes the output voltage increase, however, the linear input range will be limited by the output voltage swing of amplifiers A_1 and A_2. So the linear common-mode input range is related to the output voltage of the complete amplifier. This behavior also depends on supply voltage—see performance curves "Input Common-Mode Range vs Output Voltage".

Input-overload can produce an output voltage that appears normal. For example, if an input overload condition drives both input amplifiers to their positive output swing limit, the difference voltage measured by the output amplifier will be near zero. The output of A_3 will be near 0V even though both inputs are overloaded.

LOW VOLTAGE OPERATION

The INA128/INA129 can be operated on power supplies as low as ±2.25V. Performance remains excellent with power supplies ranging from ±2.25V to ±18V. Most parameters vary only slightly throughout this supply voltage range—see typical performance curves. Operation at very low supply voltage requires careful attention to assure that the input voltages remain within their linear range. Voltage swing requirements of internal nodes limit the input common-mode range with low power supply voltage. Typical performance curves, "Input Common-Mode Range vs Output Voltage" show the range of linear operation for ±15V, ±5V, and ±2.5V supplies.


R_G = 5.6kΩ
2.8kΩ
$R_G/2$
2.8kΩ
INA128
V_O
Ref
G = 10
RA
LA
RL
390kΩ
390kΩ
1/2
OPA2131
10kΩ
V_G
1/2
OPA2131
V_G

NOTE: Due to the INA128's current-feedback topology, V_G is approximately 0.7V less than the common-mode input voltage. This DC offset in this guard potential is satisfactory for many guarding applications.

FIGURE 4. ECG Amplifier With Right-Leg Drive.

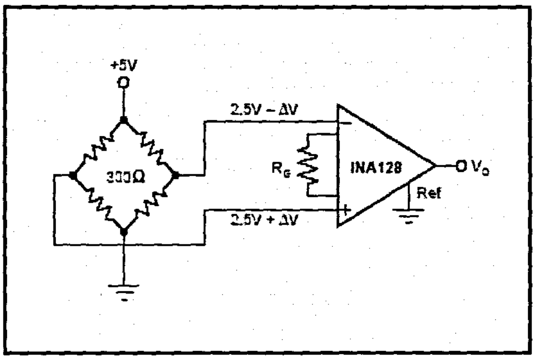
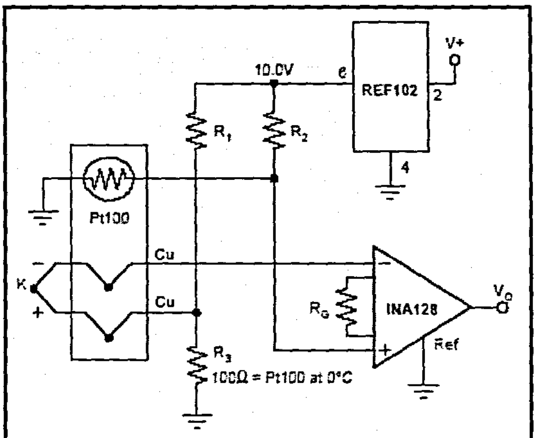

+5V
2.5V – ΔV
2.5V + ΔV
300Ω
R_G
INA128
V_O
Ref

FIGURE 5. Bridge Amplifier.


10.0V
6
REF102
V+
2
4
R_1
R_2
Pt100
Cu
Cu
K
–
+
R_G
INA128
V_O
Ref
R_3
100Ω = Pt100 at 0°C

ISA TYPE	MATERIAL	SEEBECK COEFFICIENT (μV/°C)	R_1, R_2
E	+ Chromel – Constantan	58.5	66.5kΩ
J	+ Iron – Constantan	50.2	76.8kΩ
K	+ Chromel – Alumel	39.4	97.6kΩ
T	+ Copper – Constantan	38.0	102kΩ

FIGURE 7. Thermocouple Amplifier With RTD Cold-Junction Compensation.

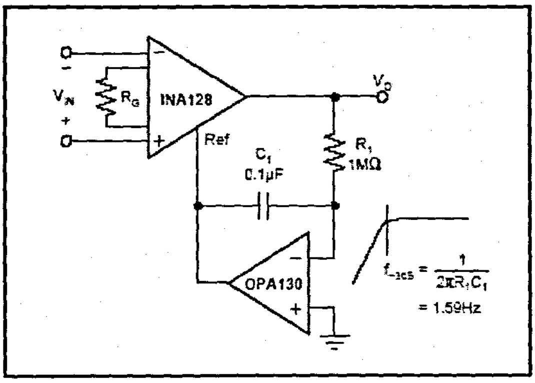
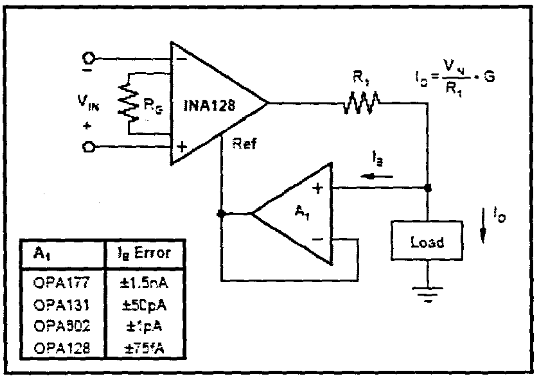

V_{IN}
–
+
R_G
INA128
Ref
V_O
R_1
1MΩ
C_1
0.1μF
OPA130
$f_{-3dB} = \frac{1}{2\pi R_1C_1}$
= 1.59Hz

FIGURE 6. AC-Coupled Instrumentation Amplifier.

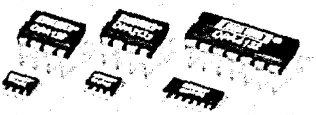

V_{IN}
–
+
R_G
INA128
Ref
R_1
$I_O = \frac{V_{IN}}{R_1} \cdot G$
I_B
A_1
Load
I_O

A_1	I_B Error
OPA177	±1.5nA
OPA131	±50pA
OPA602	±1pA
OPA128	±75fA

FIGURE 8. Differential Voltage to Current Converter.

Appendix I: OPA 2132 amplifier data sheet

Burr-Brown Products
from Texas Instruments



OPA132
OPA2132
OPA4132

SBOS054A – JANUARY 1995 – REVISED JUNE 2004

High-Speed FET-INPUT OPERATIONAL AMPLIFIERS

FEATURES

- FET INPUT: I_B = 50pA max
- WIDE BANDWIDTH: 8MHz
- HIGH SLEW RATE: 20V/μs
- LOW NOISE: 8nV/$\sqrt{\text{Hz}}$ (1kHz)
- LOW DISTORTION: 0.00008%
- HIGH OPEN-LOOP GAIN: 130dB (600Ω load)
- WIDE SUPPLY RANGE: ±2.5 to ±18V
- LOW OFFSET VOLTAGE: 500μV max
- SINGLE, DUAL, AND QUAD VERSIONS

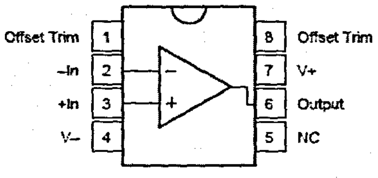
DESCRIPTION

The OPA132 series of FET-input op amps provides high-speed and excellent dc performance. The combination of high slew rate and wide bandwidth provide fast settling time. Single, dual, and quad versions have identical specifications for maximum design flexibility. High performance grades are available in the single and dual versions. All are ideal for general-purpose, audio, data acquisition and communications applications, especially where high source impedance is encountered.

OPA132 op amps are easy to use and free from phase inversion and overload problems often found in common FET-input op amps. Input cascode circuitry provides excellent common-mode rejection and maintains low input bias current over its wide input voltage range. OPA132 series op amps are stable in unity gain and provide excellent dynamic behavior over a wide range of load conditions, including high load capacitance. Dual and quad versions feature completely independent circuitry for lowest crosstalk and freedom from interaction, even when overdriven or overloaded.

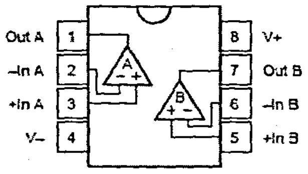
Single and dual versions are available in 8-pin DIP and SO-8 surface-mount packages. Quad is available in 14-pin DIP and SO-14 surface-mount packages. All are specified for −40°C to −85°C operation.

OPA132



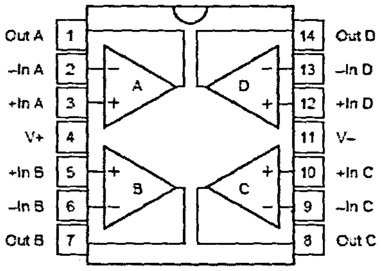
8-Pin DIP, SO-8

OPA2132



8-Pin DIP, SO-8

OPA4132



14-Pin DIP
SO-14

Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

All trademarks are the property of their respective owners.

PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.

Copyright © 1995-2004, Texas Instruments Incorporated

TEXAS INSTRUMENTS
www.ti.com

ABSOLUTE MAXIMUM RATINGS

Supply Voltage, V+ to V–	36V
Input Voltage	(V–) –0.7V to (V+) +0.7V
Output Short-Circuit(1)	Continuous
Operating Temperature	–40°C to +125°C
Storage Temperature	–55°C to +125°C
Junction Temperature	150°C
Lead Temperature (soldering, 10s)	300°C

NOTE: (1) Short-circuit to ground, one amplifier per package.

PACKAGE/ORDERING INFORMATION

For the most current package and ordering information, see the Package Option Addendum located at the end of this data sheet.

ELECTROSTATIC DISCHARGE SENSITIVITY

This integrated circuit can be damaged by ESD. Texas Instruments recommends that all integrated circuits be handled with appropriate precautions. Failure to observe proper handling and installation procedures can cause damage.

ESD damage can range from subtle performance degradation to complete device failure. Precision integrated circuits may be more susceptible to damage because very small parametric changes could cause the device not to meet its published specifications.

SPECIFICATIONS

At T_A = +25°C, V_S = ±15V, unless otherwise noted.

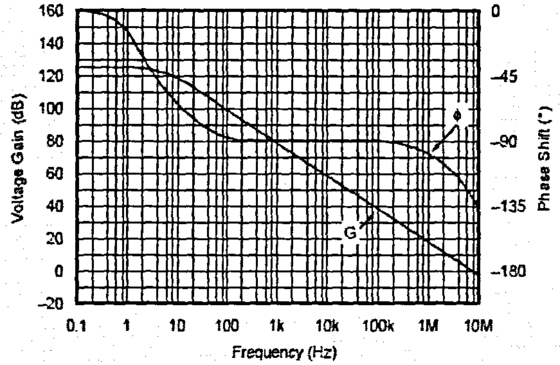
PARAMETER	CONDITION	OPA132P, U OPA2132P, U			OPA132PA, UA OPA2132PA, UA OPA4132PA, UA			UNITS
		MIN	TYP	MAX	MIN	TYP	MAX	
OFFSET VOLTAGE								
Input Offset Voltage			±0.25	±0.5		±0.5	±2	mV
vs Temperature[1]	Operating Temperature Range		±2	±10		*	*	µV/°C
vs Power Supply	V_S = ±2.5V to ±18V		5	15		*	30	µV/V
Channel Separation (dual and quad)	R_L = 2kΩ		0.2			*		µV/V
INPUT BIAS CURRENT								
Input Bias Current[2]	V_{CM} = 0V		+5	±50		*	*	pA
vs Temperature			See Typical Curve			*		
Input Offset Current[2]	V_{CM} = 0V		±2	±50		*	*	pA
NOISE								
Input Voltage Noise								
Noise Density, f = 10Hz			23			*		$nV/\sqrt{Hz}$
f = 100Hz			10			*		$nV/\sqrt{Hz}$
f = 1kHz			8			*		$nV/\sqrt{Hz}$
f = 10kHz			8			*		$nV/\sqrt{Hz}$
Current Noise Density, f = 1kHz			3			*		$fA/\sqrt{Hz}$
INPUT VOLTAGE RANGE								
Common-Mode Voltage Range		(V–)+2.5	±13	(V+)–2.5	*	*	*	V
Common-Mode Rejection	V_{CM} = –12.5V to +12.5V	96	100		86	94		dB
INPUT IMPEDANCE								
Differential			$10^{13} \parallel 2$			*		$\Omega \parallel pF$
Common-Mode	V_{CM} = –12.5V to +12.5V		$10^{13} \parallel 6$			*		$\Omega \parallel pF$
OPEN-LOOP GAIN								
Open-Loop Voltage Gain	R_L = 10kΩ, V_O = –14.5V to +13.8V	110	120		104	*		dB
	R_L = 2kΩ, V_O = –13.8V to +13.5V	110	126		104	120		dB
	R_L = 600Ω, V_O = –12.8V to +12.5V	110	130		104	120		dB
FREQUENCY RESPONSE								
Gain-Bandwidth Product			8			*		MHz
Slew Rate			±20			*		V/µs
Settling Time: 0.1%	G = –1, 10V Step, C_L = 100pF		0.7			*		µs
0.01%	G = –1, 10V Step, C_L = 100pF		1			*		µs
Overload Recovery Time	G = ±1		0.5			*		µs
Total Harmonic Distortion + Noise	1kHz, G = 1, V_O = 3.5Vrms							
	R_L = 2kΩ		0.00008			*		%
	R_L = 600Ω		0.00009			*		%
OUTPUT								
Voltage Output, Positive	R_L = 10kΩ	(V+)–1.2	(V+)–0.9		*	*		V
Negative		(V–)+0.5	(V–)+0.3		*	*		V
Positive	R_L = 2kΩ	(V+)–1.5	(V+)–1.2		*	*		V
Negative		(V–)+1.2	(V–)+0.9		*	*		V
Positive	R_L = 600Ω	(V+)–2.5	(V+)–2.0		*	*		V
Negative		(V–)+2.2	(V–)+1.9		*	*		V
Short-Circuit Current			±40			*		mA
Capacitive Load Drive (Stable Operation)			See Typical Curve			*		
POWER SUPPLY								
Specified Operating Voltage			±15			*		V
Operating Voltage Range		±2.5		±18	*		*	V
Quiescent Current (per amplifier)	I_O = 0		±4	±4.8		*	*	mA
TEMPERATURE RANGE								
Operating Range		–40		+85	*		*	°C
Storage		–40		+125	*		*	°C
Thermal Resistance, θ_{JA}								
8-Pin DIP			100			*		°C/W
SO-8 Surface-Mount			150			*		°C/W
14-Pin DIP			80			*		°C/W
SO-14 Surface-Mount			110			*		°C/W

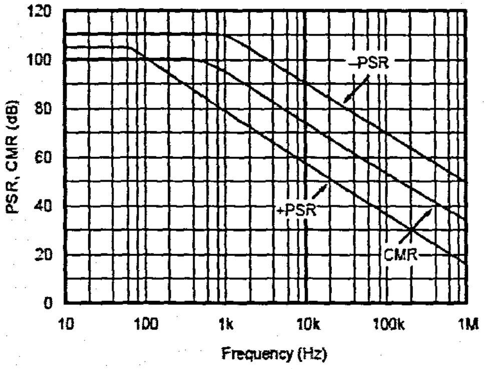
* Specifications same as OPA132P, OPA132U.

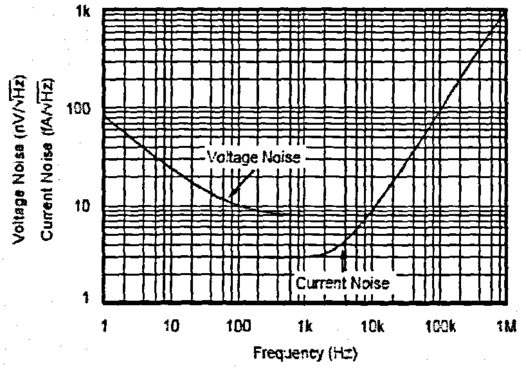
NOTES: (1) Guaranteed by wafer test. (2) High-speed test at T_J = 25°C.

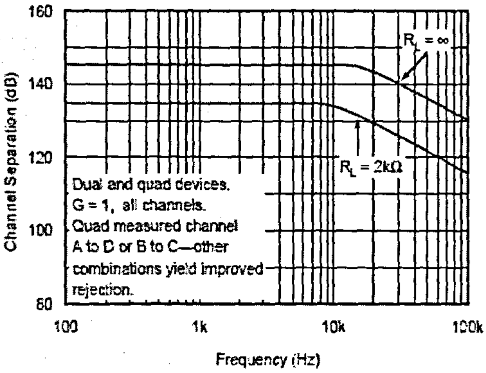
TYPICAL PERFORMANCE CURVES

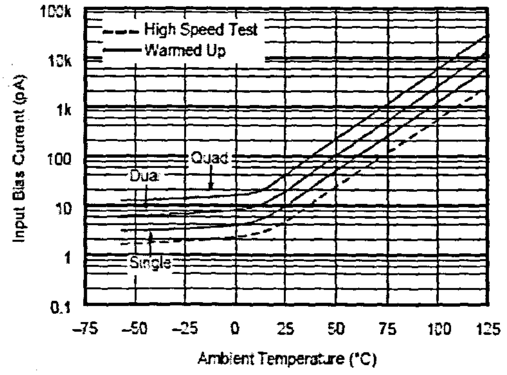
At $T_A = +25°C$, $V_S = ±15V$, $R_L = 2kΩ$, unless otherwise noted.

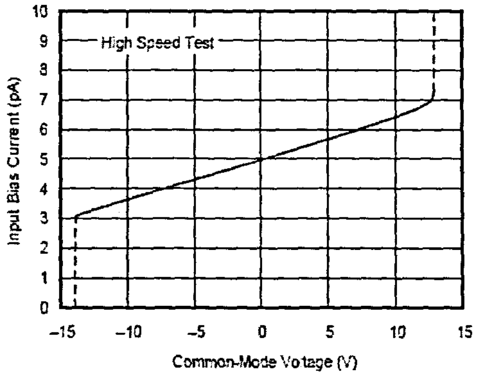

OPEN-LOOP GAIN/PHASE vs FREQUENCY


POWER SUPPLY AND COMMON-MODE REJECTION vs FREQUENCY


INPUT VOLTAGE AND CURRENT NOISE SPECTRAL DENSITY vs FREQUENCY


CHANNEL SEPARATION vs FREQUENCY

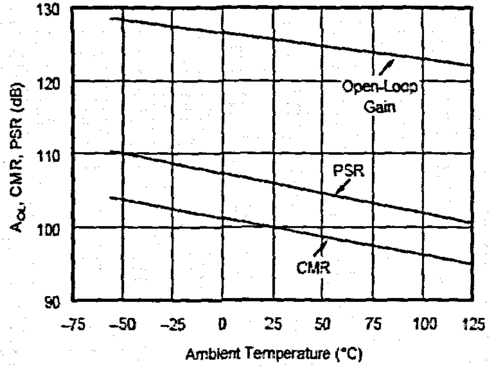

INPUT BIAS CURRENT vs TEMPERATURE


INPUT BIAS CURRENT vs INPUT COMMON-MODE VOLTAGE

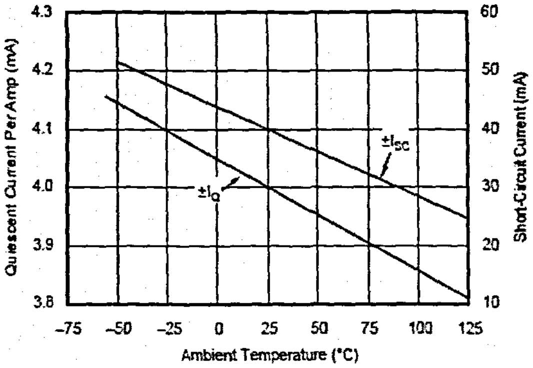
TYPICAL PERFORMANCE CURVES (Cont.)

At T_A = +25°C, V_S = ±15V, R_L = 2kΩ, unless otherwise noted.

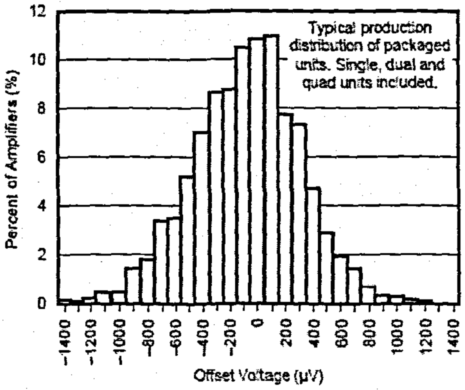
A_{OL}, CMR, PSR vs TEMPERATURE



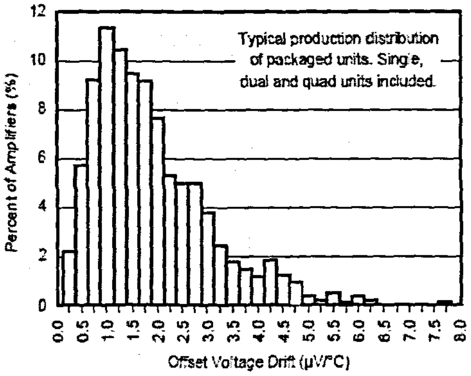
QUIESCENT CURRENT AND SHORT-CIRCUIT CURRENT vs TEMPERATURE



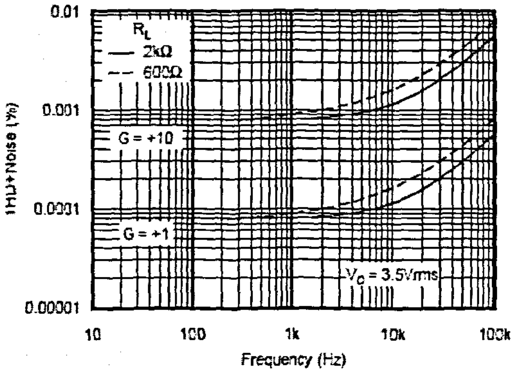
OFFSET VOLTAGE PRODUCTION DISTRIBUTION



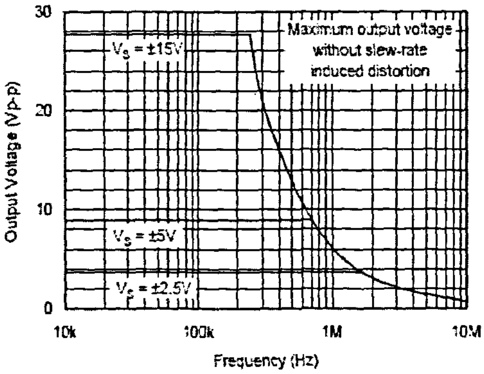
OFFSET VOLTAGE DRIFT PRODUCTION DISTRIBUTION



TOTAL HARMONIC DISTORTION + NOISE vs FREQUENCY

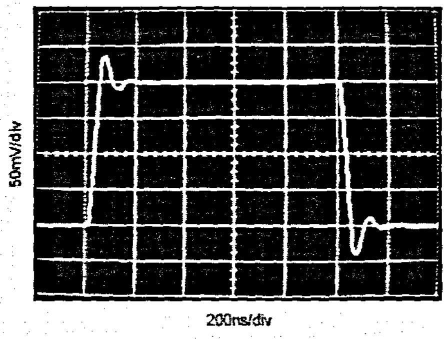


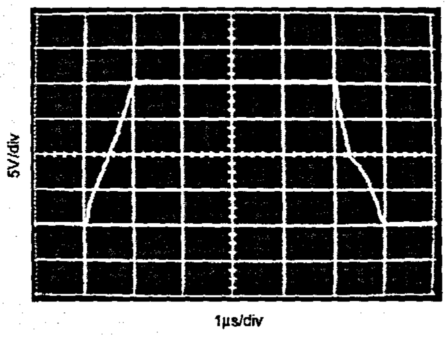
MAXIMUM OUTPUT VOLTAGE vs FREQUENCY

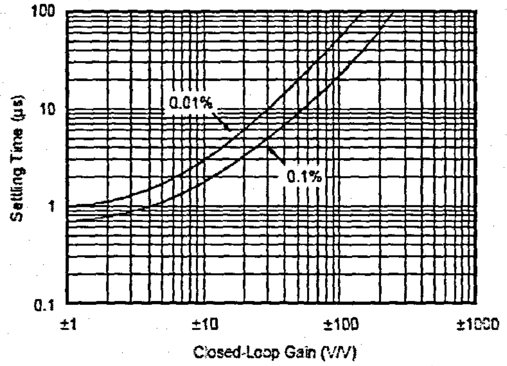


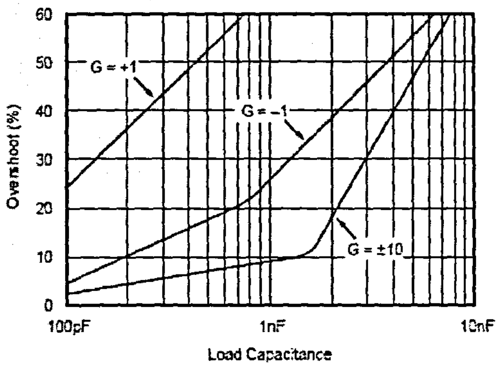
TYPICAL PERFORMANCE CURVES (Cont.)

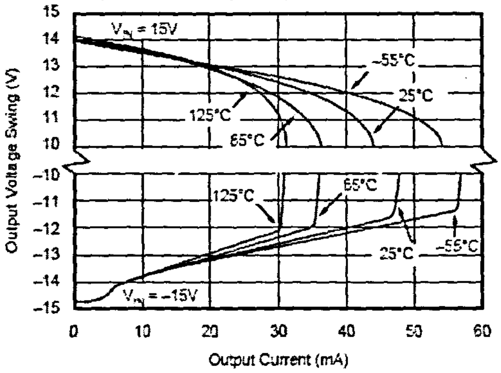
At T_A = +25°C, V_S = ±15V, R_L = 2kΩ, unless otherwise noted.


SMALL-SIGNAL STEP RESPONSE
G = 1, C_L = 100pF


LARGE-SIGNAL STEP RESPONSE
G = 1, C_L = 100pF


SETTLING TIME vs CLOSED-LOOP GAIN


SMALL-SIGNAL OVERSHOOT
vs LOAD CAPACITANCE


OUTPUT VOLTAGE SWING vs OUTPUT CURRENT

APPLICATIONS INFORMATION

OPA132 series op amps are unity-gain stable and suitable for a wide range of general-purpose applications. Power supply pins should be bypassed with 10nF ceramic capacitors or larger.

OPA132 op amps are free from unexpected output phase-reversal common with FET op amps. Many FET-input op amps exhibit phase-reversal of the output when the input common-mode voltage range is exceeded. This can occur in voltage-follower circuits, causing serious problems in control loop applications. OPA132 series op amps are free from this undesirable behavior. All circuitry is completely independent in dual and quad versions, assuring normal behavior when one amplifier in a package is overdriven or short-circuited.

OPERATING VOLTAGE

OPA132 series op amps operate with power supplies from ±2.5V to ±18V with excellent performance. Although specifications are production tested with ±15V supplies, most behavior remains unchanged throughout the full operating voltage range. Parameters which vary significantly with operating voltage are shown in the typical performance curves.

OFFSET VOLTAGE TRIM

Offset voltage of OPA132 series amplifiers is laser trimmed and usually requires no user adjustment. The OPA132 (single op amp version) provides offset voltage trim connections on pins 1 and 8. Offset voltage can be adjusted by connecting a potentiometer as shown in Figure 1. This adjustment should be used only to null the offset of the op amp, not to adjust system offset or offset produced by the signal source. Nulling offset could degrade the offset voltage drift behavior of the op amp. While it is not possible to predict the exact change in drift, the effect is usually small.

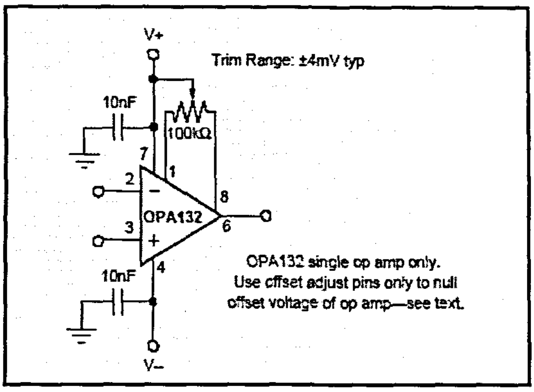

V+
Trim Range: ±4mV typ
10nF
100kΩ
7
1
2
−
8
OPA132
6
3
+
4
10nF
V−
OPA132 single op amp only.
Use offset adjust pins only to null
offset voltage of op amp—see text.

FIGURE 1. OPA132 Offset Voltage Trim Circuit.

INPUT BIAS CURRENT

The FET-inputs of the OPA132 series provide very low input bias current and cause negligible errors in most applications. For applications where low input bias current is crucial, junction temperature rise should be minimized. The input bias current of FET-input op amps increases with temperature as shown in the typical performance curve "Input Bias Current vs Temperature."

The OPA132 series may be operated at reduced power supply voltage to minimize power dissipation and temperature rise. Using ±3V supplies reduces power dissipation to one-fifth that at ±15V.

The dual and quad versions have higher total power dissipation than the single, leading to higher junction temperature. Thus, a warmed-up quad will have higher input bias current than a warmed-up single. Furthermore, an SOIC will generally have higher junction temperature than a DIP at the same ambient temperature because of a larger θ_{JA}. Refer to the specifications table.

Circuit board layout can also help minimize junction temperature rise. Temperature rise can be minimized by soldering the devices to the circuit board rather than using a socket. Wide copper traces will also help dissipate the heat by acting as an additional heat sink.

Input stage cascode circuitry assures that the input bias current remains virtually unchanged throughout the full input common-mode range of the OPA132 series. See the typical performance curve "Input Bias Current vs Common-Mode Voltage."

PACKAGE OPTION ADDENDUM

PACKAGING INFORMATION

Orderable Device	Status [1]	Package Type	Package Drawing	Pins	Package Qty	Eco Plan [2]	Lead/Ball Finish	MSL Peak Temp [3]
OPA132P	OBSOLETE	PDIP	P	8		TBD	Call TI	Call TI
OPA132P1	OBSOLETE	PDIP	P	8		TBD	Call TI	Call TI
OPA132PA	OBSOLETE	PDIP	P	8		TBD	Call TI	Call TI
OPA132PA2	OBSOLETE	PDIP	P	8		TBD	Call TI	Call TI
OPA132U	ACTIVE	SOIC	D	8	100	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
OPA132U/2K5	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
OPA132U/2K5G4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
OPA132U1	OBSOLETE	PDIP	P	8		TBD	Call TI	Call TI
OPA132UA	ACTIVE	SOIC	D	8	100	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
OPA132UA/2K5	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
OPA132UA/2K5E4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
OPA132UA/2K5G4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
OPA132UA2	OBSOLETE	PDIP	P	8		TBD	Call TI	Call TI
OPA132UAE4	ACTIVE	SOIC	D	8	100	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
OPA132UAG4	ACTIVE	SOIC	D	8	100	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
OPA132UG4	ACTIVE	SOIC	D	8	100	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
OPA2132P	ACTIVE	PDIP	P	8	50	Green (RoHS & no Sb/Br)	CU NIPDAU	N / A for Pkg Type
OPA2132PA	ACTIVE	PDIP	P	8	50	Green (RoHS & no Sb/Br)	CU NIPDAU	N / A for Pkg Type
OPA2132U	ACTIVE	SOIC	D	8	100	Pb-Free (RoHS)	CU NIPDAU	Level-3-260C-168 HR
OPA2132U/2K5	ACTIVE	SOIC	D	8	2500	Pb-Free (RoHS)	CU NIPDAU	Level-3-260C-168 HR
OPA2132U/2K5E4	ACTIVE	SOIC	D	8	2500	Pb-Free (RoHS)	CU NIPDAU	Level-3-260C-168 HR
OPA2132UA	ACTIVE	SOIC	D	8	100	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
OPA2132UA/2K5	ACTIVE	SOIC	D	8	2500	Pb-Free (RoHS)	CU NIPDAU	Level-3-260C-168 HR
OPA2132UA/2K5E4	ACTIVE	SOIC	D	8	2500	Pb-Free (RoHS)	CU NIPDAU	Level-3-260C-168 HR
OPA2132UAE4	ACTIVE	SOIC	D	8	100	Pb-Free (RoHS)	CU NIPDAU	Level-3-260C-168 HR
OPA2132UAG4	ACTIVE	SOIC	D	8	100	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
OPA2132UE4	ACTIVE	SOIC	D	8	100	Pb-Free (RoHS)	CU NIPDAU	Level-3-260C-168 HR

PACKAGE OPTION ADDENDUM

26-Mar-2007

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)
OPA4132PA	OBSOLETE	PDIP	N	14		TBD	Call TI	Call TI
OPA4132UA	ACTIVE	SOIC	D	14	50	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
OPA4132UA/2K5	ACTIVE	SOIC	D	14	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
OPA4132UA/2K5E4	ACTIVE	SOIC	D	14	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR
OPA4132UAE4	ACTIVE	SOIC	D	14	50	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-3-260C-168 HR

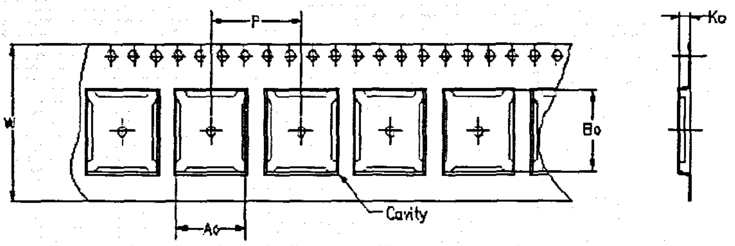
(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

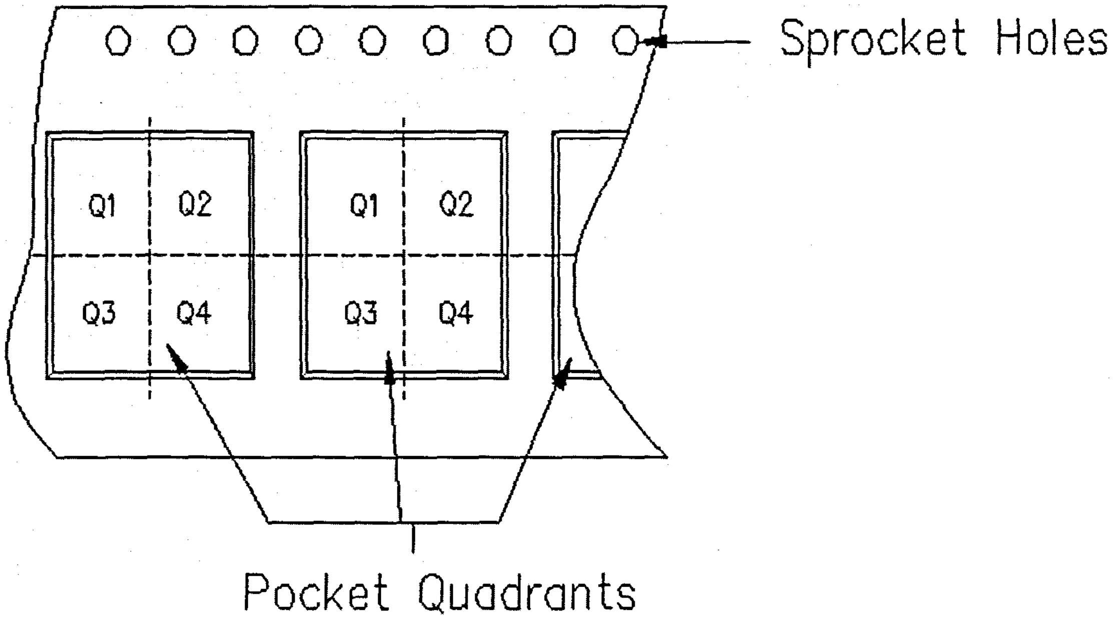
Important Information and Disclaimer: The information provided on this page represents TI's knowledge and belief as of the date that it is provided. TI bases its knowledge and belief on information provided by third parties, and makes no representation or warranty as to the accuracy of such information. Efforts are underway to better integrate information from third parties. TI has taken and continues to take reasonable steps to provide representative and accurate information but may not have conducted destructive testing or chemical analysis on incoming materials and chemicals. TI and TI suppliers consider certain information to be proprietary, and thus CAS numbers and other limited information may not be available for release.

In no event shall TI's liability arising out of such information exceed the total purchase price of the TI part(s) at issue in this document sold by TI to Customer on an annual basis.


P
W
Bo
Ko
Cavity
Ao

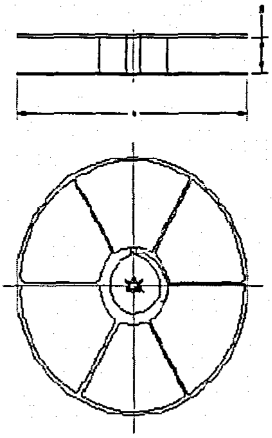
Carrier tape design is defined largely by the component lentgh, width, and thickness.

Ao = Dimension designed to accommodate the component width.
Bo = Dimension designed to accommodate the component length.
Ko = Dimension designed to accommodate the component thickness.
W = Overall width of the carrier tape.
P = Pitch between successive cavity centers.


Sprocket Holes
Q1
Q2
Q3
Q4
Q1
Q2
Q3
Q4
Pocket Quadrants

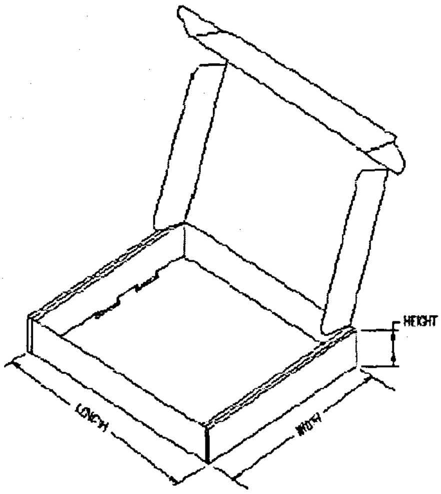
TAPE AND REEL INFORMATION

Device	Package	Pins	Site	Reel Diameter (mm)	Reel Width (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
OPA2132UA/2K5	D	8	MLA	330	12	6.9	5.4	2.0	8	12	Q1
OPA4132UA/2K5	D	14	MLA	330	16	6.5	9.5	2.1	8	16	Q1

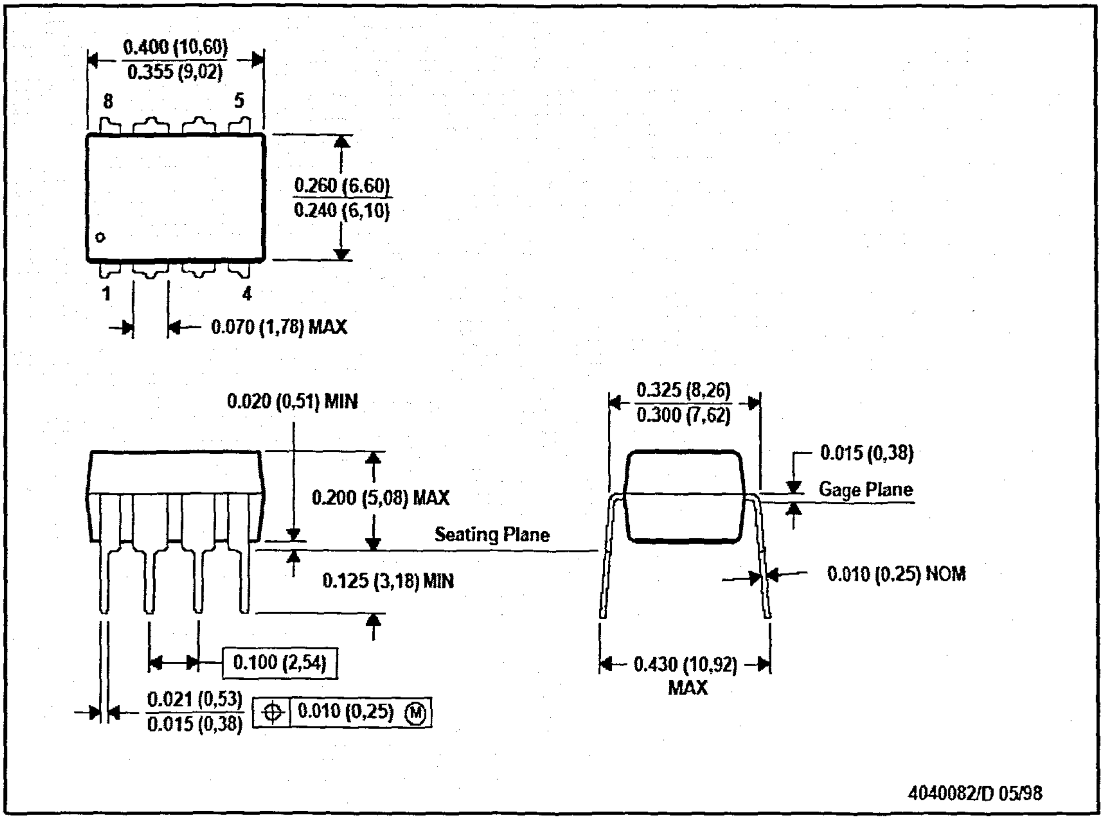


TAPE AND REEL BOX INFORMATION

Device	Package	Pins	Site	Length (mm)	Width (mm)	Height (mm)
OPA2132UA/2K5	D	8	MLA	346.0	346.0	29.0
OPA4132UA/2K5	D	14	MLA	346.0	346.0	33.0



P (R-PDIP-T8) **PLASTIC DUAL-IN-LINE**

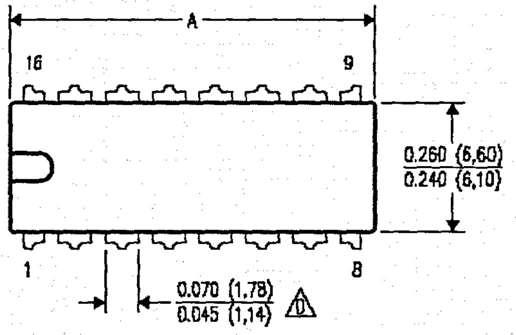

0.400 (10,60)
0.355 (9,02)
8
5
0.260 (6.60)
0.240 (6,10)
1
4
0.070 (1,78) MAX
0.020 (0,51) MIN
0.200 (5,08) MAX
Seating Plane
0.125 (3,18) MIN
0.100 (2,54)
0.021 (0,53)
0.015 (0,38)
0.010 (0,25) Ⓜ
0.325 (8,26)
0.300 (7,62)
0.015 (0,38)
Gage Plane
0.010 (0.25) NOM
0.430 (10,92)
MAX
4040082/D 05/98

NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS-001

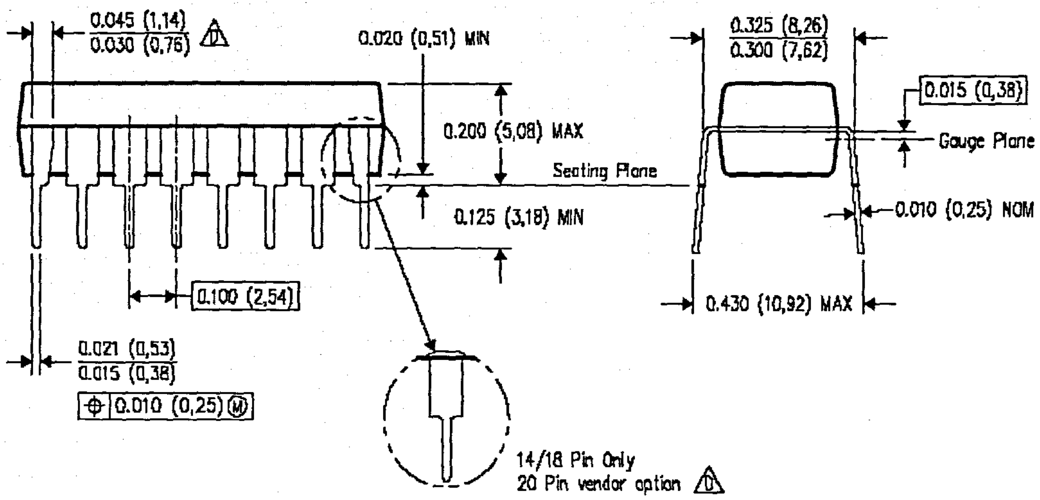
For the latest package information, go to http://www.ti.com/sc/docs/package/pkg_info.htm

N (R-PDIP-T**) PLASTIC DUAL-IN-LINE PACKAGE

16 PINS SHOWN


A
16
9
1
8
0.260 (6,60)
0.240 (6,10)
0.070 (1,78)
0.045 (1,14)
D

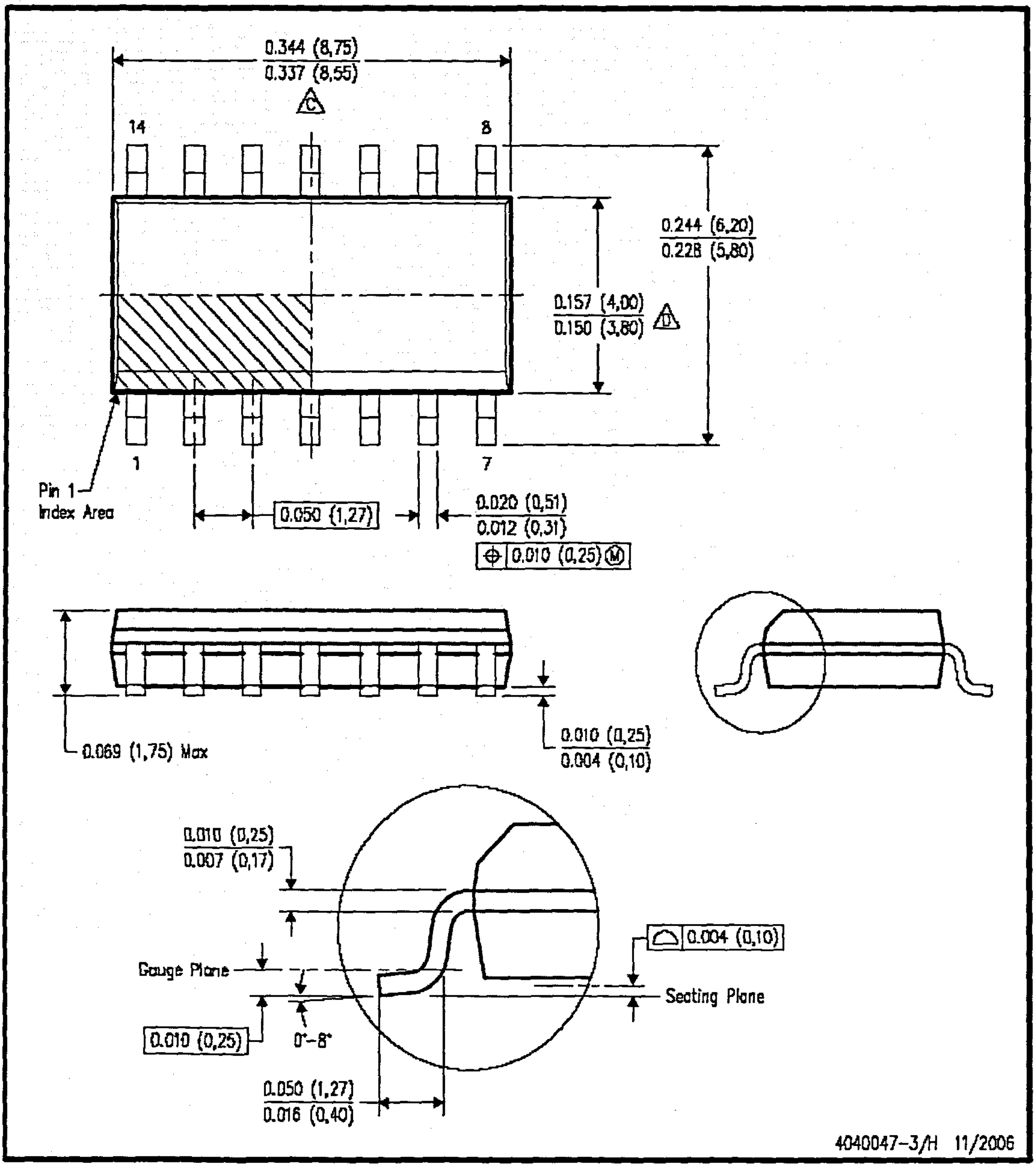
PINS ** / DIM	14	16	18	20
A MAX	0.775 (19,69)	0.775 (19,69)	0.920 (23,37)	1.060 (26,92)
A MIN	0.745 (18,92)	0.745 (18,92)	0.850 (21,59)	0.940 (23,88)
C MS-001 VARIATION	AA	BB	AC	AD


0.045 (1,14)
0.030 (0,76)
D
0.020 (0,51) MIN
0.200 (5,08) MAX
Seating Plane
0.125 (3,18) MIN
0.100 (2,54)
0.021 (0,53)
0.015 (0,38)
⊕ 0.010 (0,25) Ⓜ
14/18 Pin Only
20 Pin vendor option
D
0.325 (8,26)
0.300 (7,62)
0.015 (0,38)
Gauge Plane
0.010 (0,25) NOM
0.430 (10,92) MAX

4040049/E 12/2002

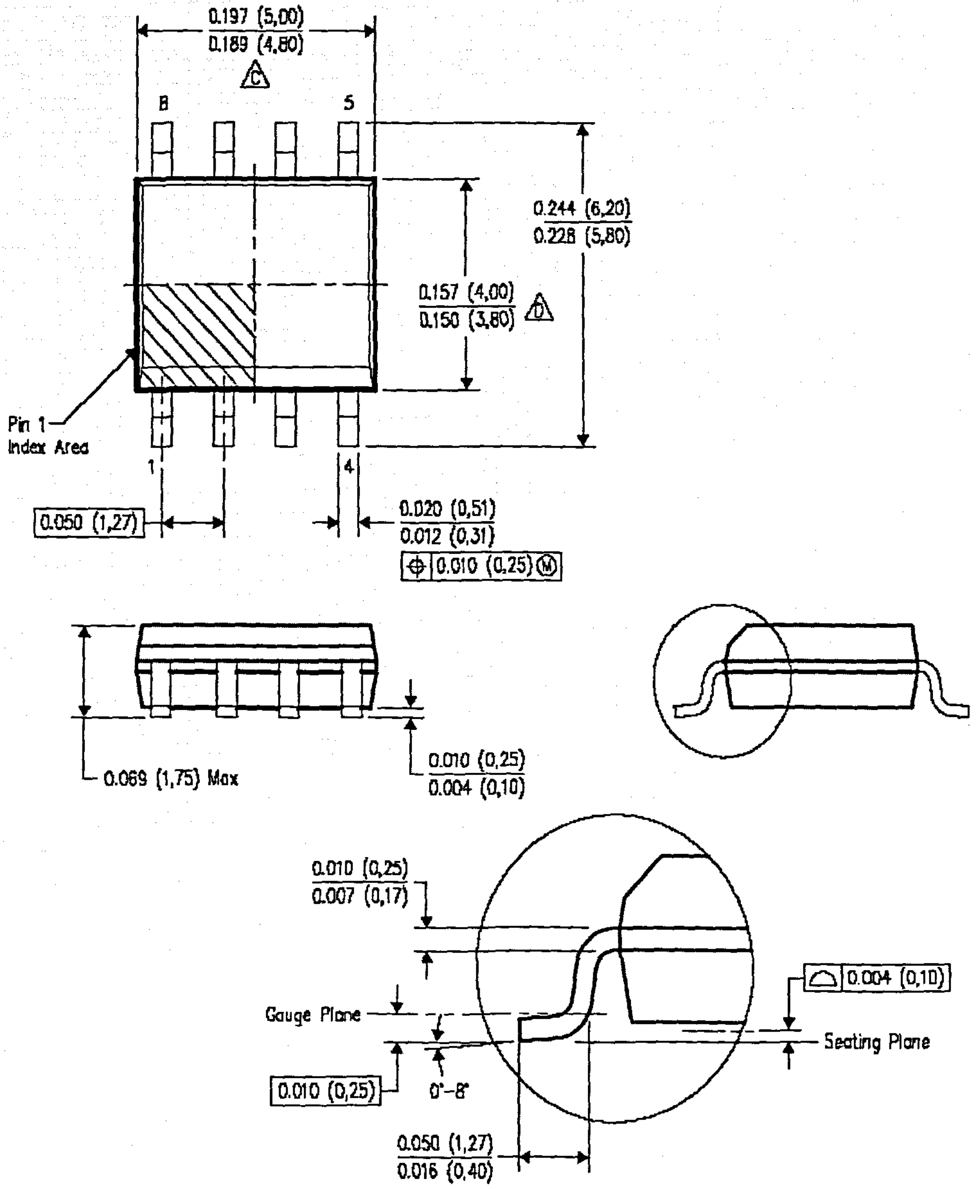
NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS-001, except 18 and 20 pin minimum body length (Dim A).
D. The 20 pin end lead shoulder width is a vendor option, either half or full width.

D (R-PDSO-G14) PLASTIC SMALL-OUTLINE PACKAGE


0.344 (8,75)
0.337 (8,55)
C
14
8
0.244 (6,20)
0.228 (5,80)
0.157 (4,00)
0.150 (3,80)
D
1
7
Pin 1
Index Area
0.050 (1,27)
0.020 (0,51)
0.012 (0,31)
⊕ 0.010 (0,25) Ⓜ
0.069 (1,75) Max
0.010 (0,25)
0.004 (0,10)
0.010 (0,25)
0.007 (0,17)
Gauge Plane
0.010 (0,25)
0°–8°
0.004 (0,10)
Seating Plane
0.050 (1,27)
0.016 (0,40)
4040047-3/H 11/2006

NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed .006 (0,15) per end.
- D. Body width does not include interlead flash. Interlead flash shall not exceed .017 (0,43) per side.
- E. Reference JEDEC MS-012 variation AB.

D (R-PDSO-G8) PLASTIC SMALL-OUTLINE PACKAGE


0.197 (5,00)
0.189 (4,80)
C
8
5
0.244 (6,20)
0.228 (5,80)
0.157 (4,00)
0.150 (3,80)
D
Pin 1
Index Area
1
4
0.050 (1,27)
0.020 (0,51)
0.012 (0,31)
⊕ 0.010 (0,25) Ⓜ
0.069 (1,75) Max
0.010 (0,25)
0.004 (0,10)
0.010 (0,25)
0.007 (0,17)
Gauge Plane
0.010 (0,25)
0°–8°
0.004 (0,10)
Seating Plane
0.050 (1,27)
0.016 (0,40)

4040047-2/H 11/2006

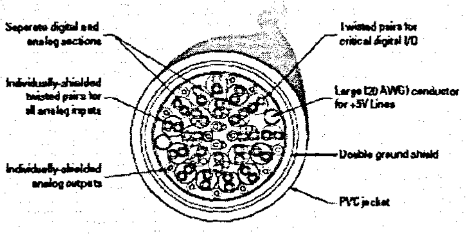
NOTES:
- A. All linear dimensions are in inches (millimeters).
- B. This drawing is subject to change without notice.
- C. Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed .006 (0,15) per end.
- D. Body width does not include interlead flash. Interlead flash shall not exceed .017 (0,43) per side.
- E. Reference JEDEC MS-012 variation AA.

Appendix J: National instrument TBX-68 DAQ card data sheet

Multifunction DAQ Cable and Accessory Selection Guides

NI Cable Design Advantages

The SH68-68-EP cable is the most commonly used E Series and S Series cable. The cable is designed to work specifically with the NI Multifunction DAQ devices to preserve signal integrity through these technologies:


Separate digital and analog sections
Individually-shielded twisted pairs for all analog inputs
Individually-shielded analog outputs
Twisted pairs for critical digital I/O
Large (20 AWG) conductor for +5V Lines
Double ground shield
PVC jacket

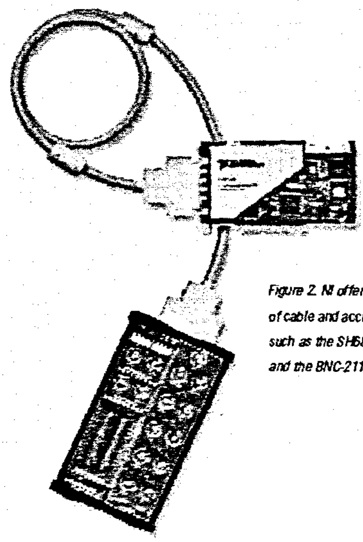


Figure 2. NI offers a wide variety of cable and accessory options, such as the SH68-68-EP cable and the BNC-2110 terminal block

A variety of cabling and accessory options are available for your needs. Use the following tables to choose the most appropriate cables and accessories. To determine which Multifunction DAQ device best fits your needs, please see page 189.

Platform	Shielding	Connect to ...	Cable	Adapter	Accessory
PCI/PXI/USB/FireWire					
	Shielded	SCC portable signal conditioning per channel	SH68-68-EP	–	SC-2345 and modules, page 251
	Shielded	SCXI high-performance signal conditioning	SCXI-1349	–	SCXI Chassis and Modules, page 270
	Shielded	Screw terminals[1]	SH68-68-EP or SH68-68R1-EP	–	SCB-68
	Shielded	BNC terminal block	SH68-68-EP	–	BNC-2110, BNC-2120, BNC-2090
	Shielded	50-pin connector	SH6850	–	CB50, custom or 3rd party
	Shielded	Configurable connectivity box	SH68-68-EP	–	CA-1000, page 351
	Unshielded	Screw terminals[1]	R6868	–	TBX-68, CB-68LP, CB-68LPR, DAQ signal accessory
	Unshielded	50-pin connector	R6850	–	CB50, custom or 3rd party
PXI only					
	Shielded	Front-mounted screw terminals	N/A	–	TB-2705
PCMCIA					
	Shielded	Screw terminals[1]	SHC68-68-EP or SHC68U-68-EP[2]	–	SCB-68, CA-1000
	Shielded	50-pin connector	SHC68-68-EP or SHC68U-68-EP[2]	68M-50F MIO	CB50, custom or 3rd party
	Unshielded	Screw terminals[1]	RC68-68		TBX-68, CB-68LP, CB-68LPR, DAQ signal accessory
	Unshielded	50-pin connector	RC68-68	68M-50F MIO	CB50, custom or 3rd party

[1] Unshielded cables can connect to shielded accessories and vice-versa. [2] In adjacent PCMCIA slots, both cables types are required because the same cable would cause mechanical hindrance.

Table 1. Cable Connection Specifications for 16-Channel E Series Devices and Basic Multifunction DAQ (except NI 6025E, which is on the next page)

Multifunction DAQ Cable and Accessory Selection Guides

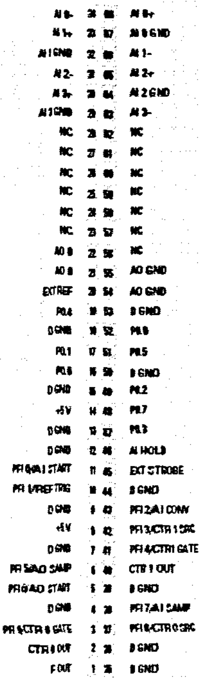


Figure 2. S Series Devices Connector

[1] No connects for boards that do not support AO or use an external reference with the SH1006868 cable.

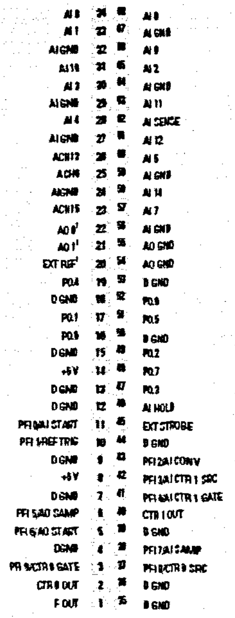


Figure 3. I/O Connector for 16-Channel E Series and Basic Multifunction DAQ Devices, except NI 6025E

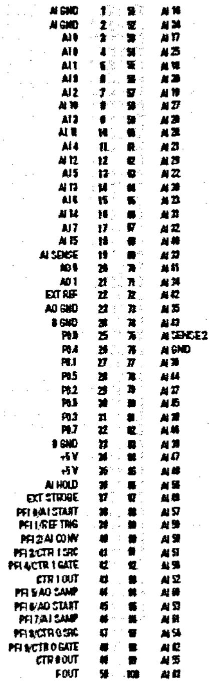


Figure 4. I/O Connector for 64-Channel E Series Devices

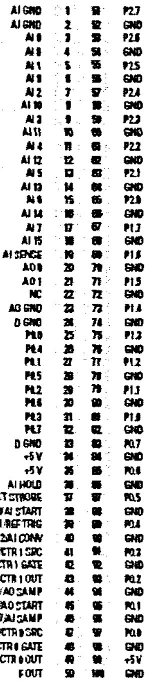


Figure 5. I/O Connector for the NI 6025E Device

E Series Devices (NI 6031E, NI 6033E, NI 6071E, NI 6025E)

Platform	Shielding	Connect to ...	Cable	Cable Leg	Adapter	Accessory
PCI, PXI						
	Shielded	Screw terminals	SH100100	-	-	SCB-100
	Shielded	Screw terminals	SH1006868	MIO	-	SCB-68
	Shielded		SH1006868	Extended	-	SCB-68
	Shielded	Screw terminals[1]	SH1006868	MIO	-	TBX-68, CB-68LP, CB-68LPR, DAQ signal accessory
	Shielded	Screw terminals[1]	SH1006868	Extended	-	TBX-68, CB-68LP, CB-68LPR
	Shielded	BNC terminal block	SH1006868	MIO	-	BNC-2110, BNC-2120, BNC-2090
	Shielded		SH1006868	Extended	-	BNC-2115
	Shielded	50-pin connectors	SH1006868	MIO	68M-50F MIO	Custom or 3rd party
	Shielded		SH1006868	Extended	68M-50F Extended	Custom or 3rd party
	Unshielded	50-pin connector	R1005050	MIO	-	Custom or 3rd party
	Unshielded		R1005050	Extended	-	Custom or 3rd party

[1] Shielded cable with unshielded accessories

Table 2. Cable Connection Specifications for 64-Channel E Series Devices and the NI 6025E

Multifunction DAQ Accessories

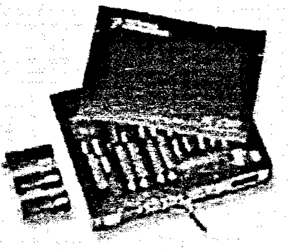


Figure 1. SCC Portable, Modular Signal Conditioning

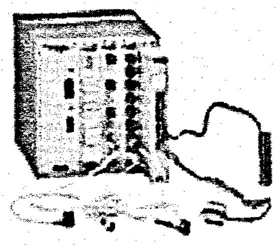


Figure 2. SCXI High-Performance Signal Conditioning

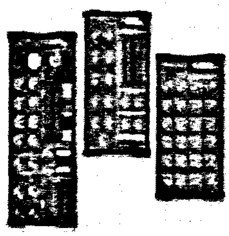


Figure 3. BNC-2100 Series Connector Blocks

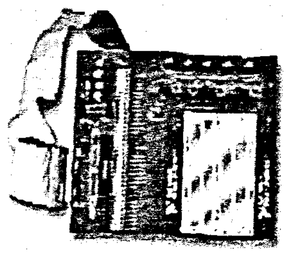


Figure 4. SC-2075 Breadboard Connector Block

SCC – Portable Modular Signal Conditioning for Low-Channel-Count Applications (See Figure 1)

SCC is a portable modular signal conditioning system consisting of modules that plug into a low-profile SC-2345 shielded carrier. SCC modules give you single or dual-channel signal conditioning for up to 16 analog input channels and eight digital I/O lines of your E Series or Basic multifunction DAQ device. The SCC Series offers signal conditioning for a variety of inputs, including thermocouples, RTDs, strain gauges, IEPE-compatible accelerometers, accelerators, analog inputs requiring isolation, high voltage (up to 100 V), current (0 to 20 mA), and optically isolated digital I/O. Lowpass filtering and breadboard modules are also available.

See page 251 for details on SCC Signal Conditioning.

SCXI – High-Performance Modular Signal Conditioning (See Figure 2)

SCXI is a high-performance modular signal conditioning platform that you use as a front end to your E Series DAQ device. With the SCXI multiplexing architecture, you can expand your analog inputs to 3,072 channels. Additionally, SCXI offers a variety of modules for connecting to thermocouples, RTDs, strain gauge transducers, LVDT position sensors, IEPE-compatible accelerometers/microphones, thermistors, millivolt inputs, voltage inputs up to 1000 V, current inputs (0 to 20 mA), frequency inputs or dynamic signals.

See page 270 for details on SCXI Signal Conditioning.

Connector Blocks

BNC-2100 Series Connector Blocks (See Figure 3)

The BNC-2100 Series are shielded connector blocks with signal-labeled BNC connectors for easy connectivity of your analog input, analog output, digital I/O and counter/timer signals to your multifunction DAQ device, including analog output devices. The BNC-2110 and BNC-2120 work with all E Series and Basic multifunction DAQ devices. The BNC-2120 also provides a function generator, quadrature encoder, temperature reference, thermocouple connector, and LED so that you can test the functionality of your hardware. The BNC-2115 has 24 BNC inputs for connecting to the extended I/O channels of our 100-pin E Series DAQ devices.

BNC-2110	777643-01
Dimensions – 20.3 by 11.2 by 5.5 cm (8.0 by 4.4 by 2.2 in.)	
BNC-2115	777807-01
Dimensions – 20.3 by 11.2 by 5.5 cm (8.0 by 4.4 by 2.2 in.)	
BNC-2120	777960-01
Dimensions – 26.7 by 11.2 by 6.0 cm (10.5 by 4.4 by 2.4 in.)	

SC-2075 Breadboard Connector Block (See Figure 4)

The SC-2075 provides breadboard area for prototyping and BNC and spring terminal connectivity for 68-pin E Series Basic multifunction DAQ devices. The built-in ±15 V or adjustable 0 to 5 V power supply and LEDs for digital lines make the SC-2075 a cost-effective device, ideal for academic laboratories.

SC-2075	778147-90
Dimensions – 26.7 by 20.7 by 4.4 cm (10.5 by 8.2 by 1.7 in.)	

Multifunction DAQ Accessories

BNC-2090 Shielded BNC Adapter Chassis (See Figure 5)

The BNC-2090 is a shielded, rack-mountable adapter with signal-labeled BNC connectors, spring terminal blocks, and component locations for passive signal conditioning. Consists of 22 BNC connectors and 28 spring terminals to simplify connection to your analog, digital, trigger and counter/timer signals. The BNC-2090 has silk-screened component locations that you use to develop simple signal conditioning circuits. For added flexibility, you can connect any E Series DAQ device to the BNC-2090 from the front or rear through dual 68-pin connectors.

BNC-2090 777270-01

Dimensions – 48.3 by 4.4 by 18.8 cm (19.0 by 1.7 by 7.4 in.)

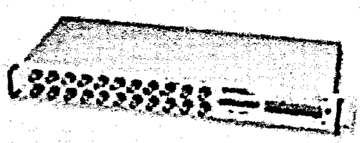


Figure 5. BNC-2090 Shielded BNC Adapter Chassis

CA-1000 Configurable Signal Conditioning Enclosure (See Figure 6)

The CA-1000 is a configurable enclosure that gives you maximum user-defined connectivity and flexibility through customized panelettes. Each enclosure can accommodate up to nine panelettes.

CA-1000 .... (See page 351)

Dimensions – 30.7 by 25.4 by 4.3 cm (21.1 by 10 by 1.7 in.)

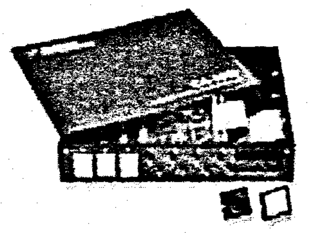


Figure 6. CA-1000 Configurable Signal Conditioning Enclosure

TB-2705 Terminal Block for 68-pin PXI E Series and S Series Devices (See Figure 7)

The TB-2705 is a screw terminal block for your PXI E Series or S Series DAQ module. It latches to the front of your PXI module with locking screws and provides strain relief and easy access to your analog, digital, trigger and counter/timer signals through screw terminals.

TB-2705 778241-01

Dimensions – 8.43 by 10.41 by 2.03 cm (3.32 by 4.1 by 0.8 in.)

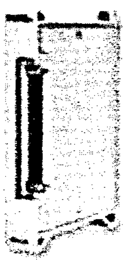


Figure 7. TB-2705 Terminal Block

SCB-68 and SCB-100 Shielded I/O Connector Blocks (See Figure 8)

The SCB-68 and SCB-100 are shielded I/O connector blocks for rugged, very low-noise signal termination for connecting to 68-pin or 100-pin E Series DAQ devices, respectively. Silk-screened component locations provide an easy addition of simple signal-conditioning circuitry for your analog input channels. They also include general-purpose breadboard areas (two on the SCB-68: three on the SCB-100) as well as an IC temperature sensor for cold-junction compensation in temperature measurements.

SCB-68 776844-01

Dimensions – 19.5 by 15.2 by 4.5 cm (7.7 by 6.0 by 1.8 in.)

SCB-100 776990-01

Dimensions – 19.5 by 15.2 by 4.5 cm (7.7 by 6.0 by 1.8 in.)

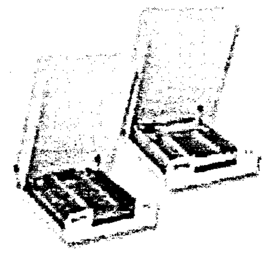


Figure 8. SCB-68 and SCB-100 Shielded I/O Connector Blocks

TBX-68 I/O Connector Block with DIN-Rail Mounting (See Figure 9)

The TBX-68 is a termination accessory with 68 screw terminals for easy connection of field I/O signals to 68-pin DAQ devices. It includes one 68-pin male connector for direct connection to 68-pin cables. The TBX-68 is mounted in a protective plastic base with hardware for mounting on a standard DIN rail.

TBX-68 777141-01

Dimensions – 12.50 by 10.74 cm (4.92 by 4.23 in.)

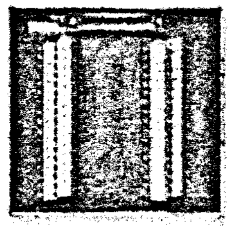


Figure 9. TBX-68 I/O Connector Block

Multifunction DAQ Accessories

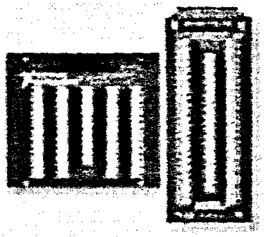


Figure 10. CB-68LP and CB-68LPR I/O Connector Blocks

CB-68LP and CB-68LPR I/O Connector Blocks (See Figure 10)

The CB-68LP and CB-68LPR are low-cost termination accessories with 68 screw terminals for easy connection of field I/O signals to 68-pin E Series or Basic multifunction DAQ devices. They include one 68-pin male connector for direct connection to 68-pin cables. The connector blocks include standoffs for use on a desktop or for mounting in a custom panel. The CB-68LP has a vertical-mounted 68-pin connector. The CB-68LPR has a right-angle mounted connector, and it is used with the CA-1000 (see page 351).

CB-68LP Dimensions – 14.35 by 10.74 cm (5.65 by 4.23 in.)	777145-01
CB-68LPR Dimensions – 7.62 by 16.19 cm (3.00 by 6.36 in.)	777145-02

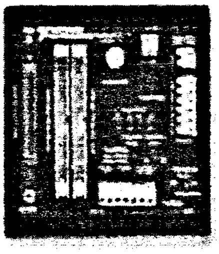


Figure 11. DAQ Signal Accessory

DAQ Signal Accessory (See Figure 11)

The DAQ Signal Accessory demonstrates and tests the use of analog, digital, and counter/timer functions of DAQ devices. You can connect the DAQ Signal Accessory directly to your DAQ device. It features a built-in function generator, quadrature encoder, solid-state relay, IC temperature sensor, noise generator, microphone jack, thermocouple jack, four LEDs, and a digital trigger button. The DAQ Signal Accessory works with all E Series DAQ devices.

DAQ Signal Accessory Dimensions – 12.7 by 12.7 cm (5.0 by 5.0 in.)	777382-01

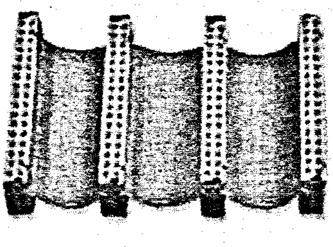


Figure 12. RTSI Bus Cable

RTSI Bus Cables (See Figure 12)

Use RTSI bus cables to connect timing and synchronization signals among measurement, vision, motion, and CAN boards for PCI. For systems using long and short boards, order the extended RTSI cable.

2 boards	776249-02
3 boards	776249-03
4 boards	776249-04
5 boards	776249-05
Extended, 5 boards	777562-05

Shielded I/O Cables

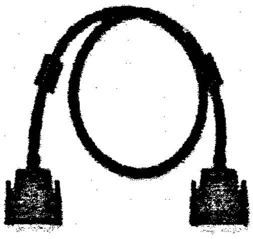


Figure 13. SH68-68-EP Shielded Cable

SH68-68-EP Shielded Cable (See Figure 13)

The SH68-68-EP is a shielded 68-conductor cable terminated with two 68-pin female 0.050 series D-type connectors. It features individually-shielded analog twisted pairs for reduced crosstalk with high-speed devices. This cable connects to all 68-pin E Series devices (except DAQCards). If you need a right-angle connector, the SH68-68R1-EP shielded cable is electrically equivalent.

1 m	184749-01
2 m	184749-02

Please call for other length options.

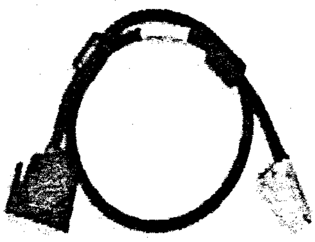


Figure 14. SH68-68R1-EP Shielded Cable

SH68-68R1-EP Shielded Cable (See Figure 14)

The SH68-68R1-EP is a shielded 68-conductor cable. One end terminates with a 68-pin female 0.050 series D-type connector and the other end terminates with a right-angle 68-pin female 0.050 series D-type connector.

1 m	187051-01

Multifunction DAQ Accessories

SH100100 Shielded Cable (See Figure 15)

The SH100100 is a shielded 100-conductor cable terminated with 100-pin male 0.050 series D-type connectors. This cable connects the 100-pin E Series devices to 100-pin accessories.

1 m	182853-01
2 m	182853-02

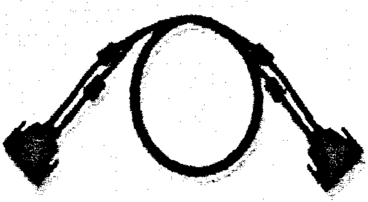


Figure 15. SH100100 Shielded Cable

68M-50F Cable Adapters (See Figure 16)

The 68M-50F cable adapter connects a 68-pin NI cable to a standard 0.1 by 0.1 in. 50-pin connector on third-party or custom accessories. The 68M-50F MIO should be used with the SH68-68-EP, SHC68-68-EP, SHC68U-68-EP, or the MIO leg of the SH1006868. The 68M-50F Extended I/O cable adapter should be used for the extended I/O leg of the SH1006868.

68M-50F MIO	184670-01
68M-50F Extended I/O	184670-02

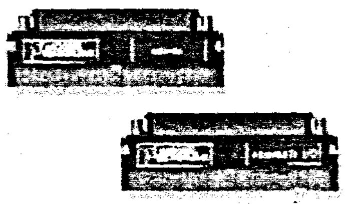


Figure 16. 68M-50F Cable Adapters

SH1006868 Shielded Cable (See Figure 17)

The SH1006868 is a shielded cable that connects to 100-pin E Series devices and terminates with two female 68-pin 0.050 series D-type connectors. See Table 2 on page 213 for accessories compatible with each 68-pin connector.

1 m	182849-01
2 m	182849-02

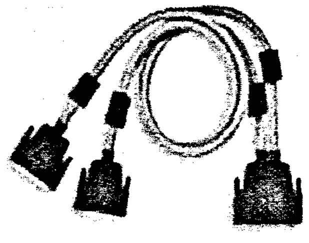


Figure 17. SH1006868 Shielded Cable

SHC68-68-EP and SHC68U-68-EP Shielded Cables for PCMCIA DAQCards (See Figure 18)

These cables connect PCMCIA to standard 68-pin accessories. Latching screws secure the shielded connector to the PCMCIA DAQCard. The SHC68-68-EP is a shielded 68-conductor cable terminated with a VHDCI 68-pin male connector at one end and a 68-pin female 0.050 series D-type connector at the other. The SHC68U-68-EP is identical to the SHC68-68-EP except it uses an inverted VHDCI 68-pin male connector. Use the SHC68-68-EP cable with a DAQCard inserted in the lower PCMCIA slot in your laptop or when using only one DAQCard. Use the SH68U-68-EP for a DAQCard located in the upper PCMCIA slot in your laptop. When using two E Series DAQCard in adjacent slots, use one SHC68-68-EP and one SHC68U-68-EP.

SHC68-68-EP

0.5 m	186838-0R5
1 m	186838-01

SHC68U-68-EP

0.5 m	187406-0R5
1 m	187406-01

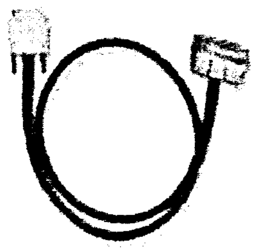


Figure 18. SHC68-68-EP and SHC68U-68-EP Shielded Cables

SH6850 Shielded Cable (See Figure 19)

The SH6850 connects a standard 68-pin E Series, S Series, or Basic multifunction DAQ product to a third party or custom standard 50-pin accessory. The cable provides a screw-latching 68-pin female connector on one side and a standard 50-pin female connector on the other side.

1 m	776784-01
2 m	776784-02

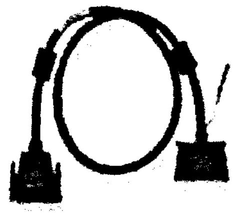


Figure 19. SH6850 Shielded Cable

Multifunction DAQ Accessories

Figure 20. R6868 Ribbon Cable

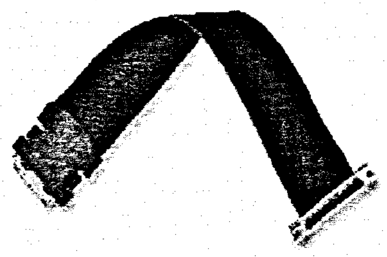


Figure 21. RC68-68 Ribbon Cable

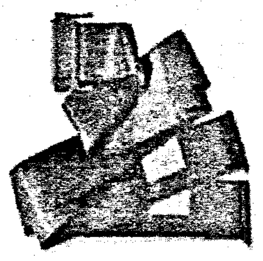


Figure 22. R1005050 Ribbon Cable

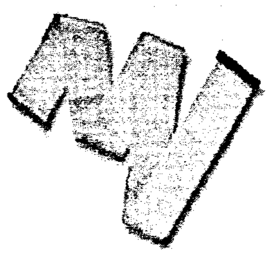


Figure 23. R6850 Ribbon Cable Kit

Ribbon I/O Cables

R6868 Ribbon Cable for E Series or Basic Multifunction Devices (See Figure 20)

The R6868 is a 68-conductor flat ribbon cable terminated with two 68-pin connectors. Use this cable to connect a 68-pin E Series or Basic multifunction DAQ device to 68-pin accessories.

1 m	182482-01

RC68-68 Ribbon Cable for DAQCards (See Figure 21)

The RC68-68 ribbon cable connects DAQCards directly to 68-pin accessories. Two RC68-68 cables can be used together in adjacent PCMCIA slots."

0.25 m	187252-0R25
1 m	187252-01

R1005050 Ribbon Cable (See Figure 22)

This cable connects 100-pin E Series devices, including the NI 6071E, NI 6033E, NI 6031E and NI 6025E to standard 50-pin third party or custom connectors.

1 m	182762-01
2 m	182762-02

R6850 Ribbon Cable Kit (See Figure 23)

This cable kit combines a 68F-50M cable adapter and a standard 50-pin cable with female connectors on both ends. The cable kit is designed to adapt an E Series, S Series, or Basic multifunction DAQ product to a third-party or custom 50-pin accessory.

1 m	776842-01

Multifunction DAQ Accessories

Custom Connectivity Components

68-Pin Custom Cable Connector/Backshell Kit (See Figure 24)

The 68-pin female mating connector and backshell kit is used to make custom cables. Solder-cup contacts are available for soldering cable wires to the connector.

68-pin connector/backshell kit	776832-01

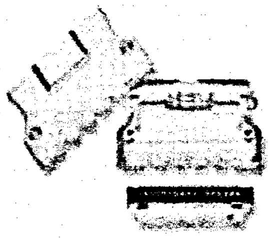


Figure 24. 68-Pin Custom Cable Connector/Backshell Kit

PCB Mounting Connectors for Custom Accessories (See Figure 25)

PCB mounting connectors are used to build custom accessories that connect to 68-conductor or 100-conductor shielded and ribbon cables. Two connectors are available, one for right-angle and one for vertical mounting onto a PCB.

68-pin, male, right-angle mounting	777600-01
68-pin, male, vertical mounting	777601-01
100-pin, female, right-angle mounting	777778-01
100-pin, female, vertical mounting	777779-01

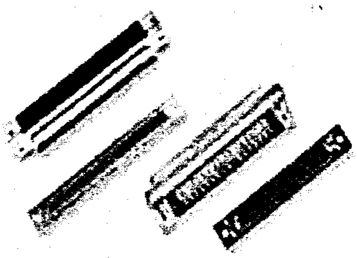


Figure 25. PCB Mounting Connectors for Custom Accessories

PCMCIA Strain-Relief Accessory (See Figure 26)

The PCMCIA Strain-Relief accessory attaches to the bottom of your notebook computer and provides adjustable strain relief for one or two PCMCIA cables attached to the installed DAQCards.

PCMCIA Strain-Relief Accessory	777550-01

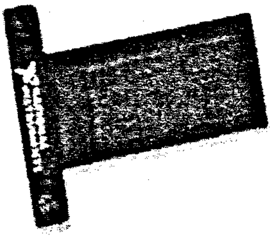


Figure 26. PCMCIA Strain-Relief Accessory