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ABSTRACT

INDIVIDUAL CELL PRESSURE CONTROL IN AIR MATTRESS FOR THE PREVENTION OF THE PRESSURE SORES

by
Kapilchandra Anand

Many kinds of pressure-relieving mattresses have been developed to prevent pressure sores in patients with spinal cord injuries (SCIs) and obesity. Current technology uses alternating air pressure mattress, foam and low pressure mattress for reducing the incidence of pressure sores in SCI and obesity patients. These mattresses do not have control of pressure in individual air chambers. They are open loop system and they do not receive any feedback from the system. They have at the most control of two different pressures. The purpose of this study is to improve the current assistive technology in reducing pressure sores and to distribute the patient's weight evenly on the air mattress by setting the appropriate pressure in each individual chamber.

The proposed mattress has an independent control of each and every chamber, flexibility in selecting firmness and range, number of chambers to be operated at a time and mode of operation. It is a closed loop system and hence, it can respond to the change in pressure inside the system to keep it stable. National Instruments (NI) software LabVIEW® 8 is used for this purpose. The proposed mattress has an accuracy of approximately 98% and reliability of approximately 96%. Correct operation of the feedback control system to maintain cell pressure in the specified ranges during patient movement was validated with a small pilot study. A patient experiment is proposed to compare this mattress with current available mattresses in the market. It is hypothesized that individual cell pressure control mattress is better than alternating pressure mattress.

INDIVIDUAL CELL PRESSURE CONTROL IN AN AIR MATTRESS FOR THE PRVENTION OF THE PRESSURE SORES

by
Kapilchandra Anand

A Thesis
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Department of Biomedical Engineering

August 2006

APPROVAL PAGE

INDIVIDUAL CELL PRESSURE CONTROL IN AN AIR MATTRESS FOR THE PREVENTION OF THE PRESSURE SORES

Kapilchandra Anand

Dr. Tara Alvarez, Thesis Advisor — Date
Associate Professor of Biomedical Engineering, NJIT

Michael T. Bergen, Thesis Co-Advisor — Date
Veterans Affairs New Jersey Health Care System, East Orange, NJ
Adjunct Professor of Biomedical Engineering Technology, NJIT

Dr. Sergei Adamovich, Committee Member — Date
Associate Professor of Biomedical Engineering, NJIT

Dr. Lisa K. Simone, Committee Member — Date
Assistant Research Professor of Biomedical Engineering, NJIT

BIOGRAPHICAL SKETCH

Author: Kapilchandra Anand

Degree: Master of Science

Date: August 2006

Undergraduate and Graduate Education:

- Master of Science in Biomedical Engineering,
  New Jersey Institute of Technology, Newark, NJ, 2006

- Bachelor of Engineering in Mechatronics Engineering,
  Shri U. V. Patel College of Engineering, Ahmedabad, India, 2003

Major: Biomedical Engineering

To my parents, Ramanlal Makwana and Nandaben Makwana and my family

for their support through out whole thesis tenure

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CHAPTER 1

INTRODUCTION

1.1 Objective

It is estimated that the incidence of spinal cord injury in US is approximately 11,000 new cases annually. According to a study conducted in 1970, the number of people in the United States in July 2005, who have spinal cord injury (SCI), was estimated approximately to 250,000 persons [1]. Majority of the spinal cord injury patients have limited mobility and many of them are even unable to get up from the bed for a long period, which causes pressure sores at their back portion of the body. At any given time, an estimated 17% to 39% of the SCI population suffers from pressure sores [19].

The goal of this thesis is to present a better and more precise control of the pressure in the air mattress and hence, to present a better way to prevent and reduce the incidence of pressure sores in the SCI patients. This thesis presents the development of hardware circuit and a LabVIEW program to control pressure in the individual air chamber of the mattress (Model Stimulus Plus, Recover Care, Plymouth Meeting, PA) and thereby provide a better comfort and blood circulation to the patient.

Current assistive technologies for prevention and treatment of pressure sores in these patients use an alternating pressure, foam, air, gel and water mattresses which does not have control of pressure in individual air chambers. Currently, the most sophisticated mattress is alternating pressure mattresses in which each alternate air chamber has equal pressure and the chambers inflate and deflate in an alternate fashion. These mattresses do

not have a feedback system and therefore, they are not able to respond to the change in pressure caused due to the patient's movement or change of posture.

The proposed mattress has an independent control of each and every chamber, flexibility in selecting firmness and range, number of chambers to be operated at a time and mode of operation. It is a closed loop system and hence, has can respond to the change in pressure inside the system to keep stable. LabVIEW programming, electronic and pneumatic circuits are used to achieve this goal.

1.2 Background

1.2.1 Spinal Cord Injury

The spinal cord is the main pathway of communication between the brain and the rest of the body. It extends from the base of the brain to the coccyx or the tail bone. The nerves within the spinal cord are upper motor neurons and their function is to carry the messages back and forth from the brain along the spinal tract to the spinal nerves. The spinal nerves called lower motor neurons; branch out from the spinal cord to the other parts of the body. Each spinal nerve has two nerve roots, motor root in the front and sensory root in the back (except the first, which has no sensory root). The motor root transmits impulses from the spinal cord to the muscles and stimulates movement and the sensory root carries sensory information like pain, touch and temperature from the body to the spinal cord. The motor nerves are grouped together and also the sensory nerves. The motor and sensory nerves of the spinal cord connect with the motor and sensory roots of the spinal nerves, respectively. The brain and the spinal cord constitute the Central Nervous System [2].

The spinal cord is protected by the vertebrae of the spine (spinal column), which are separated and protected by disks made of cartilage. The spine is divided into four areas: cervical (neck), thoracic (chest), lumbar (lower back), and sacral (pelvis). Each area is referred to by a letter (C, T, L, or S). The vertebrae in each area of the spine are numbered beginning at the top. For example, the first vertebra in the cervical spine is labeled C1, the second in the thoracic spine is T2, the fourth in the lumbar spine is L4, and so forth [2]. The spinal cord is also divided into segments and named and numbered from top to bottom. Each segment marks where spinal nerves emerge from the cord to connect to specific regions of the body. Cervical spinal nerves (C1 to C8) control signals to the back of the head, the neck and shoulders, the arms and hands, and the diaphragm. Thoracic spinal nerves (T1 to T12) control signals to the chest muscles, some muscles of the back, and parts of the abdomen. Lumbar spinal nerves (L1 to L5) control signals to the lower parts of the abdomen and the back, the buttocks, some parts of the external genital organs, and parts of the leg. Sacral spinal nerves (S1 to S5) control signals to the thighs and lower parts of the legs, the feet, most of the external genital organs, and the area around the anus [2]. The problems caused by the SCI at different locations of the spine are shown in the Figure 1.1.

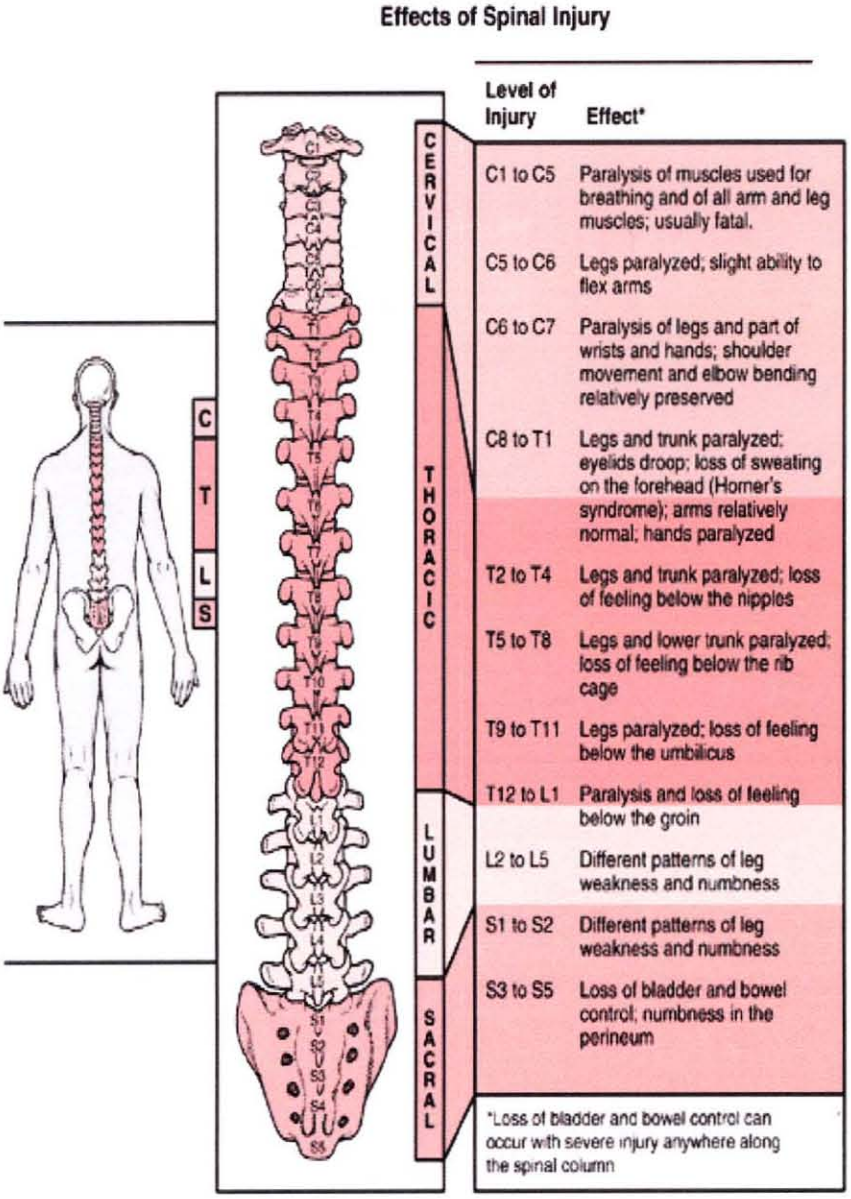


Figure 1.1 Effects of spinal cord injury [3].

Spinal Cord Injury (SCI) occurs due to the damage caused to the spinal cord which results in the loss of mobility and sensation. Common causes are trauma due to car accident, falls, etc. or diseases such as polio, spina bifida, Friedreich's Ataxia, etc. [2][6]. Due to lack of mobility, SCI patients have to remain in bed for six months or longer.

Patients having severe SCI have greater immobility [4]. Pressure caused due to lying or sitting at the same position for a long period restricts the blood flow and hence, blocks the source of oxygen and nutrients to the skin tissues. When the tissue becomes starved for a long period it begins to die and a pressure sore starts to form. Even people with SCI lack feeling or mobility, often do not feel or are unable to respond to these pressure pains and move to a new position further aggravate the pressure sores. Pressure sores occurs mostly in paraplegic patients, the aged who have limited movement and those who are anesthetized during long surgery [4].

1.2.2 Obesity

Obesity is a disease that affects nearly one-third of the adult American population (approximately 60 million). The number of overweight and obese Americans has continued to increase since 1960, and is not slowing down. In 2000, 64.5 percent of adult Americans are categorized as being overweight and 30.5 percent as being obese. Severe obesity prevalence is 4.7 percent [5].

Body mass index, expressed as weight/height^2 (BMI; kg/m^2) is commonly used to classify overweight and obesity among adults [6]. Overweight is defined as a BMI of 25 or more, obesity is 30 or more, and severe obesity is 40 or more [5]. Patients with moderate obesity have little mobility due to overweight and when they lay down in bed they can hardly turn or move their body from one posture to another and hence, they feel constant pressure on their body. The portions of the body where high intensity pressure remains for a longer period, starts developing pressure sores. Even though these patients have sensing ability for pain due to pressure, they cannot move their body due to being overweight.

1.2.3 Pressure Sores

Pressure sores can be the most devastating complication of SCI and moderate obesity patients. Pressure sores are caused by prolonged pressure or rubbing on vulnerable areas of the body that are prone to moisture and friction [6]. When a person remains in the same position, blood flow is reduced from those areas, blocking oxygen and required nutrients from maintaining healthy tissue. After a certain period of time, the tissue begins to die and pressure sore start to form [7]. Normally the nerves send messages of pain or feelings of discomfort to the brain to let patient know that he needs to change position, but in SCI patients, the damaged spinal cord keeps these messages from reaching brain due to which the patient loses sensitivity and further increasing the severity of pressure sores [6].

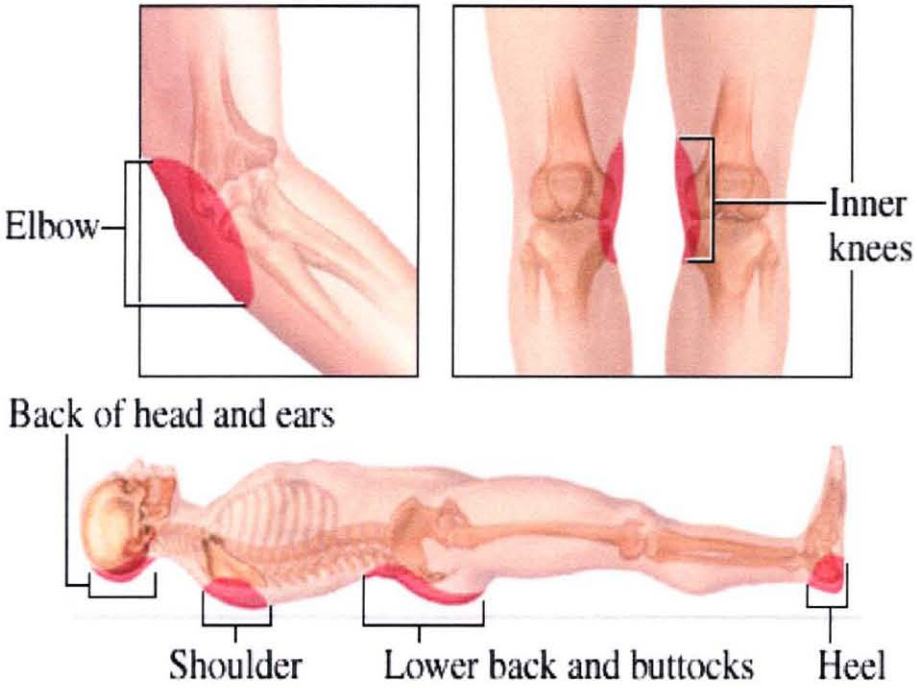


Figure 1.2 Areas of high risk of pressure sensor [8].

Pressure sores are also caused due to friction, bruises or scrapes, as well as prolonged wetness on the skin [2]. The major symptoms of the pressure sores are redness of the skin, pain and itching. Pressure sores occur most frequently over areas where bones come close to the surface. The most common sites of pressure sores are the elbows, heels, shoulders, hips, ankles, knees, buttocks [2].

Pressure sores are categorized by severity, from Stage I to Stage IV. Figure 1.3 shows the progression of pressure sores in different stages.

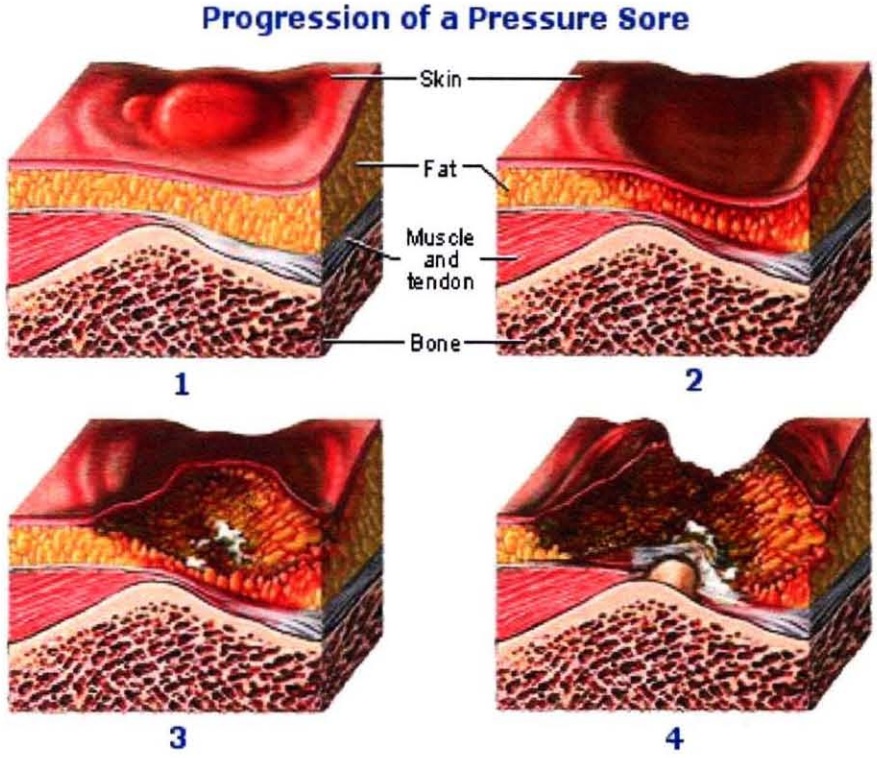


Figure 1.3 Different stages of pressure sores [2].

• Stage I: A reddened area on the skin that, when pressed, does not turn white. This indicates that a pressure ulcer is starting to develop.

• Stage II: The skin blisters or forms an open sore. The area around the sore may be red and irritated.

• Stage III: The skin breakdown now looks like a crater where there is damage to the tissue below the skin.

• Stage IV: The pressure ulcer has become so deep that there is damage to the muscle and bone, and sometimes tendons and joints [9].

As prevention is better than a cure, it is always better to take care of the parameters which increase the risk of the onset of pressure sores. Pressure sores are easier to prevent than to treat, but the process is complicated. Although wounds can develop in spite of the most scrupulous care, it is possible to prevent them in many cases. Changing patient position frequently and consistently is crucial to preventing pressure sores. Experts advise shifting position every 15 to 30 minutes when the patient is in a wheelchair and at least once every 2 hours, even during the night, even if the patient spends most of his/her time in bed [10]. Soft support surfaces can be used in wheelchairs and beds to reduce pressure. Patient's skin should be kept clean and dry to avoid wetness due to patient's urine and drugs. Lubricating creams should be used for patients having dry skin. Patients should have enough intake of fluid to keep the skin well hydrated. Patient should be provided with a well balanced diet. Foods high in protein, vitamins and minerals help the skin to stay healthy and heal more quickly [10].

Once the pressure sores start to develop, immediate treatment is required to cure them. Treatment of pressure sores is more challenging than preventing them. Pressure sores at Stage I and Stage II can be treated using conservative steps but those at Stage III and Stage IV sometimes require surgical treatment. Treatment of pressure sores includes frequently turning and repositioning and use of soft support surfaces like foam, gel, water, air mattresses depending upon the severity of the pressure sores and mobility of the patient. Wounds must be kept clean to prevent infection. A Stage I wounds can be

gently washed with water, but open sores should be cleaned with saline water each time the dressing is changed. Damaged tissues are removed from the wounds to provide proper healing to the wounds. These tissues are either removed by surgical or non-surgical method depending upon the severity of the wound. Dressing can be used to protect wounds and speed healing. There are variety of dressings used depending upon the stage and severity of the wounds. It helps in keeping the wound moist and the surrounding skin dry. Contaminated wounds can be treated with topical antibiotic cream. Patient should be given a healthy diet in adequate calories and proteins and proper range of vitamins and minerals. Surgical methods are also used to improve hygiene and appearance of the sores, preventing or treating infection and lowering the risk of future cancer [10].

1.3 Current Assistive Technology

Current assistive technology used to treat pressure sores in SCI patient are different types of foam, gel, water or air beds or pads. The air mattresses usually used for prevention and treatment of pressure sores are low pressure air mattresses, water mattress, gel mattress, alternating pressure mattress and rotating pressure mattress. In these mattresses, the pressure in the air chamber are controlled in a limited manner. Low air loss beds and mattresses have air sacs that support the user on a cushion of air. They work by increasing the surface area in contact with the skin, therefore reducing the pressure at a particular point. Air is gradually lost and continually replaced in response to the weight distribution and movement of the user [11]. Water and foam cushions are made of open foam filled with water. The foam not only helps to add stability but also helps the cushion to conform to the body shape. They are cold to sit on and can therefore reduce skin

temperature [11]. The most sophisticated mattress used for preventing or treating pressure sores is the alternating pressure mattress. In alternating pressure mattresses, the air cells are divided vertically into three sets. For example, in an air mattress of 18 air cells, the first set consists of first three air cell which supports the head portion of the patient. Second set consists of the alternate air cells from the remaining (i.e., cells 5, 7, 9, 11, 13, 15). Third set consist of the other remaining alternate air cells (i.e., cells 4, 6, 8, 10, 12, 14, 16).

Figure 1.4 Alternating Air Pressure Mattress.

The pressure in each alternate chamber in the same set remains the same at a time. For example, set 1 has 40mmHg, set 2 has 0mmHg and set 3 has 50mmHg. Therefore, each air cell in each set has the same pressure. In rotational air mattresses, the cells are divided both horizontally and vertically. It has sets of air cells. The first set has upper cells for the head portion. The second and the third set have left and right side cells, respectively. This kind of mattress is usually used to help the patient in turning right or

left. It is similar to alternating pressure mattress as left and right set of air cells inflate and deflate in an alternate manner.

The current mattresses used for the prevention of pressure sores are open loop systems. Therefore, they are not able to respond automatically to any change in pressure inside the mattress. For example, if the patient in on the mattress and some external force is applied to the mattress, then the pressure inside the chambers where an external force is applied will increase. As the system does not receive any feedback, the pressure will remain until the external force is removed. This will apply more pressure on the patient's body and if the pressure remains for very long period than the risk of developing pressure sores will increase. The current mattresses do not have flexibility in holding different pressure inside different chamber. They do not have precise firmness range control. They only have some fixed firmness levels such as soft, medium and firm. These mattresses use a pressure range of 30mmHg to 90mmHg.

CHAPTER 2

INSTRUMENTATION

Many components are used in constructing an air mattress with individual control of pressure in each cell of the air-chamber. The system for this research project consists of air mattress, pneumatic pump, directional control valves and a software program to control the system so that it can inflate and deflate the chamber according to the requirements of the patient or medical staff. The control of air pressure in the individual air chamber is controlled using a pneumatic directional control valves. A pressure sensor is attached to each air chamber which gives feedback to the software program through the data acquisition card NI PCI 6024E, National Instruments, Austin, TX. According to the feedback, the software program will inflate or deflate the air chamber by opening or closing the control valve of an air chamber.

Control of these valves is accomplished by providing a trigger from a software program written in National Instruments (NI) software LabVIEW® 8. The software receives feedback from the NI DAQ PCI 6024E card through NI NBC-2090 connector block interface and it provides output through a 96 port digital input/output card (NI DAQ PCI DIO 96, National Instruments, Austin, TX). This whole system requires 32 digital outputs from the PCI DIO 96 card to trigger on/off state of the pneumatic valves. This section will explore the role, constitution, advantages and limitations of these components. The block diagram of the whole individual cell pressure mattress system is shown in Figure 2.1.

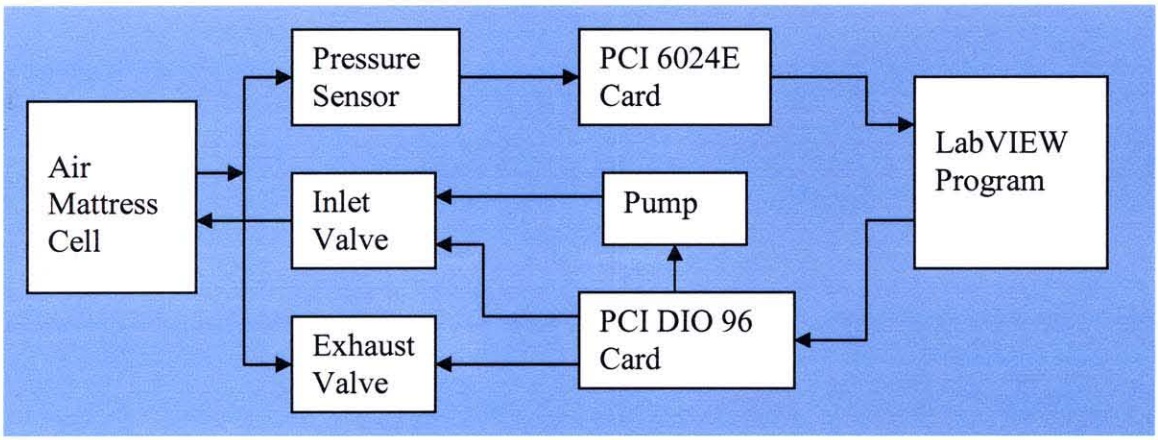


Figure 2.1 Block diagram of the air mattress system.

2.1 Air Mattress

The air mattress used in this system is an alternating pressure mattress (Model Stimulus Plus, Recover Care, Plymouth Meeting, PA). In this mattress air chambers inflate and deflate alternatively. It has 18 air chambers in total. The top three chambers are interconnected to each other and they support the head of the patient. These top three chambers are interconnected to each other and have the same pressures at a time. Figure 2.2 shows the connection of these top three chambers.

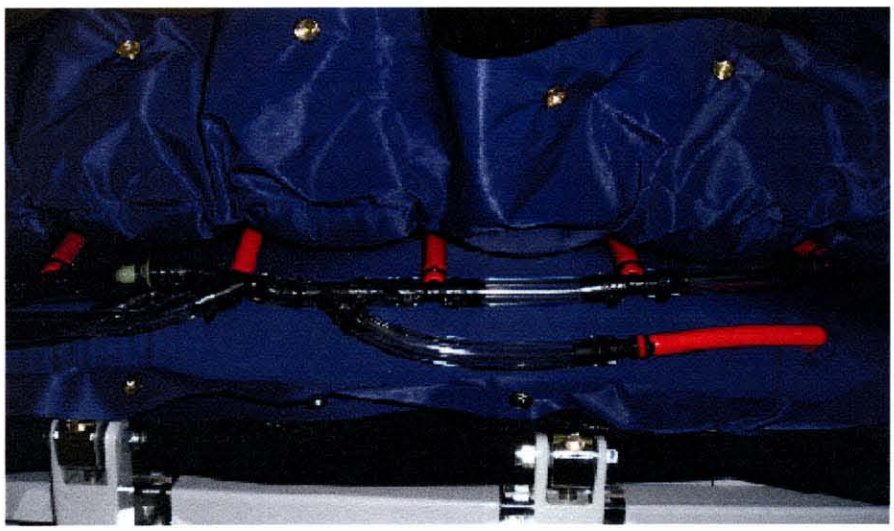


Figure 2.2 Hose connections for the first three chambers of the air mattress.

The other remaining 15 chambers are connected to each alternate chamber externally by a hose which is connected to the pump. There are two main hoses connected to the pump and each hose is connected to each alternate chambers. Figure 2.3 shows the connections for alternating pressure mattress.

Figure 2.3 Stimulus Plus alternating pressure mattress.

This mattress is of size 80"x 35"x 9", weight capacity 350 lbs and having 18 air chambers (cells). The control unit attached to the mattress controls the mechanism of inflate and deflate of the mattress. It also has a control to set different levels of firmness. The control unit attached to this mattress is shown in Figure 2.4.

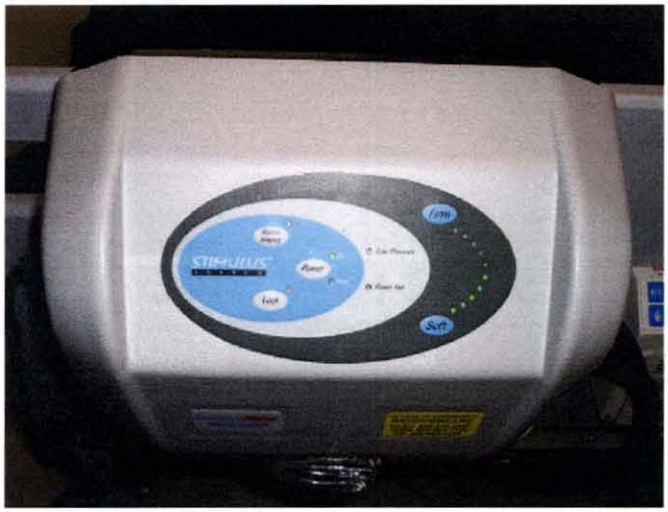


Figure 2.4 Control unit of Stimulus Plus Air mattress.

Modification of the Mattress

The mattress is modified by disconnecting the main hoses which connects air chambers to the pump. Each chamber has a small hose connected to it which is normally connected to the main hoses. The upper three chambers which supports the head portion remains unchanged and acts as a single chamber. A single main hose of 3/8" inner diameter is used to connect to all the small hoses coming out of each chamber mattress and the pump. Small secondary hoses are used to connect the air chamber to the main hose. Each hose coming out of the air-chamber forms a double T-junction with the secondary hose. Each secondary hose is connected to the one end of the double T-junction through a 2-way 2-position directional control valve which acts as an inlet valve for that particular chamber. The other end of the junction is connected to the air chamber. The pressure sensor and another 2-way 2-position directional valve which acts as an exhaust valve are connected to the remaining ends of the double T-junction. Figure 2.5 shows the modified connection of air mattress.

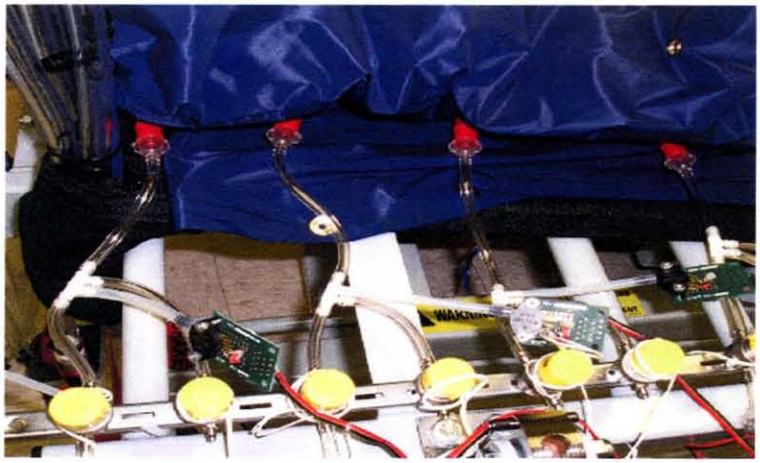


Figure 2.5 Modified connections of the air mattress.

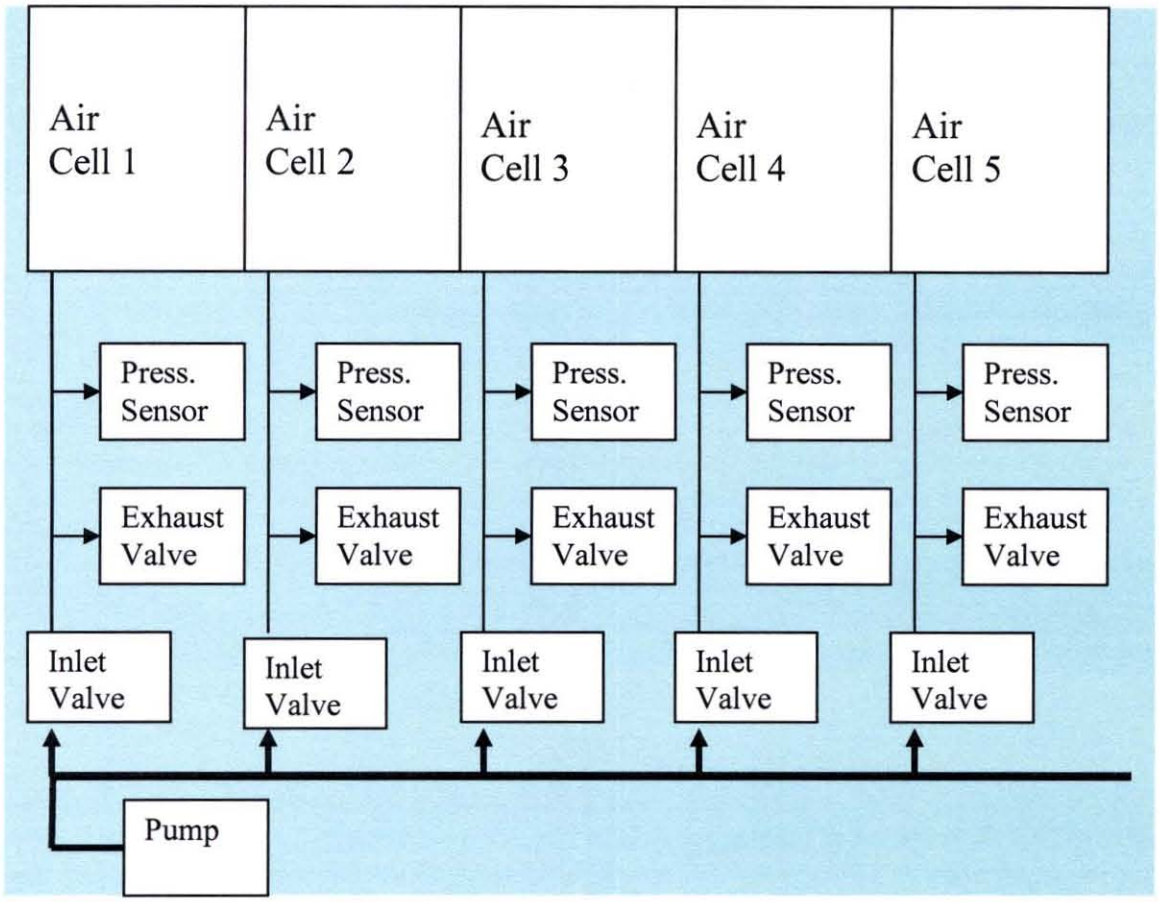


Figure 2.6 Block diagram of the individual cell pressure control mattress.

Figure 2.6 shows the block diagram of the modified connection of the individual cell pressure control mattress. It shows the manner in which valves, pressure sensors and the pump is connected to the mattress. There are 32 normally closed directional valves connected to the mattress for inflating and deflating the air chambers. One safety valve is also provided which acts as a main exhaust valve. It is also a normally closed 2-way directional control valve and it only opens when all other valves are closed. This provides a way for the pressure to be release out of the system when the system is stable at a particular setting.

2.2 Control Valves

The control valves used in this integrating this model are normally closed 2-way 2-position directional control valves (EV-2-12 VDC, Clippard Instruments Laboratory Inc., Cincinnati, OH) These valves are electronically controlled valves. The pressure range for this valve is 0 to 25psi. Figure 2.7 shows the 2-way directional control valve used in this project.

Figure 2.7 2-way directional control valve.

These valves are used to allow the air into the mattress and let the air out of the mattress. Two control valves are connected to each chamber, one acting as inlet valve and other acting as exhaust valve. The inlet valve is connected between the pump and the air chamber. The exhaust valve is connected to the air chamber and it release air to the atmosphere. Hence, control valves play a major role in inflation and deflation of the air mattress.

2.3 Pressure Sensor

A pressure sensor (MPX5100AP, Motorola, Phoenix, AZ) was used to measure the air pressure inside the air mattress. It is an integrated silicon pressure sensor. The MPX5100 series piezoresistive transducer is a monolithic silicon pressure sensor designed for a wide range of applications using analog to digital converter (A/D) inputs [12]. In resistive sensors, pressure changes the resistance by mechanically deforming the sensor, enabling the resistors in a bridge circuit, for example, to detect pressure as a proportional differential voltage across the bridge [12]. The schematic diagram is shown in the Figure 2.8.

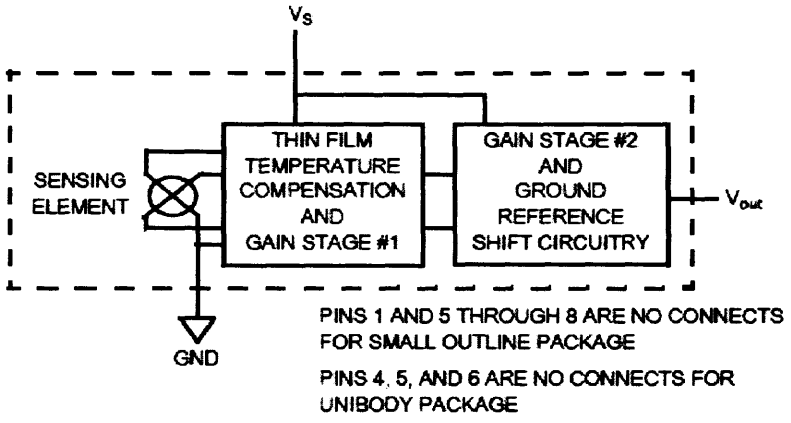


Figure 2.8 Fully Integrated Pressure Sensor Schematic [12]

This sensor provides accurate, high level analog output signal that is proportional to the applied pressure. It gives 2.5% maximum error over 0° to 85°C [12]. The operating characteristics of this sensor are supply voltage Vs=5.0Vdc, temperature Ta=25°C. It measures absolute pressure and its pressure range is 15 to 115 kPa (2.18 to 16.68psi) and its output range is 0.2 to 4.7V.

Figure 2.9 illustrates the absolute sensing chip in the basic chip carrier (Case 867 i.e., Stainless Steel Cap). A fluorosilicone gel isolates the die surface and wire bonds from the environment, while allowing the pressure signal to be transmitted to the sensor diaphragm. The operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media, other than dry air, may have adverse effects on sensor performance and long-term reliability.

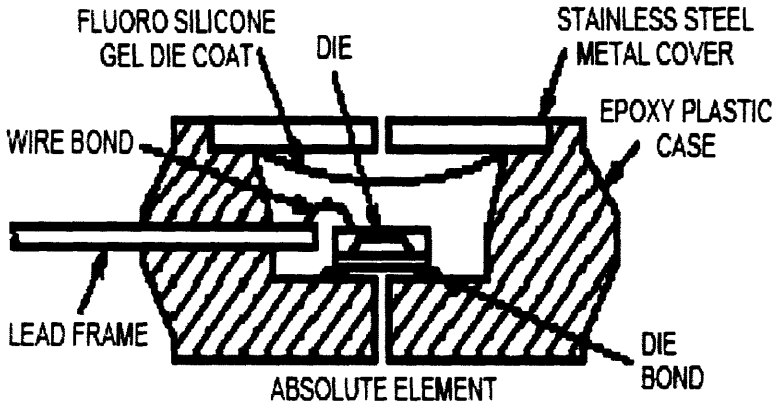


Figure 2.9 Cross-sectional diagram [12].

The pressure sensor is attached to each chamber externally. When there is no air in the mattress chamber the output from the pressure sensor is 4.11V. As pressure increases the output voltage also increases in a proportional manner. The output voltage from the pressure sensor at 0psi is the offset voltage for the sensor i.e., 4.11V. The output

of this pressure sensor when it is connected to the air mattress is in the range of 4.0 V to 5.0 V. The Figure 2.10 shows the linearity of the sensor.

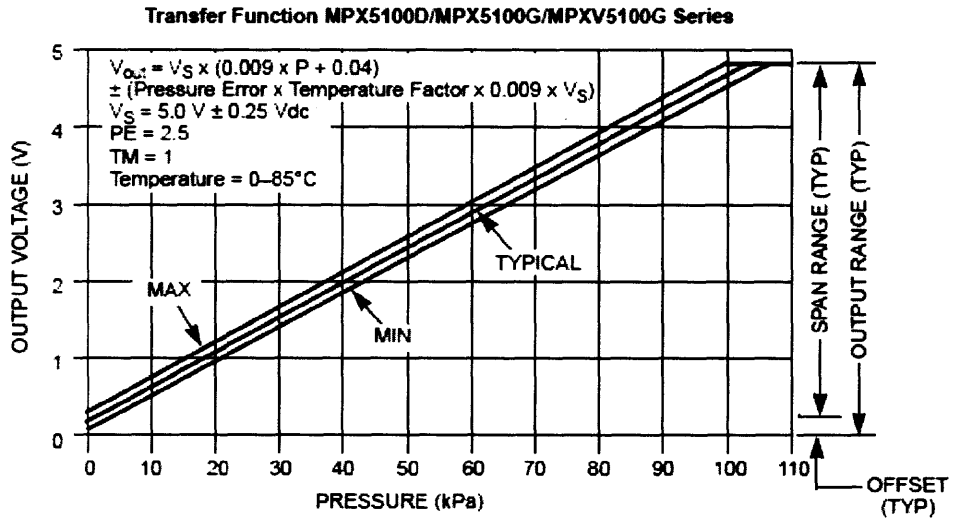


Figure 2.10 Output versus pressure differential [12].

This sensor has six pins. Pins 4, 5 and 6 are internal device connections and are not connected to external circuitry or ground. Pin 1 is the output Vout pin and is noted by the notch in the lead. Pin 2 is ground and pin 3 is the supply voltage, Vs= 5V.

2.4 Voltage (Offset) Subtraction Circuit (Differential Amplifier)

The output from the sensor is sent to the voltage offset removal circuit which removes the offset voltage. This circuit also provides a gain to the output. The voltage offset removal circuit can be built using an Op-Amp which is used to subtract two signals as shown in Figure 2.11.

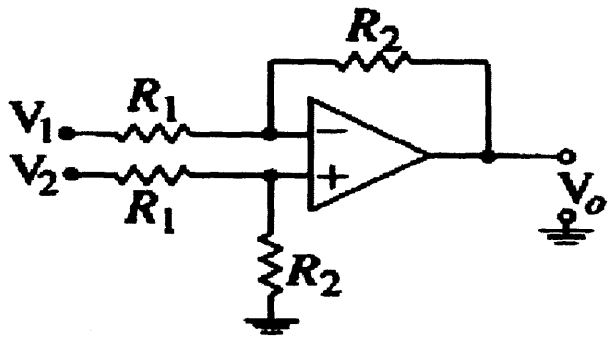


Figure 2.11 Voltage offset removal circuit.

This circuit is commonly used to remove unwanted voltage offset. The output of this circuit is given as Vout = $(V_2-V_1)*R_2/R_1$ where V_2 is the output of the sensor and V_1 is the signal (voltage) to be removed and gain of this circuit is equal to R_2/R_1. This circuit is developed using an Op-Amp LM324 with resistors R_1=10K and R_2=100K. This circuit subtracts the offset of 4.11V from the pressure sensor output and then provide a gain of R_2/R_1=100K/10K=10 to the output. For example, for the output of 4.21V from the pressure sensor the output from this circuit would be (4.21-4.11)*10V=10V. Hence, the output range from the voltage subtraction circuit is approximately from 1.0V to 10.0V. The pressure sensor has a range of around 6mV/10mmHg, which is a very low resolution. The output from the voltage offset removal circuit with a gain of 10 has a range of approximately 60mV/10mmHg. Hence, this circuit increases range of the output from the pressure sensor and thereby increases resolution. Table 2.1 shows the output in DC volts from the pressure sensor and output from the circuit after removing the offset voltage and giving a gain of 10.

Table 2.1 Correspondence Between Pressure and Output from the Pressure Sensor

Pressure (mmHg)	Output from Pressure Sensor (volts)	Output after Offset Removal And gain of 10 (volts)	Theoretical Value (Volts)	Percentage of error %
0	4.11	0.06	0.00	----
5	4.14	0.31	0.30	3.33
10	4.17	0.60	0.60	0.00
15	4.20	0.88	0.90	2.22
20	4.23	0.18	1.20	1.66
25	4.26	1.49	1.50	0.67
30	4.29	1.85	1.80	2.77
35	4.32	2.08	2.10	0.95
40	4.35	2.38	2.40	0.83
45	4.38	2.71	2.70	0.37
50	4.41	3.06	3.00	2.00
55	4.44	3.31	3.30	0.30
60	4.47	3.62	3.60	0.56
65	4.50	3.92	3.90	0.51
70	4.53	4.26	4.20	1.43
75	4.56	4.51	4.50	0.22
80	4.59	4.79	4.80	0.21
85	4.62	5.10	5.10	0.00
90	4.65	5.45	5.40	0.93
95	4.68	5.72	5.70	0.35
100	4.71	6.04	6.00	0.67
105	4.74	6.35	6.30	0.80
Avg. Error				**0.95**

2.5 Data Acquisition Cards

In order to read data from the pressure sensor connected to each air chamber and the activating and deactivating of pneumatic control valves, a data acquisition system is needed for the software program control. The DAQ Card used for this project was

National Instruments PCI-6024E which is a low cost data acquisition card which uses E series technology to deliver high performance, reliable data acquisition capabilities in a wide range of applications The DAQ Card E series are multifunction analog, digital and timing I/O cards for computer equipped with PCI slots [13]. Sampling rate up to 200 kS/s and 12-bit resolution on 16 single-ended analog inputs can be received [13]. It has two 12-bit analog outputs, 8 lines of TTL-compatible digital I/O and two 24-bit counter/timers for timing I/O [13]. The resolution of the A/D converter is the number of steps in which the input range is divided. The resolution is usually expressed as bits (n) and the number of steps is 2 to the power n. A converter with 12-bit resolution, for instance, divides the range into 2^{12}, or 4096, steps. For example, 0-10 V range will be resolved to 0.25 mV. The PCI-6024E multifunction data acquisition card is shown in the Figure 2.12.

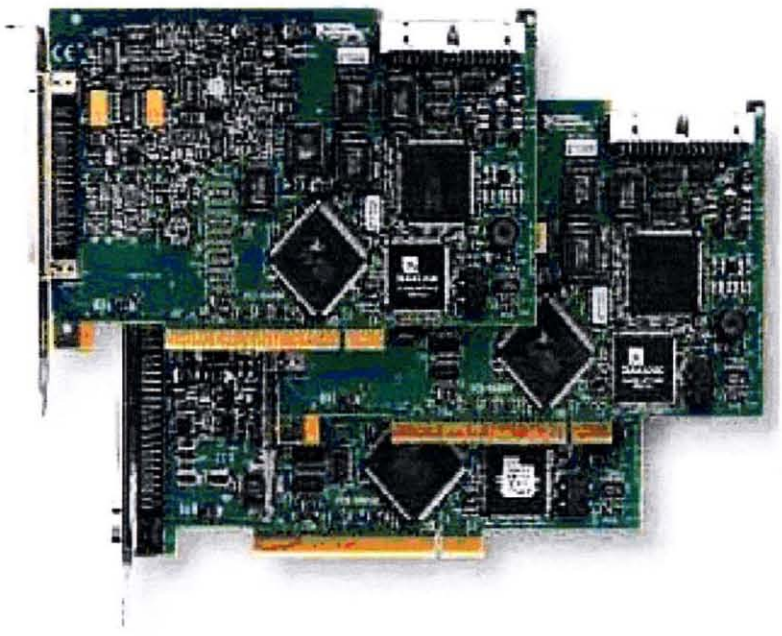


Figure 2.12 NI PCI-6024E [20].

The software used to control the air mattress pressure was written in National Instruments (NI) LabVIEW v.8i. The other device used for data acquisition is NI DAQ PCI DIO 96 card. The PCI DIO-96 is a 96-bit parallel digital I/O board for computers with PCI. This board uses four 24-bit programmable peripheral interfaces (PPIs). Each PPI can be divided into three 8-bit ports. The PCI DIO 96 is flexible for interfacing to peripherals or other computers. The board can operate in either a unidirectional or bidirectional mode or handshake with peripheral equipment [14]. Figure 2.13 shows NI DAQ PCI DIO 96 card.

Figure 2.13 NI DAQ PCI DIO 96 card [13].

The PCI DIO 96 card is connected to the CB-50LB connector block using a ribbon cable. The CB-50LB is a termination board with 50 screw terminals for easy connection of field I/O signals to NI DAQ devices. It also includes one 50-pin header for direct connection to 50-pin cables. Figure 2.14 shows the CB50-LB connector block and the ribbon cable.

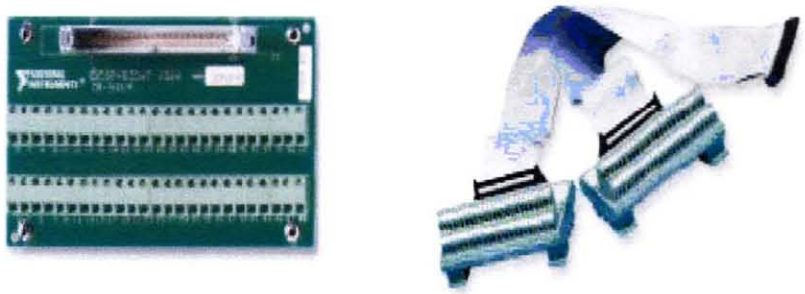


Figure 2.14 CB-50LB connector block and ribbon cable.

The analog output from the pressure sensor circuit is sent to the PCI 6024E card through the BNC 2090 block. The PCI 6024E card send this data to the software program. The output from the software program as a triggering signal to the control valves is provided by the PCI DIO 96 card. The BNC 2090 connector block has 16 I/O lines and the PCI DIO 96 card has 96 digital I/O lines. As this project requires 32 digital outputs, the BNC 2090 connector block which has just 16 output lines, is not enough and hence, there is need to use the PCI DIO 96 card having 96 digital I/O lines. So the PCI 6024E card acts as an input card and the PCI DIO 96 card acts as an output card. The reason to use both of these cards is, as the PCI DIO 96 card cannot read analog values from the pressure sensor but the PCI 6024E card can read it through the BNC 2090 connector block. And as the BNC 2090 card has only 16 digital I/O lines which are not enough for the project, the PCI DIO 96 card is also used.

The development software used for data acquisition and control applications is LabVIEW. It has extensive libraries for data acquisition, instrument control, data analysis, and graphical data presentation. LabVIEW is a powerful graphical programming

language having interactive graphics, better user interface. The LabVIEW Data Acquisition VI Library, a series of VIs for using LabVIEW with National Instruments DAQ hardware, is included with LabVIEW. The LabVIEW Data Acquisition VI Library is functionally equivalent to the NI-DAQ software. NI-DAQ has both high-level DAQ I/O functions for maximum ease of use and low-level DAQ I/O functions for maximum flexibility and performance. NI-DAQ does not sacrifice the performance of National Instruments DAQ devices because it lets multiple devices operate at their peak performance. NI-DAQ also internally addresses many of the complex issues between the computer and the DAQ hardware such as programming interrupts and DMA controllers.

CHAPTER 3

CONTROL LOGIC

The individual air cell pressure control system is controlled by LabVIEW® 8.0 software. The LabVIEW programs are called Virtual Instruments (VI's) because they imitate the actual instrumentation of electronic instruments. LabVIEW has two basic components, front panel and block diagram. The front panel is similar to any graphical user interface of any language program. It consists of the indicators, controls, led display, knobs etc. The displays can be user controlled or may be already a constant value, depending on the need of the system. The block diagram appears as a circuit diagram of the instrument. It consists of several blocks and sub VIs needed for the software to work as per the system needs. The flow of the data in the block diagram is from the left to right. It includes the data acquisition blocks for reading the data from the device attached to it. The function palette consists of all the functions used to program the VI's. It is widely used as it is user friendly and has good data acquisition ability.

3.1 Software Logic

The front panel in this project is divided into two parts, one part for the programmer and other part for the end user. The programmer part contains controls for the pressure range, indicators for the pressure in each air chamber, indicators for the activation or deactivation status of the control valves, selection of the firmness, start and stop buttons. The end user part contains start and stop activation buttons, selection of the mode of operation of the air mattress i.e., standard air pressure mattress, alternating pressure

mattress or individual cell pressure control mattress and selection of firmness. The diagram of the front panel is shown in Appendix G. Figure 3.1 shows the flow diagram of the whole system control.

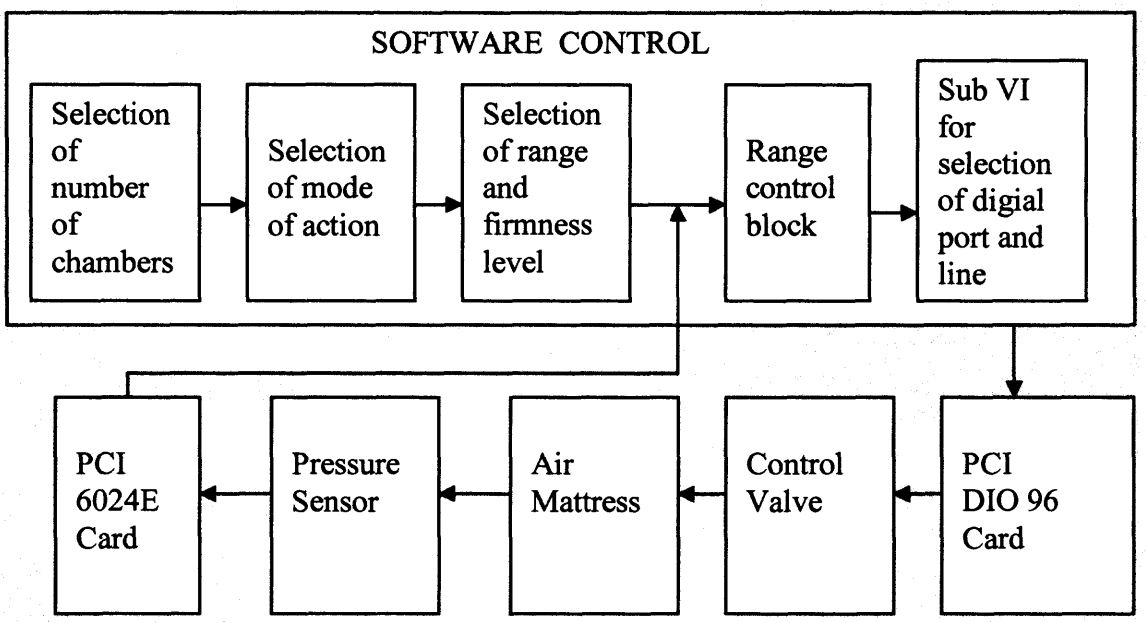


Figure 3.1 Flow diagram of the individual cell pressure control mattress.

The block diagram is similar to a wiring diagram of the project. In this project, the block diagram has many blocks in it. The first block is for the selections of the firmness and mode of the activation of the mattress. It is shown in Figure 3.2. In this block, once any one firmness level from the comfort selection section and any one mode from the mode section are selected and a "Done" button is pressed, it will execute a particular case for that selection which will control the mattress to operate in that particular selected mode and having the selected firmness.

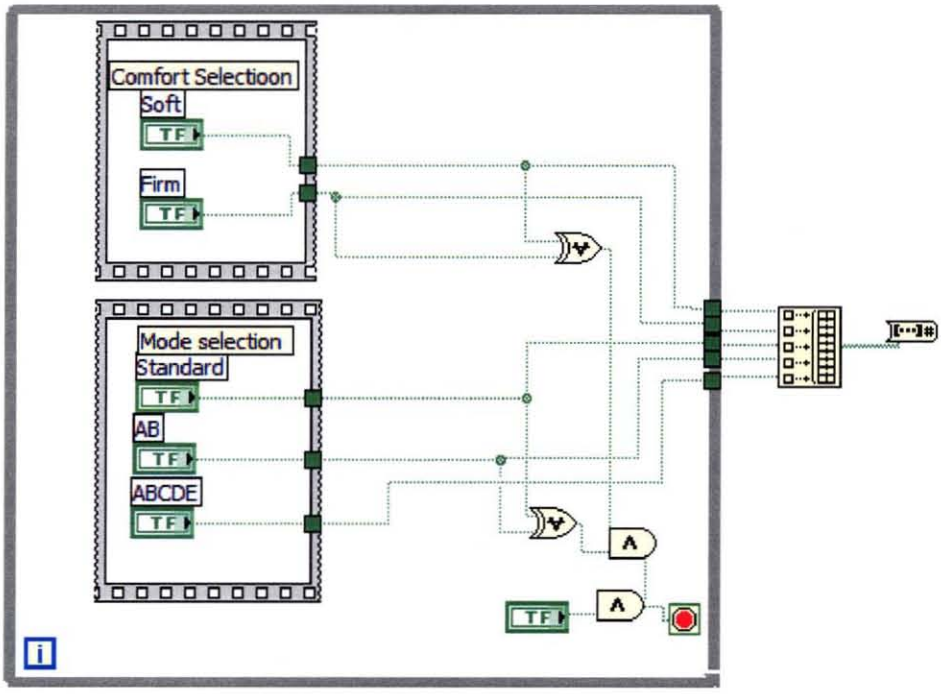


Figure 3.2 Block diagram for the selection of mode of action and firmness level of the mattress.

Once the firmness level and mode of the mattress is selected and the program is run, the data from all pressure sensor is read by using a "AI Config.vi" which configure the device 1 (PCI 6024E) to get an analog input, "AI Start.vi" which start getting the signal from the input device, and "AI Read.vi" start reading analog data received from the device 1. These data are stored in an index array and a median of the data from each pressure sensor is taken to get the accurate value. This value is sent to each range control block for each chamber. Each range control block has range comparator block which has upper pressure limit (in volts) and lower pressure limit (in volts) and the input pressure which is the output voltage from the pressure sensor. The range comparator block then compares the input with the upper and lower limits and gives the output accordingly. This output goes to the sub VI and the sub VI has three cases. It has different outputs for each case. For case 1, if the input is lower than the lower pressure limit, then the output which

controls the inlet valve is high and the one controlling the exhaust valve is low, for case 2, if the input is greater than the upper pressure limit, then the output controlling the inlet valve is low and the output controlling the exhaust valve is high. In the last case, case 3, when the input is within the upper and lower pressure limits, then both the outputs controlling inlet and exhaust valve are low.

These cases are for the selection of the digital line of the digital port of the PCI DIO 96 card to the control the inflation and deflation of the air chamber. Each digital port has eight digital lines. For controlling the pressure in each chamber it requires two digital lines. One is for the inlet valve and the other is for the exhaust valve. Therefore, one digital port can control eight valves four inlet valves and four exhaust valves of four chambers. For example, if the pressure value from the pressure sensor attached to the first air chamber is over the upper range than it gives a low output to the digital line 0 which is connected to the inlet valve and high output to digital line 1 which is connected to the exhaust valve of the first chamber of the air mattress. Hence, each sub VI controls two digital line and two valves and one chamber pressure. We have four sub VIs each for lines 0 and 1, lines 2 and 3, lines 4 and 5, and lines 6 and 7. Hence, for controlling pressure in all the 16 air chambers of the mattress, and 16 range control blocks each are required and having one range control function, four sub VIs and four digital port each controlling eight digital lines or eight control valves. The allocation of the digital port and lines for each chamber is shown below in table 3.1.

Table 3.1 Selection of the Digital Port, Lines and Control Valves for the Air Chamber

PORT NUMBER	DIGITAL LINE	AIR CHAMBER	CONTROL VALVE
0	0	1	Inlet 1
	1	1	Exhaust 1
	2	2	Inlet 2
	3	2	Exhaust 2
	4	3	Inlet 3
	5	3	Exhaust 3
	6	4	Inlet 4
	7	4	Exhaust 4
1	0	5	Inlet 5
	1	5	Exhaust 5
	2	6	Inlet 6
	3	6	Exhaust 6
	4	7	Inlet 7
	5	7	Exhaust 7
	6	8	Inlet 8
	7	8	Exhaust 8
2	0	9	Inlet 9
	1	9	Exhaust 9
	2	10	Inlet 10
	3	10	Exhaust 10
	4	11	Inlet 11
	5	11	Exhaust 11
	6	12	Inlet 12
	7	12	Exhaust 12
3	0	13	Inlet 13
	1	13	Exhaust 13
	2	14	Inlet 14
	3	14	Exhaust 14
	4	15	Inlet 15
	5	15	Exhaust 15
	6	16	Inlet 16
	7	16	Exhaust 16
4	0	Main tube	**Exhaust Main**

The last phase of the block diagram is for the control of the main exhaust valve. When the preset pressure for each chamber is set by the programmer is reached, all inlet and exhaust valves connected to the chambers get closed and hence, the air pressure coming from the pump needs some way to be released out. So a main exhaust valve which is connected to the main tube is needed to be open to release that pressure. It acts as a safety valve.

3.2 Software Controlled Features

This system has more flexibility than compared to other air mattresses currently used for prevention of pressure sores. It has flexibility in selecting any number of chambers to be operated at a time, range of firmness level, firmness level, and mode of action of the mattress. If the firmness level is selected as 1) by clicking one button named "Firm" on the front panel, a medical staff can inflate all chambers to firm. This would assist in helping people to get in or out of the bed and 2) by clicking "Soft" button on the front panel, all chambers can be deflated up to soft firmness. It is also possible to use this mattress as a standard air mattress, alternating air pressure mattress as well as few other patterns. This mattress can be operated in different modes such as 1) AB mode alternating pressure mattress, where A and B will be different pressure 2) ABC mode alternating pressure mattress where A, B and C are different pressure. More modes such as ABCD, ABCDE, etc. can be selected.

The modified mattress is a closed loop system and it can respond to the change in pressure inside the chamber either by inflating or deflating the chamber. For example, if an external force is applied on the mattress, then the pressure inside those chambers

where the external force is applied will increases. The pressure sensor connected to those cells will sense this increase in pressure and will give an increased value of input to the system. If the change in pressure inside the chamber is within the lower and upper limits of pressure for that chamber, then the system will not respond and remain stable. But if the change is pressure is not within the range, then the software will give an output to control directional control valves to make the necessary changes.

CHAPTER 4

VERIFICATION, RELIABILITY AND SAFETY OF THE SYSTEM

4.1 Verification of the System

Verification of the system is required in any project before implementing it. To verify the system it is compared with some medium or its performance it evaluated. The system should be accurate and reliable enough to fulfill the purpose for which it is developed. To validate the individual cell pressure control mattress, the accuracy, the repeatability and the feedback validation tests are conducted and the percentage of error is calculated.

4.1.1 Accuracy Test

For the accuracy test, the system is operated in 1) ABCDE mode and Soft firmness level and in 2) ABCDE mode and Firm firmness level. For this, five chambers are selected other than the chambers supporting head. At each five chambers a sphygmomanometer is connected to check that when the system is operated, the pressure hold by each chamber match the pressure shown by the respective sphygmomanometer connected to that particular chamber. For the ABCDE mode of operation and the Soft firmness level, each of the five cells has a different pressure ranges between 20mmHg to 50mmHg, and for the ABCDE mode of operation and Firm firmness level, each of the five cells has a different pressure range between 50mmHg to 75mmHg. The output of each pressure sensor is noted which is in volts. The mean value of the readings is calculated and compared with the sphygmomanometer reading. Percentage of error is calculated for each of the five chambers to check the accuracy of the system. The following table shows the details of the accuracy check of the system.

Table 4.1 Results of the Accuracy Test When the Mattress is Operated in ABCDE Mode and Soft Firmness Level

Cell	Pressure Range (mmHg)	Sphygmomanometer reading (mmHg)	Pressure Sensor Output (Volts)	Chamber Pressure mmHg	Error (%)
1	25-30	26.0	1.585	26.41	**1.57**
2	30-35	31.5	1.895	31.58	**0.25**
3	35-40	36.5	2.145	35.75	**2.05**
4	40-45	41.5	2.470	41.11	**0.94**
5	45-50	47.0	2.805	46.75	**0.53**

Table 4.2 Results of the Accuracy Test When the System is Operated in ABCDE Mode and Firm Firmness Level

Cell	Pressure Range mmHg	Sphygmomanometer reading mmHg	Pressure Senor Output Volts	Chamber Pressure mmHg	Error (%)
1	50-55	51.5	3.140	52.33	**1.61**
2	55-60	56.5	3.405	56.75	**0.44**
3	60-65	62.0	3.710	61.83	**0.27**
4	65-70	67.0	4.020	87.00	**0.00**
5	70-75	71.5	4.333	72.2	**0.71**

The results for ABCDE mode with both Soft and Firm firmness, show that the maximum error in the system is 2.05%, which is very low. It shows that the system has an accuracy of 98% when it is operated up to the pressure range of 75mmHg.

4.1.2 Repeatability Test

To check the repeatability of the system, five different chambers are selected and three different pressure ranges are selected for each chamber. For each pressure range the chambers are operated five times. For example, for chamber 1 if the selected range is 10mmHg to 20mmHg and the system is operated, as soon as chamber 1 holds the

pressure within 10mmHg to 20mmHg pressure range, the first reading from the pressure sensor is noted. For the second reading, chamber 1 is deflated totally and it is operated again for the same pressure range. When it holds the pressure within that pressure limits, the second reading of the pressure sensor output is noted. This is repeated five times for each five chamber. Different ranges are selected to check the repeatability of the system at various pressures. Table 4.3 shows the readings obtained and the calculated mean, variance and standard deviation for these readings to verify the system.

Table 4.3 Results of the Repeatability Test of the System

Cell	Pressure Range mmHg	Readings (Volts)						Variance	S.D	Error %
		1	2	3	4	5	Mean			
1	30-35	1.96	2.02	2.01	1.95	1.98	1.99	0.00078	0.029	**1.45**
	50-55	3.07	3.08	3.11	3.10	3.07	3.09	0.00028	0.017	**0.55**
	70-75	4.28	4.32	4.27	4.33	4.39	4.32	0.00182	0.043	**0.99**
2	40-45	2.47	2.41	2.47	2.51	2.53	2.48	0.00170	0.041	**1.65**
	60-65	3.69	3.65	3.77	3.75	3.69	3.71	0.00192	0.044	**1.19**
	80-85	4.82	4.83	4.81	4.94	4.88	4.86	0.00212	0.046	**0.94**
3	50-55	3.12	3.24	3.18	3.12	3.16	3.17	0.00202	0.045	**1.42**
	70-75	4.36	4.31	4.29	4.34	4.30	4.32	0.00068	0.026	**0.60**
	85-90	5.24	5.14	5.13	5.25	5.23	5.20	0.00270	0.051	**0.98**
4	60-65	3.74	3.71	3.74	3.80	3.79	3.75	0.00118	0.034	**0.91**
	40-45	2.45	2.50	2.60	2.43	2.54	2.50	0.00380	0.062	**2.48**
	20-25	1.36	1.30	1.23	1.33	1.34	1.31	0.00176	0.042	**3.21**
5	70-75	4.33	4.30	4.26	4.36	4.29	4.31	0.00118	0.034	**0.79**
	30-35	1.87	1.88	1.90	1.96	1.94	1.91	0.00134	0.037	**1.93**
	50-55	3.16	3.23	3.14	3.26	3.19	3.19	0.00198	0.044	**1.37**

Table 4.3 shows that for each chamber and for each range the readings are not spread more away from the mean. Even the system has maximum of 3.21% of error when the system is operated number of times. This error is very low and the results show that the system is reliable.

4.1.3 Validation of the System Feedback

The individual cell pressure control mattress is a closed loop system and it can give feedback to the system. To check the feedback of the system, a small pilot study is shown in this section. In this test, when there is a subject on the mattress, two consecutive cells supporting the buttocks region of the patient are selected. The pressure range selected for cell 1 is 60-70mmHg and for cell 2 is 50-60mmHg. The cell 1 supports the high pressure region of the buttocks and cell 2 supports the low pressure region of the buttocks. The system is operated by selecting a delay of 6 seconds for the feedback loop. The system has the ability to read the pressure sensor output every second. For this test, the pressure sensor output is displayed every 2 seconds. When the system reach a stable state i.e., when each cells holds the preset pressure and all the inlet and exhaust valves connected to each cell are closed, the subject is told to move his high pressure region of buttocks from cell 1 to cell 2. This causes change in pressures in both the cells. When the subject will move high pressure region of his buttocks on cell 2, the pressure in cell 1 will decrease and the pressure in cell 2 will increase. And the system becomes unstable at that time. The output from the pressure sensors connected to cell 1 and cell 2 are noted every 2 seconds. As the system has a delay of 6 seconds, the control valves will get a feedback every 6 seconds. The feedbacks for control valves connected to cell 1 and cell 2 are noted. These feedbacks, at every 6 seconds, compares the new recorded pressure sensor

output with the upper and lower limits for that particular cell and accordingly either inflate or deflate the mattress. When the pressures inside cell 1 and cell 2 returns back to the preset range, the output of the pressure sensor is noted. The pressure sensor output at the start and at the end of the test is compared to check the system ability to recover the change is pressure. This test is performed to check the working of the feedback loop. The expected results for this test are when the subject moves from position 1 to position 2 and if that position is maintained for longer than 6 seconds, the inlet valve for the cell 1 should open to raise the pressure back to specified levels, and the exhaust valve for cell 2 should open to release air and lower the pressure in cell2 to the specified levels. Table 4.4 shows the output of the pressure sensor connected to cell 1 and cell 2 when a patient moves his body from one position to another.

Table 4.4 Output of the Pressure Sensor for Cell 1 and Cell 2

Sr. No.	Feedback Cycle (Interval is 6 sec)	Time (sec)	Cell 1 Output (Volts) (When Pressure Range is 60-70mmHg) (3.62V-4.20V)	Cell 2 output (Volts) (When Pressure Range is 50-60mmHg) (3.06V-3.62V)
1	1	2	3.87	3.27
2		4	3.85	3.28
3		6	3.86	3.27
4	2	8	3.82	3.29
5		10	3.73	3.40
6		12	3.64	3.52
7	3	14	3.50	3.68
8		16	3.37	3.86
9		18	3.28	4.13
10	4	20	3.33	3.99
11		22	3.45	3.87
12		24	3.53	3.72
13	5	26	3.65	3.63
14		28	3.74	3.51
15		30	3.84	3.43
16	6	32	3.90	3.31
17		34	3.91	3.29
18		36	3.89	3.28

The output of the pressure sensor connected to cell 1 and cell 2 are plotted against time to verify the change in the pressure due to patient movement. It is visible from Figure 4.1 that when the high pressure buttocks region of the patient's body moves from cell 1 to cell 2 the pressure in cell 1 decreases and pressure in cell 2 increases.

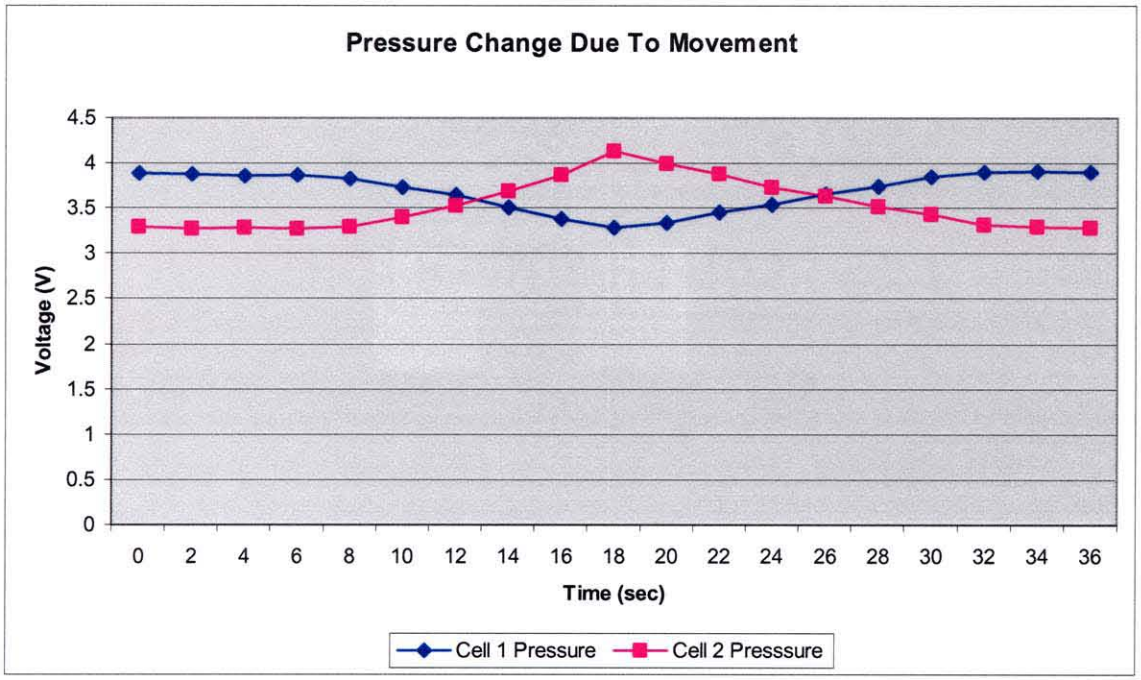
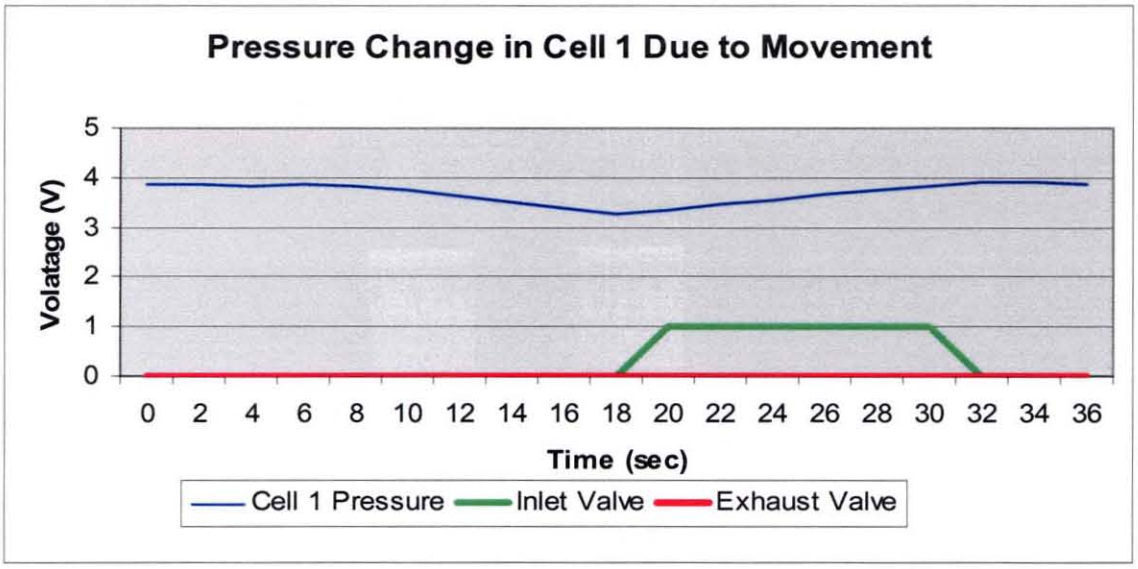


Figure 4.1 Pressure sensor output for cell 1 and cell 2 due to patient movement.

The feedback of the system for the cell 1 and cell 2 is shown in Figure 4.2. The output of the control valves is compared with the change in pressure to check the feedback system. For cell 1 when the pressure inside the cell decreases below the lower limit 60mmHg i.e., 3.62V, the inlet valve will open and the pressure inside cell 1 starts increasing again As soon as it reaches between the upper and lower limits, the inlet gets closed. The exhaust valve remains closed for the entire period for cell 1. For cell 1 when the pressure inside cell increases, the exhaust valve opens and relieves the pressure. As soon as the pressure reaches between the upper and lower limits, the exhaust valve gets closed. Inlet valve remains closed for the entire time period for cell 2.



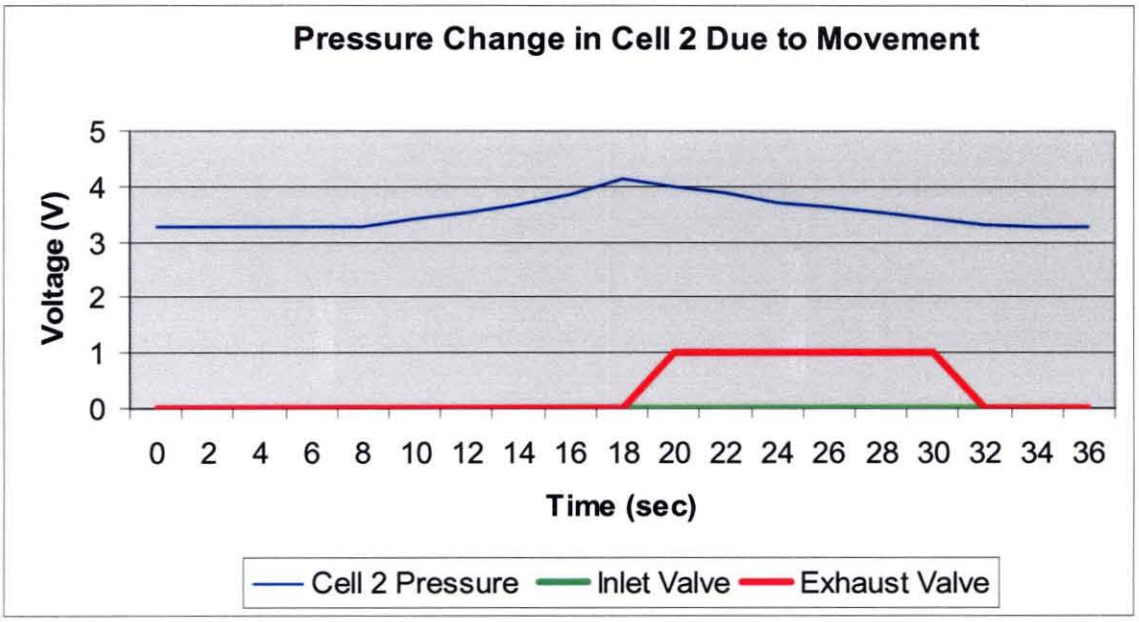


Figure 4.2 Feedback for cell 1 and cell 2 due to patient movement.

One more test is conducted to check the system capability to reject short period deflections or force onto the mattress. To check this, one cell is randomly selected and the range for that cell is selected 60mmHg to 70mmHg. The system response or feedback time is kept 6 seconds. An external force is applied at on the cell for 1 to 2 seconds of

time period. The output of the pressure sensor is measured at every second. The expected result for this test is if an external force is applied on the cell between the time intervals of 6 seconds, which is the system response time, the system should not respond to the applied external force and none of the valves should open. Table 4.5 shows the results of the test.

Table 4.5 Pressure Sensor Output for Short Period Impulse Force

Sr. No	Feedback Cycle (Interval is 6 sec)	Time (sec)	Pressure Sensor Output (Volts)
1	1	1	3.87
2		2	3.89
3		3	4.60
4		4	4.21
5		5	3.90
6		6	3.87
7	2	7	3.85
8		8	3.86
9		9	3.89
10		10	3.88
11		11	3.87
12		12	3.86

The output of the pressure sensor increases when an external force is applied on the cell. It is clear from the results that when the force was applied at the third second. This increases the output of the pressure sensor. As the feedback has a delay of 6 seconds, the system would compare the output of the pressure sensor with the upper and lower limits of pressure at the every sixth second and respond accordingly. As the system

recovers the original pressure before the sixth second, it will not respond to that change. And the output of the inlet and exhaust valves connected to that cell is also low as they do not receive any feedback and remain closed. The output from the pressure sensor is compared with the output of the inlet and exhaust control valves connected to that chamber. The following figure shows that. Figure 4.3 shows the pressure change and feedback of the system when a short period impulse force in applied on a cell.

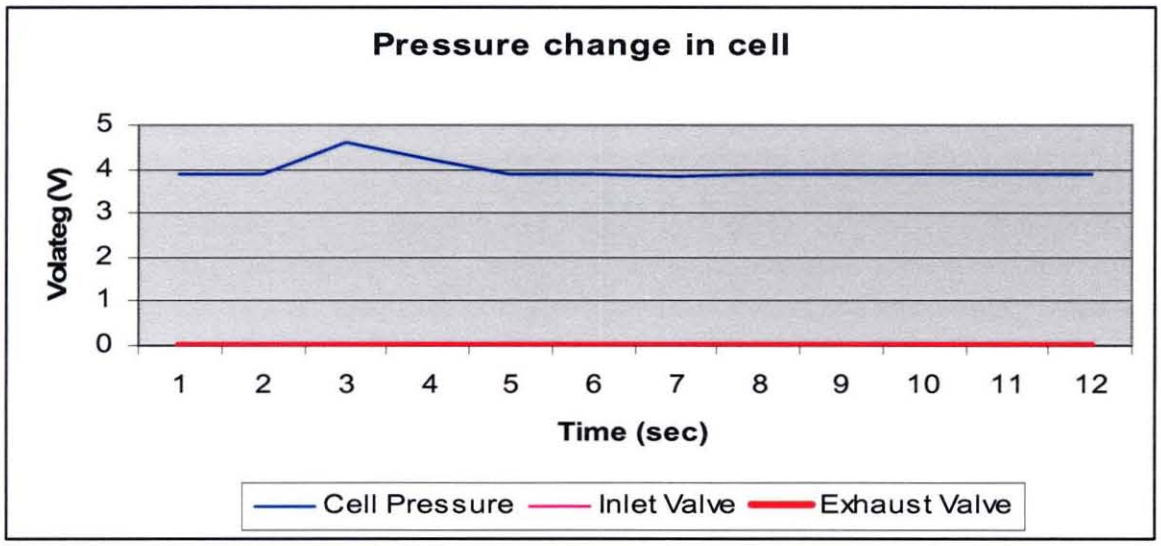


Figure 4.3 Pressure change and system feedback for a short period impulse force.

4.2 Reliability and Safety of the System

The reliability and safety check of the any system is also necessary before implementing it. The data received from the pressure sensor during system check matches with the theoretical values with an average error of 0.95%. The output from the pressure sensor is linear with respect to the air pressure inside the mattress. The system is a closed looped system which responds well.

To check the reliability and safety of the system, some of the situations are taken into consideration. For example, if the main analog power (120V) turns off. As this system controls the air pressure using electronically control normally closed 2-way directional control valves, as soon as the power turns off both the inlet and exhaust control valves get closed and also the pump shuts down. So the air pressure inside the mattress at that particular time would remain in the mattress i.e., no inflation or deflation can occur.

In another situation, when the software logic has a problem such as either in comparing the chamber pressure with the preset range of the pressure, or in selection of proper digital port or digital line for providing a triggering signal to the control valves, the software is developed in such a way that it has the ability to detect a problem in the system and even it can show in which part the of the system the problem exists. An LED corresponding to that particular chamber will flash showing the fault in that portion of the system. Thus, instead of checking the whole system only a small part of the system may require service or replacement which would make the operator's work easier.

In a situation, when there is a crack in a mattress or in tubes, due to leakage of air in the system, the preset pressure inside the chambers would not be reached. But as in this system, the pump is controlled by the software, it will detect if the pump remains ON for more than 5 minutes continuously, the software will then turn it OFF and a LED will blink indicating the problem. Hence, it will make the system safer.

The system uses upper and lower range of pressure for each chamber as a reference for comparing the input pressure instead of just one reference. This will make the system more stable by avoiding small distortion in the pressure inside the chamber.

For example, if the patient movers or roll over a little, there will be a little change in pressure inside the chambers. But as there is a upper and lower limits of pressure for each chamber, if this small change in pressure inside the chamber is within that limits than the system will not respond and remain stable. This will make the system more reliable against unwanted disturbance.

Some of the limitations of the individual cell pressure control air mattress are as it uses an external pump which makes noise which might cause irritation to the patients. As the system has mechanical components, maintenance and servicing would be a problem. It requires a computer and a lot of hardware to operate and hence, it requires more care and space.

CHAPTER 5

EXPERIMENTATION

The duration of the human interface experiment for this type of research is very long, often in years. It is also hard to get patients for this type of research. Therefore, due to the time limitation a human interface experiment is out of the scope of master's thesis. Thus, a research plan of experiment is proposed. Healthcare professionals attempt to reduce the incidence of severe pressure sores by the identification of people at high risk and the use of prevention strategies such as pressure-relieving equipment. Many studies have been conducted for evaluation of methods used for prevention and treatment of pressure sores [15]. Prevention studies also conducted to evaluate the prevalence and incidence of pressure ulcers and their relationship with different mattresses [16]. In treatment studies, pressure relieving interventions are evaluated for the healing of pressure sores. The objectives of these studies are to compare different pressure relieving cushions, beds, mattress overlays and mattresses and to find out which one reduce the incidence of pressure sores compared to others, to find out which support surfaces increase the healing rate of pressure sores compared to other support surfaces. Each of these studies requires data sources, type of trials, pressure relieving interventions and results.

5.1 Identifying Population for Application of Methods

To implement any method the first step is to identify people at risk. As interventions to prevent pressure sores can be very expensive, the resources should be targeted at patients who are at high risk of developing sores. These high risk patients are identified using

various pressure sores risk assessment scales. These scales are based on assessment of clinical variables such as mobility, incontinence, and activity. The total score is compared to a standard reference value to classify the level of risk. Potential applications of these scales are to aid rational allocation of limited resources to those who are likely to benefit the most, as an indicator of patient risk in order to judge the comparability of patients between different parts of trials. Scales usually used are Norton, Braden, Waterlow, etc. [17]. Example of the one of the scales named the Norton scale is shown in Table 5.1.

Table 5.1 Norton Pressure Sore Prediction Score [17]

Physical Condition	Mental State	Activity	Mobility	Incontinence
4 Good	4 Alert	4 Ambulant	4 Full	4 Not
3 Fair	3 Confused	3 Walks with help	3 Limited	3 Occasional
2 Poor	2 Apathetic	2 Chair bound	2 Very limited	2 Usually urine
1 Bad	1 Stuporous	1 In bed	1 Immobile	1 Doubly incontinent

Previous research concludes that these scales are developed in an ad-hoc fashion and it is still unclear which is the most accurate. There is little evidence which supports that using a pressure sore risk scale is better than clinical judgment or that the use of such a scale improves outcomes [15] [17]. The reliable way of constructing such a scale involves the use of statistical regression models to choose and weight the factors which best predict the development of a sore [17]. As currently used scales are not constructed in above manner, they are not considered as the optimal method to identify high risk patients. Table 5.2 shows the results from previous studies of the predictive validity of risk assessment tools.

Table 5.2 Studies of the Predictive Validity of Risk Assessment Tools [17]

Study	Scale (Scores for group at risk)	Setting	Sample Size	Proportion developing sores	Follow -up	Sensitivity** (95% CI)	Specificity** (95% CI)	Masking of Outcome Assessment	Masking of Score to Nurses	Lowest Grade Sore Included
Bergstrom et al, 1992[21]	Braden (16 or less)	Medical-Surgical Unit (Shorter stay)	100	7%	Not clear	100%* (59%, 100%)	90% (82%, 96%)			Grade I
Bergstrom et al, 1992[21]	Braden (16 or less)	Medical-Surgical Unit (Longer stay)	100	9%	Not clear	100%* (66%, 100%)	90% (53%, 74%)			Grade I
Bergstrom et al, 1992[21]	Braden (16 or less)	Adult Intensive Care Unit (with follow-up on other units)	60	40%	2 weeks (or discharge if earlier)	83% (63%, 95%)	90% (46%, 79%)	✓	✓	Grade I
Langemo et al, 1991[22] (e)	Braden (16 or less)	Medical-Surgical & Orthopaedic Acute Care	74	15%	2 weeks (or discharge	64% (30%, 89%)	87% (75%, 95%)	✓	✓	Grade I
Salvadalena et al, 1992[23] (f)	Braden (16 or less)	Medical Acute Care Unit	99	20%	3 weeks (or discharge	40% (19%, 64%)	70% (59%, 80%)	✓	✓	Grade I
Barnes et al, 1993[24]	Braden (16 or less)	General Medical and Cardiovascular Unit	361	6%	15 days (or discharge if earlier)	73% (50%, 89%)	91% (87%, 94%)	0	0	Grade I
Braden et al, 1994[17]	Braden (16 or less)	Nursing Home	102	28%	4 weeks (or discharge if earlier)	46% (28%, 66%)	88% (78%, 94%)	✓	0	Grade I
Norton et al, 1962[4]	Norton (14 or less)	Care of the Elderly Unit	250	24%	8 weeks (or discharge if earlier)	63% (50%, 75%)	70% (64%, 77%)	0	0	Grade II
Goldstone et al, 1982[25] (a)	Norton (14 or less)	Orthopaedic Unit (emergency elderly admissions)	40	45%	Until discharge	89% (65%, 99%)	36% (17%, 59%)	0	0	Not clear
Lincoln et al, 1986[26] (b) (c)	Norton (14 or less)	Medical-Surgical Unit (elderly patients)	36	14%	Until discharge (max length of stay was 4weeks)	0% * (0%, 52%)	94% (79%, 99%)		✓	Grade II
Stotts 1988[27]	Norton (14 or less)	Elective Cardiovascular and Neurosurgury Units	387	17%	3 weeks	16% (8%, 28%)	94% (91%, 97%)	0	✓	Grade I
Smith 1989[28] (c) (g)	Norton (16 or less)	Elective and Emergency Orthopaedic Admissions	101	30%	Until discharge	60% (41%, 77%)	31% (21%, 43%)			Grade I
Towey et al, 1988[29]	Knoll (12 or less)	Long-term Care (elderly patients)	60	47%	4 weeks (or transfer if earlier)	86% (67%, 96%)	56% (38%, 74%)			Grade I
Lowthian 1989[30]	PSPS (6 or above)	Orthopaedic Patients	1244	4%	3 weeks	89% (77%, 96%)	76% (74%, 78%)			Grade I
Andersen et al, 1982[31]	Own (2 or more)	General Hospital Acute Care Admissions	3398	1%	3 months	88% (73%, 96%)	86% (85%, 87%)			Grade II
Gosnel 1973[14]	Gosnell (15 or less)	Long-term Care (elderly patients)	30	13%	3 weeks (or discharge if earlier)	50%* (7%, 93%)	73% (52%, 88%)			Unclear
Smith 1989[28] (c) (g)	Waterlow (20 or more)	Elective and Emergency Orthopaedic Admissions	101	30%	Until discharge	73% (54%, 86%)	38% (27%, 50%)			Grade I

Notes

* These results are calculated on data from less than 10 individuals

** Calculation of all confidence intervals and many of the sensitivities and specificities was performed by the author

(a) Patients with 'unique factors' were excluded

(b) Patients staying less than 3 days were excluded (26%)

(c) Surgical patients were evaluated prior to surgery

(d) Categories in the Norton scale were defined re Gosnell

(e) Only patients with expected length of stay of at least 5 days were included

(f) Only patients with expected length of stay of at least 3 days were included

(g) Only patients with expected length of stay of at least 7 days were included

There is a great variation in the estimates of predictive validity both across scales and between assessments of the same scale. As there is a large variation between the settings and the methods, it is not possible to make better comparisons of the predictive validity of these scales.

5.2 Types of Pressure Relieving Interventions

The aim of pressure sore prevention strategies is to reduce the magnitude and/or duration of pressure between a patient and their support surface (the interface pressure). This may be achieved by regular manual repositioning (e.g. 2-hourly turning), or by using pressure-relieving support surfaces such as cushions, mattress overlays, replacement mattresses. This project focuses on the effectiveness of risk prediction and pressure reliving mattresses. Other aspects of pressure sore managements are not considered. Pressure relieving mattresses are constant low pressure devices and alternating pressure devices. Alternating pressure (AP) mattresses usually alternate inflate and deflate the air cells and hence, generate alternating high and low pressures between the patient's body and support surface. These mattresses reduce the duration of the applied pressure and provide a continuous redistribution of the pressure beneath the patient. Constant low pressure (CLP) mattresses are grouped according to foam, foam and air, foam and gel, air fluidized. These mattresses mould around the patient body to distribute patient's weight over a large area. Figure 5.1 shows the mechanism of the action of alternate pressure mattress.

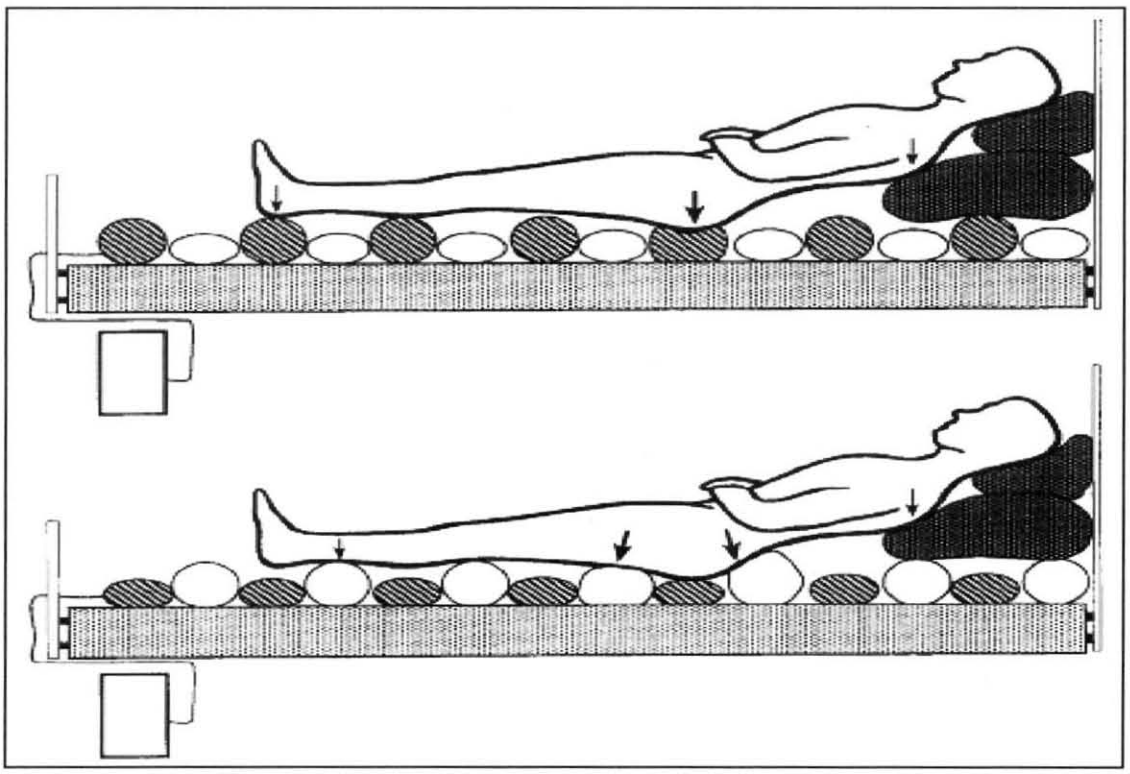


Figure 5.1 Diagram showing the mechanism of action of alternating pressure devices [17].

5.3 Evaluating Pressure Relieving Intervention

Pressure relieving interventions are evaluated for prevention or treatment of pressure sores. Randomized controlled trials are used for evaluation because; they provide the most reliable evidence for the efficacy of interventions. Random allocation of patients to treatment and control groups improves the comparability of the groups and so differences in outcomes can be more confidently attributed to a particular treatment, once random error is excluded by significance testing [17]. Many studies have simply measured the interface pressure between the body and the support surface. Interface pressure is an intermediate or surrogate outcome measure which has many limitations as a proxy for clinical outcomes [17]. The effect of the mattress for prevention of pressure sores is

assessed by the presence of at least one pressure ulcer of any stage and to the presence of at least one pressure ulcer of Stage II or higher [16]. Previous research shows that evaluating pressure relieving mattresses for incidence of pressure sore of Stage II or greater is more likely to be reliable [15]. Literature shows that pressure sores prevalence rates should not be used as a measure of the quality of care and incidence rates may only be used as an indicator of the quality of the preventive care if the patient's risk of developing a sore is taken into account [17]. Pressure relieving interventions when evaluated as an aid to the healing of pressure sores, wound healing rates are taken into consideration. Both objective and subjective measures are widely used by researchers. Most subjective measures, such as visual estimates of oedema, erythema, granulation, pus and debris, are unlikely to be applied consistently between wounds or by different assessors. Unless assessment is blinded to treatment allocation this method is likely to result in significant biases [15]. Objective measures of healing are usually based on wound area and/or volume. Measurements of wound volume are infrequently reported in the literature. These methods are often cumbersome and their accuracy has not been proven [15] Even though objective measures reduce or eliminate subjective biases and reduce random measurement errors, they cannot address inherent biases if the patients being compared have wounds of different baseline size. The major outcomes considered are incidence of new pressure sores, stage of new pressure sores, quality of life, reliability of the system and cost effectiveness. Quality of life measures for patients who have pressure ulcers and/or who use pressure-relieving devices.

5.3.1 Data Collection and Data Synthesis

Data from included trials were extracted by two medical reviewers into prepared data extraction tables. If there are any discrepancies, they must be discussed and resolved. The data extracted from each trial are patient inclusion and exclusion criteria, care setting, key baseline variables such as age, sex, baseline risk, description of the interventions and numbers of patients randomized to each intervention, duration and extent of follow-up, outcomes (incidence and severity of new pressure sores), acceptability and reliability of devices [15]. The methodological quality of each trial should be assessed by two researchers independently to eliminate the bias. Relative risk for each trial must be calculated for different outcomes such as number of patients developing sore and the number of pressure sores healed. The 95% confidence intervals are included when sufficient detail for their calculation is provided.

5.4 Proposed Experiment

This aim of this project is to show that individual cell pressure control mattress is better than any standard, constant low pressure and alternating pressure mattress for the prevention and treatment of pressure sores. As individual cell pressure control mattress has more flexibility, it can be used either as constant low pressure mattress, alternating pressure mattress with different modes. This project concentrates on comparison of constant low pressure mattress, alternate pressure mattress (AB mode) and ABCDE mode. AB mode means the air cells of the mattress have A and B pressure in alternate manner and in ABCDE mode the pressure in cells alternate in ABCDE manner where A, B, C, D and E are different pressures. The Table 5.3 shows the mechanism of ABCDE

mode alternating pressure mattress having 18 air cells. As the head portion has three cells the pressure in these cells is same. Cells 4,9,14 has pressure A, cells 5,10,15 has pressure B, cells 6,11,16 has pressure C, cells 7,12,17 had pressure D and cells 8,13,18 has pressure E.

Table 5.3 Mechanism of ABCDE Alternating Pressure Mattress

1. Head
2. Head
3. Head
4. Pressure A
5. Pressure B
6. Pressure C
7. Pressure D
8. Pressure E
9. Pressure A
10. Pressure B
11. Pressure C
12. Pressure D
13. Pressure E
14. Pressure A
15. Pressure B
16. Pressure C
17. Pressure D
18. Pressure E

The population required for this experiment is SCI and moderate obesity patients with high risk of developing pressure sores. The inclusion and exclusion criteria should be mentioned. Patients of any age between 20 to 60 years are included. Gender of the patient is not taken into consideration for inclusion. As previous studies shows that clinical judgment is better than any risk assessment scale, clinical judgment should be used for identifying people at high risk. Risk assessment scale can be used as a supplement with this. Even previous studies shows that it is not clear which scale is better

for assessing risk for developing pressure sores, so any scale can be used but should be same for all trials. Once the patients are selected, they are randomly allocated to different air mattress as randomized controlled trials provide better evidences [17]. As this experiment focuses on prevention of pressure sores, the effect of mattress was assessed by the presence of at least one pressure sore of stage two or higher as it is a better way of evaluating air mattress [15]. Incidence rates are used as an indicator of quality of support surface rather than prevalence rates [17].

For this proposed experiment, mattresses having same cell size should be used for each group to neglect the effect of cell size and to evaluate the mattresses according to the sophistication of these mattresses. The main parameter for comparison between constant low pressure air mattress, AB mode alternating air pressure mattress and ABCDE mode alternating pressure mattress are range of pressure in air cell, level of firmness of the mattress. The firmness of mattresses is divided into two parts soft and firm. Soft firmness means a pressure from 20mmHg to 50mmHG and firm means a pressure from 50mmhg to 80mmhg. The soft level is further divided into lower range which is from 20 to 35 mmHg of pressure and higher range from 35mmHg to 50 mmHg of pressure. Same way firm level is also divided into lower range which is from 50mmHg to 65mmHg of pressure and higher range from 65mmHg to 80mmHg of pressure. In order to compare these different groups, 50 patients per each group are selected. Previous studies show that when there are more patients the outcome gives better results. Previous studies had selected 20 to 150 patients per each group [17]. Table 4.4 shows the way of allocating patients into different settings. Hence, for this experiment it required 600 patients either SCI patients or patients with moderate obesity or both.

Table 5.4 Distribution of Patients for the Experiment

Firmness- Range/ Mode	Standard/ Constant Low pressure	AB Mode Alternating pressure	ABCDE Mode Alternating Pressure
Soft- Lower	50	50	50
Soft-Higher	50	50	50
Firm-Lower	50	50	50
Firm-Higher	50	50	50

The data from each setting are extracted by a single reviewer into pre-prepared data extraction tables and are checked by second reviewer to eliminate the bias. The data extracted are type of mattress mode, firmness level and range, key baseline variables like age, sex, baseline risk, number of patient randomized to each setting, duration and extend of follow-up. The follow-up period of 2 weeks is chosen for this experiment as most of the previous studies comparing different support surface for pressure sore prevention has used the same period. If this follow-up period is not enough to evaluate the mattresses, a second follow up-period of 1 month from the date of start of the care is chosen. The data extraction table records the outcome, reliability and acceptability of mattresses. For evaluating the mattresses, incidence rates of pressure sores of Stage II or higher in patient without sores at the entry should be taken into consideration and relative risk is calculated using confidence interval of 95% to show the reliability of each system.

CHAPTER 6

HYPOTHESIZED RESULTS AND DISCUSSION

6.1 Results from Comparative Study of the Three Pressure Relieving Surfaces

Application of the proposed experiment requires 600 patients having high risk of developing pressure sores and all of these 600 patients needs to lie down on the mattresses for a long period, approximately 2 to 4 months or more. As it is not easy to get patients and due to time constraints in this project, just a prediction of the results is done based on previous research. There are several studies done for evaluating support surfaces for the prevention of pressure sores. Several comparisons were done between alternating pressure supports and standard/constant low pressure support. Even there are few studies that compared different types of alternating supports.

6.1.1 Results for Comparison Between AP Mattress and Standard Mattress

The results from one of randomized controlled trial (RCT) from one study comparing alternating pressure mattress and standard hospital mattress shows that the alternating pressure support surfaces reduces the incidence of pressure sores as compared with standard hospital mattress (RR= 0.32; 95% CI, 0.14 to 0.74) [15]. Table 6.1 shows the results obtained from the comparison of AP mattress and standard mattress when incidence of pressure of Stage II or greater is considered as a measure of outcome.

Table 6.1 Results from the Comparison Between AP Mattress and Standard Mattress, when Incidence of Pressure Sores of Stage II or Greater is Considered as a Measure of Outcome [15][17]

Study	Patients	Devices (sample size)	Follow-up period	Incidence of pressure sores in patients without sores at entry	Healing of established sores	Notes
Andersen et al., 1982[42]	Acute patients with high risk of pressure sores (own sore scale) without existing pressure sores	1. Alternating air mattress (166) 2. Water-filled mattress (155) 3. Standard mattress (161)	10 days	Grade 2 or greater sores: Alternating air mattress, 4.2% (7/166) Water-filled mattress, 4.5% (7/155) Standard mattress, 13.0% (21/161)	-	118/600 selected patients withdrew in the first 24 hours, before skin inspection The alternating air mattress is easily punctured and in this study was not always set at the optimum pressure The water-filled bed is heavy and time-consuming to fill Patients were more satisfied with the ordinary bed; they complained about the noise and pressure changes of alternating air mattress

6.1.2 Results from Comparison between AP Mattress and Constant Low Pressure Mattress

The results from one study comparing a range of AP supports with a range of CLP supports in a range of specialties in acute-care setting shows significantly more pressure sores in patients in CLP group (34% compared to 13% in the AP group), (RR=0.38; 95% CI, 0.22 to 0.66) [15]. There are many studies which had compared AP devices with CLP devices and thy shows conflicting evidences to their relative effectiveness [17]. In one of

the study comparing AP and CLP devices results shows that eight of the twenty patients allocated to a variety of low pressure supports developed Stage II or greater pressure sores compared to none of the twenty three patients allocated to AP support. [17]. Table 6.2 shows the results obtained from the study in which incidence of pressure sores of Stage II or greater is considered as measure of outcomes.

Table 6.2 Results from the Comparison Between AP Mattress and CLP Mattress, when Incidence of Pressure Sores of Stage II or Greater is Considered as a Measure of Outcome [17]

Study	Patients	Devices (sample size)	Follow-up period	Incidence of pressure sores in patients without sores at entry	Healing of established sores	Notes
Gebhardt, 1994[54]	Newly admitted patients aged >18 years in intensive care unit, oncology, general medicine, care of the elderly, orthopaedic). Norton scores <14 and no existing pressure sores Groups well matched at baseline for age, sex and Norton score	1. Alternating pressure air mattresses (115): various 2. Constant low-pressure supports (115): foam, fibrefill, air, water, gel (various) Patients with deteriorated sores were transferred to a more sophisticated medium-cost support in the same group (e.g. Pegasus, Nimbus, Orthoderm, Convertible, Roho)	Mean 16 days	Grade 2 or greater sore: 1. Alternating pressure, 16% (18/115) 2. Constant low-pressure, 55% (63/115)	-	Analysis by intention to treat Mechanical unreliability and poor management of alternating pressure supports was a problem

The Table 6.3 shows the results obtained from studies in which incidence of pressure sores of any Stage are considered as a measure of outcomes.

Table 6.3 Results from the Comparison Between AP Mattress and CLP Mattress, when Incidence of Pressure Sores of Any Stage is Considered as a Measure of Outcomes [15]

Study	Patients	Devices (sample size)	Follow-up period	Incidence of pressure sores in patients without sores at entry	Healing of established sores	Notes
Conine et al., 1990[51]	Non-geriatric adult patients (aged 18–55 years) in an extended care facility for chronic neurological conditions; Norton score ≤14	1. Alternating air overlay (72): 10 cm air cells; manufacturer not given 2. Silicore (Spenco) overlay (76): siliconised hollow fibres in waterproofed cotton, placed over standard hospital mattress	3 months	Included grade I sores: 1. Alternating air overlay, 54% (39/72) 2. Spenco overlay, 59% (45/76)	The alternating air overlay group had a slightly lower Exton-Smith severity score (1.59 vs 1.69) and a shorter healing duration (25 days vs 29 days); these differences were not statistically significant	The alternating air overlay needed frequent monitoring and expensive prolonged repairs. It was reported that the patients sank into the Spenco overlay and found it difficult to move. Patients complained of bad odour build-up, instability (especially of the Spenco), and the noise of the alternating pressure motor. High dropout rate due to discomfort
Daechsel and Conine, 1985[52]	Patients , aged 19–60 years, in a long-term care hospital for chronic neurological conditions at high risk of developing pressure sores, but with no pressure sores at entry	1. Alternating pressure overlay (16): Gaymar 2. Silicore (JW Westman Inc.) overlay (16)	3 months	Included grade I scores: 1. Alternating pressure overlay, 25% (4/16) 2. Spenco overlay, 25% (4/16) No statistically significant differences were found between the two groups with regard to location and severity of pressure sores	-	100% follow-up Patients' satisfaction was similar for both devices

6.1.3 Results from Comparison Between AB Mode AP Mattress and ABCDE Mode AP Mattress

There are several comparisons done between different types of AP mattresses for the prevention of pressure sores. The depth of the air cells, the mechanical robustness and sophistication vary between different alternating pressure devices, and these factors may be important in determining effectiveness [17]. As alternating pressure devices differs in structures including the size of the inflatable air cells, the results from previous studies comparing different AP mattresses are unclear [17]. Also previous studies show that, the trials used to compare different alternating pressure mattresses did not adequately describe the equipment being evaluated, including the size of the air cells. In this proposed experiment, mattresses with same cell size are used and hence, the comparison is solely based on the sophisticated features of the mattresses. The ABCDE mode mattress has more flexibility in selection of number of chambers to be operated, level of firmness, range of firmness level, pressure setting in different chambers, than AB mode mattress. In ABCDE mode AP mattress five different pressures can be set in five different cells supporting the high pressure intensity portions of the body and hence it might provide a better pressure relief in high pressure regions. So ABCDE mode has better resolution in selecting different pressure in different number of cells than AB mode mattress (i.e., two pressures in AB mattress versus five pressures in ABCDE mattress).

This shows that ABCDE mode mattress has more sophistication than AB mode AP mattress. Hence, ABCDE mode mattress may be able to provide better options for the prevention of pressure sores due to presented features, than existing mattresses. But subject testing is required to validate this belief.

6.2 Discussion

In this project, a comparison between standard, alternating pressure (AP) mattress and individual cell pressure control (ICPC) air mattress is shown. Both AP and ICPC have more sophisticated features than standard mattresses. Thus, the major comparison is shown between AP and ICPC mattress. ICPC mattress have better control of pressure as it uses upper and lower limits of pressures as a reference rather than only one pressure. This makes the system more stable against the unwanted small changes in pressure due to little movements of the patient body.

The interface pressure between different parts of the patient's body and different cells of the air mattress are different. Pressures at the heels, ankles, shoulders, lower back, buttocks, and head region which are more likely to develop pressure sores in SCI and moderate obesity patients would be more than the other portions of the body. Also pressure at the different points in the larger region of the body such as shoulders and lower back and buttock would not be the same. If an AP mattress is used then these portions of the body would be exposed to just two different pressure range of the mattress. If an individual cell pressure control mattress is used then different pressures in each chamber can be set according to the intensity of the pressure at that particular chamber. Hence, as the modified system provides more flexibility in selection of pressures it may have a better pressure relieving property than an AP mattress.

The individual cell pressure control mattress is a closed loop system and AP mattress is an open loop system. In AP mattress, the system does not respond to any change in the pressure inside the chamber due to external force or position change of the patient. This will increase the pressure on the patient body and the risk of developing

pressure sores increases. An operator is required to make changes in the settings if the pressure at any portion of the patient body changes by a remarkable value. But in ICPC mattress, the system gets feedback. Hence, if the pressure inside the mattress increases due to an external force or patients position change, it can respond to relieve the increased pressure either by inflating or deflating the chambers automatically according to the software settings.

The pressure sensor has a range of around 6mV/10mmHg, which is a very low resolution and increases quantization error. The output from the voltage offset removal circuit with a gain of 10 has a range of approximately 60mV/10mmHg. Hence, this circuit increases range of the output from the pressure sensor and thereby increases resolution. This leads to the increase in system resolution.

The modified system has a software control rather than a hardware control. The software used has a good data acquisition capabilities and it is user friendly which makes the system operation easy. The modified system provides more flexibility by operating in different mode such as standard, AP or ICPC mattress.

The validity and reliability of the system is checked by measuring the output from the pressure sensor for different pressures inside the chamber. To know the exact pressure inside the chamber, a sphygmomanometer is connected to the chamber. The pressure sensor output (after offset voltage removal and by providing a gain of 10) for 0mmHg to 105mmHg is measured. These values are compared to the theoretical values and percentage of error is calculated. These obtained outputs values in Volts are taken as a reference values instead of the pressure in mmHg. These results have an average error of 0.95%.

In accuracy test, the system is operated at various levels of action and firmness and the system is checked by setting different pressure ranges for different chambers. When the system reaches the preset pressure for each chamber, the output of the pressure sensor is measured. In addition, the actual pressure hold by the chamber is measured by sphygmomanometer. The output of the pressure sensor in Volts is converted into mmHg value and is matched with the sphygmomanometer reading. Percentage of error is calculated for these outputs. The results show that the system has maximum error of 2.05% when it is operated up to the range of 75mmHG. This shows that the system is accurate till this range.

The reliability of the system is check by inflating and deflating each chamber for a particular pressure range for five numbers of times, and each time the output of the pressure sensor for each pressure range for each chamber is measured. To find the variability, standard deviation of the outputs obtained for the same chamber and same pressure range are calculated. Percentage of error is also calculated to show the reliability of the system. The system has maximum 3.21% of error when the system is operated five numbers of times which shows that the system is reliable.

The feedback of the system is also checked by the feedback validation test. The results of this test show that the system has the ability to recover the change in pressure by using the feedback. The system also neglects the short period impulse of force and it remains stable. Also, the system has many safety features against total power loss and leakage in the system.

CHAPTER 7

CONCLUSION

This study is based on improvement of the current assistive technology available to the SCI and moderate obesity patients suffering from pressure sores. In this study a comparison between various mattresses and the ICPC mattress is shown to evaluate these mattresses for the prevention of pressure sores. From the discussion, it has become clear that ICPC has more sophisticated features than both standard/constant low pressure mattress and AP mattress. The ICPC mattress has greater flexibility in selecting number of chambers, pressure range, and firmness level than AP mattress. In ICPC mattress it is possible to set any pressure range from 0mmHg to 100mmHg in any cell, but the system is checked only up to 75mmHg pressure. The pressure relief quality of the modified system might be better than AP mattress but patient study is required to validate this belief.

The engineering data such as the output from the pressure sensor, the results of the accuracy test, the results from the repeatability test and the results from the system feedback validation test show that the system is safer, more reliable and more accurate. The modified system includes additional mechanical components such as directional control valves and a pump which may requires maintenance or service in long term. But as individual cell pressure control air mattress is more flexible, it is hypothesized that it has the more potential to prevent of pressure sores in SCI and moderate obesity patients having high risk of developing pressure sores. This system is ready for further scientific study.

CHAPTER 8

FUTURE DEVELOPMENTS

The individual cell pressure control air mattress system requires a lot of hardware and also more space to be installed. Future research is needed to replace a computer and hardware circuits by a small microcontroller. A PDA version of LabVIEW® 8 can be used that is more portable than the current system. Scientific studies can be conducted using the proposed experiment to evaluate this system for the prevention of pressure sores in SCI and moderate obesity patients. This system has independent control of each chamber and it can be operated in different patterns such as wave, pulsation which may improve the blood circulation and it might have therapeutical benefits, but further research and patient studies are needed.

APPENDIX A

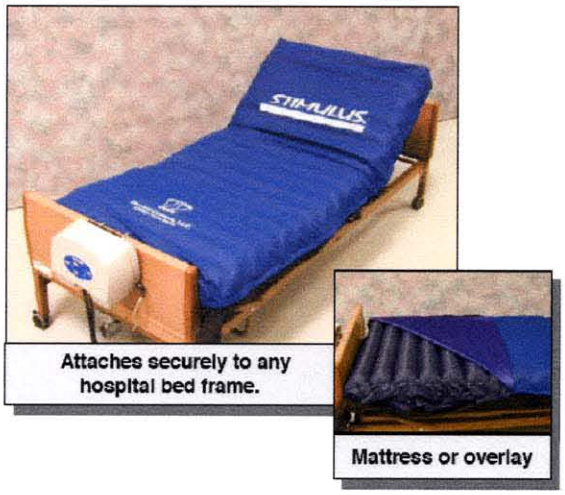
SPECIFICATION AND FEATURES OF THE AP AIR MATTRESS

This appendix describes the features, specifications and structure of the Stimulus Plus Alternating Pressure Mattress.

STIMULUS PLUS™
Alternating Pressure Mattress

Structure:	Powered mattress system
Therapy:	Pressure-relief
Therapy Type:	Dynamic alternating pressure
Cost:	Medium high
HCPCS Code:	E0277; Group 2
Size:	80" x 35" x 9" *
Weight Limit:	350 lbs.

* *Available as mattress or overlay.*



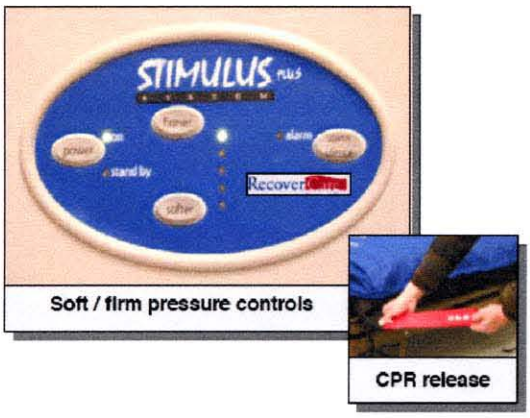
Description:

Stimulus products utilize *dynamic alternating pressure* technology. A powered, microprocessor-driven pump controls the time of exposure to pressure and stimulates a physiologic response that promotes blood flow to the wound site. Cushion pressure alternates on a frequent and automatic basis.

Clinical Considerations:

- Multiple stage 2, 3 or 4 pressure ulcers.
- Gradient high pressure induces reactive hyperemia (capillary refill).

Features	
Quiet Operation:	Whisper quiet control unit.
Power Alarm:	Indicates loss of power or sudden drop in pressure.
Power Outage Protection:	Remains inflated up to 12 hours in a power-loss.
Cleaning:	Top cover is easily cleaned by wiping with mild soap & water; air-dry.
Low Power Consumption:	Less than 20 watts per hour.
Cover:	Waterproof and vapor-permeable stretch cover reduces friction and shear.



RecoverCare®
Bariatric & Wound Technologies

APPENDIX B

SPECIFICATION OF THE PRESSURE SENSOR MPX5100AP

This appendix describes about the specifications of the pressure sensor used in this project. It shows the data sheet of MPX5100AP pressure sensor. Details such as supply voltage, operating conditions, range of the pressure and range of output voltage are described in this appendix.

Table 1. MAXIMUM RATINGS(NOTE)

Rating	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	400	kPa
Storage Temperature	T_{stg}	–40° to +125°	°C
Operating Temperature	T_A	–40° to +125°	°C

NOTE: Exposure beyond the specified limits may cause permanent damage or degradation to the device.

Table 2. OPERATING CHARACTERISTICS (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range[1] Gauge, Differential: MPX5100D/MPX5100GC/MPXV5100G Absolute: MPX5100A	P_{OP}	0 15	—	100 115	kPa
Supply Voltage[2]	V_S	4.75	5.0	5.25	Vdc
Supply Current	I_o	—	7.0	10	mAdc
Minimum Pressure Offset[3] (0 to 85°C) @ V_S = 5.0 Volts	V_{off}	0.088	0.20	0.313	Vdc
Full Scale Output[4] Differential and Absolute (0 to 85°C) @ V_S = 5.0 Volts	V_{FSO}	4.587	4.700	4.813	Vdc
Full Scale Span[5] Differential and Absolute (0 to 85°C) @ V_S = 5.0 Volts	V_{FSS}	—	4.500	—	Vdc
Accuracy[6]	—	—	—	± 2.5	$\%V_{FSS}$
Sensitivity	V/P	—	45	—	mV/kPa
Response Time[7]	t_R	—	1.0	—	ms
Output Source Current at Full Scale Output	I_{o+}	—	0.1	—	mAdc
Warm-Up Time[8]	—	—	20	—	ms
Offset Stability[9]	—	—	± 0.5	—	$\%V_{FSS}$

NOTES:
1. 1.0kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm-up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

Table 3. MECHANICAL CHARACTERISTICS

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams
Weight, Basic Element (Case 482)	1.5	grams

APPENDIX C

SPECIFICATION OF NI DAQ PCI 6024E CARD

This appendix describes about the specifications, operating condition and features of the data acquisition card PCI 6024E. It shows the data sheet of NI DAQ PCI 6024E.

E Series Multifunction DAQ Specifications

12-Bit E Series (NI 607xE, NI 606xE, NI 604xE, NI 602xE)

These specifications are typical for 25 °C unless otherwise noted.

Analog Input

Accuracy specifications ..... See tables in E Series Product pages.

Input Characteristics

Number of channels

6070E 6060E 6062E 604xE 602xE	16 single-ended or 8 differential (software selectable per channel)
6071E 6061E	64 single-ended or 32 differential (software selectable per channel)

Type of ADC ..... Successive approximation
Resolution ..... 12 bits, 1 in 4,096
Maximum sampling rate

607xE	1.25 MS/s
606xE	500 kS/s
604xE	500 kS/s single-channel scanning 250 kS/s multichannel scanning
6061E	500 kS/s single-channel scanning 333 kS/s multichannel
6023E 6024E 6025E	200 kS/s
6020E 6021E	100 kS/s

Streaming-to-disk rate (system dependent)

607xE	1.25 MS/s
606xE	500 kS/s
604xE	250 kS/s
6023E 6024E 6025E	200 kS/s
6020E 6021E	100 kS/s[1]
Streaming-to-disk rates do not apply to RT Series devices.	
[1] DAQPad-6020E rates with SCSI or DMA-enabled EIDE.	

Input signal ranges

Device	Range (Software Selectable)	Input Range	
		Bipolar	Unipolar
607xE	20 V	±10 V	–
606xE	10 V	±5 V	0 to 10 V
604xE	5 V	±2.5 V	0 to 5 V
6020E	2 V	±1 V	0 to 2 V
6021E	1 V	±500 mV	0 to 1 V
	500 mV	±250 mV	0 to 500 mV
	200 mV	±100 mV	0 to 200 mV
	100 mV	±50 mV	0 to 100 mV
6023E	20 V	±10 V	–
6024E	10 V	±5 V	–
6025E	1 V	±500 mV	–
	100 mV	±50 mV	–

Input coupling ..... DC
Maximum working voltage
(signal + common mode) ..... Input should remain within ±11 V of ground

Overvoltage protection

Device	Powered On	Powered Off
607xE 606xE 604xE	±25 V	±15 V
6023E 6024E 6025E	±40 V	±25 V
6020E 6021E	±35 V	±25 V

Inputs protected

6070E, 6060E 6062E, 604xE 602xE	ACH<0..15>, AISENSE
6071E, 6061E	ACH<0..63>, AISENSE, AISENSE2

FIFO buffer size

AT-MIO-16E-1 DAQCard-6062E	8,192 samples
DAQPad-6020E	4,096 samples
6060E/6061E DAQPad-6070E DAQCard-6024E	2,048 samples
6041E	1,024 samples
PCI-MIO-16E-1 PXI-6070E 6071E, 6040E PCI-602xE (except DAQPad) PXI-6025E	512 samples

Data transfers
PCI, PXI, AT, DAQPad for IEEE 1394 ..... DMA, interrupts, programmed I/O
DAQCard, DAQPad for USB ..... Interrupts, programmed I/O
DMA modes
PCI, PXI, DAQPad for IEEE 1394 ..... Scatter-gather (single-transfer demand transfer)
AT ..... Single transfer demand transfer
Configuration memory size ..... 512 words

Transfer Characteristics

Relative accuracy

Device	Typical Dithered	Maximum Undithered
607xE 606xE 604xE 6023E 6024E 6025E	±0.5 LSB	±1.5 LSB
6020E 6021E	±0.2 LSB	±1.5 LSB

DNL

Device	Typical	Maximum
607xE 6060E 6061E 604xE 6023E PCI-6024E 6025E	±0.5 LSB	±1.0 LSB
6020E 6021E	±0.2 LSB	±1.0 LSB
6062E DAQCard-6024E	±0.75 LSB	-0.9, +1.5 LSB

No missing codes ..... 12 bits, guaranteed

E Series Multifunction DAQ — Specifications

12-Bit E Series (NI 607xE, NI 606xE, NI 604xE, NI 602xE) (continued)

Amplifier Characteristics

Input impedance

Device	Normal Powered On	Powered Off	Overload
6070E 606xE 6040E PCI-6071E PXI-6071E	100 GΩ in parallel with 100 pF	820 Ω	820 Ω
6041E	100 GΩ in parallel with 100 pF	1 kΩ	1 kΩ
602xE	100 GΩ in parallel with 100 pF	4.7 kΩ	4.7 kΩ

Input bias current ..... ±200 pA
Input offset current ..... ±100 pA

CMRR, DC to 60 Hz

Device	Range	CMRR
607xE	20 V	96 dB
6060E	10 V	100 dB
6061E	100 mV to 5 V	106 dB
604xE	10 to 20 V	85 dB
6062E	5 V	95 dB
	100 mV to 2 V	100 dB
6023E	10 to 20 V	85 dB
6024E	100 mV to 1 V	90 dB
6025E		
6020E	100 mV to 20 V	90 dB
6021E		

Dynamic Characteristics

Bandwidth

Device	Small Signal (-3 dB)	Large Signal (1% THD)
607xE	1.6 MHz	1 MHz
6060E/6061E	1 MHz	300 kHz
6062E	1.3 MHz	250 kHz
6041E	800 kHz	400 kHz
6040E	600 kHz	350 kHz
6023E PCI-6024E 6025E	500 kHz	225 kHz
DAQCard-6024E	500 kHz	265 kHz
6021E	150 kHz	120 kHz

Settling time to full-scale step

Device	Range	Accuracy ±0.012% (±0.5 LSB)	Accuracy ±0.024% (±1 LSB)	Accuracy ±0.098% (±4 LSB)
6070E	20 V	2 µs typical 3 µs max	1.5 µs typical 2 µs max	1.5 µs typical 2 µs max
	10 V	2 µs typical 3 µs max	1.5 µs typical 2 µs max	1.3 µs typical 1.5 µs max
	200 mV to 5 V	2 µs typical 3 µs max	1.5 µs typical 2 µs max	0.9 µs typical 1 µs max
	100 mV	2 µs typical 3 µs max	1.5 µs typical 2 µs max	1 µs typical 1.5 µs max
PCI-6071E PXI-6071E	20 V	3 µs typical 5 µs max	1.9 µs typical 2.5 µs max	1.9 µs typical 2 µs max
	10 V	3 µs typical 5 µs max	1.9 µs typical 2.5 µs max	1.2 µs typical 1.5 µs max
	200 mV to 5 V	3 µs typical 5 µs max	1.9 µs typical 2.5 µs max	1.2 µs typical 1.3 µs max
	100 mV	3 µs typical 5 µs max	1.9 µs typical 2.5 µs max	1.2 µs typical 1.5 µs max
6060E	All	2 µs typical 4 µs max	1.9 µs typical 2 µs max	1.8 µs typical 2 µs max
6061E		5 µs max	3 µs max	2 µs max
6062E	All	2.5 µs typical 4 µs max	2.5 µs typical 3 µs max	2 µs typical 2.5 µs max
604xE	All	4 µs typical 8 µs max	4 µs max	4 µs max
6023E 6024E 6025E	All	5 µs typical	5 µs max	5 µs max
6020E 6021E	All	10 µs max	10 µs max	10 µs max

System noise (LSBrms, not including quantization)

Device	Range	Dither Off	Dither On
6070E	1 to 20 V	0.25	0.5
PCI-6071E	500 mV	0.4	0.6
PXI-6071E	200 mV	0.5	0.7
	100 mV	0.8	0.9
6060E	200 mV	0.3	0.6
6061E	100 mV	0.5	0.7
6062E	1 to 20 V	0.25	0.6
	500 mV	0.4	0.75
	200 mV	0.5	0.8
	100 mV	0.8	1.0
604xE	1 to 20 V	0.2	0.5
	500 mV	0.25	0.5
	200 mV	0.5	0.7
	100 mV	0.9	1.0
6023E	1 to 20 V	0.1	0.6
PCI-6024E, 6025E	100 mV	0.7	0.8
DAQCard-6024E	10 to 20 V	0.1	0.65
	1 V	0.45	0.65
	100 mV	0.70	0.90
6020E	1 to 20 V	0.07	0.5
6021E	500 mV	0.12	0.5
	200 mV	0.25	0.6
	100 mV	0.5	0.7

Crosstalk, DC to 100 kHz

Device	Adjacent Channels	All Other Channels
607xE, 606xE, 604xE	-75 dB	-90 dB
602xE	-60 dB	-80 dB

E Series Multifunction DAQ Specifications

12-Bit E Series (NI 607xE, NI 606xE, NI 604xE, NI 602xE) (continued)

Analog Output

Output Characteristics

Number of channels

607xE 606xE 6040E 6020E 6021E 6024E 6025E	2 voltage outputs
6041E 6023E	None

Resolution ..... 12 bits, 1 in 4096

Type of DAC ..... Double buffered, multiplying

Maximum update rate

Device	Waveform Generation			
	FIFO Mode		Non-FIFO Mode	
	Internally Timed	Externally Timed	1 Channel	2 Channels
607xE 6060E, 6061E 6040E	1 MS/s	950 kS/s	800 kS/s, system dependent	400 kS/s, system dependent
6062E	850 kS/s	850 kS/s	800 kS/s, system dependent	400 kS/s, system dependent
6023E PCI-6024E 6025E	N/A	N/A	10 kS/s with DMA 1 kS/s with interrupts system dependent	10 kS/s with DMA 1 kS/s with interrupts system dependent
DAQCard-6024E	N/A	N/A	1 kS/s with interrupts system dependent	1 kS/s with interrupts system dependent
6020E; except DAQPad-6020E	N/A	N/A	100 kS/s, system dependent	100 kS/s, system dependent
DAQPad-6020E	N/A	N/A	20 S/s, system dependent	20 S/s, system dependent

FIFO buffer size

607xE, 606xE	2,048 samples
6040E	512 samples
602xE	None

Data transfers

PCI, PXI, AT, DAQPad for IEEE 1394 ..... DMA, interrupts, programmed I/O

DAQCard, DAQPad for USB ..... Interrupts, programmed I/O

DMA modes

PCI, PXI, DAQPad ..... Scatter-gather (single transfer demand transfer)

AT ..... Single transfer demand transfer

Transfer Characteristics

Relative accuracy

After calibration (6062E, DAQCard-6024E) ..... ±0.5 LSB typical, ±1.0 LSB max

After calibration (all others) ..... ±0.3 LSB typical, ±0.5 LSB max

Before calibration ..... ±4 LSB max

DNL

After calibration (6062E, DAQCard-6024E) ..... ±0.5 LSB typical, ±1.0 LSB max

After calibration (all others) ..... ±0.3 LSB typical, ±1.0 LSB max

Before calibration ..... ±3 LSB max

Monotonicity ..... 12 bits, guaranteed after calibration

Gain error (relative to external reference)

6062E ..... ±0.5% of output max, not adjustable

All others ..... 0 to 0.67% of output max, not adjustable

Voltage Output

Ranges

607xE, 6060E 6061E, 6040E 6020E, 6021E	±10 V, 0 to 10 V, ±EXTREF, 0 to EXTREF; software selectable
6062E	±10 V, ±EXTREF, software selectable
6020E, 6021E 6024E, 6025E	±10 V

Output coupling ..... DC

Output impedance ..... 0.1 Ω max

Current drive ..... ±5 mA max

Protection ..... Short-circuit to ground

Power-on state ..... 0 V (±200 mV)

External reference input (not available on 6024E or 6025E)

Range ..... ±11 V

Overvoltage protection

607xE 606xE 604xE	±25 V powered on, ±15 V powered off
602xE	±36 V powered on, ±25 V powered off

Input impedance ..... 10 kΩ

Bandwidth (-3 dB)

607xE 6060E, 6061E 604xE	1 MHz
6062E	50 kHz
602xE	300 kHz

Dynamic Characteristics

Settling time and slew rate

Device	Settling Time for Full-Scale Step	Slew Rate
607xE 606xE 6040E	3 µs to ±0.5 LSB accuracy	20 V/µs
602xE	10 µs to ±0.5 LSB accuracy	10 V/µs

Noise ..... 200 µVrms, DC to 1 MHz

Glitch energy (at mid-scale transition)

Magnitude

Device	Regltching Disabled	Regltching Enabled
DAQPad-6070E PCI-MIO-16E-1 PCI-6071E PXI-6070E PXI-6071E	±20 mV	±4 mV
AT-MIO-16E-1 6060E, 6061E 604xE	±200 mV	±30 mV
PCI-6024E 6025E	±42 mV	N/A
DAQCard-6024E	± 13 mV	N/A
6020E 6021E	±100 mV	N/A
6062E	±80 mV	±30 mV

Duration

607xE 6060E, 6061E 604xE	1.5 µs
6024E 6025E	2 µs
6020E 6021E 6062E	3 µs

Stability

Gain temperature coefficient

External reference ..... ±25 ppm/°C

Digital I/O

Number of channels

6021E 6025E	32 input/output
All others	8 input/output

E Series Multifunction DAQ — Specifications

12-Bit E Series (NI 607xE, NI 606xE, NI 604xE, NI 602xE) (continued)

Compatibility ..... 5 V/TTL
Power-on state ..... Input; high impedance
Digital logic levels
DIO<0..7> on all devices
PA<0..7>, PB<0..7>, PC<0..7> on remaining 24 lines of 6021E and 6025E

Level	Minimum	Maximum
Input low voltage	0 V	0.8 V
Input high voltage	2 V	5 V
Output low voltage (I_{out} = 24 mA)	–	0.4 V
Output high voltage (I_{out} = 13 mA)	4.35 V	–

Level	Minimum	Maximum
Input low voltage	0 V	0.8 V
Input high voltage	2 V	5 V
Output low voltage (I_{out} = 2.5 mA)	–	0.4 V
Output high voltage (I_{out} = 2.5 mA)	3.9 V	–

Data transfers

6021E 6025E	Interrupts, programmed I/O
All others	Programmed I/O

Handshaking (6021E and 6025E only)
Direction ..... Input or output
Modes 2-wire
Transfer rate (1 word = 8 bits)
Maximum with NI-DAQ™, system dependent

DAQPad-6070E	5 kwords/s
All others	50 kwords/s

Constant sustainable rate ..... 1 to 10 kwords/s, typical

Timing I/O

General-Purpose Up/Down Counter/Timers

Number of channels 2
Resolution ..... 24 bits
Compatibility ..... 5 V/TTL
Digital logic levels

Level	Minimum	Maximum
Input low voltage	0 V	0.8 V
Input high voltage	2 V	5 V
Output low voltage (I_{out} = 5 mA)	–	0.4 V
Output high voltage (I_{out} = 3.5 mA)	4.35 V	–

Base clocks available ..... 20 MHz and 100 kHz
Base clock accuracy ..... ±0.01%
Maximum source frequency ..... 20 MHz
External source selections ..... PFI0..PFI9, RTSI0..RTSI6, analog trigger, software selectable
External gate selections ..... PFI0..PFI9, RTSI0..RTSI6, analog trigger, software selectable
Minimum source pulse duration ..... 10 ns
Minimum gate pulse duration ..... 10 ns, edge-detect mode
Data transfers
PCI, PXI, AT, DAQPad for IEEE 1394 ..... DMA, interrupts, programmed I/O
DAQCard, DAQPad for USB ..... Interrupts, programmed I/O
DMA modes
PCI, PXI, DAQPad for IEEE 1394 ..... Scatter-gather (single transfer, demand transfer)
AT ..... Single transfer, demand transfer

Frequency Scaler

Number of channels 1
Resolution ..... 4 bits
Compatibility ..... 5 V/TTL
Digital logic levels

Level	Minimum	Maximum
Input low voltage	0 V	0.8 V
Input high voltage	2 V	5 V
Output low voltage (I_{out} = 5 mA)	–	0.4 V
Output high voltage (I_{out} = 3.5 mA)	4.35 V	–

Base clocks available ..... 10 MHz, 100 kHz
Base clock accuracy ..... ±0.01%
Data transfers ..... Programmed I/O

Triggers

Analog Triggers

Number of triggers

607xE 606xE 604xE	1
602xE	None

Purpose
Analog input ..... Start and stop trigger, gate, clock
Analog output ..... Start trigger, gate, clock
General-purpose counter/timers ..... Source, gate
Source

6070E 6062E, 6060E 604xE, 602xE	ACH<0..15>, PFI0/TRIG1
6071E 6061E	ACH<0..63>, PFI0/TRIG1

Level
Internal source, ACH<0..15/63> ..... ±Full-scale
External source, PFI0/TRIG1 ..... ±10 V
Slope ..... Positive or negative; software selectable
Resolution ..... 8 bits, 1 in 256
Bandwidth (-3 dB)

Device	Internal Source	External Source
607xE	2 MHz	7 MHz
6060E, 6061E	1 MHz	7 MHz
6062E	500 kHz	2.5 MHz
604xE	2 MHz	3 MHz

Hysteresis ..... Programmable
Accuracy ..... ±5% of full-scale range max

Digital Triggers (all devices)

Number of triggers 2
Purpose
Analog input ..... Start and stop trigger, gate, clock
Analog output ..... Start trigger, gate, clock
General-purpose counter/timers ..... Source, gate
Source ..... PFI0..PFI9, RTSI0..RTSI6
Slope ..... Positive or negative; software selectable
Compatibility ..... 5 V/TTL
Response ..... Rising or falling edge
Pulse width ..... 10 ns minimum
External input for digital or analog trigger ..... (PFI0/TRIG1)
Impedance
6062E ..... 12 kΩ
All others ..... 10 kΩ
Coupling ..... DC
Protection
Digital trigger ..... -0.5 to Vcc + 0.5 V
Analog trigger
On/off/disabled ..... ±35 V

Calibration

Recommended warm-up time ..... 15 minutes; 30 minutes for DAQCard and DAQPad
Calibration interval ..... 1 year
Onboard calibration reference
DC level ..... 5.000 V (±3.5 mV) over full operating temperatures, actual value stored in EEPROM
Temperature coefficient ..... ±5 ppm/°C max
Long-term stability ..... ±15 ppm/$\sqrt{1000\ h}$

E Series Multifunction DAQ Specifications

12-Bit E Series (NI 607xE, NI 606xE, NI 604xE, NI 602xE) (continued)

RTSI (PCI, DAQPad-6070E for IEEE 1394, and ISA only)

Trigger lines
- PCI, ISA 7
- DAQPad for IEEE 1394 4

PXI Trigger Bus (PXI only)

- Trigger lines 6
- Star trigger 1

Bus Interface

- PCI, PXI, DAQPad for IEEE 1394 ..... Master, slave
- AT, DAQCard, DAQPad for USB ..... Slave

Power Requirements[1]

Device	+5 VDC (±5%)*	Power Available at I/O Connector
607xE	1.1 A	+4.65 to +5.25 VDC, 1 A
6060E, 6061E 6040E	1.0 A	+4.65 to +5.25 VDC, 1 A
602xE, (except DAQPad and DAQCard)	0.7 A	+4.65 to +5.25 VDC, 1 A
DAQCard-6062E	340 mA typical 750 mA maximum	+4.65 to +5.25 VDC, 250 mA
DAQCard-6024E	270 mA typical 750 mA maximum	±4.65 to +5.25 VDC, 250 mA
DAQCard-AI-16E-4	280 mA typical 400 mA maximum	+4.65 to +5.25 VDC, 250 mA

Device	Power	Power Available at I/O Connector
DAQPad-6020E	15 W*, +9 to +30 VDC	+4.65 to +5.25 VDC, 1 A
DAQPad-6070E	17 W*, +9 to +25 VDC	+4.65 to +5.25 VDC, 1 A

Discharge time with BP-1 battery pack

*Excludes power consumed through I/O connector.

- IEEE 1394 DAQPads ..... 2.5 hours, typical
- USB DAQPads ..... 3 hours, typical

Physical[1]

Dimensions (not including connectors)
- PCI[2] ..... 17.5 by 9.9 cm (6.9 by 3.9 in.)
- PXI ..... 16.0 by 10.0 cm (6.3 by 3.9 in.)
- AT (long) ..... 33.8 by 9.9 cm (13.3 by 3.9 in.)
- AT (short) ..... 17.5 by 9.9 cm (6.9 by 4.2 in.)
- DAQPad (30 cm enclosure) ..... 25.4 by 30.5 by 4.6 cm (10 by 12 by 1.8 in.)
- DAQPad (15 cm enclosure) ..... 14.6 by 21.3 by 3.8 cm (5.8 by 8.4 by 1.5 in.)
- DAQCard ..... Type II PC Card

I/O connector[2]

6070E 6060E 6040E 6020E 6023E PCI-6024E	68-pin male 0.050 D-type
DAQCard-6062E, DAQCard-6024E	68-pin female VHDCI
6071E 6061E 6021E 6025E	100-pin female 0.050 D-type
DAQCard-AI-16E-4	68-pin female PCMCIA

Environment

- Operating temperature ..... 0 to 55 °C; 0 to 40 °C for DAQCard-6062E and DAQCard-6024E with a maximum internal temperature of 70 °C as measured by onboard temperature sensor; case temperature should not exceed 55 °C for any DAQCard
- Storage temperature ..... -20 to 70 °C
- Relative humidity ..... 10 to 90%, noncondensing

Certifications and Compliances

CE Mark Compliance CE

1 Refer to RTSI™ specifications for available RTSI trigger lines.

2 See page 184 for RT Series devices power requirements and dimensions.

APPENDIX D

PIN ASSISGNMENT OF NI PCI DIO-96 DIGITAL I/O CONNECTOR

This appendix shows the pin assignment for data acquisition card PCI DIO 96 used in this project.

APC7	1	51	CPC7
BPC7	2	52	DPC7
APC6	3	53	CPC6
BPC6	4	54	DPC6
APC5	5	55	CPC5
BPC5	6	56	DPC5
APC4	7	57	CPC4
BPC4	8	58	DPC4
APC3	9	59	CPC3
BPC3	10	60	DPC3
APC2	11	61	CPC2
BPC2	12	62	DPC2
APC1	13	63	CPC1
BPC1	14	64	DPC1
APC0	15	65	CPC0
BPC0	16	66	DPC0
APB7	17	67	CPB7
BPB7	18	68	DPB7
APB6	19	69	CPB6
BPB6	20	70	DPB6
APB5	21	71	CPB5
BPB5	22	72	DPB5
APB4	23	73	CPB4
BPB4	24	74	DPB4
APB3	25	75	CPB3
BPB3	26	76	DPB3
APB2	27	77	CPB2
BPB2	28	78	DPB2
APB1	29	79	CPB1
BPB1	30	80	DPB1
APB0	31	81	CPB0
BPB0	32	82	DPB0
APA7	33	83	CPA7
BPA7	34	84	DPA7
APA6	35	85	CPA6
BPA6	36	86	DPA6
APA5	37	87	CPA5
BPA5	38	88	DPA5
APA4	39	89	CPA4
BPA4	40	90	DPA4
APA3	41	91	CPA3
BPA3	42	92	DPA3
APA2	43	93	CPA2
BPA2	44	94	DPA2
APA1	45	95	CPA1
BPA1	46	96	DPA1
APA0	47	97	CPA0
BPA0	48	98	DPA0
+5 V	49	99	+5 V
GND	50	100	GND

APPENDIX E

SPECIFICATION AND CAD DRAWING OF CONTROL VALVE

This appendix describes the CAD drawing, specifications and features of the directional control valve used in this project.

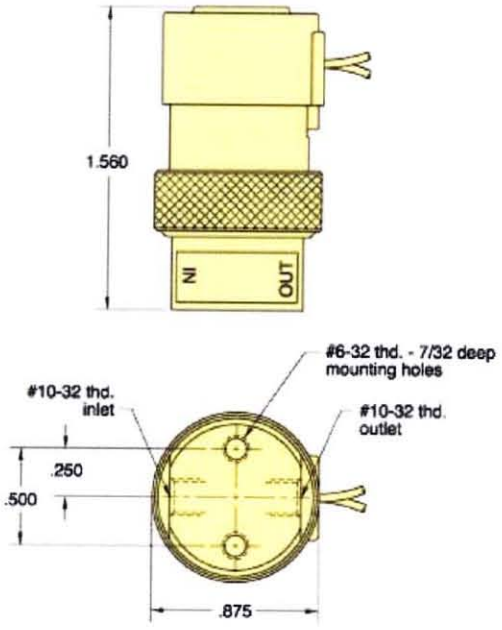


Figure E.1 CAD diagram of control valve.

Table E.1 Specifications of Control Valve

Medium:	Air (40 Micron Filtration)
Poppet Travel:	0.007"
Life Cycles:	Over 1 Billion
Response Time:	5-10 Milliseconds
Body Material:	Nickel Plated Brass
Control:	Electronics
Connection:	0.25 Square Pin Connector
Connector P/N:	C2-RB18
Connector:	AMP #103959-1
Used As:	Normally Closed
Function:	2 way valve
Ports:	10-32 Female Inline ports
Mounting:	#6-32 thd. Mounting Holes
Voltage:	12 Volts DC
Power:	0.67 watts
Pressure Range:	28" Hg Vac. to 105 PSIG
Flow:	0.6 SCFM @ 105 PSI
Temperature:	Minus 20 to 180 F

APPENDIX F

SPECIFICATION OF LM324 OP-AMP

This appendix describes about LM324 IC which is a low power quad op-amp. It is used In the voltage offset removal circuit. This appendix shows the pin diagram and specifications of the LM324.

Low power quad op amps

LM124/224/324/324A/ SA534/LM2902

DESCRIPTION

The LM124/SA534/LM2902 series consists of four independent, high-gain, internally frequency-compensated operational amplifiers designed specifically to operate from a single power supply over a wide range of voltages.

UNIQUE FEATURES

In the linear mode, the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage.

The unity gain crossover frequency and the input bias current are temperature-compensated.

FEATURES

- Internally frequency-compensated for unity gain
- Large DC voltage gain: 100dB
- Wide bandwidth (unity gain): 1MHz (temperature-compensated)
- Wide power supply range Single supply: $3V_{DC}$ to $30V_{DC}$ or dual supplies: $\pm1.5V_{DC}$ to $\pm15V_{DC}$
- Very low supply current drain: essentially independent of supply voltage (1mW/op amp at $+5V_{DC}$)
- Low input biasing current: $45nA_{DC}$ (temperature-compensated)
- Low input offset voltage: $2mV_{DC}$ and offset current: $5nA_{DC}$
- Differential input voltage range equal to the power supply voltage
- Large output voltage: $0V_{DC}$ to V_{CC}-$1.5V_{DC}$ swing

PIN CONFIGURATION

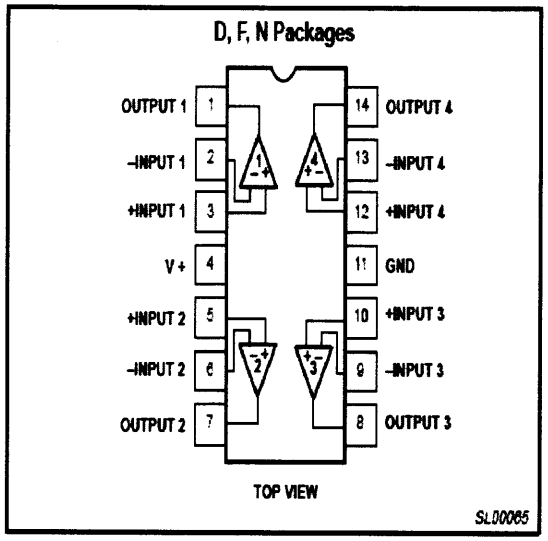
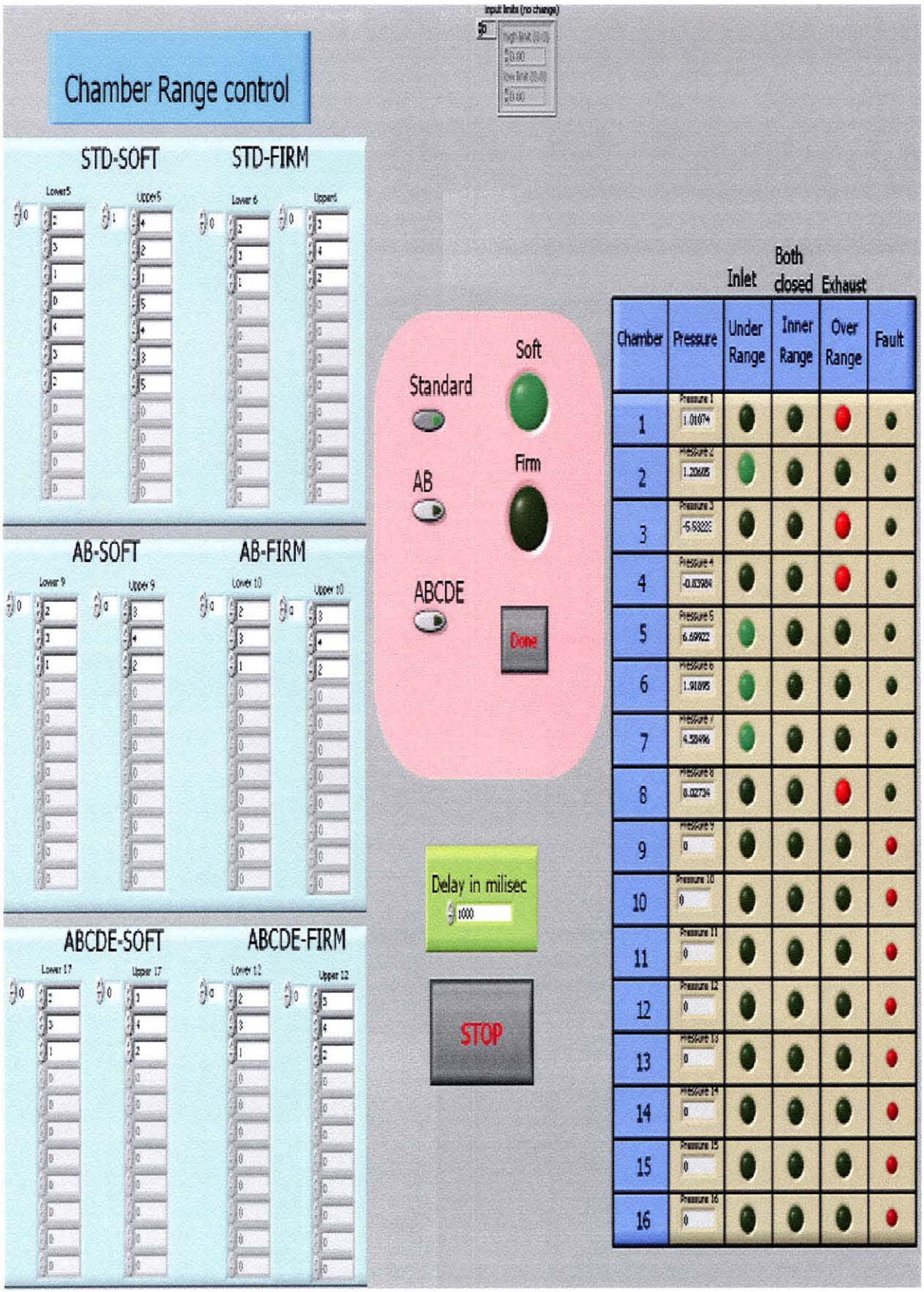


Figure 1. Pin Configuration

APPENDIX G

FRONT PANEL OF THE LABVIEW CODE

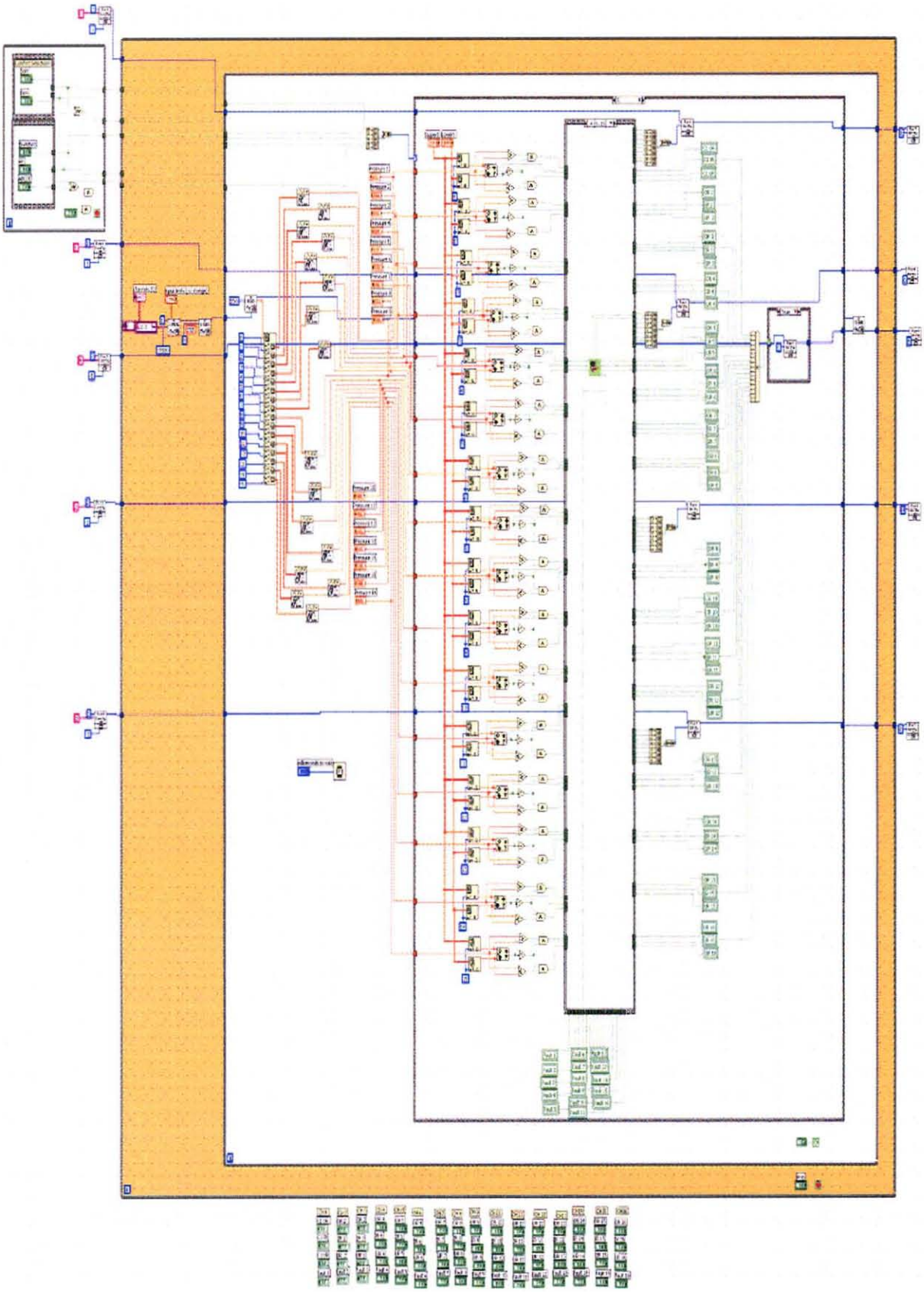
This appendix shows the front panel of the LabVIEW code.


Chamber Range control
STD-SOFT
STD-FIRM
AB-SOFT
AB-FIRM
ABCDE-SOFT
ABCDE-FIRM
Standard
Soft
AB
Firm
ABCDE
Done
Delay in milisec
1000
STOP
Inlet
Both closed
Exhaust
Chamber
Pressure
Under Range
Inner Range
Over Range
Fault
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

APPENDIX H

BLOCK DIAGRAM OF THE LABVIEW CODE

This appendix describes about block diagram of the LabVIEW code.



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