

**AUTOMATION BY PC INTERFACE OF A MULTICUSP  
VOLUME ION SOURCE , DENISE.**

**A thesis for the degree of  
M.Sc.**

**Presented to  
DUBLIN CITY UNIVERSITY**

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**October 1996**

**Declarations**

I hereby certify that this material, which I now submit for assessment on the programme of study leading to the award of Master of Science is entirely my own work and has not been taken from the works of others save and to the extent that such work has been cited and acknowledged within the text of my work.

Signed: \_\_\_\_\_  
Deirdre Boilson

***Dedicated to My Parents.***

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## **Abstract.**

DENISE is an acronym for Deuterium Negative Ion Source Experiment and originated in FOM the Institute for Atomic and Molecular Physics in DCU where it is being recommissioned as a test bed for the production and extraction of negative hydrogen ion for use in proposed nuclear fusion reactors. These reactors require the neutralisation of particle beams of up to hundreds of amps and energies of about 1MeV for use in Neutral Beam Injection (N.B.I.).

The objective of this project was to automate the multicusp volume ion source called DENISE.

Automation is the technology concerned with the application of mechanical, electronic, and computer-based systems in the operation and control of production. This process of technological development lends real-time monitoring and quick error detection and correction to parameters and components that need to be controlled. Another feature is the ease of use and the attraction of the safety features that are inherent in this technology.

The parameters and components that are to be controlled are decided upon and the methods in which this is to be achieved discussed. The control system consists of a software/hardware interface to the pressure system, the cooling system and the pumping system. The Windows software monitors and displays the status of the



physical system. An optoisolated electronic interface circuit allows control of the physical processes.

## **Chapter One**

### **Introduction to Volume Ion Sources.**

#### **1. Introduction.**

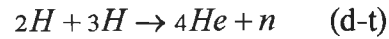
Thermonuclear reactions have been taking place in the universe since its creation in the presumed cosmic "big bang" of some 15 billion years ago. Such reactions have taken place on earth, however, only since November 1952 when the first fusion or hydrogen bomb was exploded. The high temperatures needed to sustain the thermonuclear reactions in this case are provided by a fission bomb as a trigger.

A sustained and controllable thermonuclear power source a fusion reactor - is proving much more difficult to achieve. The goal, however, is being vigorously pursued because many see the fusion reactor as the ultimate power source of the future, at least as far as the generation of electricity is concerned.[1]

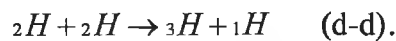
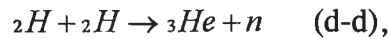
#### **1.1. Nuclear Fusion**

In nuclear Fusion, two light nuclei combine to form a heavier one whose binding energy per nucleon is greater. The difference in binding energies is liberated in the process. To bring about a nuclear fusion reaction, the initial nuclei must be moving rapidly when they collide to overcome their electrical repulsion. Nuclear fusion is the source of energy in the sun and star, where the high temperatures in the interiors mean that nuclei there have sufficiently high velocities and the high pressures mean that nuclear collisions occur frequently. In the operation of a hydrogen bomb, a fission bomb is first detonated to produce the high pressure and temperature necessary for fusion reactions to occur. The problem in constructing a fusion reactor for controlled energy production is to contain a sufficiently hot and dense mixture of suitable isotopes for long enough to produce a net energy output.

The most attractive reactions for terrestrial use appear to be the deuteron-triton and the deuteron-deuteron reactions,



and



A fusion reactor would have a number of advantages over the fission reactors currently in operation. Firstly it would be safer in operation since the process gives rise to such low levels of radiation. Secondly, the serious problem of radioactive waste associated with fission reactors would not exist. Thirdly the fuel, Deuterium, would be very cheap, widely available, and most importantly virtually limitless. It has been estimated that there is enough deuterium in the oceans of the world to provide energy at the current rate of usage for 1000 million years!

There are three basic requirements for the successful operation of a thermonuclear reactor:

#### **1.1.1. A High Particle Density $n$**

The number of interacting particles per unit volume must be great enough to ensure sufficiently high deuteron-triton collision rate. At the high temperatures required, the gas would be completely ionised into a neutral plasma consisting of free nuclei and electrons.

### **1.1.2. High Plasma Temperature**

The plasma must be very hot, otherwise the colliding deuterium and tritium ions will not be energetic enough to penetrate the mutual Coulomb barrier that tends to keep them apart.

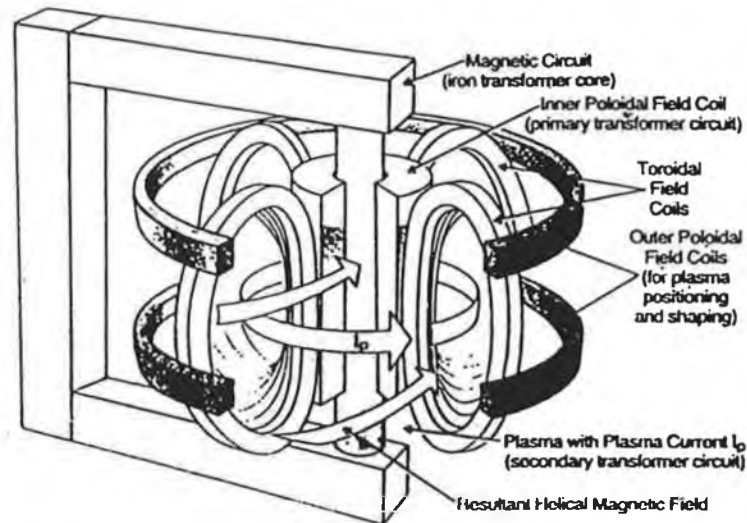
### **1.1.3. Long Confinement Time.**

A major problem is containing the hot plasma long enough to ensure that its temperature and density remain sufficiently high.

## **1.2. The TOKAMAK.**

TOKAMAK, a Russian acronym, for "toroidal magnetic chamber" refers to a thermonuclear fusion device, first developed in the USSR. It is thought to be a good way of achieving a self sustaining thermonuclear fusion reaction.

In a TOKAMAK the charged particles that make up the hot plasma are confined by a particular magnetic field configuration to the geometry of a doughnut or torus. As Fig. 1.1 suggests, the confining magnetic sheath of helical lines of force, of which only one is shown in this schematic, that spiral around the plasma "doughnut". The magnetic forces acting on the moving charges of the plasma keep the hot plasma from touching the walls of the vacuum chamber.



**Figure 1.1 Representation of TOKAMAK for use in NBI.**

The helical magnetic field is the resultant of two component fields, shown to the left of this figure, the toroidal field component  $B_T$  is generated by a current  $i_p$  in windings that wrap around the toroidal vacuum chamber. The so called poloidal field component generated by a toroidal current  $i_t$  that is induced in the plasma itself by an alternating current in the windings of the transformer-magnet arrangement not shown. This induced toroidal current is also used to heat the plasma to the desired high temperature. Additional heating may be provided by firing one or more beams of energetic neutral particles into the plasma.

### **1.3. Neutral Beam Injection.**

The basis of Neutral Beam Injection is that fast high power neutrals are injected into a magnetically confined plasma. These neutrals penetrate the plasma unaffected by the magnetic field, and deposit their energy through collisions with the ionised gas. This transfer of energy results in the heating of the fusion plasma. The neutral beams

with the energy power and collimation required for these injection systems are only achievable through the neutralisation of high power positive or negative ions beams. [2]

Ion beams are generally produced at low energy by the attachment to or ionisation of a source gas, they are then extracted and accelerated in an electrostatic field. These beams are then passed through a neutraliser usually a gas target/plasma and the resultant neutral beam is then used to heat the fusion plasma.

#### 1.4. Negative ions

The proposed reactors require the neutralisation of charged particle beams of currents of several amps and energies of 1MeV. To produce an energetic beam for neutral beam injection the ions must be accelerated to the required energies of 1MeV. Positive ions cannot be used for this operation, this can be explained in the following graph Fig. 1.2 . [3]

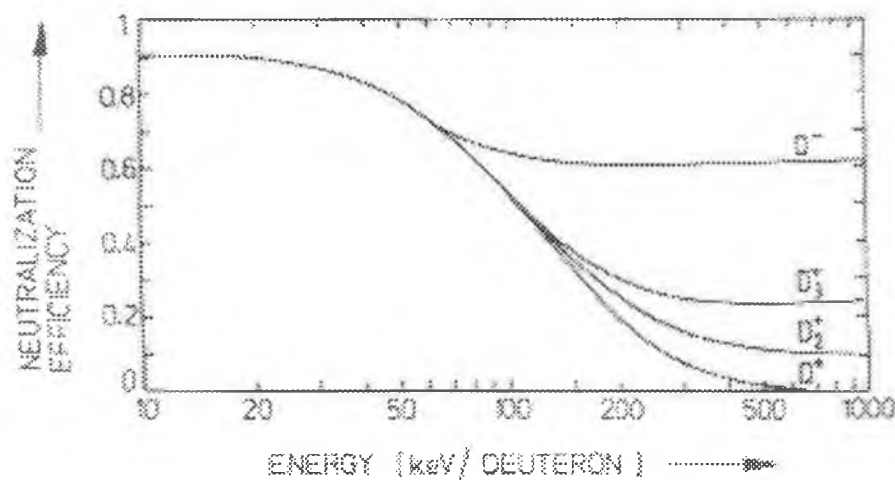
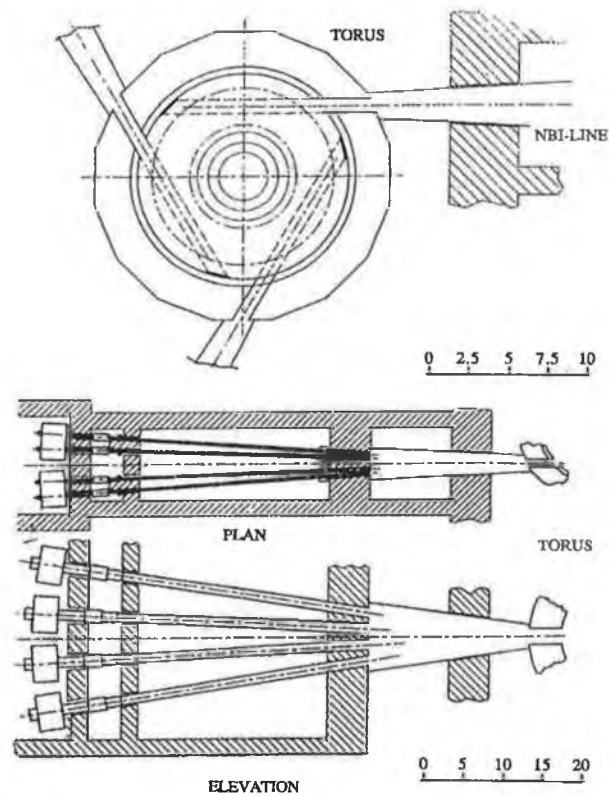


Figure 1.2 Graphical Representation of Neutralisation Efficiency plotted against Energy.

Even though it is easier to produce a high current beam of positive Deuterium ions than negative Deuterium ions, from Figure 1.2 it can be seen that the positive deuterium ions are not efficiently neutralised at 1MeV. For energies of 1000keV the neutralisation efficiency drops away dramatically, so for the proposed nuclear fusion reactors which require energies of 1MeV the neutralisation cross-section would be very small. The neutralisation efficiency of the negative ions at these high energies is 60% compared to less than 1% for positive ions.

Thus the need for high power low pressure negative ions for NBI becomes apparent. It is thought that the ITER tokamak will require NBI powers of up to 100MWatts. This means a negative ion current of 150A, if conventional neutralisers are used. Using several individual ion sources of lower power output this could be achieved. Fig 1.3 shows a representation of a possible NBI system for the ITER experiment.



**Figure 1.3 Representation of NBI system for ITER.**

In this several beam lines are focused into a single neutral beam giving a very high power beams which will enter the plasma almost tangentially, depositing their energy in the centre of the tokamak.

### **1.5. Volume Ion Sources**

It was shown by Bacal et al,[4] that large densities of negative hydrogen ions exist in a hydrogen discharge or volume source. The possibilities of extracting high densities of negative hydrogen ions from a volume ions source for neutral beam heating applications has been shown by Holmes et al [5] Leung et al [6], and Hiskes and Karo[7].



In the volume ion source, which is a hot cathode discharge, the filaments, made either of tungsten or tantalum act as the cathode, while the chamber walls act as the anode. The tungsten filaments are heated and biased typically between 50 and 100V negative with respect to the anode. The electrons emitted by thermionic emission are accelerated towards the walls which act as the anode. The walls have permanent magnets affixed in an arrangement known as a multicusp configuration. This means that each magnet alternately faces north or south towards the inside of the chamber. It is because of this configurations that the name magnetic multicusp source originates. The result is that a magnetic field is generated which extends a short distance into the chamber near the anode surface.

It is thought that the field has the effect of confining the primary electrons, which are emitted from the filaments due to thermionic emission, in the discharge, this in effect increases the characteristic length of the source.

Buzzi et al [8] have shown that the increase in the plasma density is due to the reflections of the primary electrons by the magnetic wall. In doing so they also showed the difference in the travel length of the primary electrons with and without the magnets affixed. Without the magnets the distance travelled by the primaries is the same as the filament to wall distance , while the distance is increased quite substantially by the magnets. The background gas becomes ionized as these fast electrons are accelerated towards the anode. For efficient operation the mean free path of the primaries must be comparable to the characteristic length of the source or else the electrons may be lost to the walls. It may be concluded that the effective increase in the source length caused by the magnetic confinement adds considerably to the efficient operations of the source.

## 1.6. Generation of Negative Deuterium/Hydrogen ions

It is generally accepted that negative hydrogen ions are produced in the following way. First  $H_2$  is excited by primary electrons, with energies  $> 16\text{eV}$  to an electronically excited state. This state decays radiatively, but due to the Frank Condon Principle, it populates vibrationally excited states, negative Hydrogen ions are produced by dissociative attachment of slow plasma electrons with energies of about  $1\text{eV}$ , to vibrationally excited molecules.[9]

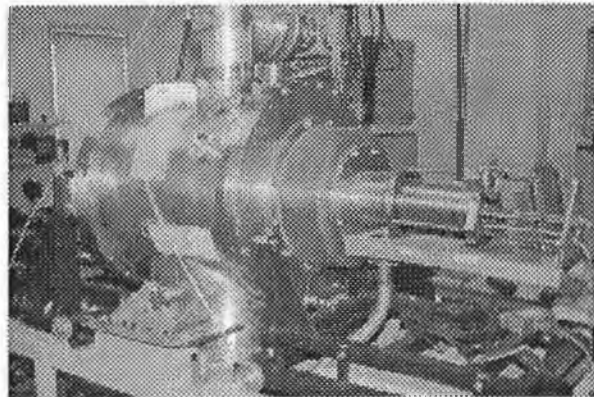
For the first stage of the reaction, fast energetic electrons are required whereas for the second stage slow electrons are used. It is also noted that electrons with energy greater than  $3\text{eV}$  can destroy the produced negative hydrogen ions by collisional detachment.

Therefore the presence of energetic electrons is beneficial for vibrational excitement of the molecules, but this is countered by the large collisional losses of the negative ions subsequently produced. Also volume negative ion sources have much lower gas and power efficiencies than the positive counterpart.

It is for this reason that most volume sources are divided into two regions by a magnetic filter. There are two sources that overcome these problems successfully by using a magnetic filter, the tandem source and the hybrid source. Both of these sources enhance the volume production mechanism by having separate plasma regions. This filter keeps the two stages of the productions process separate. In the first region the energetic electrons excite, ionise and dissociate the gas molecules. This region is called the "driver". This is where the production of the vibrationally highly excited molecules takes place. Only the slow thermal electrons, the vibrationally excited molecules and the cooler ions can diffuse through the magnetic filter into the second region which is called the extractor region, where a cooler plasma exists, in which the dissociative attachment process results in negative ion production.

These multipoles are being considered as candidates for etching plasmas used in the microelectronics industry as the cool extractor region is rich in negative ions and provides a low damage etching environment.

## **1.7. DENISE.**



**Figure 1.4**      **Photograph of Volume Ion Source DENISE.**

The volume ion source being operated on in D.C.U. has been given the acronym DENISE which stands for "DEuterium Negative Ion Source Experiment". DENISE originated in FOM the Institute for Atomic and Nuclear Physics in Amsterdam and is currently located in D.C.U. where it is being used as a test bed for the production and extraction of negative hydrogen ions for the use in these proposed nuclear fusion reactors which have been discussed.

### **1.7.1. DENISE Physical Characteristics**

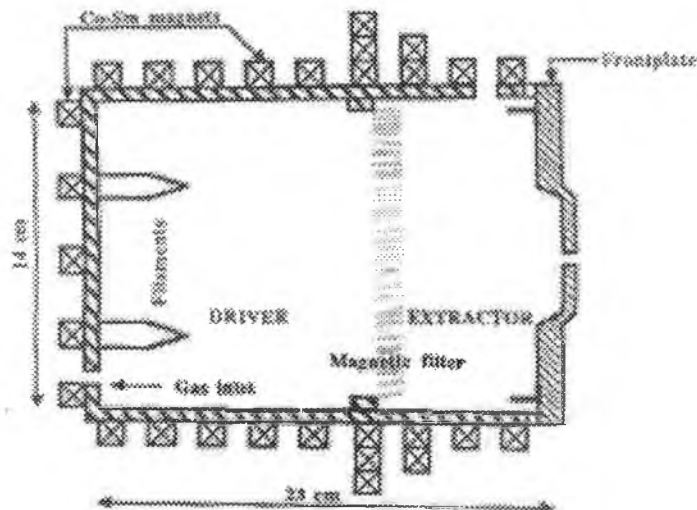
The main characteristics of the DENISE Volume Ion Source are summarised here. DENISE is a medium sized multicusp ion source as shown in Fig. 1.5

It is a magnetic bucket source of dimensions 14cm \*14cm \*19cm. Three sets of two tungsten filaments are mounted on the front plate. The filaments are approximately 15cm long and 1.5mm thick. The walls are water-cooled and covered by a layer of

tungsten evaporated from the filaments. A series of ports are available to facilitate the use of diagnostics on the source. The diagnostics include the extraction of an ion beam, photodetachment measurements of the negative hydrogen ion density, langmuir probe measurements, and laser diagnostics.

The frontplate is electrically insulated from the outer walls, and can be biased to a separate potential with respect to these walls.

Except for the backplate all the walls of the chamber have permanent Co-Sm magnets affixed, arranged in a lineacusp configuration. The magnetic field generated keeps the primary electrons in the source and therefore enhances the plasma density.



**Figure 1.5** Schematic of bucket source of DENISE.

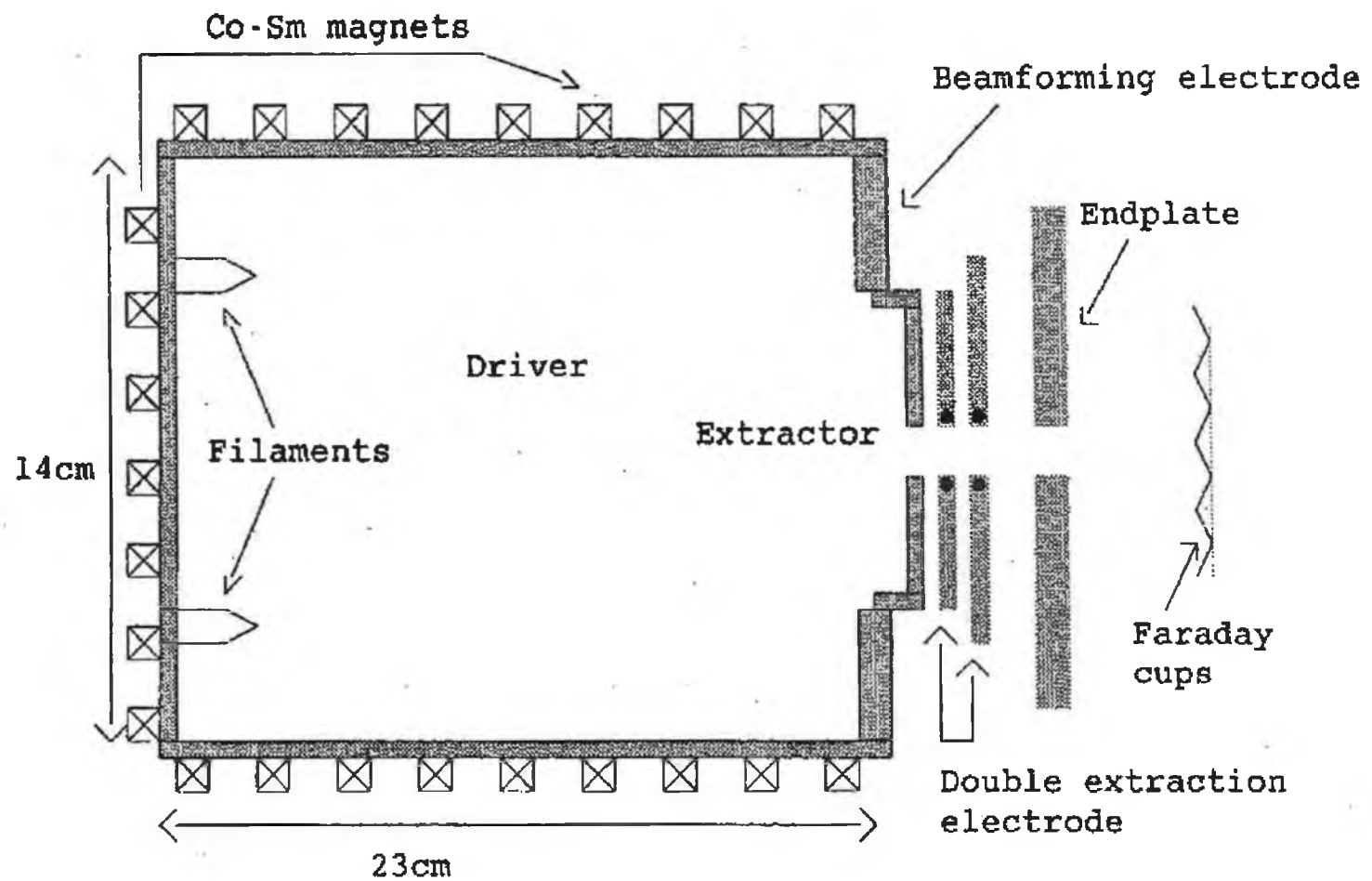
### **1.7.2. The Extraction System on DENISE.**

The main objective of acceleration performance of a negative ion accelerator is the focusing of the ion beam across as wide a range of currents and beam energies as possible without significant beam aberrations and to control the number of extracted co-drifting electrons and prevent them from reaching the detector. This is achieved by

operating at the perveance match and where the aspect ratio is small enough and where the beam is space charge compensated .[10]. The design of the accelerator is shown here in Fig.1.6. The accelerator consists of a 3mm thick front plate which has an aperture of 8mm, this we call the beam forming electrode, 3mm behind this the extraction electrode is placed. This consists of two plates insulated from each other, this extractor electrode is biased to 4kV, it has small magnets affixed in the octopole configuration to prevent co-drifting electrons to be extracted with the negative hydrogen ion beam. This plate is 12mm thick and the apertures are also 8mm in diameter. Positioned 5mm behind this plate is the end plate which is biased to a potential of 15kV.

At this point it is mainly negative hydrogen that are accelerated and focused onto the Faraday Cup which is positioned 30mm behind this plate. The Faraday Cup detects either the net current density or the ion current density. If only the ion current density is required then the extracted electrons current have to be removed from the net current.

A discharge in Argon can then be run and no measurable current should be detected from the Faraday Cup as all negative electrons should have been trapped in the extraction electrode. If however there is a measurable extracted electron current then perhaps a magnetic field could be generated in front of the Faraday Cup to deflect the stray electrons.



## **1.8. Conclusion.**

The NBI system presently in use are positive ion based sources but the future tokamaks will require the use of negative ion sources.

This chapter dealt with the need for high power low pressure negative ion sources and a brief description on how to generate negative Hydrogen ions. This thesis is concerned with the automation of the experimental set-up just described and the following chapters will describe the process required to do this.

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Richard D. Gill.

## Chapter Two.

### Introduction To Automation.

#### **2. Introduction.**

New terms have evolved over the years to describe the technology of automation. These terms such as numerical control, manufacturing systems, and computer-aided manufacturing were unknown 30 years ago. The development of new automation technology represents a continuous evolutionary process which has existed for many decades. Automation is a process of technological development that will proceed into the foreseeable future.

Automation is the technology concerned with the application of mechanical, electronic, and computer-based systems in the operation and control of production.

A sound strategy must be developed before a control system can be designed. Developing a strategy includes selecting the variables to be measured, specifying the sensors and where and how these should be installed, and specifying the final control elements and how these are to be used to execute the control function in order to produce the desired action. Sometimes the functions which the control components must perform can be stated in general terms, but considerable knowledge of the process, control components, and objectives is always required to achieve satisfactory results. Control hardware attached to a process, the performance characteristics of which are unknown, has a low probability of success if the demands are at all critical.

Strategies of control are derived heuristically. Theory can lend some guidance and judgement, of course, but in the main, the basic strategy is evolved after an intuitive understanding of the process is acquired. This implies a rather intimate knowledge of the system performance.

To control the system DENISE , the function of the system must first be understood, this has been explained in chapter 1, from this it can then be determined what parameters and therefore which systems must be automated. The main parameter on the system to be monitored and controlled is the source pressure, so therefore it is necessary to understand how the pressures required to carry out the experiments are to be achieved. This is explained here in the section on Vacuum Technology.

## **2.1. Vacuum Technology**

The operation theory, range, and practicality of the various vacuum pumps on the system DENISE are dealt with in this chapter. The pumps discussed here are of two general types. Roughing pumps which are used in the rough and medium gas range, and remove the major gas load, and high vacuum pumps which are used in the high and ultra high vacuum range, and generally cannot operate in the viscous region. The roughing pumps discussed here is the Rotary Vane Pump. The high vacuum pumps discussed include the cryopump and the turbo pump.

The methods that pumps use to operate are compression, momentum transfer, cryosorption, and cryocondensation. Compression is used to decrease the volume of a number of molecules, which increases their pressure so the gas can be expelled into another pump or the scrubber system. Pumps that use compression are the rotary and the turbo.

Momentum Transfer is the ability of a pump to redirect the molecules flow and keep them away from the chamber. Pumps that use momentum transfer include the turbo.

Cryosorption is the ability of a cold substance to cool a gas and prevent it from returning to the chamber. The cryo pump uses this method.

Cryo condensation is the ability to freeze gases on a very cold surface. The cryopump uses this method.

Each of the pumps used to operate DENISE are discussed with regard to their operation in this chapter.

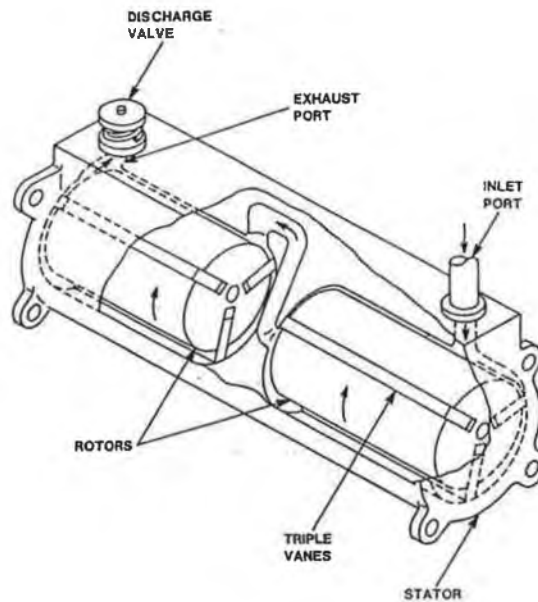
### **2.1.1. Rotary Vane Pump.**

The rotary Vane pump is classified as a compression or gas transfer pump. This pump is rated by pumping speed in CFM(Cubic Feet Per Minute) and sized from a few CFM to more than 140 CFM.

The rotary Vane is basically used for two functions, to rough pump the vacuum chamber, i.e. to bring the pressure down to  $10^{-3}$  Torr, and to aid high vacuum pumps, such as diffusion pumps, that cannot discharge directly into the atmosphere. The diffusion pump exhausts into the mechanical rotary van pump, which compresses the molecules and then expel them into the atmosphere in one or more stages of compression. On the DENISE system the function of the rotary pump is to bring the pressure to  $10^{-3}$  Torr.

These pumps cannot be used in any application where oil molecules cannot be tolerated and where particles are accessible. The pump, being oil sealed, operates from atmospheric pressure to the  $10^{-3}$  Torr range, a range that requires a compression ratio of 4 to 5 orders of magnitude.

The rotary vane pump consists of a finned alloy housing surrounding a cylindrical housing called a stator, in which an eccentrically mounted or offset rotor rotates. Those pumps that use a speed reduction pulley operate in the 400 to 600 rpm range, while direct drive pumps operate at speeds of 1500 to 1725 rpm. A schematic of the Rotary Vane Pump is shown on Fig. 2.1.



**Figure 2.1 Schematic of Rotary Vane Pump.**

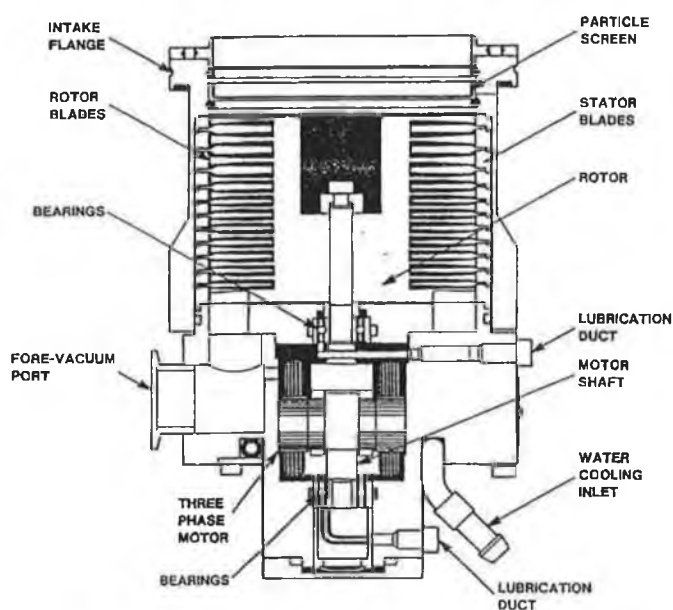
### **2.1.2. Turbomolecular Pump.**

The axial-flow molecular turbine, or turbo pump as it is commonly known, is a clean, high-vacuum, bladed molecular turbine that compresses gas molecules by momentum transfer or impact from the rapidly rotating blade surfaces to the gas molecules. The active or pumping part consists of a fixed stator and a rotating rotor. Both have angled turbine blades around their circumference and each rotor/stator pair of circular blade rows from one stage, so that the whole assembly is composed of multiple stages mounted in series. The angle of these blades varies in each stage.

The turbine rotor is mounted on a drive shaft directly driven by a medium-frequency motor that is powered and automatically controlled by an external, solid-state frequency converter that ensures a very low noise level. The pump operates at a speeds ranging from 24000 to almost 80,000 rpm, and ultimate pressures in the range of  $2 \times 10^{-10}$  to  $5 \times 10^{-11}$  Torr are possible. The motor is housed in the fore-vacuum space

within the rotor so that no rotary shaft leadthrough to the outside atmosphere is necessary.

Turbo pumps cannot directly vent to atmosphere and must be backed by a roughing pump such as a rotary vane. They cannot withstand sudden high pressures and do not handle particulates well. Large turbo pumps vibrate and are inherently noisy. A schematic of the Turbo Pump is shown in Fig. 2.2.



**Figure 2.2 Schematic of Turbo Pump.**

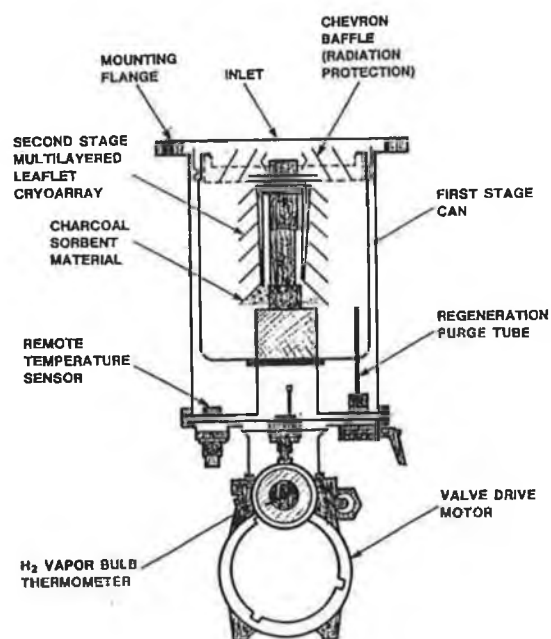
### **2.1.3. Cryo Pump.**

The cryopump is a closed loop, heat transfer mechanism which utilises compressed 5-9's pure helium at its source of internal cooling. It traps molecules by both cryocondensation and cryosorption. The sticking of most molecules to a chilled surface of around 20K is called cryocondensation. At this temperature, the combined partial pressures of most gasses is around  $10^{-9}$  torr or lower.

The other cryopumping mechanism, cryosorption, is used to trap remaining molecules. Gas molecules such as neon, helium, and hydrogen will not stick to chilled surfaces due

to their vapour pressures. The use of a very porous material such as activated coconut charcoal, which has a vast surface area, is used to trap these molecules. These lighter molecules strike the porous surface of the charcoal, progressively lose thermal energy and stick to its surface. Once these molecules are inside the charcoal, the probability of their finding their way out is very low. The outer surface of the cold head is left uncoated to provide an adequate surface for the harder to pump molecules. The charcoal is also less accessible to the easy to pump molecules by being bonded only to the inner surface of the cold head. A baffle is placed around the cold head to limit the conductance to the charcoal surface and to shield the cold head from radiant heat sources.

The base Pressure of Denise is  $2 \times 10^{-8}$  mBarr. A schematic of the Cryo Pump is shown in Fig. 2.3.



**Figure 2.3** Schematic of the Cryo Pump

Having now described how the required pressure of the chamber is to be achieved it becomes obvious that the pumps which are described above are the key to

obtaining the pressure required, how this pressure is monitored is also important. Obviously then the pumping system and the monitoring system must be automated.

## **2.2. Monitoring and Controlling the Source Pressure.**

The source Pressure must be both controlled and monitored, while the chamber pressure needs only be monitored. The method of controlling the source pressure is described here, the system uses a Capacitance Diaphragm Gauge, (CDG), and an automatic control unit.

In the CDG, the fluid gas interacts with the diaphragm wall and exchanges momentum in accordance with Newton's first law. As the gas molecules hit the wall with one momentum and leave with another, a momentum transfer occurs which translates into a force against the diaphragm.

The diaphragm responds to this force in a predictable manner and therefore senses pressure as it is defined as force per unit area.

CDG's use a highly pre-tensioned, thin metal diaphragm. This diaphragm can be considered a membrane because the diaphragm response is linear for deflections many times its thickness since the increase in tension due to the deflection is insignificant compared to the initial pre-tension. Because the pressure is supported by the pre-tension, hysteresis and creep are reduced to the point of being negligible.

The use of capacitance sensing allows a no-contacting scheme that is easy to employ. Capacitance as a sensing technique yields theoretically infinite resolution and a high output voltage with little or no power dissipation. This high output voltage allows good signal to noise ratio to make meaningful measurements over a dynamic range of several decades.



The Automatic Pressure Controller is designed to maintain a pre-set pressure by controlling an inlet-gas leak valve. The control system consists of a controller , a pressure transducer, and a control valve. The controller operates by comparing a signal from any pressure transducer that outputs a DC voltage proportional to pressure, the CDG, with a pre-set pressure set point. If the actual pressure differs from the pre-set pressure, an output voltage drive signal is sent to the inlet control valve to adjust the valve opening and vary the gas flow through the system, thereby raising or lowering the pressure to the desired level.

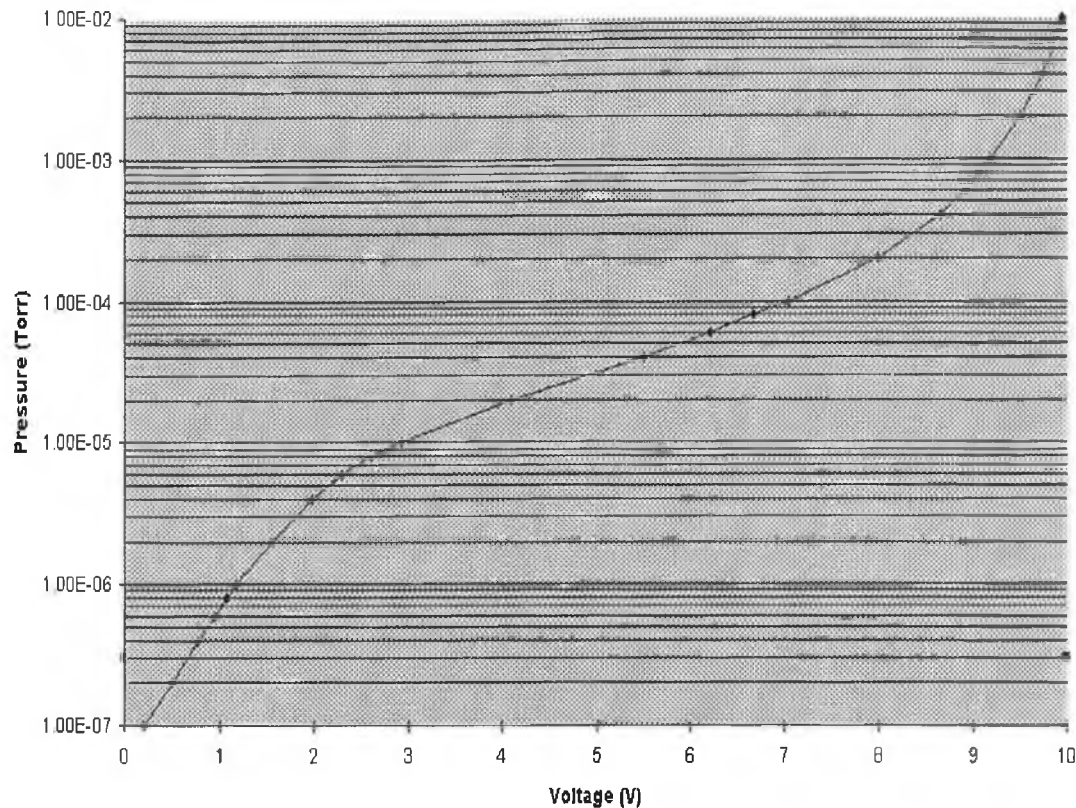
Two methods of pressure-level selection are possible, one from the set point potentiometer on the front panel and the other by input of an external set point through the rear panel.

### **2.3. Monitoring the Chamber Pressure.**

The chamber pressure is only to be monitored, this is done with the use of a Penning head and meter. The instrument used has a wide easy-to-read meter scale, and pressure reading is continuous round the scales. Range switching is not required, the pressure range is  $10^{-2}$  to  $10^{-7}$  mbar/torr. The meter gives clear pressure indication with a fast response.

A recorder output is provided on the rear panel giving an output of 0 to 10 volts. A graph of the voltage vs. pressure is shown below in Fig. 2.4.

**Calibration Curve for Penning Gauge**



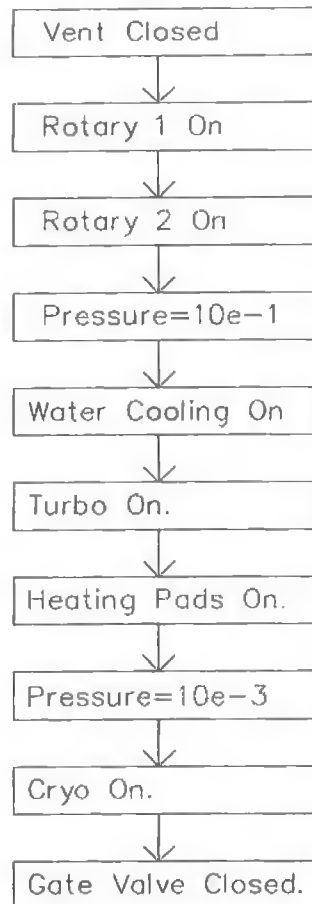
**Figure 2.4 Calibration Curve For Penning.**

From this graph it could be determined what the equation of the line is. This is necessary to determine the relationship between pressure and voltage, so as to monitor the pressure.

Another important feature in the system DENISE is the gas and water flow, the gas because it provides the particles that form the plasma and the water flow because it prevents the chamber from being damaged due to overheating, and is also necessary for the correct use of the pumps, to prevent any damage occurring to them.

Information pertinent to control-system performance and the relationship of the control system to the process can be organised by the use of a flow chart. These flow charts prove useful because the variables of interest are associated both with the process

and the control components. The objective is to visualise how the control systems interact with the apparatus.



**Figure 2.5** Flowchart to represent scheme of events

At this point it is now possible to create a list of the functions that must be automated so that the system can be controlled from the PC.

This list can be broken down into two different sections, analogue and digital electronics.

The underlying principle defining digital electronics is that a device can only have a finite number of states. In binary digital systems there are two discrete states, represented in base two arithmetic by the numerals 0 and 1. Digital systems, with their

discrete states are contrasted with analogue systems, in which voltages or other quantities vary in a continuous manner

The analogue list includes: 1)The Source Pressure

2)The chamber Pressure.

The digital list includes : 1)The Rotary Pumps

2)The turbo pump

2)The cryo pump

3)The heat pads

4)The Gate Valve

5)The vent valve

6)Water flow

7)Gas flow

## **2.4. Conclusion.**

In this chapter the idea of automation is introduced. The components and parameters are decided upon that need to be monitored and controlled for the complete automation of the system DENISE. Knowing the operation of these components make it possible to complete a flow chart so as to plan the method in which this automation is to be carried out. The process of the automation can now be described in the next two chapters.

## **Chapter Three.**

### **Hardware.**

#### **3. Introduction.**

At this point of the control system design , having decided the parameters to be controlled and the components required for the automation, the method in which this can be achieved must be decided upon. It is at this point that the automation can now be broken down into the two main parts, hardware and software. The software where the operator of the system DENISE controls the system from the PC and the hardware where the signal from the PC is transferred to the individual components to carry out the instruction decided by the operator.

This chapter will deal with the design and implementation of the hardware for both the digital and analogue signals that are to be transferred to the system DENISE.

#### **3.1. Analogue and Digital Control Systems.**

Control systems can be classified based on their operating techniques. In an analogue control system, analogue techniques are used to process the input signal and control the output signal, whereas in a digital control signal, digital techniques are used to control the output. For a given signal, the choice of techniques used depends on a number of factors; reliability, accuracy, simplicity, and economy are some of the most important. Once a system is designed, its performance is evaluated using certain techniques

### **3.2. Characteristics of Control Systems.**

Although different systems are designed to control different functions, all of them have to meet certain requirements. The major characteristics of a typical control system include stability, accuracy, speed of response, and output sensitivity to component and environmental changes. The degree of importance between these characteristics is prioritised by the designer based on the nature of the system as well as its application. However for a system to be of practical use, it must be stable. Often stability, accuracy, speed of response, and sensitivity are the criteria for a good control system. The significance of each of these characteristics is examined next.

#### **3.2.1. Stability.**

A system is said to be stable if its output attains a certain value in a finite time after an input is applied. A stable system attains a steady-state value at a time  $t$  after an input is applied at a time  $t = 0$ . When the output of a system remains constant and does not change as a function of time, the output is said to attain a steady-state value. On the contrary, an unstable system never attains a steady-state value. The output of an unstable system increases with an increase in time until the system breaks down. A practical system must be stable. An unstable system may be made stable by using certain techniques, of which the most common is the use of compensating networks. Thus stability is a criterion of good control and must be achieved by all practical control systems.

#### **3.2.2. Accuracy.**

Another important parameter that is used to evaluate a given control system is accuracy. Accuracy indicates deviation of the actual output from its desired value and

is a relative measure of system performance. In most practical systems, stability and accuracy interact with each other. In other words, if care is not taken, the stability of a system may be lost in trying to improve the accuracy, or in trying to improve the stability of a system the accuracy may be decreased.

In practice systems are not expected to be totally accurate. A 12-bit DAC is used in sending the signal to the CDG to control the source pressure, this improves the accuracy.

### **3.2.3. Speed Of Response.**

In addition to accuracy and stability, the speed of response is an important factor to consider in designing control systems. Speed of response is a measure of how quickly an output attains a steady-state value after an input is applied. In a time domain the response, an output, of a given system is composed of a transient portion and a steady-state portion.

The digital signals speed of response is not as important as the analog signal to control and monitor the pressure parameters. The speed of response is accommodated for in both the hardware and the software, through the code and interface cards used respectively.

### **3.2.4. Sensitivity.**

The sensitivity of a system is a measure of how sensitive its output is to changes in the values of physical components as well as environmental conditions. In a well designed system the output depends primarily on the input and not on undesired signals, referred to as disturbances. It is for this reason that the signal to noise ratio must be kept to a minimum. This then raises the question of ground isolation which is discussed later in this chapter.

### 3.3. Interface Cards

At this point it is necessary to discuss how the signal generated in the PC can be transmitted to the control component in question. This is achieved by use of an input output card for the digital signals, and an ADC/DAC card for the analogue signals.

To transfer the signal, to control the pressure in the source, from the PC to the outside world an eight bit digital to analogue converter is used. The digital to analogue converter(DAC) performs the function of transforming an n-bit digital input to an analogue voltage level. Thus an eight-bit DAC accepts an eight-bit digital input and generates at its output a unique analogue voltage level.

Similarly to monitor the pressure in the source or in the chamber, an ADC is utilised, this transfers the signal from the outside world as an analogue voltage back to the PC as a digital input.

The Bytronic Multifunction I/O Card is used for this function, which consists of a 12 bit 8 channel analogue to digital converter and a 12 bit 2 channel digital to analogue converter.

The input/output card used is the PBIO-48, a 48 channel TTL digital input/output board. This card provides 48 programmable digital I/O channels, It is suitable for sensing the presence of or driving TTL connections only. There is provision for a set of on-board pull up resistors to enable the board to be used to detect contact closures on relay contacts, push buttons etc.

The signals are taken from the interface cards to the outside world by use of a circuit shown in Appendix A, Fig. 1. Ribbon cable connects the interface cards to this circuit where half the signals from the input/output card are used to write information to the outside world while the other half are used to read information from the outside. These signals are buffered by a 74LS245 chip which is powered up by a 5V power supply with a 7805 voltage regulator. lines 1 to 15 are set up to send information while the lines specified in the circuit diagram are used to collect information.



### **3.4. Ground Isolation.**

Before breaking the hardware down into analogue and digital electronics it is necessary to discuss the problem of ground isolation.

The connecting of electronic equipment to an electromagnetic reference common to itself, its power source, its environment, and the environment of its users is known as electronic equipment grounding. Electronic equipment is grounded to protect users from shock, to protect the equipment from spurious currents or voltages, and especially to isolate it from noise that contaminates its environment.

Usually electronic equipment is powered from the electric service that supplies the building where the equipment is being used. To provide security against hazards of electric shock or fire ignition, equipment frames and power conductor enclosures are connected and grounded.

In addition, grounding together with the shielding, isolation, compensation and equalisation is applied to minimise the entrance of extraneous signals, noise, into the equipment. The sophistication of electronic equipment has advanced a long way. The necessary intensity of electrical signals has been diminished generally to below 1V. The amount of time allocated for the transmission of one bit has been progressively diminished to below 1 micro second. These advances aggravate the likelihood that spurious error signals will be of sufficient magnitude to create an error response. The effect of an error response, if not identified and corrected for, can produce tragic results. The controlling parameter can be expressed as the signal to noise ratio. The problem is ultimately one of ensuring acceptably high levels of signal to noise ratio.

The most vulnerable circuits are typically those associated with information gathering, because they generally operate at low signal level and are followed by high gain amplifiers within the data processing system. Techniques that are effective in

establishing a high signal to noise ratio need to be reviewed here, as the situation that we are dealing with is that of a computer at one ground and DENISE at another. Spurious and unwanted electric impulses, noise, may be mixed with true information signals in a number of ways, the one we are interested in here is conductive coupling. In conductive coupling, the error voltage owes its origin to the fact that the reference grounding conductor system is not at a common potential throughout. Consider that our computer is at ground G1 and DENISE is at ground G2, the presence of a second ground connection on the same signal conductor at a different location G2 will likely result in severe noise in low level signal circuits. After making the first ground connection at G1, it will be unlikely that another spot can be found along that conductor with a zero-voltage difference to the adjacent reference ground. When a second ground connection is made along a signal conductor, it forces the voltage difference, which had previously existed here, to vanish and appear as an impedance voltage drop around the loop circuit formed by the second ground connection.

By reviewing the character of the impedance elements forming this loop, it becomes evident that the signal-circuit conductor between grounding points G1 and G2 will principally account for the ground loop impedance. The remainder of the loop will be made up of such low-resistance conductors as heavy building structural members and large pipes. Thus most of the voltage difference which, prior to the second ground connection, had existed between the signal conductor and the adjacent reference ground G2 has, after the second ground connection, become an impedance voltage drop along only one signal conductor between locations G1 and G2. This voltage represents a normal-mode error voltage in the signal circuit.

To establish an acceptably high signal to noise ratio demands that normal-mode noise be maintained at levels below a specified tolerable value. One solution to this problem is achieved using isolation amplifiers.[1] Isolation amplifiers are commercial

devices intended for coupling an analogue signal from a circuit with one ground reference to another circuit with a completely different ground reference.

These isolation-amplifiers are intended for analogue signals, of modest bandwidth. The same sort of ground problems can arise in digital electronics where the solution is simple and effective: Optically coupled isolators (opto-isolators) are available with plenty of bandwidth (10mhz or more), isolation of several kilovolts, and low cost. [2]

It is at this point that the hardware can be broken down into its two sections the analogue and the digital, each will be treated separately here.

### **3.5. Analogue Electronics.**

#### **3.5.1. Isolation Amplifiers.**

The electrically isolated transfer of analogue signals is a frequent occurrence in measurement techniques, for instance, in measurements on the mains supply, or on signals that are largely unknown. Also for safety reasons, it is often required to isolate ground connections . These requirements are usually met by the use of an isolation amplifier. [3]

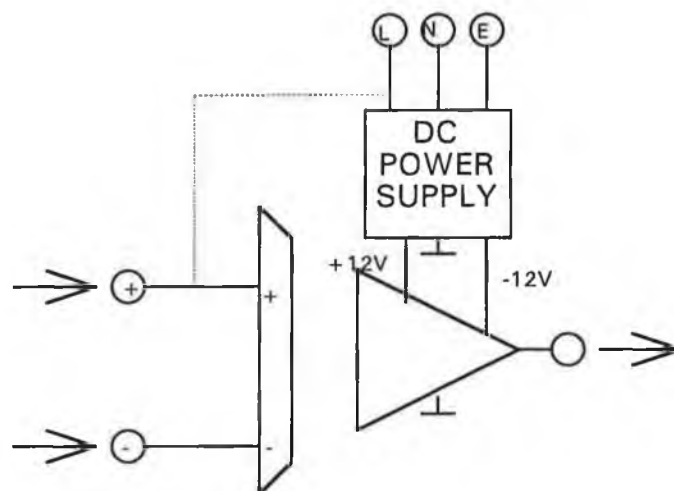
An isolation amplifier can be defined as an operational amplifier which also has isolation properties. This amplifier performs the transfer of analogue data, that is voltage and current, between two points without an electrical connection between these points. Isolation amplifiers prevent ground loops, suppress common mode signals, ensure separation of potentials and lessen the effect of capacitive and inductive interference.

Isolation amplifiers can be divided into three categories, that use capacitive, transformer or optical coupling respectively. Techniques that are based on acoustic, piezo-electric, thermal or mechanical coupling are used only in special applications.

#### **Capacitive Coupling**

An isolation amplifier that uses capacitive coupling for signal transfer is brought about by two small capacitors, which alternately pass on pulse edges that contain the information. Use is made of a modulation/demodulation combination in which the modulator forms a control loop via a reference modulator. This configuration compensates linearity errors produced in the modulator.

Isolation amplifiers that use capacitive coupling are easy and inexpensive to produce, since the capacitors, together with the semiconductor chips are normally housed in a modified ceramic DIL enclosure. They have a large bandwidth, about 60 - 200kHz, are dc. stable and have a good linearity. The output signal is staircase shaped owing to the sample and hold trap.



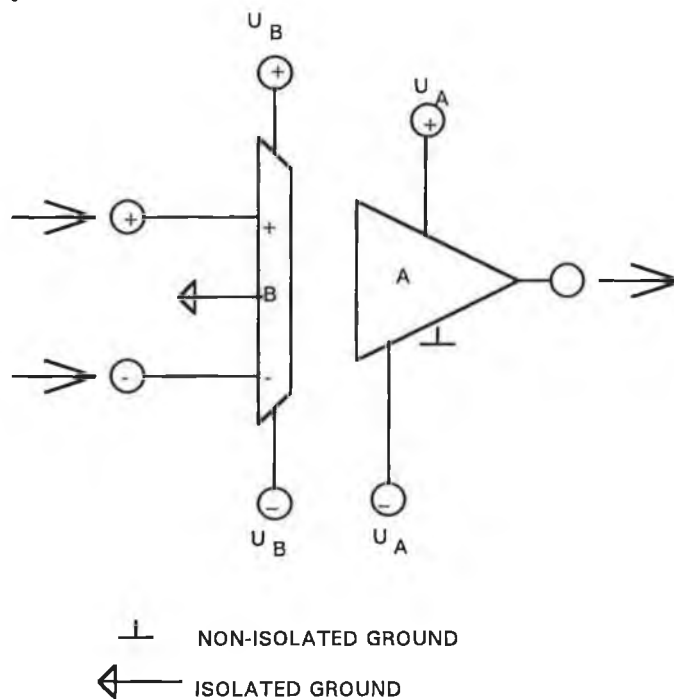
**Figure 3.1** Block diagram of a typical isolation amplifier.

An isolation amplifier as shown in the above Fig. 3.1 is an amplifier that has an extremely high impedance between the signal inputs and its main DC power supply terminals. These terminals are usually connected to the DC power supply that is in turn connected to the AC power mains. Thus in isolation amplifiers there is an extremely high resistance between the amplifier input signals and the AC power mains.

Modern isolators can provide more than  $10^{12} \Omega$  of insulation between the signal and the mains power and are suited for all classes of problems that involve ground isolation.

Several different circuit symbols are used to denote the isolation amplifier in electronic schematic diagrams, but the one that is most common is shown in the diagram below. It consists of a regular triangular amplifier symbol broken in the middle to indicate isolation between the "A" and "B" sections. The following connections are usually found on the isolation amplifier:

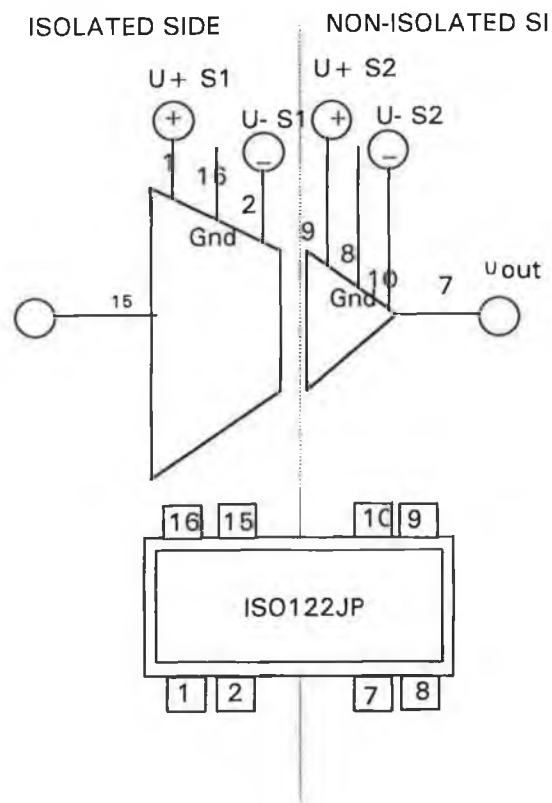
- \* Non-isolated "A" side:  $U_+$  and  $U_-$  DC power supply lines, to be connected to the DC supply powered by the AC mains, output to the rest of the non isolated circuitry, and in some designs a non-isolated ground or common. This ground is connected to the chassis or main system ground also served by the main DC power supplies.
- \* Isolated "B" side: isolated  $U_+$  and  $U_-$ , isolated ground or common and the signal inputs. The isolated power supply and ground are not connected to the main power supply or ground systems.



The ISO122JP device is an isolation amplifier contained in a 16-pin single wide plastic DIP package. One of the main features of this chip is that it functions at a low

cost. The ISO122JP features unity gain, a high isolation mode rejection of 140dB, and 0.020% non linearity.

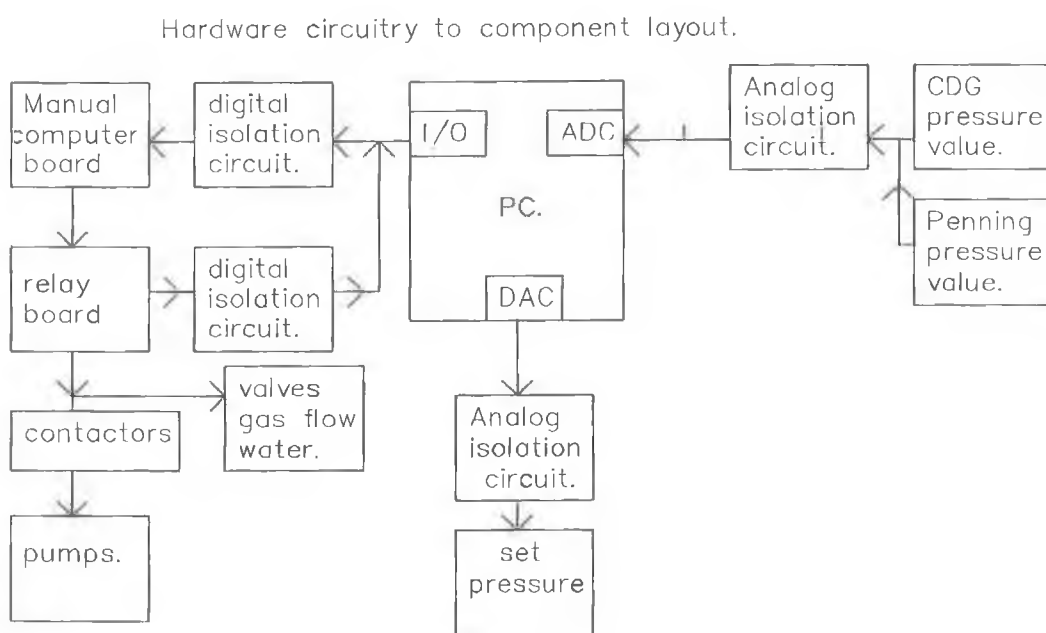
It can be used alone or in conjunction with other circuitry on either the isolated or non isolated sides. Fig. 3.2 shows the schematic symbol and the 16-pin DIP enclosure pin design.



**Figure 3.2** ISO122JP circuit diagram and pin outs.

Although the operational amplifier is considerably more expensive than the common IC linear amplifiers, this is an application where these amplifiers are absolutely essential. In both cases of analogue and digital signals transferring information from the PC to the system these amplifiers must be used to overcome the ground loop problem described earlier.

The analogue signals coming from the PC through the interface card are sent directly to a PCB shown in Fig. 1, Appendix A, which brings the signals to the outside world. A flow chart of the signals and circuitry is shown in Fig.3.3 , this diagram gives a clearer understanding of the flow of signals from the PC, through the interface cards, to the relevant circuits, to the component to be controlled.



**Figure 3.3 Flow Chart of Hardware to component layout.**

From the discussion we have seen that ground loops pose quite a problem in our analogue signal which is required to read and control the pressure in the source and monitor the pressure in the chamber, the solution utilises the isolation amplifiers described above.

Fig.2, Appendix A, shows the circuit designed to bring the signal between the CDG to the computer while keeping both grounds isolated from each other. The control signal from the computer is passed through a DAC, where it is amplified by an operational amplifier the LM358N and carried through the isolation amplifier which separates the

reference ground of the computer from the reference ground of the automatic pressure controller on the CDG. The isolation amplifier used is the one described above the ISO122JP and the isolated signal is then carried through a buffer, CA3140E, through to Vout.

The monitored signal is sent back through Vin from the CDG to the computer through an ADC, but in this case the reference grounds on the ISO122JP are the opposite way around. In short the signal sent from the PC through the DAC to set the pressure goes in through Vin 1 to the control unit via Vout 1, while the monitored signal is sent back through Vin 2 from the CDG via Vout2 to the PC.

Another precaution used to ensure a good signal to noise ratio is that this circuit, the only analogue circuit used, is kept separate from the digital electronics, to alleviate noise, this circuit is kept shielded in a dyecast box, also all the cables are shielded twisted pair.

Thus the source pressure can be both controlled and monitored. The chamber pressure on the other hand needs only to be monitored and therefore the signal is just sent from the penning on DENISE through Vin3 and isolated from the PC where the signal is then read on the PC at Vout3. Vin4 and Vout4 are not utilised but were included for use in further diagnostics if required.

From the above circuit diagram it can be seen that two separate power supplies are required to power up each side of the circuit board, one supply for the PC side and one supply for the DENISE side. The circuit diagrams for these supplies are described next, and are shown in Fig. 2 Appendix A.



### **3.6. Power Supplies.**

The purpose of a power supply is to convert a mains supply, 240V ac to a lower DC voltage or voltages. Simply this involves four steps : 1) Transforming to a lower voltage, 2) rectifying 3) smoothing, 4) regulating.

The input power comes from the mains source. A transformer changes the 240V supply to a lower voltage, which is still AC. When the wave form is then rectified it is then seen as a series of bumps, each bump corresponds to one half cycle of the original AC voltage wave form. This rectification is usually achieved with the use of diodes. Even though the wave form is now of a DC nature, it is considered to irregular to be considered useful, and therefore needs to be smoothed, this is generally achieved by the use of a capacitor, and a more level DC voltage is given. The value achieved however is dependant on the current drawn from the circuits, so a more constant DC voltage level is required, this is produced by regulation. [4]

### **3.7. Digital Electronics.**

As stated earlier the TTL signal from the input/output card is brought out into the real world by means of the circuit Fig. 3 in Appendix A. These signals have a high or a low level state (5V, 0V), with the ability to turn on or off a relay. Obviously then it is the control of the components that is an issue here, and the monitoring of the state of each component .

As the same problems arise with grounds in digital electronics, the question of ground isolation arises again, however the solution is simple and effective: Optically coupled isolators, opto-isolators, are available with plenty of bandwidth, 10Mhz or more, isolation of several kilovolts and low cost.[5]

### **3.7.1. Opto-isolators/Optocouplers.**

An LED emitter, combined with a photodetector in close proximity forms a very useful electronic device known as an optocoupler/opto-isolator. Basically optocouplers let you send digital signals between circuits with separate grounds. This galvanic isolation is a good way to prevent ground loops in equipment that drives a remote load, which is the case here. Optocouplers typically provide 2500Volts(rms.) isolation,  $10^{12}$  ohms insulation resistance and less than a picofarad coupling between input and output.[6]

### **3.8. Digital Circuitry.**

The circuit that isolates the digital signals reference grounds is shown in Fig. 4, Appendix A. The signal is brought from the PC via the input output card described earlier, through the circuit in Fig. 3, Appendix A, also explained previously. The TTL signal is then buffered by a 74LS245, and passed through an optocoupler the TIL119, which separates the reference grounds on either side of the signal, for the signal being sent from the PC on the write channel the left hand side of the optocoupler is grounded on the PC side while the signal leaving is grounded on the DENISE side. The signal also goes through an LED which lights when a signal is sent down the line. This allows ease in problem shooting the circuit. 16 TTL signals can be sent through this circuit.

Similarly the signal that is read back goes through a similar circuit, but in this case the left hand side of the optocoupler belongs to the DENISE side, while the right hand side isolates the ground of the PC.

16 channels are read back from here to the circuit Fig. 3 Appendix A, back to the input/output card and back to the PC.

At this point an isolated signal is being sent from the PC to the outside world from here it is possible to control the operation of the pumps by use of a relay circuit.

there are 4 relay circuits with 4 relays on each to facilitate each of the 16 TTL signals. The relay circuit is shown in Fig. 5, Appendix A, each relay is rated at 10 Amps. An LED is placed in parallel with each relay to facilitate trouble shooting.

The option of running the system by either PC or Manually by a number of switches is facilitated for by use of a manual/Computer circuit board. This circuit is shown in Fig. 6, Appendix A. In this circuit a TTL signal is taken from the input output card which we call the watch dog line, this signal must be in a predetermined state if the user wishes to operate the controls via the PC. This is a safety precaution in case a power failure happens to the PC. The watchdog lines, one of which is high and the other is low, show that the PC is ready and that the option to control by PC has been made. TTL1 and TTL2 in on the circuit diagram are the watchdog lines, all other TTL signals are signals which come from the digital isolation board which control some digital component. This circuit uses tri-state logic, and logic gates.

TTL2 is inverted by the use of a NAND gate. This inverted signal is now the input of another NAND gate, the other input being the other watch dog line TTL1 . The output is then sent to each of the 74LS245 chips two of which are carrying information from the PC and two of which are carrying information from the switches on the control panel. Depending on whether the output is high or low, it is then passed through another NAND gate where the other input comes from a latch relay which is connected to a PTM/PTB button. On pushing the PTM button the relay becomes energised, and this signal NAND'ed with the correct signal from the watchdog lines then enables the user to operate the system in computer mode, ie. the computer is enabled. However on pressing the PTB button the computer is disabled and the buffers, the 74LS245's carrying the control signals from the front panel switches on the box of electronics are enabled. On power up of either the box of electronics and the PC, the circuit is designed so that the operation of DENISE is automatically in manual mode, ie. operated from the switches on the front panel. This is an added safety precaution.

The signals then go to the relay circuit described earlier, from here the pumps are connected directly and so the operation is controlled and automated. A signal is also brought back from the relay board through another digital isolation circuit to show which components are being controlled.

At this point the analogue electronics required to monitor and control the pressure has been designed and the digital electronics to control the operation of the components also designed.

### **3.9. Conclusion**

In this chapter the difference between analogue and digital electronics has been described and the method in which both were used to generate the signal required to automate the system as far as the hardware is concerned. The main problem encountered in this section was that of ground loops which was discussed and the methods used as a solution to the problem. It is now necessary to generate the software for this system so that the status of the whole system can be seen at one glance. This is described in the next chapter.

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## **Chapter Four**

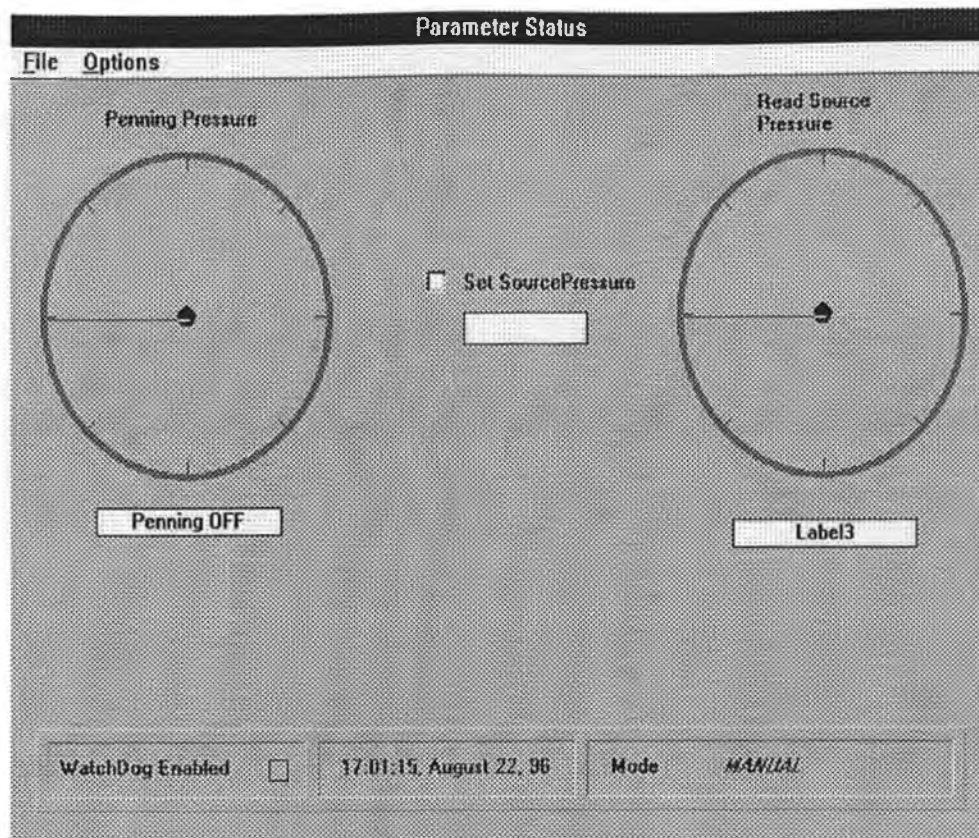
### **Introduction to Software.**

#### **4. Introduction.**

Having implemented a hardware solution for the transmission of signals to and from the control system for DENISE, an easy and accessible interface was required. A visualisation of the status of the control system with the ability to manually and automatically change the settings was implemented. The implementation was designed to be intuitive and accessible to the user. To this end a graphical user interface (GUI) was written for the windows environment.

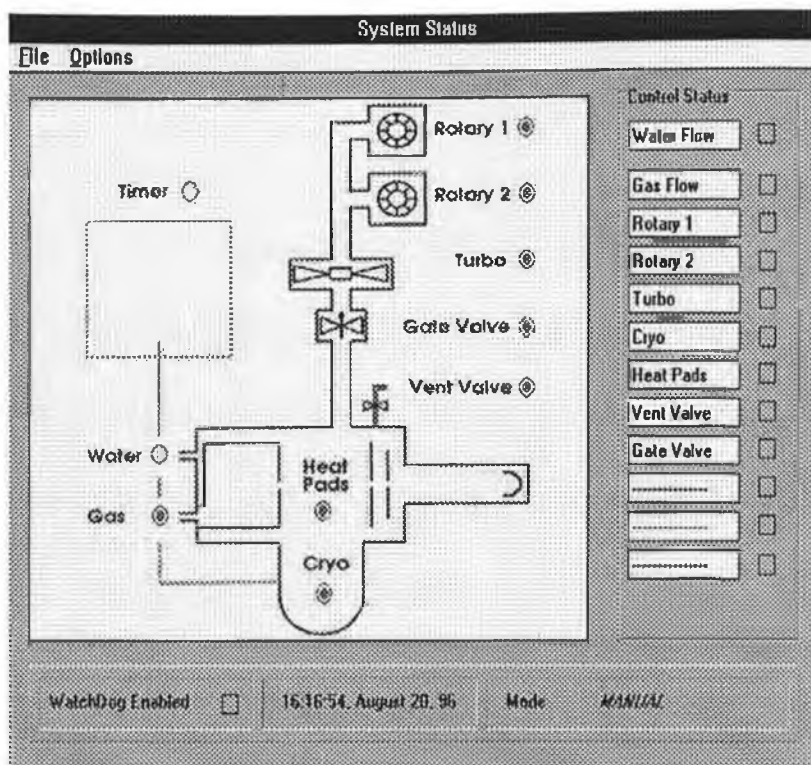
#### **4.1. Implementation of Design Specification.**

Visual Basic was chosen to implement the GUI. Using the native design workbench of this language a GUI was quickly built which would allow the user easy access to the information being relayed from the system.



**Figure 4.1**      **Parameter Status Screen**

Using the GUI the user can control the status of the system, eg. pumps and valves, using the onscreen representation of the control electronics. This enables the user to virtually control the experiment from a distance. The schematic of the GUI used for the system status screen is shown in Fig. 4.2.



**Figure 4.2 System Status Screen**

The software has the capability to externally control the pressure in the source by use of an automated feedback loop. The user can set the required pressure using the parameter status screen, Fig. 4.1. This set value is then compared to the pressure read from the transducer. Using a software feedback loop the pressure is maintained at the set point.

The signal coming from the control components through the hardware is brought back to the interface board in the PC. Since Visual Basic does not have the library of functions necessary to read this information from the interface board an external function library was written and implemented using C. Another aspect of using a DLL (Dynamic Link Library) written in C is speed. Visual Basic code is compiled to p-



code. P-code is not in executable format and must be interpreted using an external set of commands (VBRUN300.DLL). this system is substantially slower than fully compiled code. In contrast to this C is a fully compiled language. C works at a level close to native machine code which increases the execution speed of functions written in C. This was advantageous as the library written in C was used to access the information in the interface card. The information read by the functions in the DLL were passed to the GUI functions in Visual Basic. These functions interpreted and displayed the information on screen for the user. Information from the computer was passed back to the interface board through the functions in the DLL to control components in the system. This path to and from the control components is transparent to the user who can control the system at the push of a button.

#### **4.2. Conclusion.**

The control software using the tools inherent with Visual Basic and some functions written in C was used to create a user friendly environment which has the power to manually and automatically set and monitor the state of the control hardware.

## **Chapter Five**

### **Conclusion**

#### **5. Summary of Work.**

The objective of this project was to control by computer interface the operation of the multicusp volume ion source DENISE. The system itself is discussed and the reasons that research is being carried out in this field.

The characteristics of Automation was discussed with respect to the given system and the final product was found to be accurate, quick, stable and sensitive. This was achieved through an interface of hardware and software.

The hardware utilised involved both analogue and digital electronics, to facilitate the monitoring and controlling of the parameters and components involved in the operation of this system. A clean, quick stable and accurate signal is transferred through an ADC/DAC card and an I/O card to the electronics described and then on to the parameters that need to be monitored and controlled. The signal to noise ratio was determined to be good, due to the use of ground isolating features inherent in the hardware.

The software used a GUI in Visual Basic that provided a user friendly environment . The functions were written in C and then both packages combined by the use of a DLL.

Combined the end result was one that was both efficient and effective in automating the volume ion source DENISE.

**6. APPENDIX A CIRCUIT DIAGRAMS.**

CIRCUIT DIAGRAM 1 : ANALOG ISOLATION, TO PREVENT GROUND LOOPS.

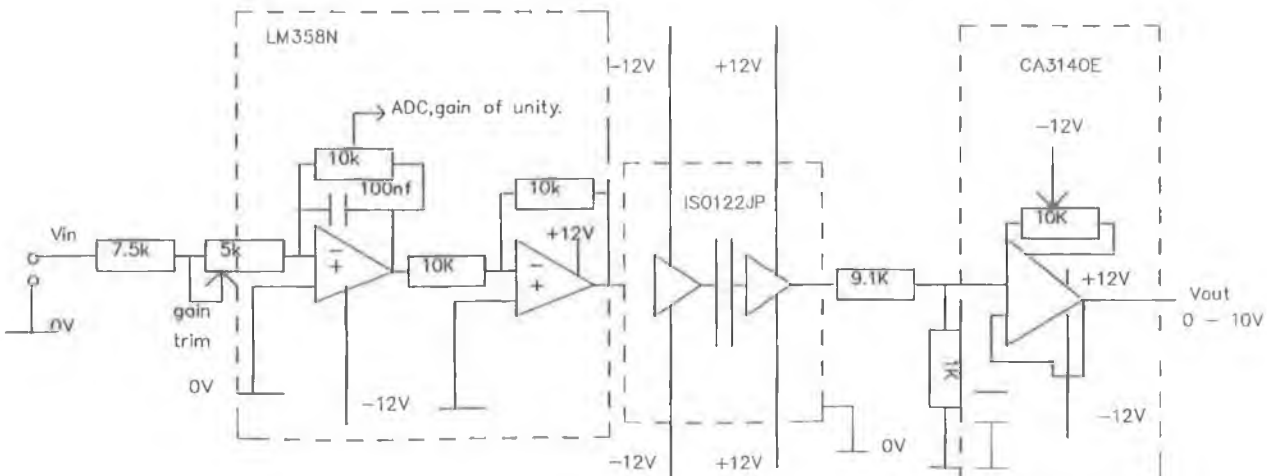
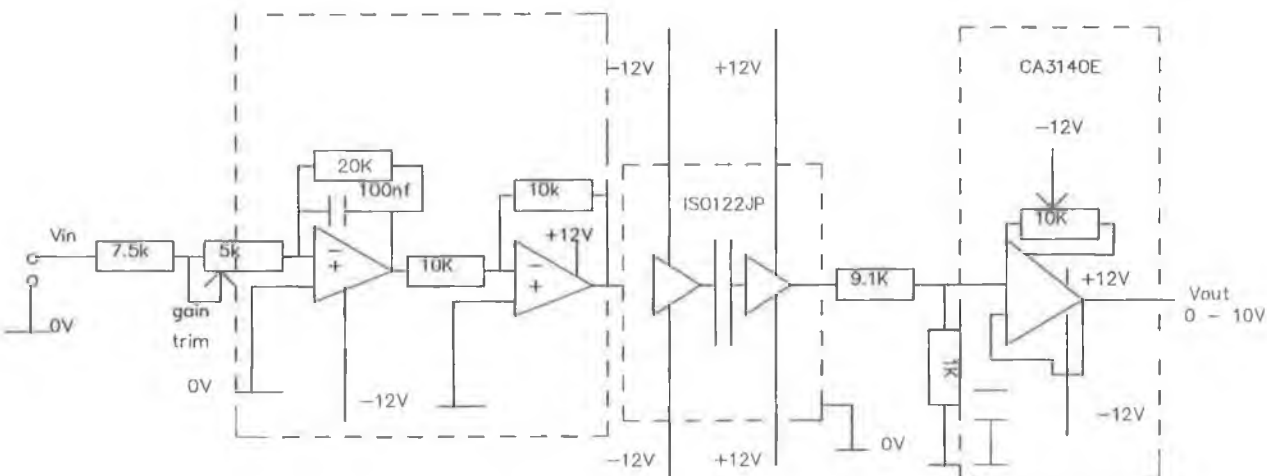
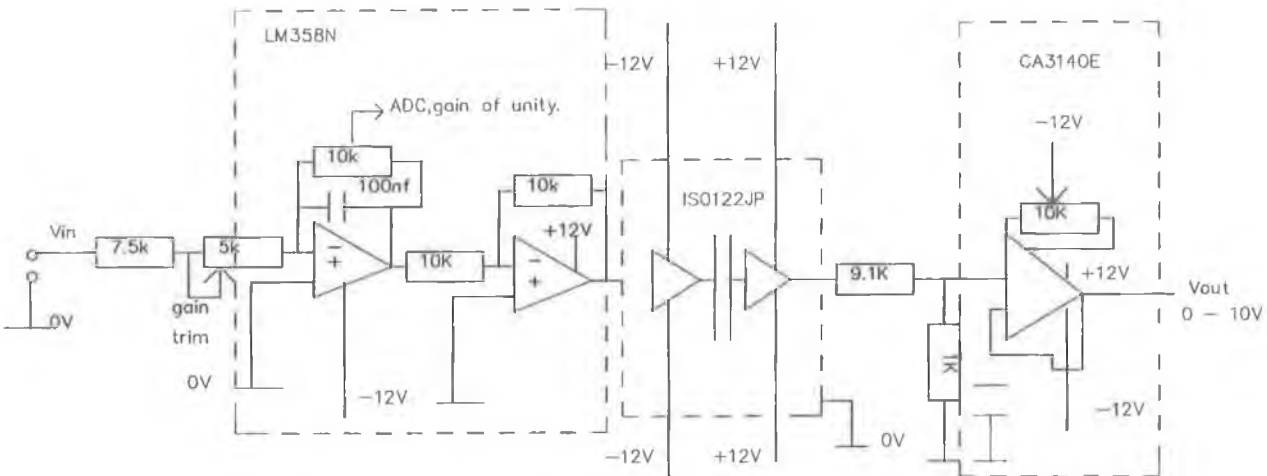
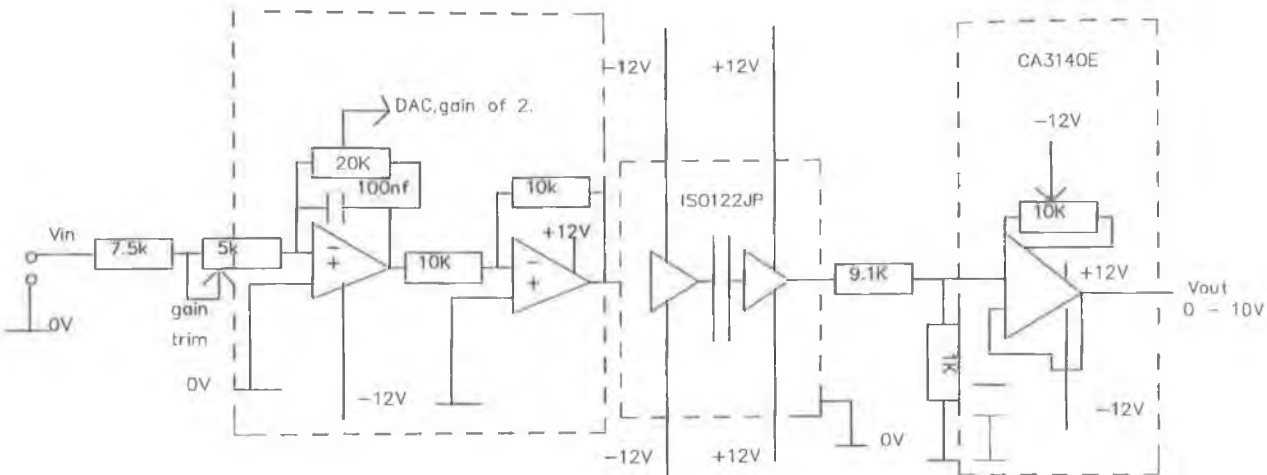
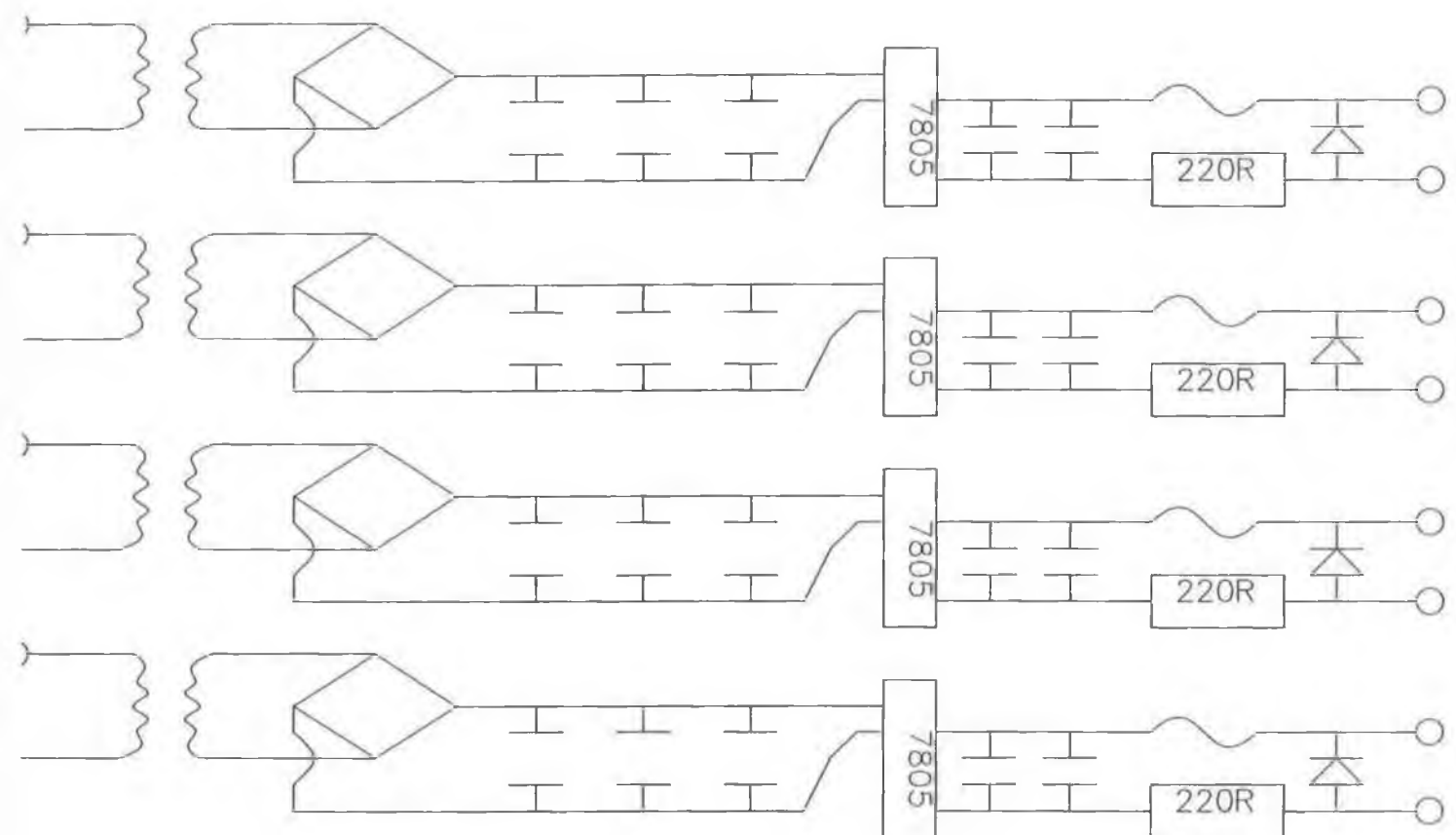


Fig 2. Power Supplies



**Fig 3. Circuitry to transfer signal from PC to control Circuitry.**

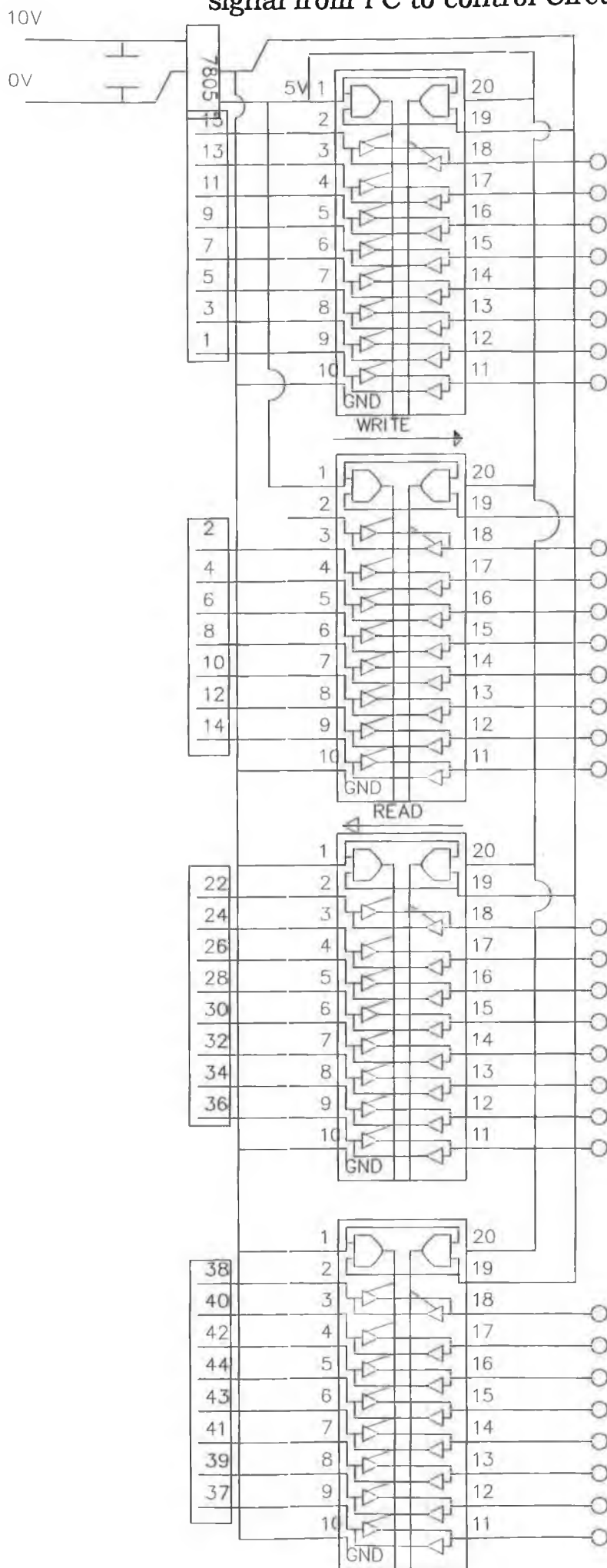


Fig 4 Digital Isolation Circuitry.

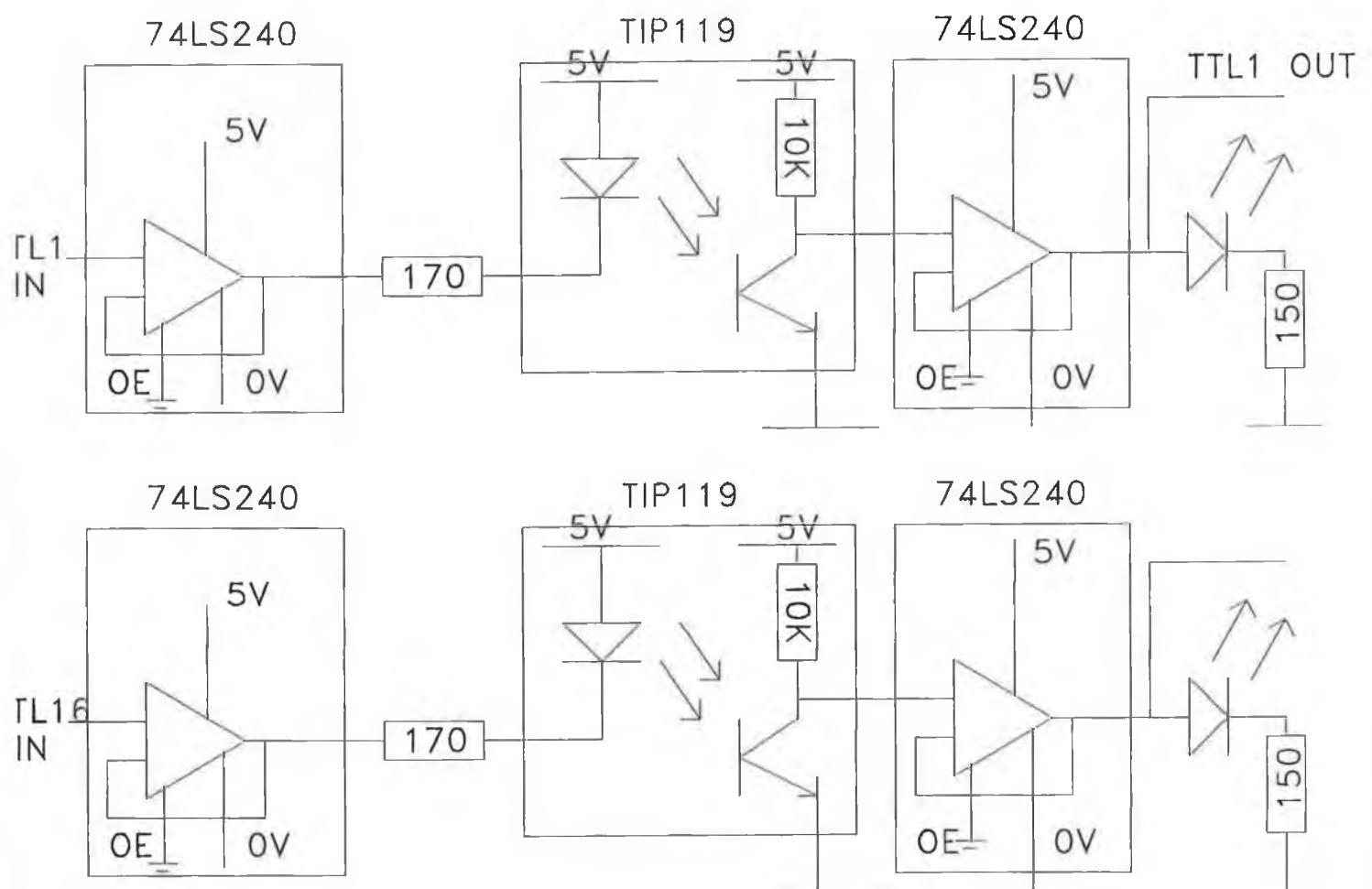


Fig. 5 Relay Circuitry

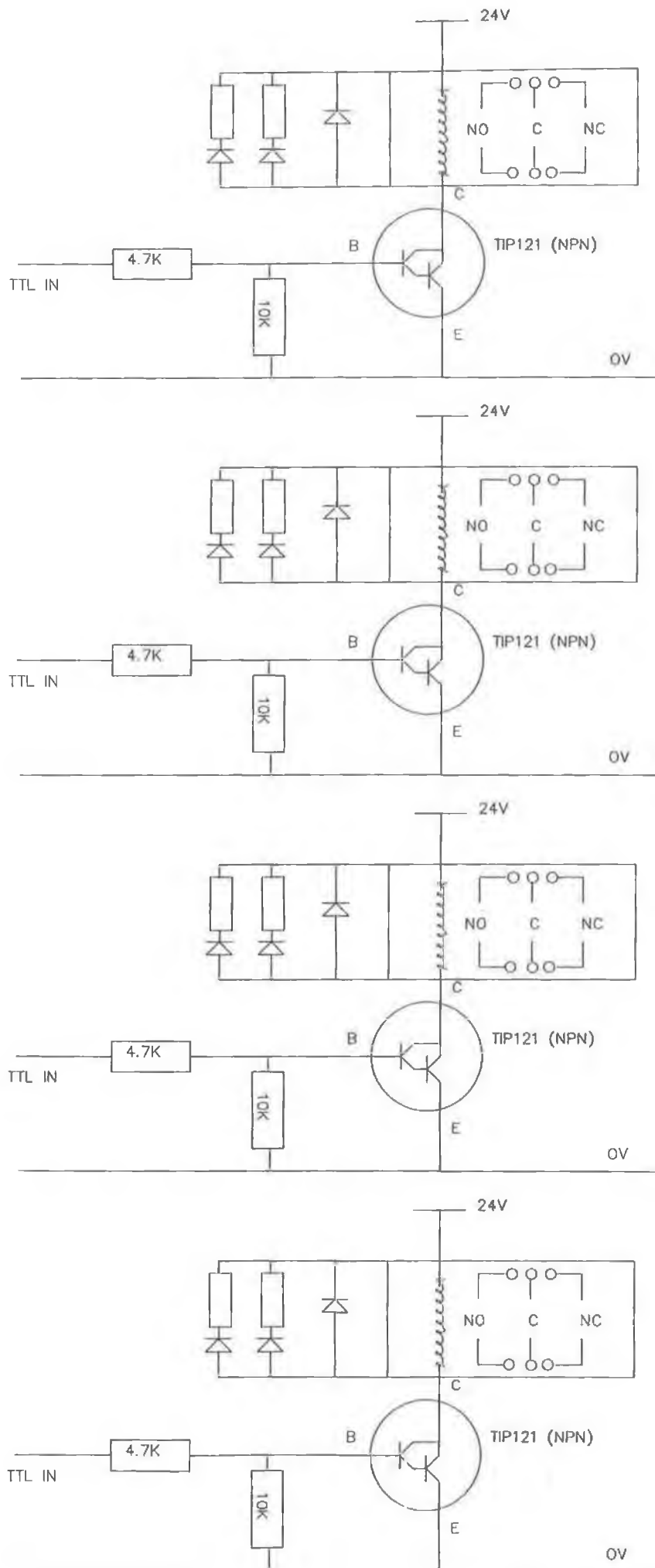
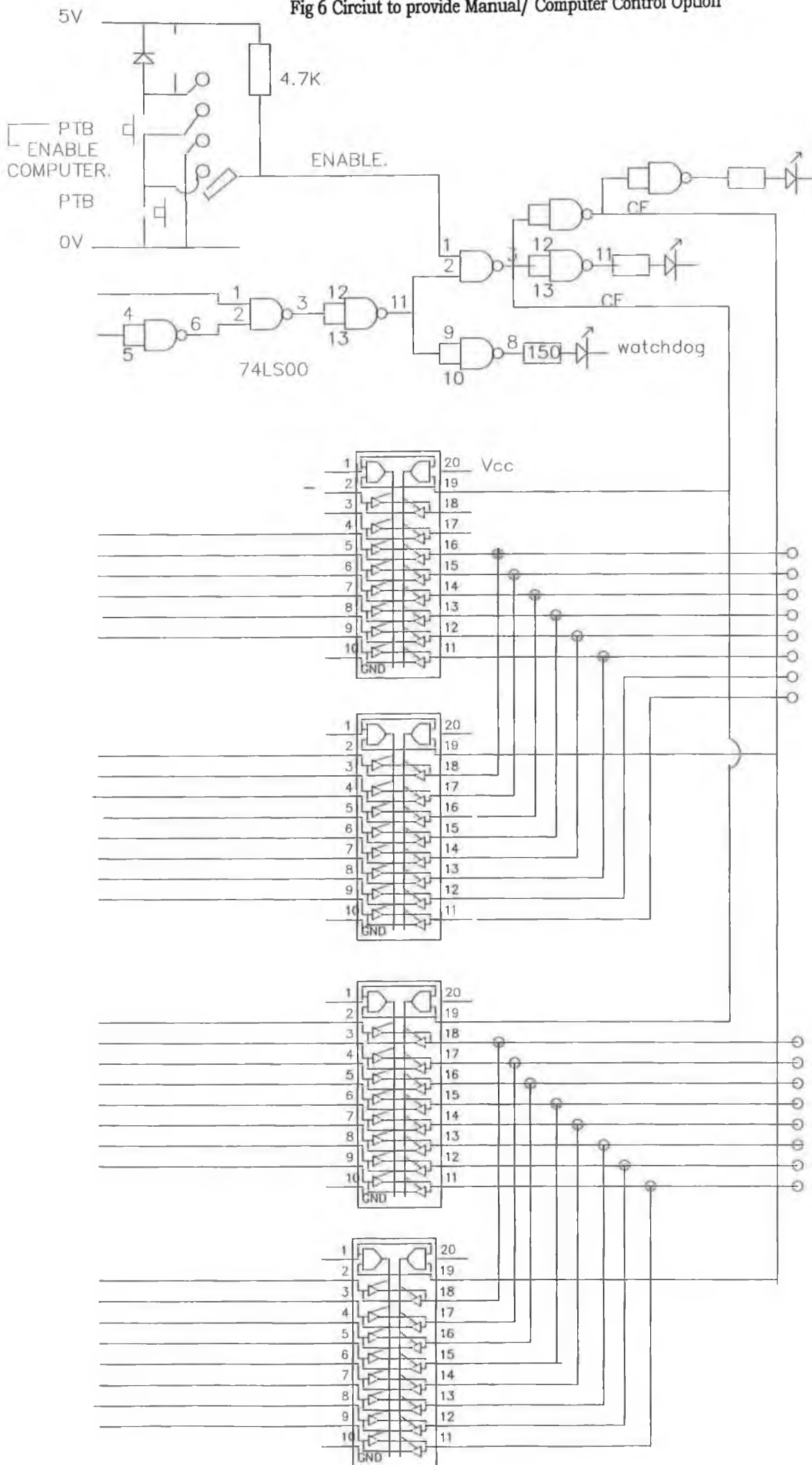




Fig 6 Circiut to provide Manual/ Computer Control Option



## **7. APPENDIX B SOFTWARE**

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Option Explicit

```
Declare Sub OUT Lib "PORTDLL.DLL" (ByVal PORT As Integer, ByVal OUT_BIT As Integer)
Declare Function IN Lib "PORTDLL.DLL" (ByVal PORT As Integer) As Integer
Declare Sub WRITEDAC Lib "PORTDLL.DLL" (ByVal DACOUT As Integer)
Declare Function READADC Lib "portdll.dll" (ByVal ADCPORT As Integer) As Integer
```

Option Explicit

```
Sub ControlInputA_Click (Index As Integer)
Dim i As Integer
Dim boxoutput As Integer

If watchdoginput = 1 Then
    boxoutput = 1

    For i = 0 To 5
        If controlInputA(i).Value = 1 Then
            boxoutput = boxoutput + 2 ^ (i + 2)
        End If
    Next i
End If
If controlInputA(3).Value = False Then
    controlInputA(5).Value = False
End If

    Call out(768, boxoutput)
Else
    Call out(768, 0)
End If

End Sub
```

```
Sub ControlOutputA1_Click (Index As Integer)
Dim J As Integer
Dim boxoutput1 As Integer

If watchdoginput = 1 Then
    boxoutput1 = 0
    For J = 0 To 5
        If ControlOutputA1(J).Value = 1 Then
            boxoutput1 = boxoutput1 + 2 ^ (J + 2)
        End If
    Next J
    Call out(772, boxoutput1)
Else
    Call out(772, 0)
End If

End Sub
```

**Sub ControlWater\_Click (Index As Integer)**

**End Sub**



```
Sub Form_Load ()  
Call out(771, 139)  
Call out(775, 139)
```

```
End Sub
```

**Sub GasFlowInput\_Click ()**

**End Sub**

```
Sub ModeTimer_Timer ()
If in(773) = 228 Then
    ModeStatus.Caption = "COMPUTER"
Else
If in(773) = 244 Then
    ModeStatus.Caption = "MANUAL"
End If
End If
End Sub
```

```
Sub PenningTimer_Timer ()

Dim Volt As Single
Dim logpress As Single

Dim a As Single
Dim b As Single
Dim c As Single
Dim d As Single
Dim e As Single
Dim f As Single
Dim g As Single

a = .000104
b = -.00283
c = .0283
d = -.112
e = .018
f = 1.16
g = -7.25

PenningGauge.Value = readadc(0)

Volt = (PenningGauge.Value * (10 / 4095))

logpress = (a * (Volt ^ 6)) + (b * (Volt ^ 5)) + (c * (Volt ^ 4)) + (d * (Volt ^ »
» 3)) + (e * (Volt ^ 2)) + (f * (Volt ^ 1)) + g
If Volt >= .21 Then
    readPenning.Caption = Format$(10 ^ logpress, "#.##E+00") + " Torr"
Else
    readPenning.Caption = "Penning OFF"
End If

End Sub
```

```
Sub PortB1Timer_Timer ()
Dim num As Integer
Dim b As Integer
Dim value As Integer

num = 63 - in(774)

value = 0

For b = 0 To 3

    value = num And (2 ^ (b + 2))
    If value > 0 Then

        If b = 0 Then
            GasOption.Value = 1
        End If
        If b = 1 Then
            HeatPadOption.Value = 1
        End If
        If b = 2 Then
            CryoOption.Value = 1
        End If
        If b = 3 Then
            VentValveOption.Value = 1
        End If

        value = 0
    Else
        If b = 0 Then
            GasOption.Value = 0
        End If
        If b = 1 Then
            HeatPadOption.Value = 0
        End If
        If b = 2 Then
            CryoOption.Value = 0
        End If
        If b = 3 Then
            VentValveOption.Value = 0
        End If

    End If
Next b
End Sub
```

```
Sub PortCTimer_Timer ()
Dim num As Integer
Dim b As Integer
Dim value As Integer

num = 63 - in(770)

value = 0

For b = 0 To 3

    value = num And (2 ^ (b + 2))
    If value > 0 Then

        value = 0
        If b = 2 Then
            TurboOption.Value = 1
        End If
        If b = 0 Then
            Rotary1Option.Value = 1
        End If
        If b = 1 Then
            Rotary2Option.Value = 1
        End If
        If b = 3 Then
            GateValveOption.Value = 1
        End If

    Else

        If b = 2 Then
            TurboOption.Value = 0
        End If
        If b = 0 Then
            Rotary1Option.Value = 0
        End If
        If b = 1 Then
            Rotary2Option.Value = 0
        End If
        If b = 3 Then
            GateValveOption.Value = 0
        End If

    End If
Next b

End Sub
```

```
sub SystemFileExitMenu_Click ()  
call out(768, 0)  
End  
  
End Sub
```

```
Sub SystemOptionsParameterMenu_Click ()
schematic.Visible = False
controlstatusframe.Visible = False
SystemStatusForm.Caption = "Parameter Status"
readPenning.Visible = True
PenningGauge.Visible = True
PenningLabel.Visible = True

readsourcepress.Visible = True
SetSourcePressure.Visible = True
ReadSPress.Visible = True
readsource.Visible = True
sourceset.Visible = True
pressset.Visible = True
```

End Sub



```
sub SystemOptionsStatusMenu_Click ()
schematic.Visible = True
controlstatusframe.Visible = True
systemStatusForm.Caption = "System Status"
readPenning.Visible = False
PenningGauge.Visible = False
PenningLabel.Visible = False

readsourcepress.Visible = False
SetSourcePressure.Visible = False
ReadSPress.Visible = False
readsource.Visible = False
sourceset.Visible = False
presssset.Visible = False
```

End Sub

```
Sub Timer1_Timer ()
Dim number As Integer
number = in(773)

If number = 248 Then

    WaterOption.Value = 1
Else
If number = 252 Then

    WaterOption.Value = 0
End If
End If

TimeStatus.Caption = Format(Now, "ttttt, mmm dd, yy")

End Sub
```

```
Sub Timer2_Timer ()  
  
Dim press As Integer  
  
Dim dacvoltage As Integer  
Dim num As Integer  
Dim reading As Integer  
If pressset.Value = True Then  
    press = sourceset.Text  
    dacvoltage = press / 10  
    num = (4096 * dacvoltage) / 3  
    writedac (num)  
End If  
readsourcepress.Value = readadc(4)  
reading = (readsourcepress.Value / 4096)  
  
readsource.caption=reading  
End Sub
```



Sub WaterFlowInput\_Click ()

End Sub

**8. APPENDIX C TEST PROGRAM.**

**Note:** This is a test program to ensure the correct operation of the interface cards being utilized in this project. The object of this program is to cut down on problem solving time should any errors arise with the automation system. This program was written in Borland C for Windows.

```

#include<windows.h>
#include<stdio.h>
#include<conio.h>
#include<string.h>
#include <dos.h>

#pragma argsused

int id_con_to_bin(char *,int);
int id_screen(int,int,int,int,int,int,int,int,int,int,int);
int id_write_dac(unsigned int ,unsigned int );
int id_signed int read_adc(unsigned int );

int PASCAL WinMain(HANDLE hInstance, HANDLE hPrevInstance,LPSTR lpszCmdLine,int
int ovalue0,ovalue1, value1,value0, dac1=0,dac0=0,x,ans,ix,iy,iz,ox=0,oy=0,oz
int ng mean;

int id EasyWin();
int id tportb(771,139); /*Control Command which sets only A and A'as outputs*/
int id tportb(775,139);

0

for (mean=0,x=0;x<100;x++) mean+=(long)read_adc(0);
value0=mean/100;
for (mean=0,x=0;x<100;x++) mean+=(long)read_adc(1);
value1=mean/100;

ix=(int)inportb(773); iy=(int)inportb(770); iz=(int)inportb(774); /* Read
if ((ix!=oix)|| (iy!=oiy)|| (iz!=oiz))
if ((ovalue0!=value0)|| (ovalue1!=value1))
{
screen(ix,iy,iz,ox,oy,oz,value0,value1,dac1,dac0);
oix=ix; oiy=iy; oiz=iz; ovalue0=value0; ovalue1=value1;
}
while(!kbhit());

ans=getch();
if ((ans>='a')&&(ans<='h')) ox^=(1<<(ans-'a'));
if ((ans>='i')&&(ans<='p')) oy^=(1<<(ans-'i'));

if (ans=='q')

clrscr();
printf("Enter now value for DAC0 : ");
scanf("%u", &dac0);
printf("Enter now value for DAC1 : ");
scanf("%u", &dac1);
write_dac(dac0,dac1);

* Write ox,oy to the ports */
outportb(768,ox); /* Port A */
outportb(772,oy); /* Port A' */

ix++;

* if (ans=='q') then dac1 update etc... */

```



```
while(ans!='z');
```

```
return 0;
```

```
*****/  
Convert num to binary string */  
*****/  
void con_to_bin(char text[],int x)
```

```
int y;  
strcpy(text,"");  
while(y=0;y<8;y++)  
if((x&1) !=0) strcat(text,"1"); else strcat(text,"0");  
x/=2;
```

```
*****/  
Writing a number to the DAC*/  
*****/  
void write_dac(unsigned int x,unsigned int y)
```

```
outportb(648,(unsigned char)(x&255));  
outportb(649,(unsigned char)(x>>8));  
outportb(650,(unsigned char)(y&255));  
outportb(651,(unsigned char)(y>>8));  
outportb(652,0);
```

```
*****/  
Reading a number from the adc*/  
*****/  
unsigned int read_adc(unsigned int x)
```

```
inportb(664,x);  
inportb(656,x);  
while((inportb(660)&1)!=1);  
return(((unsigned int)inportb(659)>>4)+((unsigned int)inport(658)<<4));
```

```
*****/  
Output all port values to the screen */  
*****/  
void screen(int ix,int iy,int iz,int ox,int oy,int oz,int value1,int value0,int
```

```
char text[10];  
clrscr();  
gotoxy(2,2);printf("DIGITAL INPUT");  
gotoxy(2,3);printf("Port B");  
gotoxy(2,4);printf("01234567");  
con_to_bin(text,ix);
```

```

toxy(2,5);printf("%sb = %dd = %2Xh",text,ix,(unsigned int)ix);

oxy(24,3);printf("Port C");
oxy(24,4);printf("01234567");
to_bin(text,iy);
oxy(24,5);printf("%sb = %dd = %2Xh",text,iy,(unsigned int)iy);

oxy(46,3);printf("PORT C'");
oxy(46,4);printf("01234567");
to_bin(text,iz);
oxy(46,5);printf("%sb = %dd = %2Xh", text, iz, (unsigned int)iz);

oxy(2,7);printf("DIGITAL OUTPUT");
oxy(2,8);printf("Port A");
oxy(2,9);printf("01234567");
oxy(2,10);printf("ABCDEFGH");
to_bin(text,ox);
oxy(2,11);printf("%sb = %dd = %2Xh",text,ox,(unsigned int)ox);

oxy(27,8);printf("Port A'");
oxy(27,9);printf("01234567");
oxy(27,10);printf("IJKLMNOP");
to_bin(text,oy);
oxy(27,11);printf("%sb = %dd = %2Xh",text,oy,(unsigned int)oy);

oxy(2,13);printf("ANALOG OUTPUT");
oxy(2,14);printf("DAC 0");
oxy(2,15);printf("SET VALUE (0-1000) : %u",dac0);

oxy(2,17);printf("ENTER Q TO UPDATE DAC VALUES");

oxy(46,14);printf("DAC1");
oxy(46,15);printf("SET VALUE (0-1000) : %u",dac1);

oxy(2,19);printf("ANALOG INPUT");
oxy(2,20);printf("ADC1");
oxy(2,21);printf("%u",value0);
oxy(2,23);printf("PRESS ANY KEY TO UPDATE THE ADC VALUES");

oxy(22,20);printf("ADC2");
oxy(22,21);printf("%u",value1);

oxy(2,25);printf("Z to Quit");

```