Mat Noh. M.

Liquid Level Sensing Device

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE DEGREE OF MASTER OF SCIENCE IN MSC AUTOMATION & CONTROL

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ABSTRACT

The project designed to be implemented to measure the level of molten iron liquid inside a tank. The design is based on a torque-controlled drive where the level of the liquid in the tank is measured using a suspended float. The float is lowered from the disc drilled around its perimeter and a lightweight rope, using torque sensitive electric drive and rotary encoder circuit to produce the pulse that is used to calculate the level of the liquid inside a tank. When the float makes contact with the liquid level surface, the torque reduces and the number of revolutions made by the disc is counted and the level is calculated using an appropriate formula and displayed.

CHAPTER 1: INTRODUCTION

1.1 Introduction

The determination of liquid level applications has been developed for many years especially for process industries. There are many ways or methods to determine the level of a liquid. Whatever method we chosen, much depend on the nature of the liquid itself and sometimes the environment also might limit our choice of the methods available. For example, to determine the level of molten iron in a blast furnace it is not a straightforward and many delicate sensing devices cannot operate in this corrosive and extremely high temperature. Therefore before choosing any sensing method, we have to investigate what are the methods available and should be operable in very hazardous environment and extremely high temperature.

After consideration of the specification and the conditions where the method will be applied, it was decided to design a liquid level sensing device using torque controlled drive. Therefore a small permanent magnet brushes dc motor is used to lower a float with a disc and cable at the liquid, using a torque sensitive drive. When the float makes contact with liquid, the torque reduces due to up-thrust force exerted from the liquid to the float and the number of revolution made by the disc is used to calculate the level, which is displayed according to the appropriate formula has been set in the program. The overall system is controlled using PIC.

1.2 Problem Specifications

Design of a liquid level sensing device not a straightforward. In order to determine the level, we need to make the motor rotate and control it, otherwise we far from what we are targeting for this project. Many factors need to put into account to avoid any unnecessary problem a rise after completing the project. The work performed in this project incorporates a number of different fields of work:

a) Power electronic circuit: This is the most important part of the project. The correct switching current needed in order to make the motor rotate and produce the torque. This basic operation is common for most types of motors.

b) Encoder circuit: The encoder circuit is used to provide feedback to the software therefore can update the microcontroller how much the motor has travelled by counting the number of revolution made by the disc.

c) Sensor Technology: The motor controller has a number of sensors, which provide feedback to the software control loops. The sensor used in the motor controller is current transducer for measuring the current and voltage measurement.

d) Display circuit: The display circuit is used to display the level of a liquid using seven-segment-display. This is very common requirement in modern electronics is that displaying alphanumeric characters.

e) Software development: This is the brain of the project. The control algorithm is maintained by PIC microcontroller. The BASIC language is used to perform the control algorithm.

1.3 Project objectives

The primary and most important goal of my project was:

To design and construct a liquid level sensing device which will determine the level of liquid inside a tank

To make this become reality, there are a few factors need to be considered:

i) To control the torque by controlling the armature current
ii) Motor speed is set to be constant
iii) To detect the motor shaft position

1.4 Organisation of the Theses Document

The remainder of the theses describes all work completed, problems encountered and how these problems were overcome. Detailed descriptions including theory are presented to support practical design choices. The following chapters form the body of the thesis document, and may be summarised as follows:

Chapter 2 : Liquid level technique literature, presents a literature review of all relevant works in the field of liquid level sensing techniques

Chapter 3: Theory, presents the background material necessary to understand how a permanent magnet brushed DC motor operates, and gives an insight of how to control such a motor and the theory of all key components used in the project.

Chapter 4: Mechanical design, presents a mechanical design aspects where later the encoder circuit had to be fitted in.

Chapter 5: Hardware design and construction, analyses the circuits designed and describes their operation down to component level. Design formulas indicate how component values were obtained.

Chapter 6: Software development, describes the control algorithms implemented in software, which control the motor. There is a full listing of the code completed to date in Appendix E.

Chapter 7: Result and discussion, presents a discussion of the liquid level sensing device, the result and the issues that emerged from such a project.

Chapter 8: Conclusion, concludes the document with a short summary of the findings throughout the thesis project. Some possible future work is given as suggestions to improve the liquid level sensing algorithm. A final note is then given to the overall picture of liquid level sensing device and where the future of such a technology is headed.

CHAPTER 2: LIQUID LEVEL SENSING TECHNIQUES LITERATURE

2.1 Introduction

An extensive literature search was carried out to review work completed previously. A list of keywords relating to the topic for searching databases: e.g. liquid level, liquid depth gauge was drawn up. A general WWW search resulted in a number of results however I found many of the web sites were usually a company trying to sell their product, and offer little or no technical information. The WWW is a very convenient way of obtaining product data sheets. A comprehensive search using
the networked databases Inspec, Compendex, Engineering & Applied Science. This search resulted in some journal and magazine articles relevant to aspects on liquid level sensing technique.

It was discovered there are a few techniques being used to determine a liquid level. However requirement of this project is to design the liquid level sensing device that can be used to determine the molten iron liquid level inside a tank. Therefore before discuss all the techniques available; we should look into the characteristics of the blast furnace, which is used to produce molten iron.

2.2 The Blast Furnace

The blast furnace is used to produce molten iron. Figure 2.2.1 shows the cross-section of a blast furnace plant showing the material handling, charging, tapping, gas handling and hot-blast equipment[1].

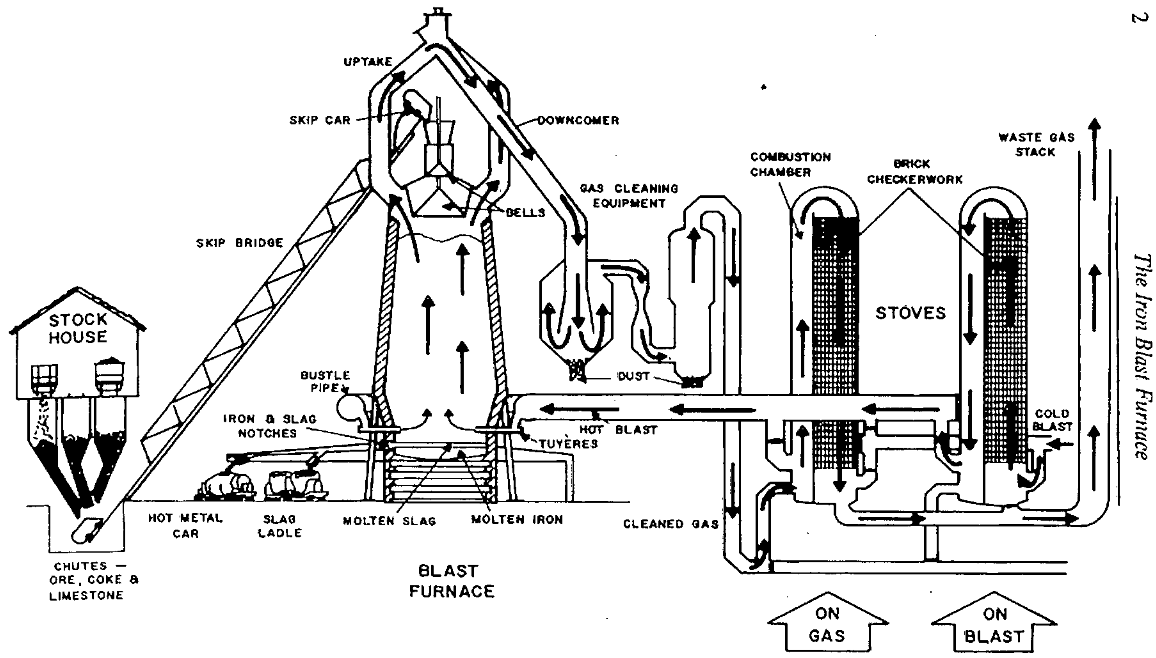

Figure 2.1: Schematic cross-section of a blast furnace plant showing materials handling, charging, tapping, gas handling and hot-blast equipment[1].

The blast furnace working temperature is always greater than 1700°K[1] (1427°C). Since we know that the melting point of molten iron itself is around1600°K, therefore it is very important to ensure that the temperature of the blast furnace should be kept higher than the molten iron melting point.

Figure 2.2 shows the structure of a blast furnace tower[2]. The blast furnace tower comprises of 6 sections that starts from the top to the bottom, which are the bell, throat, shaft or stack, cylindrical belly, bosh, and hearth. The bell consists of two bells in different sizes (sometimes four or even less), which are small bell on the top and large bell at the bottom. The solid materials are charged through the bell. The throat is attached with a movable deflector to get a uniform burden across the furnace. The stack or shaft is the largest section of the blast furnace, which is about 3/5 of the total height[2] where its diameter increases from top to bottom of the section to facilitate a uniform flow of the gases and the materials. The cylindrical belly has largest diameter where the process of getting metal and slag starts at this region. The diameter is decreases at bosh that connects with the most bottom section of furnace, which is hearth where the molten iron and slag are accumulated. Other than these six sections, there are two openings at the top of the furnace (left and right) for releasing the output gases from reaction process in the furnace.

The molten iron made up from the combination of solid materials and gases. The materials balance is shown in figure 2.3[1]. The solid materials are charged through the top of the furnace consists of iron oxide (ore) usually hematite, sometimes magnetite, metallurgical coke that is produced by heating mixtures of the powdered coking coal in absence of air[1] and flux which reduce the melting point of coke and ore. There are materials that are charged via the tuye`res which are the hot-blast air (sometimes also enriched with oxygen) and hydrocarbons (could be solid, liquid or gas). The hot-blast air burns the coke in front of tuye`re which is used for heating and melting the charge and products. Therefore it is important to maintain the temperature of the hot-blast air above the melting point of the molten iron and slag.

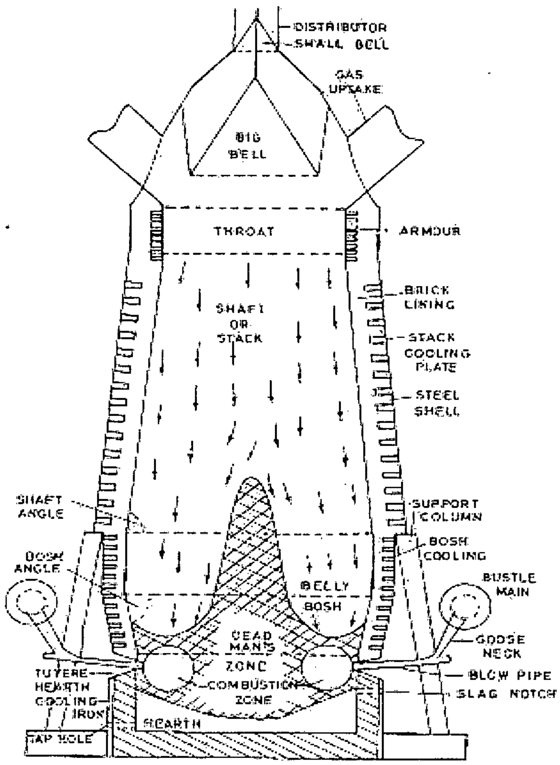

Figure 2.2: The structure of the blast furnace[2].

As mentioned before the main product of the blast furnace is molten iron. However there are two other by-products are formed by the blast furnace, which are slag, which contains very little iron oxide, which indicate the efficiency of the furnace. The second by-product is gas which leaves through the gas-collection system at the top of the furnace as shown in figure 2.3.

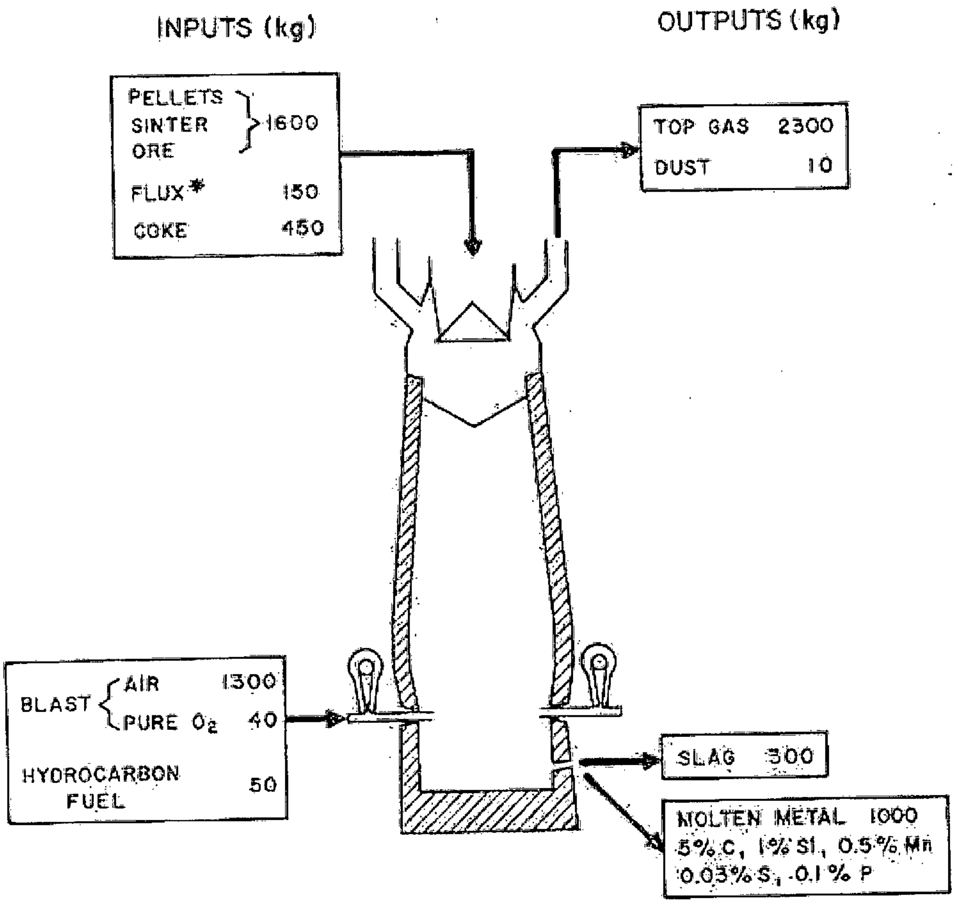

Figure 2.3 : Representative materials balance for a large blast furnace[1]

2.3 The Liquid Level Sensing Techniques

2.3.1 Fibre Optic

There are many works done using this method. Pekka Raatikainen and team, using this method in their project named "Fibre-Optic Liquid Level Sensor" was published in October 1996[3]. The project was based on total reflection of light that is distributed by a contact of a sensor tip with a liquid. There are four different tip of shapes being fabricated which are conical, rounded conical, second order polynomial and third order polynomial[3].

Figure 2.4 shows the sensor system, which comprises of a control unit, a transmitter, a receiver, two fibres that is coupled together and the sensor is attached at the end of the coupled fibres. The coupled fibres are used for forward path (transmitter) and return path (receiver). LED is used as a transmitter, which is the source of the light, and photodiode is used as a receiver as to response to the sensor signal.

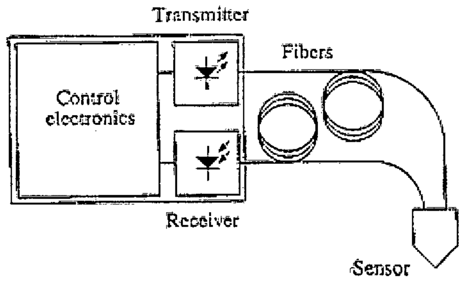

Figure 2.4 : Schematic liquid level sensing system[3]

The basic operation of this system, the light from the LED (transmitter) is transferred to the sensor through the fibre (first fibre – forward path). When the sensor in air, we know that, in air the light reflection is 100% or also called total internal reflection (TIR)[4] whereas when the sensor immersed in liquid, the light reflection is decreased because some of the light being refracted into a liquid. The light then passes into the second fibre (return path) that is connected to receiver (photodiode), which detects the optical power[3]. The value of optical power is decreased when the sensor immersed in liquid as the light also being refracted into a liquid. The condition of the light reflection when sensor is in air and in liquid is shown in figure 2.5 (a) and (b).

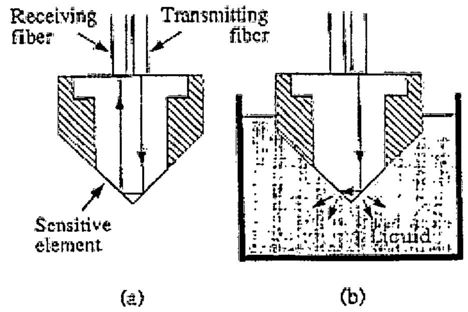

Figure 2.5: Principle of operation: (a) The sensor in air, (b) The sensor in liquid[3]

Another application of fibre optic as liquid level sensor is in cryogenic environment[4]. In this project optical time domain reflectometer (OTDR) was used to display the relative power of the returned signal of probe versus distance. Two types of probes were designed which are shorter face and hypotenuse face types that illustrated in figure 2.6 (a) and (b).

The principle operation of this system is based on angle of incident is compared to the critical angle of the media. As both designs using right angle prism[4] as a sensor, therefore the incident angle would be 45°[4]. When the sensor in vapour which its critical angle is 41°[4] therefore the incident angle is greater than the critical, as a result light will be reflected into a fibre (total internal reflection) and when the sensor in a liquid, the critical angle of liquid (nitrogen) is 51°[4] is greater than the angle of incident, therefore most of the energy will be refracted into a liquid. Thus, we can detect whether the probe is in vapour or in liquid, by monitoring the intensity of light being reflected.

The different between these two types of sensor, in shorter face, the light reflects from the surface of prism's shorter face is around the tip whereas in hypotenuse face, the light reflects in the middle of the hypotenuse surface of a prism which can seen in figure 2.6 (a) and (b).

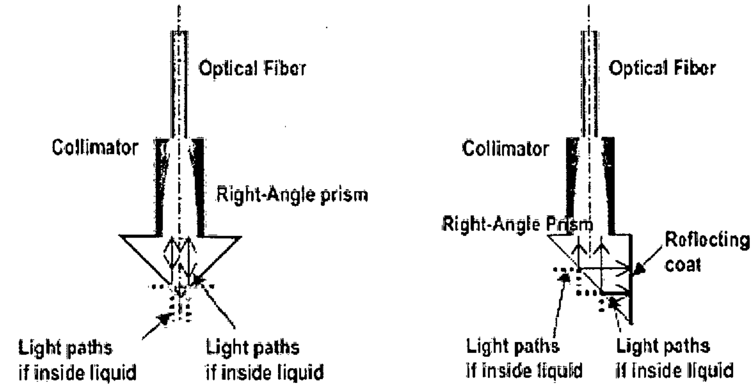

Figure 2.6: The Probe Shapes: (a) "Shorter face" type, (b) "Hypotenuse face" type[4]

2.3.2 Ultrasonic (Ultrasound)

This method can be used in many applications. Using of acoustic impedance as based on measuring attenuation of longitudinal ultrasonic wave in waveguide sensing element to control the level of coolant industrial power-generating equipment[5]. This ultrasonic attenuation is determined when the sensing element is immersed in liquid.

The system comprises of an acoustic converter, waveguide communication, and the sensing element as shown in figure 2.7[5]. The acoustic converter used is piezo-crystal converter, which its operating frequency is 500KHz[5]. The principle operation of the system, the impulses from the converter travel through the waveguide communication to the sensing element. Therefore it is very important to use a good waveguide communication to minimise losses of the signal when impulses travels through it to reach the sensing element, in order to get a desired output. In addition, it is important to ensure the waveguide communication is protected from ambient factors.

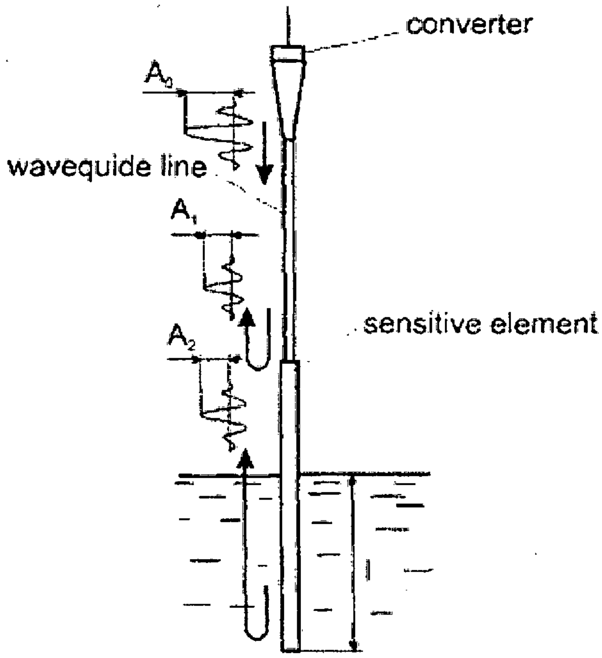

Figure 2.7: Principle elements of the transducer[5]

Another application of ultrasonic is in monitoring system for container filling[6]. The sensing system is based on ultrasonic impulses from a transducer. The system set-up is shown in figure 2.8[6]. The system consists of fluid tank, dispensing valve, a control unit, a container and a transducer to detect the fluid at the optimum level wanted (set-up).

To determine the level of a liquid in the container, the sensor was mounted at 3 different positions, which are side, bottom and top of the container as shown in figure 2.9[6]. The sensor positions require different ultrasound monitoring techniques. Consequently, three monitoring techniques used to ensure the interpretation of liquid level is successful. The techniques are wall resonance approach[6] (for side and bottom positions), far wall echo approach[6] (for side position) and air transmission approach[6] (for top position).

In wall resonance technique, a transducer generates a short ultrasonic pulse that causes a local resonance in the wall. When the pulse ends, the resonance will dies away whereby the ringing time will depend on whether the container already fill with fluid or not. If the container is empty, logically the ringing time will be longer as compared to the one when container is full. The transducer now react as a receiver immediately detects this ringing time (as sensor is located just behind the wall) and generates an empty or full signal as appropriate[6]. This technique detects the level of liquid without relying on the far reflection. In second technique which is far wall echo used the principle in wall resonance technique, however now, a contact of the transducer is acoustically coupled to the side of a container, instead of coupled to the wall exited with a pulse, an echo will be detected a short time denoting the first wall. If the liquid is present between the transducer and the far wall of the container, echo will be detected after a longer time (dependent on the diameter or width of the container).

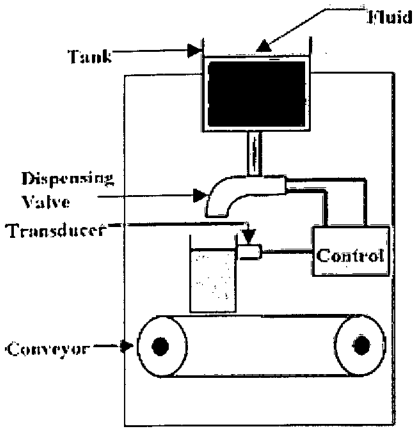

Figure 2.8: Sketch of fluid filling rig[6]

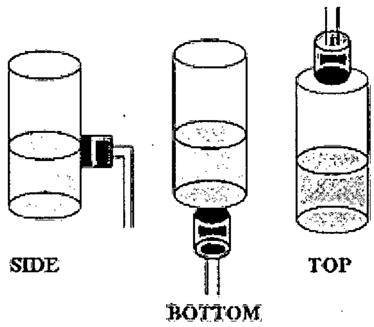

Figure 2.9: Sensor mounting positions[6].

Lastly, the third technique is air transmission approach. Although air is a reasonable good sound carrier in the frequency of interest, it is poses a major obstacle. The acoustic impedance of air is much differs from the acoustic impedance of transmitter and test parts, the most acoustic energy being reflected, and only a very small fraction of that energy penetrates in and out of the part and transducers. One solution to overcome this problem without introducing an additional sound transmitting medium consists in generating high enough sound levels and to use high-gain, low amplification.

2.3.3 CAPACITIVE

A capacitive instrument also can used to determine the level of liquid helium[7]. The sensor system consists of two concentric cylindrical plates that are an inner and an outer rod of stainless steel. The level of liquid helium can be determine by partially immerse the plates in the liquid helium. By doing this, as plates immerse in liquid, the capacitance of the plates is increased as the liquid level is increased. The capacitance of the plates can be measured using LC oscillator that is based on a tunnel diode.

Figure 2.10 shows the schematic of the liquid helium temperature tunnel diode based on LC oscillator[7]. The tunnel diode is used to eliminate parasitic resistance introduced by the inductor. The tunnel diode biased circuit is shown in figure 2.11[7]. These two circuits are connected together by using a coaxial cable (RG-178B/U)[7]. The output frequency of the bias circuit indirectly measure the capacitance value, hence level of helium liquid is detected.

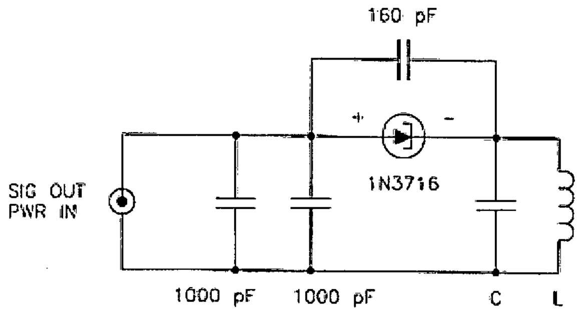

Figure 2.10: The tunnel diode diode based LC oscillator circuit schematic of the capacitive liquid helium level sensor instrument[7]

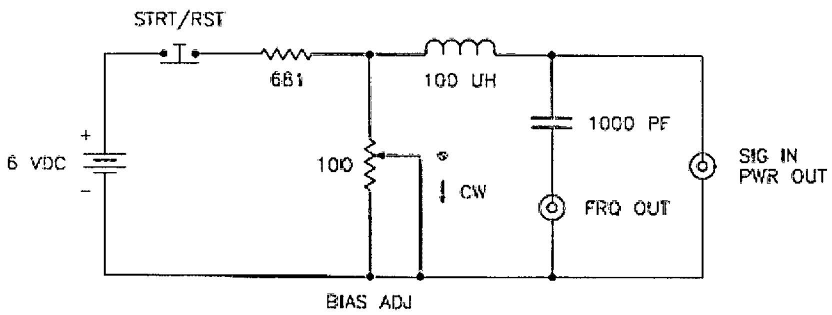

Figure 2.11: The schematic of tunnel bias circuit[7].

2.3.4 TIME DOMAIN REFLECTOMETRY (TDR)

A TDR method is widely used in fields of hydrology and soil science. A TDR can be used to measure water level in tank that collecting surface run-off[8]. The probes are designed to measure the water level. Figure 2.12[8] shows the isometric drawing of water level probe[8]. The probe then connected to 50 coaxial cable, which both the probe and coaxial cable made from stainless steel and connected using 50/200 (1 : 4) balun transformer[8]. The balun transformer is used to match the impedance of the probe and coaxial cable and convert from unbalanced to balanced transmission line and thus, reducing the signal losses.

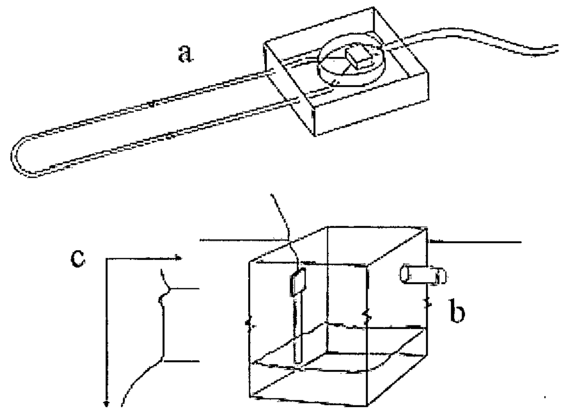

Figure 2.12: Isometric drawing of water level probe[8]

The water level is determined by measuring distance between the probe head that is placed at a known distance above the bottom level and the water level in the tank. The distance of the probe above water level is estimated from the TDR trace using suitable software.

2.4 Discussion

Four techniques of determination of liquid level were presented. The techniques presented were fibre optic, ultrasonic (ultrasound), capacitive and time domain reflectometry (TDR).

Fibre optic method used in many applications especially in area of chemical and process industries. Fibre optic is a good candidate in this area since it is electronically passive and inherently spark free, thus very suitable used in flammable environments such as hydrogen or oxygen. Consequently, fibre optic is frequently used in low temperature environment because temperature will gives effect on the light generated by the transmitter such as in [3] and [4] as it change the behaviour and characteristics of the light as temperature is increased. Therefore fibre optic will not survive in corrosive and extremely high temperature environment of molten iron.

Ultrasonic (ultrasound) method demonstrated used in power plant steam generator [5] and in food and drink industries [6]. Both applications presented being used in room temperature and in temperature up to 350°C environments. Although this method was successfully working in temperature up to 350°C, however there is insufficient prove to ensure it is working or survive in temperature over 1000°C. For this reason, this method is not suitable to be used in corrosive and extremely high temperature environment of molten iron.

Capacitive method is known by name that is very sensitive to heat and therefore capacitive method definitely cannot be used to measure a molten iron level liquid.

TDR is widely used in area of hydrology and soil science, which is frequently dealing with low temperature range, and therefore this method would not be used in determining of molten iron liquid level.

2.5 Conclusion

Various methods of liquid level sensor were presented. All the methods presented were used in many temperature ranges such as extremely low temperature (cryogenic environment), room temperature and even in high temperature, which not exceed 500°C.

As mentioned in introduction section, in this project, we are dealing with molten iron which known it temperature is extremely high. However all the techniques presented only applicable for temperature ranging from extremely low temperature (cryogenic environment) to high temperature which is not exceed 500°C and therefore none of the methods presented will survive in this corrosive and extremely high temperature (over 1000°C).

CHAPTER 3: THEORY

3.1 Permanent Magnet Brushed D.C Motor

In a Permanent Magnet motor a coil of wire (called the armature) is arranged in the magnetic field of a permanent magnet in such a way that it rotates when a current is passed through it. Now, when a coil of wire is moving in a magnetic field a voltage is induced in the coil - so the current (which is caused by applying a voltage to the coil) causes the armature to rotate and so generate a voltage. It is the nature of cause and effect in physics that the effect tends to cancel the cause, so the induced voltage tends to cancel out the applied voltage (indeed were the effects to add, we should have a perpetual motion machine!).

Voltage is electrical pressure. Current is electrical flow. Pressure tends to cause movement, or flow so an electrical pressure is a force, which moves electricity - or an 'electromotive force' (EMF). The induced voltage caused by the armature's movement is a 'back EMF' - 'back' because it tends to cancel out the applied voltage so that the actual voltage (pressure) across the armature is the difference between the applied voltage and the back EMF.
The value of the back emf is determined by the speed of rotation and the strength of the magnet(s) such that if the magnet is strong the back emf increases and if the speed increases, so too does the back emf. It follows from this that if a weaker magnet is used to make a particular motor, we will get a higher speed motor.

If we now apply the load to the armature, it will slow down. The back emf will decrease so the difference between applied voltage and back emf will increase. It is this difference that causes the current in the armature to flow; therefore the current will increase as we increase the mechanical loading. It should be apparent therefore that an unloaded motor would take little current. It should also be clear that if we apply more voltage, the motor will speed up, apply less and it will slow. This is what the motor speed controller does; it varies the voltage applied to the motor.

Many small dc motors use a permanent magnet like the one shown in figure 3.1 to establish the required flux. The reason using permanent magnet rather than an excited field winding is mostly concerned with space, efficiency and the avoidance of having to provide a field supply. The flux densities obtainable with permanent magnets are less than with exited poles,