بسم الله الرحمن الرحيم

Palestine Polytechnic University

College of Engineering & Technology

Mechanical Engineering Department

Mechatronics Engineering

Graduation Project

"Design and Implementation of Balance Testing Machine for Grinding and Cut-off Wheels "

Project Team

Mohammad Amayreh **Mohammad Albakri**

Project Supervisor

Dr.Yousef Al-Sweiti

Hebron-Palestine

June 2010

Palestine Polytechnic University

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Mohammad Amayreh **Mohammad Albakri**

According to the project supervisor and according to the argument of the testing committee members, this project submitted to the department of mechanical engineering at college of engineering and technology in the total fulfillment of the requirements of bachelor's degree

Supervisor Signature

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Committee Members Signatures

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Department Head Signature

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DEDICATION

To our god who gives us patience and faith

To our parents who

spent nights and days

Doing their best to give us the best…

To our teachers and doctors who

did their efforts to make us

better and better…

To all students and who wish to look

for the future..

To whom who loves the knowledge and

looking for the new to help

people and make the life easy…

To our beloved country Palestine…

To all of our friends…

Project Team

Acknowledgments

First we thank ALLAH, who bestowed us with strength and patience to complete this work.

We shall always remain indebted to our thesis supervisor, Dr Yousef Al-Sweiti, who helped us through out the thesis by his invaluable inspiration, encouragement and continuous guidance; he was always there to help us in the difficult time during the thesis.

We are also thankful to the previous project team Eng. Mohammad Nofal and Eng. Thaer Al Zier for their work.

Special thanks are also given to Eng. Khaled Al-Tmezi, Eng. Sami Salamen for their help in this work.

We are extremely thankful to our friends for their support and help.

Finally we would like to thank our parents who prayed and provided us the moral support that we needed throughout our study

Mohammad Amayreh

Mohammad Albakri

Abstract

In this project a device for measuring unbalance in cutoff and grinding wheels that are manufactured in the factory of JELANCO has been implemented successfully, in addition to determining the value of the unbalance in a given cutoff or grinding disc, the device is able to measure the disc's weight and it can calculate the mass that should be compensated on the outer perimeter of the wheel in order to remove unbalance, and in order to facilitate compensation for unbalance the wheel perimeter is divided into ten sectors and the one on which the compensation must take place will light.

The device is static and there exist no rotating parts and the results takes only a few seconds to appear as if it is a commercial weigh scale.
The device is based on static unbalance measurements for planner objects in which object is put on some fixture and three reaction forces are measured on the surface of the object, from these reaction forces, the unbalance, the weight and the angle of compensation can be calculated.

Three load cells are used to measure the three reaction forces on the cutoff or grinding wheel, the output of these load cells is in mill volts at the rated loads so it must be amplified and filtered, the signal conditioning circuits have been implemented such that they provide large amplification with minimum noise.

External analog to digital converters are used to convert the load cell's amplified voltage into digital form that is suitable for processing in the PIC microcontroller that is used as a processing unit that performs the computations in the device.
The ADC communicates with the microcontroller through serial communication protocol and it can provide a noise free resolution of 14 bit which corresponds to a weight resolution of 0.0382 gram.
Experimental results showed that the device is accurate and repeatable to a value that is enough for measuring unbalance in cutoff and grinding wheels.

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Chapter One

Introduction

Introduction

Requirements

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1.1 Introduction

Grinding and cutoff wheels are widely used in industry, metal working and construction for cutting materials and reshaping of tools. Here in Hebron these wheels are manufactured in the factory of JELANCO.

This factory manufactures grinding and cutoff wheels with different diameters that can be used with different machines which are rotating at different rotational speeds ranging form 4000 to 15000 rpm.

With these huge rotational speeds if the wheels aren't manufactured perfectly _which means that the mass of the material form which the wheels are manufactured isn't distributed normally_ then a large centrifugal force will be exposed to the worker's hands and he may not be able to control the machine and then he may harm himself,

Also these centrifugal forces will cause harmful effects on the machine that rotates the disc corresponding to tremendous internal stresses on the shaft that holds the disc; another effect also appears on the work piece corresponding to the non rectal cutting path.

For these reasons the cutoff and grinding wheels must be tested for rotating unbalance before they are used in order to guarantee that they are balanced.

Because these wheels have different diameters and different rotational speeds the have different allowable values for unbalance, these allowable values increases as the diameter of the wheel increases because the rotational speed decreases.

The purpose of this project is to design a non rotating unbalance testing device for cutoff and grinding wheels that can be used by the JELANCO factory for testing.

The device must be static (non rotating) because it will be used to test wheels during the manufacturing process in which the disc is not fully manufactured and it is brittle to a decree that it cannot sustain rotational speeds.

The device should satisfy a set of requirements that will be discussed briefly in this chapter.

The device is intended to give full information about the mass of the disc under testing, the value of the compensation mass and on what angle this mass must be put in order to compensate for original unbalance i.e. the centrifugal force resulted from the compensation mass has same magnitude and opposite direction to the centrifugal force result from the original unbalance which occurs due to errors in the manufacturing process.

An attempt to design such a device was made by two students (Mohammad Nofal and Thaer Al Zier) last year, good work was done by them but the project was not completed ,the purpose of this project is to complete there work and finally resulting in a complete device that is ready for use in the factory .

The complete device is shown in figure (1.1)

Figure (1.1) final product

1.2 Requirements

The cut-off wheels unbalance measurement system must satisfy the following requirements.

- Accuracy: accuracy of a measurement system is the degree of closeness of measurements of a quantity to its actual (true) value; the accuracy of this device is divided into three categories, first it must gives accurate weight measurements, second it must gives accurate measurement of the unbalance masses for a given disc with known unbalance ,and finally it must detects accurately the value of the angle at which the unbalance exists ,experimental results of this kind will be shown in the last chapter .

- Precision. the precision of a measurement system, sometimes called reproducibility or repeatability is the degree to which repeated measurements under unchanged conditions give the same results; the unbalance detection device must be repeatable which means that if the same disc is tested for several times it must give similar results, difference between precision and accuracy is illustrated in figure (1.2).

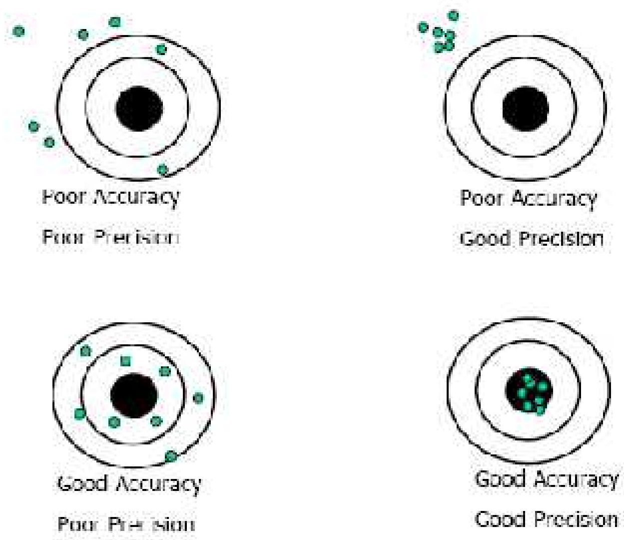


Figure (1.2) Difference between Accuracy and Precision

- Resolution. the device must be able to detect small unbalance mass as possible because even though the unbalance mass is small it may cause dangerous effects due to the large rotational speed, the developed device can detect unbalance masses with mass of 0.1 gram or above which is enough for such application (cutoff and grinding wheels) also it is designed to give a weight resolution of 1 gram.

- The device must be cost effective which means that it must be of low cost as possible.

- The device must be easy to use which means that it mustn't need special procedures to deal with, and the worker must not have any difficulty to test discs with the device, for this purpose the device is programmed to give measurement online, without any procedure, as all ordinary weigh scales.

- The device must be suitable for a factory environment, and for this purpose PCB (printed circuit board) design is used for signal conditioning circuits in order to reduce noise due to the magnetic interference of the power lines in the factory.

1.3 Problems of the Previous Design

1) Large noise .
2) Zero drift. means that the device will give values with zero load (if no disc is located on it)
3) Non repeatability. means that if the same disc is test several times with a time interval between each time then the device will give different measurements.
4) The device implementation is not suitable for a factory, since data acquisition card is used to acquire the load cells measurements, and a personal computer is used to perform computations

1.4 Solutions

For the purpose of solving the large noise problem a low pass filter with a cutoff frequency of 3.2 Hz is used to provide the largest attenuation of the noise, but this introduced a delay of about 1.54 sec to the system which will make the update rate of the device some what slow but it is remained acceptable for such application. The basic principle of the low pass filter and the design procedure will be discussed later,
PCB design is used for the purpose of reducing the noise, and for the same purpose a special ADC that used in very precise weight scales is used, this ADC is designed to work in noisy environments and actually it has the effort in solving the problem of noise, complete description of electrical networks is shown in chapter three.

The zero drift has no longer become a problem because experimentations showed that the offset in the device is changing slowly with time, so there is no need to take the offset each time a measurement is done , instead of that since the measurements are taken online then the worker should reset the device only if he watches an offset on the screen.

PIC microcontroller will be used to operate the device i.e. perform computations and accept data from the user and display useful information to hem, the use of microcontroller will reduce the cost of device and make it suitable for a factory environment .

1.5 Time Table of the First Semester

	Time (week)															
Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Selection of the project																
Search about information																
Identification of problems of previous design																
Searching for solution of Problems																
Evaluation and reviewing																
Writing																
Final edition																

Table (1.1) Time Table of the First Semester

1.6 Time Table of the Second Semester

	Time (week)															
Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Solving problems of previous design																
Printing of circuits																
Learning PIC programming																
Writing PIC program																
Testing and Calibration																
Writing																
Final edition																

Table (1.2) Time Table of the Second Semester

Chapter Two

Mathematical Modeling and Analysis

Fundamental Terms

Unbalance Effect

Principle of Operation

Mathematical Model

2.1 Fundamental Terms

Center of mass: center of mass of a body is the point at which the body's mass can be considered to be concentrated in for the purpose of calculation, the center of mass is often called the center of gravity but this fact is only true in a system where the gravitational field is uniform.

Axis of rotation: The axis of rotation is the true centerline of rotation (the instantaneous line about which a part rotates) It is also referred to as the shaft axis or the geometric axis.

Principle inertia axis: The mass moment of inertia is the rotational counterpart of mass and is a measure of mass distribution about an axis. For a particle it is the product of mass times the square of the distance from the axis to the particle, $\mathbf{I = m \cdot r^2}$. For a rigid body it is an integral, $\mathbf{I = \int r^2 \cdot dm}$. Since the mass moment of inertia is calculated with respect to an arbitrarily specified axis, it can have just about any value depending on the axis chosen. It turns out that all rigid bodies have at least one set of axes about which the body is perfectly balanced. These axes are known as the principal axes. They are mutually orthogonal and have their origin at the mass center. There are corresponding principal moments of inertia for each.

In balancing, it is useful to describe the central principal axis as the principal axis that is most closely in line with the axis of rotation. It is also known as the *balance axis* or the *mass axis*. A rotor with an axis of rotation that is not coincident with the central principal axis has unbalance. The magnitude of unbalance will be a function of the angle between the axes and the distance of the origin (mass center) from the axis of rotation.

Unbalance

Unbalance can be defined as the condition which exists when the principle mass axis of a rotating body does not coincide with the rotational axis.

There are two types of unbalance

1) Static unbalance.

2) Dynamic unbalance.

Static unbalance: is present in a rotor when the mass axis does not coincide with rotational axis and is parallel to the rotational axis, it is also known as a single plane unbalance.

Dynamic unbalance: is defined as that the condition where the mass axis does not coincide with the rotational axis and is not parallel to it, it is also called two plane unbalance.

The figure below shows the difference between static and dynamic imbalance

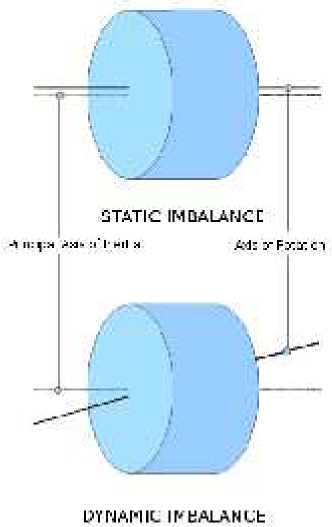
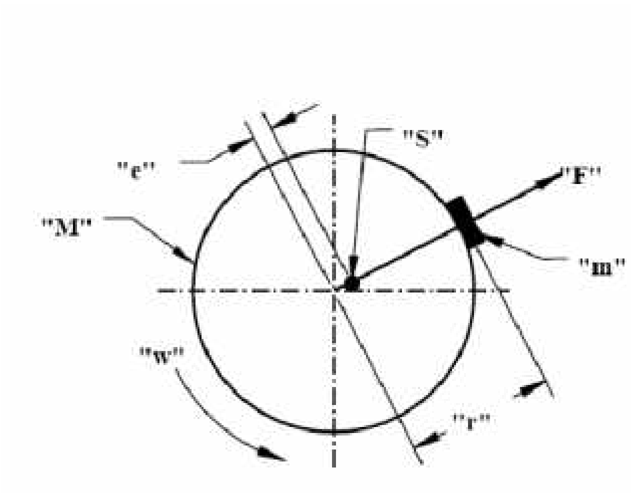


Figure (2.1) Difference between static and dynamic unbalance

In the case of cut off wheels the type of unbalance under consideration is the static unbalance because the disc is approximately planer.

Centrifugal Force: represents the effects of inertia that arise in connection with rotation and which are experienced as an outward force away from the center of rotation. A rotor with mass center slightly displaced form the axis of rotation will generate centrifugal force.

2.2 Unbalance Effect



"M" = Disc Mass

"*S*" = Center of Mass

"*e*" = Displacement of Mass Center

"*r*" = Distance from center of rotor to C.G. of unbalance mass "m"

"ω" = Angular Velocity

"*m*" = Unbalance Mass

"*U*" = Disc Unbalance

The unbalance "U" can be calculated form the following equations

$$U = m * r \qquad (2\text{-}1)$$

$$U = M * e \qquad (2\text{-}2)$$

Unbalance "U" is always expressed as mass times distance (gram. Millimeter)

The centrifugal force F can be calculated by the following formula

$$F = U\omega^2 \qquad (2\text{-}3)$$

Where ω is the angular speed of the disc in radians per second

The most important point to be determined from the previous formula is that as the rotational speed of the disc increased the centrifugal force due to the unbalance increases as a **square** of the rotational speed.

Even though a disc has a low unbalance, this unbalance may become significant at high speeds of the cutting machine. The figure below shows the centrifugal force resulted from different values of unbalance at different rotational speeds

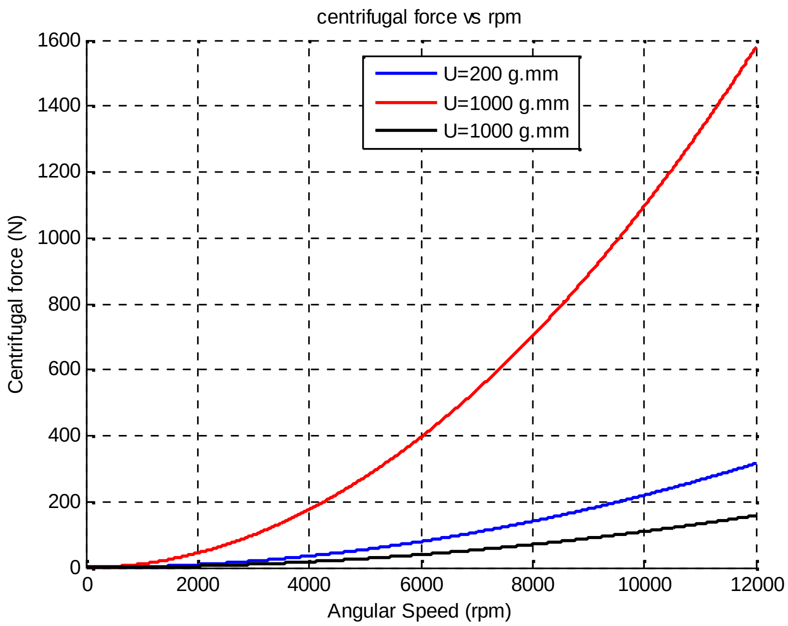


Figure (2.2): centrifugal force with respect to angular speed at different unbalance values

2.3 Principle of Operation

This device utilizes the principle of measuring the center of gravity of planer objects in which the object is put on some device that measures three reaction forces at three different points on the on the objects, these three points can be put any where on the object but there location must be known precisely, for the purpose of simplicity it is preferable to have these three points located symmetrically on the object.

In this device these three points located at 120 degree from each other at a distance of 5 cm from the center of the disc, this lead to very simple equations that can be programmed easily.

Once these three reaction forces have been calculated the value of the unbalance, the center of gravity and the angle of compensation can be calculated easily by writing simple static equations which will be shown later in this chapter.

Load cells are used to measure reaction forces of the cutoff wheel or grinding disc ,the load cell arrangement is shown in figure 2.3.

Complete description of load cell, signal conditioning circuit and processing unit will be described briefly in the next chapter.

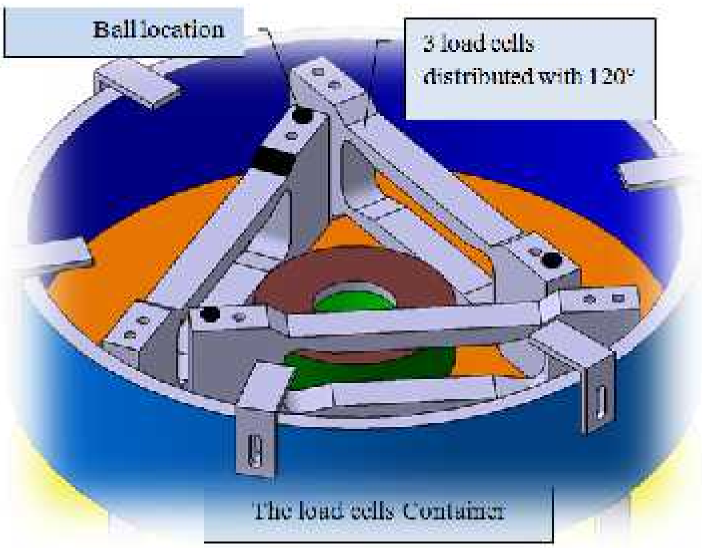


Figure (2.3) load cells arrangement

2.4 Mathematical Model

Unbalance mass changes the center of gravity of the cutting wheel from the origin to a new position on it , the value of this misalignment in the center of gravity depends on the quantity of the unbalance mass and where it on the cutting wheel , if the cutting wheel is balanced the output of the load cells (the value of the reaction forces)will be identical and equals to the disc mass over three otherwise if these forces are different then the center of gravity will be aligned in the direction of the larger reaction forces and compensation masses should be put on the opposite direction to remove this unbalance .

The purpose of this section is to provide the equations necessary for calculating the center of gravity ,the unbalance mass and the unbalance location provided that the three reaction forces are measured

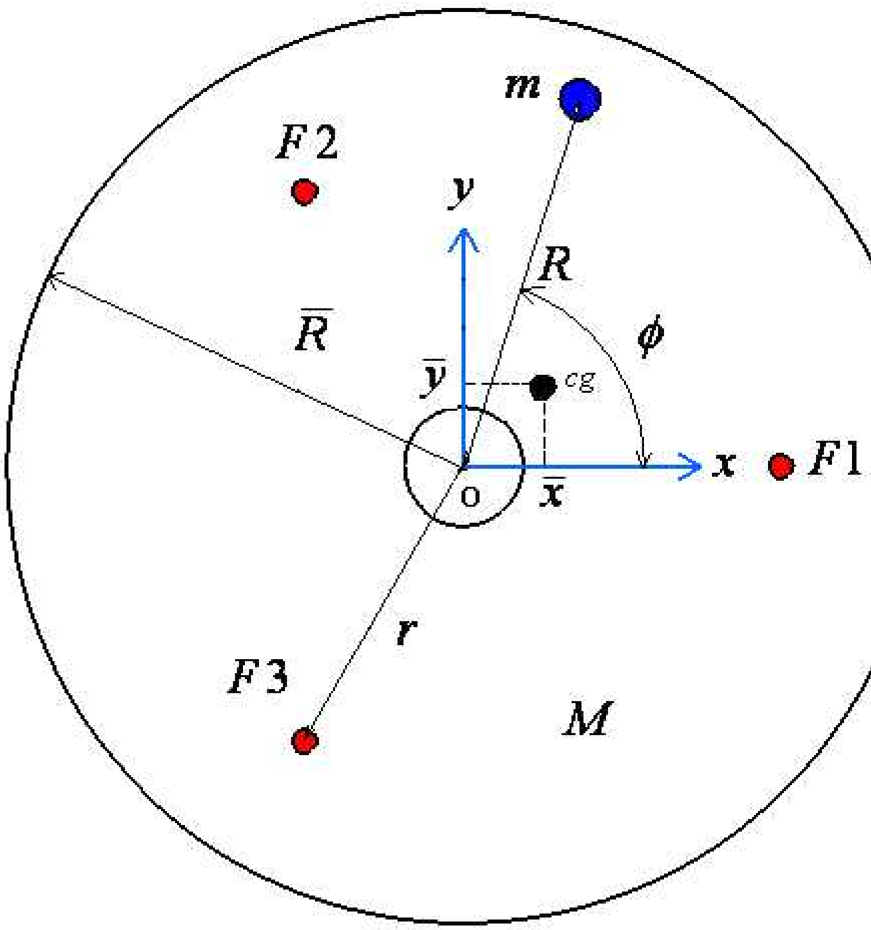


Figure (2.4) mathematical model

To calculate the new center of gravity ,the value of unbalance and the angle of unbalance , assume that an unbalance mass m exists on the cutting wheel of mass M , R is the distance between the mass m and the origin of cutting wheel O, and the mass m located at an angle ¤ , F_1,F_2,F_3 are the reaction forces measured a distance r from the origin and located at an angle 120 degrees from each other , $\bar{x}, \bar{y}$ are the coordinates the center of gravity cg to be calculated .

2.4.1 Center of Gravity Calculation

The following equations are used to calculate the center of gravity:

$$\bar{x} = \frac{\sum mixi}{\sum mi} = \frac{mR\cos ¤ + Mx}{M+m} \qquad (2.4)$$

where x is the x coordinate of the center of gravity without unbalance

Since x = 0;

$$\bar{x} = \frac{mR\cos ¤}{M+m} \qquad (2.5)$$

Similarly

$$\bar{y} = \frac{\sum miyi}{\sum mi} = \frac{mR\sin ¤ + My}{M+m} \qquad (2.6)$$

where y is the y coordinate of the center of gravity without unbalance.

Since y = 0:

$$\bar{y} = \frac{mR\sin ¤}{M+m} \qquad (2.7)$$

Because the center of gravity locates original at origin O it will have the same angle as the unbalance mass m.

The total mass of the disc $\overline{M} = M + m = \frac{F_1 + F_2 + F_3}{g}$ (2.8)

Squaring (2.5) and (2.7) and adding them results in

$$e = \frac{mR}{\overline{M}} \qquad (2.9)$$

Where (e) is the eccentricity value

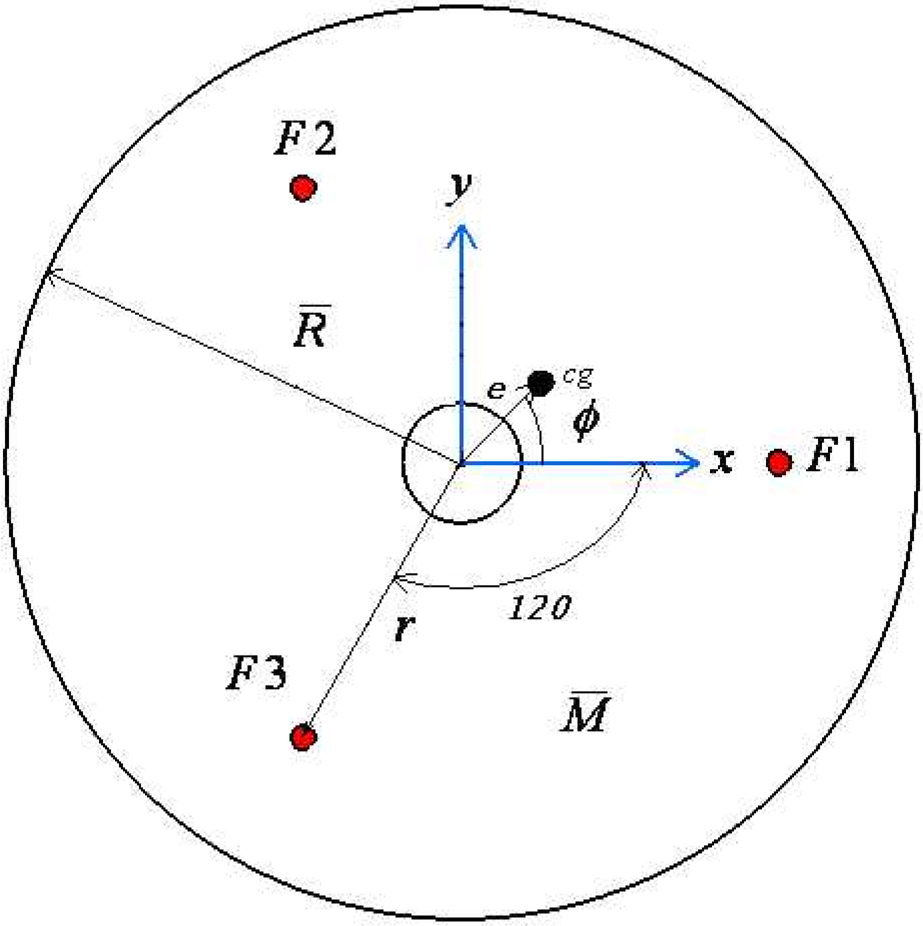


Figure (2.5) Unbalance calculation

2.4.2 Unbalance Calculation

The three reaction forces are located 120 degree from each other, and located at equal distance of *r* from center *O* as shown in figure (2.5)

writing the moment equation about x axis yields

$$\sum M_x = 0$$

$$-\overline{M}ge\sin\phi + F_2 r\cos 30 - F_3 r\cos 30 = 0 \qquad (2.10)$$

$$\overline{M}ge\sin\phi = F_2 r\cos 30 - F_3 r\cos 30 \qquad (2.11)$$

Writing the moment equation about y axis results in:

$$\overline{M}ge\cos ¤ - F_1 r + F_2 r\sin 30 + F_3 r\sin 30 = 0 \qquad (2.12)$$

$$\overline{M}ge\cos ¤ = F_1 r - F_2 r\sin 30 - F_3 r\sin 30 \qquad (2.13)$$

Dividing equation 2.11 by equation 2.13 gives ¤

$$¤ = \tan^{-1}\left(\frac{2\cos 30(F_2 - F_3)}{2F_1 - F_2 - F_3}\right) \qquad (2.14)$$

The (*tan*$^{-1}$) gives results in the range of $(\frac{-®}{2}, \frac{®}{2})$ in order to have results in the range of $(-®, ®)$, the (*atan2*) function must be used which gives not only the value of the angle satisfies the equation but also the quarter in which it is located .

Compensation masses should be put at the opposite side of the unbalance

$¤_c = ¤ + 180$

By squaring equation (2.11) and equation (2.13) and adding them gives

$$\overline{M}e = r\sqrt{\frac{F_1^{\ 2} + F_2^2 + F_3^2 - F_1F_2 - F_1F_3 - F_2F_3}{g^2}} \qquad (2.15)$$

But $\overline{M}e = mR = U$ where U is the unbalance.

In order to compensate for U a mass m_c should be put at an angle of $¤_c$ such that

$$m_c = \frac{U}{\overline{R}} \qquad (2.16)$$

where $\overline{R}$ is the radius of the disc under testing.

Finally equations (2.14), (2.15) and (2.16) will be implemented inside the microcontroller which will perform the computation in the device .

The values of F_1, F_2 and F_3 are calculated from the load cells measurements.

Complete description about load cells and Microcontroller algorithm is shown in the next chapter.

Chapter Three

Electrical design

Introduction

Load Cell

Signal Conditioning

Analog to Digital converter

Microcontroller

Program Flow Chart

3.1 Introduction

The electronic components used in the project can be classified into power supply, signal conditioning, interfacing and processing.

Power supply component consists of a rectifier that converts the ac power supply into a dc one needed by the other circuits, voltage regulators are also used to regulate this dc voltage and provide different voltage levels for digital and analog circuits .

Signal conditioning circuit (the analog part of the device electronics) consists of both amplification and filtration circuits in order to amplify the voltage from the load cell which has a very low value (typically 7.5mv at a load of 1.5kg for the load cell used in the device) and remove all unwanted noise signal that is always associated with this voltage to make it ready for conversion to the digital form.

Interfacing components are divided in to categories the first is interfacing the analog part with digital part using analog to digital converters (ADC),and the second is interfacing human with the device using liquid crystal display (LCD) as output and a Keypad as input.

Processing component is the one at which the unbalance mass and location is calculated and it is the one that manages the human machine interfacing and it consists of a PIC microcontroller.

The load cell is the sensor part of the device which coverts the force into voltage complete description of the previously mentioned components will be discussed in the remaining sections of this chapter.

The block diagram of the device components is shown in figure (3.1)

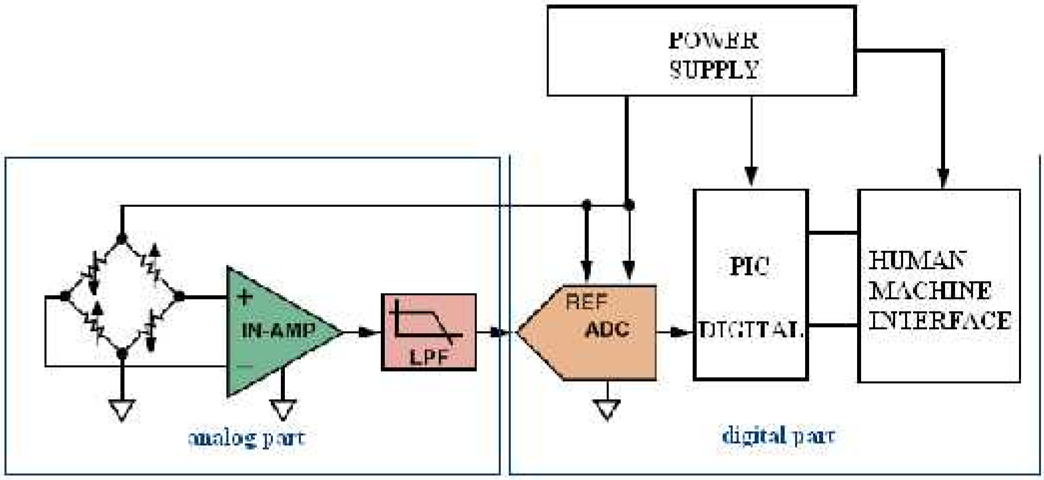


Figure (3.1) Block diagram of the electrical network

3.2 Load Cell

3.2.1 Load Cell Principle

A load cell is a sensor (transducer) that is used to convert a force into voltage. This conversion is indirect and happens in two stages. Through a mechanical arrangement, the force being sensed deforms a strain gauge. The deformation of the strain gauges change their resistance, this change in resistance is detected by a Wheatstone bridge and converted to voltage.

One or two strain gauges can be used in a load cell but for the purpose of maximizing the output of the Wheatstone bridge four strain gauges are used in some load cells, these strain gauges are arranged on the load cell surface such that two are subjected to compression and the others subjected to tension and they arranged in the Wheatstone bridge as shown in figure (3.2)

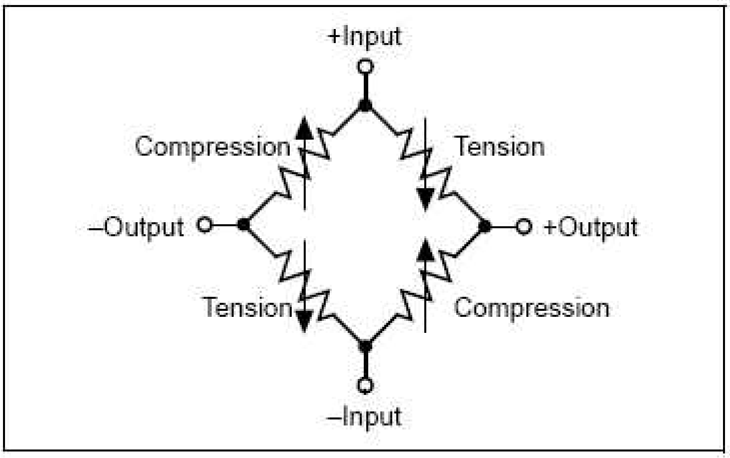


Figure (3.2) Bridge arrangement for the Strain gauges in a full bridge load cell

The voltage output is typically in the order of a few mill volts and requires amplification by an instrumentation amplifier before it can be used. The output of the transducer is plugged into an algorithm to calculate the force applied to the transducer.

3.2.2 Temperature Effect on Load Cells

The sensitivity of the load cell is affected by temperature variation; this change is caused by two factors.

1. variation in the modulus of elasticity
2. altered dimensions

Variation of the modulus of elasticity is the more important of the two effects , amounting to roughly 4.5% per 100 C change . On the other hand the increase of cross sectional area of a tension member of steel will amount to only 0.27% per 100 C change.

Obviously, when accuracies of 0.5% are desired, a means for compensation particularly for variation in Young's modulus must be supplied , this compensation is accomplished electrically by causing the bridge's electrical sensitivity to change in the opposite direction to the modulus effect, as temperature increases ,the deflection constant for the elastic element decreases as a result it becomes more springy and therefore deflects a greater amount for a given load. This increased sensitivity is offset by reducing the sensitivity of the strain gauge bridge through use of a thermally sensitive compensating resistance element in series at the top of the bridge as shown in figure (3.3).

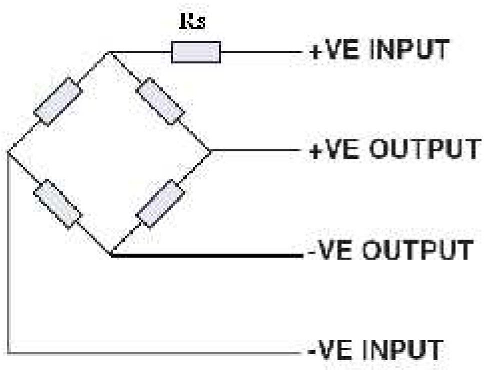


Figure (3.3) a temperature compensated load cell

3.2.3 Load Cell Specifications

The load cells must be selected such that there specifications meet the requirement in the application in which these load cells will be used, some of these specifications include

1. Rated capacity. maximum load that can be applied to the load cell and get useful measurements, this specification must be chosen carefully, it must be chosen such that the maximum load in the application be two-thirds of the rated capacity of the selected load cell for the same application because the load cell will be linear in this range and the force can be calculated by simply multiplying the voltage with a gain .
The load cell chosen in the device has a rated capacity of 1.5kg but the maximum load on it is of 350g which is the weight of the largest disc (16") divided by three, adding to this the weight of the fixture at which the wheels are mounted results in a maximum load of approximately 500g, so the load cell rated capacity is larger than needed ,the value of the voltage at 500g load is amplified to approximately 4volts which is 1 volt smaller than the ADC reference voltage.
2. Change in output voltage per volt of excitation, the maximum this value is the larger the accuracy and the amplification gain will be smaller.
The load cell selected in the device gives 0.9mv/volt of excitation.
3. The change in output voltage versus temperature at both no and full load
4. Safe overload Limits. If the load exceeds the maximum overload, then the load cell may be permanently damaged.
5. The input impedance which determines how much current will be consumed by the load cell so the larger this value is the better will be the load cell.
6. The output impedance: since the output of the load cell is always connected to an instrumentation amplifier which has very large input impedance, this value is not so important but the smaller this value is the better the load cell will be.
7. The safe temperature Range
8. Linearity error
9. Hystersis specification.
10. Repeatability specification
11. Creep. A weight left sitting on the load cell will result in the load cell's output voltage changing over time. The change in output voltage would ideally be zero, but

practical load cells will show a small change in output voltage over many minutes (generally, the specification is given over 10 minutes or 20 minutes).

12. Cost.

The load cell used in the device is a single point, low capacity, high precision, full bridge and temperature compensated; figure (3.4) shows the chosen load cell.

Figure (3.4) the load cell that is used in the project

3.3 Power supply

An ideal power supply can give a constant voltage value without looking to the value of current consumed by the load , and it can supply the load with any value of current requested but actually this always impossible , the value of the voltage supplied by the power sources always decreases as the current consumed by the load increases and any power supply has a maximum value of current that can be supplied otherwise an overload case occurs ,another major problem that rises with power supplies in tiny applications is the noisy output ,since the major source of noise is from the power supply and this noise has a frequency of typically 50 to 60 Hz .

To solve this problem usually a notch filter is used in order to attenuate the noises at a certain frequency, this filter must have a very low resistance in order to reduce the voltage drop lost on this resistance.

In the unbalance measuring device the device was powered directly from the power lines using a commercially available rectifier which gives two voltage levels (12,5volts).

A 9 volt regulator (7809) was used to regulate the 12 volt level to 9 volts to supply the load cell excitation voltage but since the load cell consumes about 27 mA the voltage of the regulator drops to 8.26 volts.

The 5 volt is used to supply the digital circuits in the device .

3.4 Signal Conditioning

The signal conditioning circuit consists of an instrumentation amplifier for amplification of the load cell output voltage and a low pass filter for filtering the voltage after amplification to make it ready for conversion to digital form.

3. 4. 1 Instrumentation Amplifiers

In practice, transducer signals are often small voltage differences that must be accurately amplified in the presence of large common –mode signals, simultaneously, the current drawn from the transducer must remain small to avoid loading the transducer and degrading its signal.

Standard op-amp circuits such as the differential amplifier may not provide adequate input impedance or CMRR when high –accuracy measurements are needed.

The instrumentation amplifier uses three op amps to solve these problems figure (3.7)

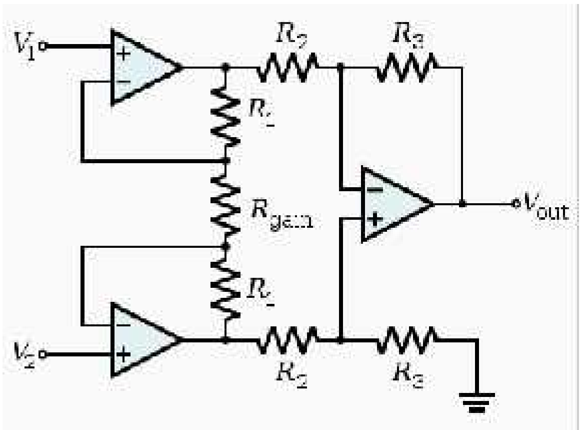


Figure (3.5) internal arrangement of the instrumentation amplifier

The instrumentation amplifier is essentially a differential amplifier with a voltage follower placed at the each input. The voltage followers increase the (+) and (-) input impedances to the op-amp impedances.

The addition of R1 between the two voltage followers has the effect of raising the CMRR. Resistor matching is less critical for circuit than for a differential op-amp circuit alone.

Instrumentation amplifiers may be built from discrete components or they may be purchased as a single integrated circuit

Instrumentation Amplifier Specifications

Before choosing an instrumentation amplifier for a specific application one should study the specification of this amplifier to choose the amplifier whose specifications meet the requirements. The most important specifications are.

1. **Gain**. the relationship between the output and input of the instrumentation amplifier, in this type of amplifier the gain is determined by only one external resistor called RG, a typical instrumentation amplifier has a maximum gain of 1000 or more.

2. **Input impedance**. If input impedance of the instrumentation amplifier is very large then very small current will be drawn from the transducer whose signal will be amplified, a typical instrumentation amplifier will have an input impedance of 10^9 ohms.

3. **Output impedance**. The smaller the output impedance of an instrumentation amplifier the better its performance.

4. **Common mode rejection ratio**. which measure the tendency of the amplification device to reject input signals common to both input leads. A high CMRR is important in applications where the signal of interest is represented by a small voltage fluctuation superimposed on a (possibly large) voltage offset, or when relevant information is contained in the voltage difference between two signals.

The CMRR is a very important specification, as it indicates how much of the common mode signals will appear in your measurement. CMRR is often important in reducing noise on transmission lines, for example when measuring force by a load cell, the noise from the environment appears as an offset on both input leads, making it a common-mode voltage signal. A typical instrumentation amplifier will have a CMRR of 130dB or more.

5. **Maximum input and output voltages**: the maximum input and output voltages of an instrumentation amplifier depends of the +VCC voltage supplied to them, an output voltage above +VCC will not appear, and some instrumentation amplifiers saturate at a voltage less than +VCC.

6. **Minimum input and output voltages**: instrumentation amplifiers have minimum output and input voltages that depend on the –VCC voltage supplied to them, an

output voltage less than –VCC will not appear and some instrumentation amplifiers saturate at negative output voltages that are larger than –VCC.

7. **Offset** some instrumentation amplifiers have offset voltages that can be determined externally, if the output after amplification is less than this offset then it will not appear on the output of the instrumentation amplifier, this specification is useful in applications that don't have precise ground

8. **Power supply rejection**: which is a very useful feature in applications that works with noisy power supply, in this specification the instrumentation amplifier is designed to reject 50/60 Hz power supply noises.

Other specifications which are of less importance include power supply and temperature ranges and dynamic response.

AD620 Instrumentation Amplifier

The chosen amplifier is the same amplifier that was used in the previous project which is the AD620 shown in the figure (3.8)

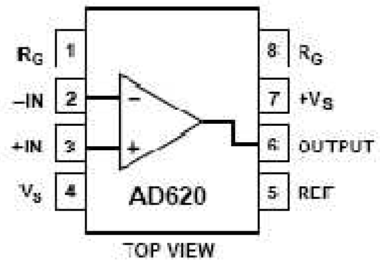


Figure (3.6) AD620 Instrumentation amplifier

The AD620 is a low cost, high accuracy instrumentation amplifier that requires only one external resistor to set the gain.

It has the following features.

1. easy to use
2. gain set with one external resistor (gain range from 1 to 10,000)
3. low noise 0.28 µV p-p Noise (0.1 Hz to 10 Hz) and a Common-Mode Rejection Ratio DC to 60 Hz of 130 dB
4. Wide Power Supply Range (2.3v to 18v)
5. excellent DC and AC performance

But it has some disadvantages like it saturates if the output voltage reaches Vs-1.4 volt and when operating with single power supply positive) it has an output offset of 0.67 volt that varies with time.

AD620 is suitable for many applications which include.

- Weigh Scales
- ECG and Medical Instrumentation
- Transducer Interface
- Data Acquisition Systems
- Industrial Process Controls
- Battery Powered and Portable Equipment

The gain of the AD620 can be evaluated by the following equation

$$G = 1 + (49.4\ k/RG)$$

3.4.2 Grounding

Ground or **earth** may be the reference point in an electrical circuitry from which other voltages are measured, or a common return path for electric current .

In electronic circuit theory, a "ground" is usually idealized as an infinite source or sink for charge, which can absorb an unlimited amount of current without changing its potential.

An electrical ground system should have an appropriate current-carrying capability in order to serve as an adequate zero voltage reference level.

When low level circuitry is employed, some form of grounding is inevitably required Grounding is needed for one or both of two reasons.

1. To provide an electrical reference for the various sections of the device.
2. To provide a drainage path for unwanted current.

A ground reference may be either of two types

1. Earth ground in which the Earth serves as a (reasonably) constant potential reference against which other potentials can be measured. In this type a direct physical connection to the earth is exist.

2. Chassis ground in this type the enclosure within which the circuitry is mounted is used as a ground reference.

System where the system ground is not actually connected to another circuit or to earth is often referred to as a floating ground. Figure (3.10) shows the conventional symbols for ground references.

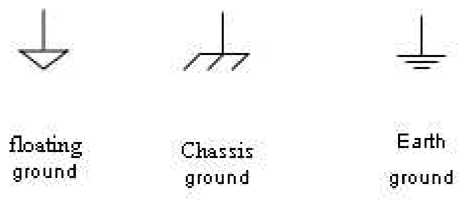


Figure (3.7) Conventional symbols for ground reference

3.4.3 Filters

Filters are frequency - selective networks that favors certain frequencies of input signals at the expense of others.

Filters are classified into two major classifications

1. Passive filters. are combinations of capacitors, resistors and inductors and don't include external power supply.
2. Active filters. in which integrated circuits IC particularly op amps are combined with resistors and capacitors to simulate the performance of inductance- capacitance filter they are called active because they need external power supply.

It's better to use active filters rather than passive filters for the following reasons.

1. low cost
2. Isolation. due to the very large input impedance and the very low output impedance, this makes the response of active filters independent of source and load impedances.
3. Gain. active filters can provide a gain or loss as needed to suit the system requirements

4. no field sensitivity . due to the common mode rejection ratio of the op amp in the active filter

Two types of filters will be discussed here which are.

- Low pass filter
- High pass filter

The one that will be used in the project is the low pass filter because useful signals to be measured form the load cells in this application are pure Dc and no frequency is needed to be passed so a low pass filter must be used

Low Pass Filter

A low pass filter allows signals up to a certain frequency to pass while attenuate frequencies larger than this cutoff frequency, figure (3.11) shows a passive and an active network for a low pass filter

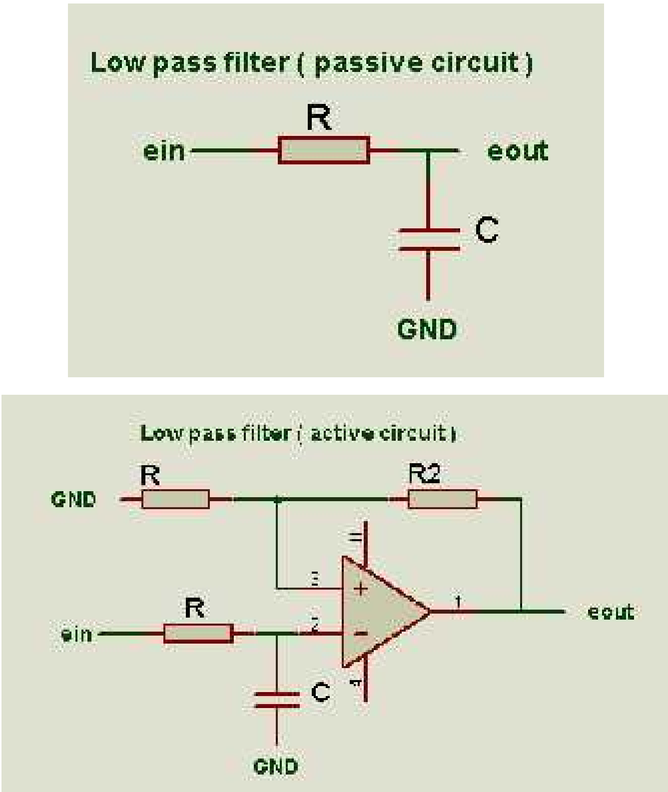


Figure (3.8) passive and active circuits for a low pass filter

For the active low pass filter shown in the figure above, the output voltage is related to the input by the following equation.

For the active network

$$eout = (1 + \frac{R_2}{R_1})(\frac{1}{RCs+1})ein$$

For the passive network $eout = \frac{1}{RCs+1} ein$

In both network the cut off frequency $f_c = \frac{1}{RC} rad/\sec$

It is seen from the previous two equations that in the active network the gain can be adjusted but in the passive network the filter always have a gain of one .

Although it is preferable to use an active network, a passive one is used is used in the device because an active network for precise application must have low noise op-amp which is not available, besides that a low noise and high CMRR instrumentation amplifier is used which made a passive low pass filter a reasonable choice .

The frequency response of the low pass filter with a cutoff frequency of 5Hz is shown on figure (3.9)

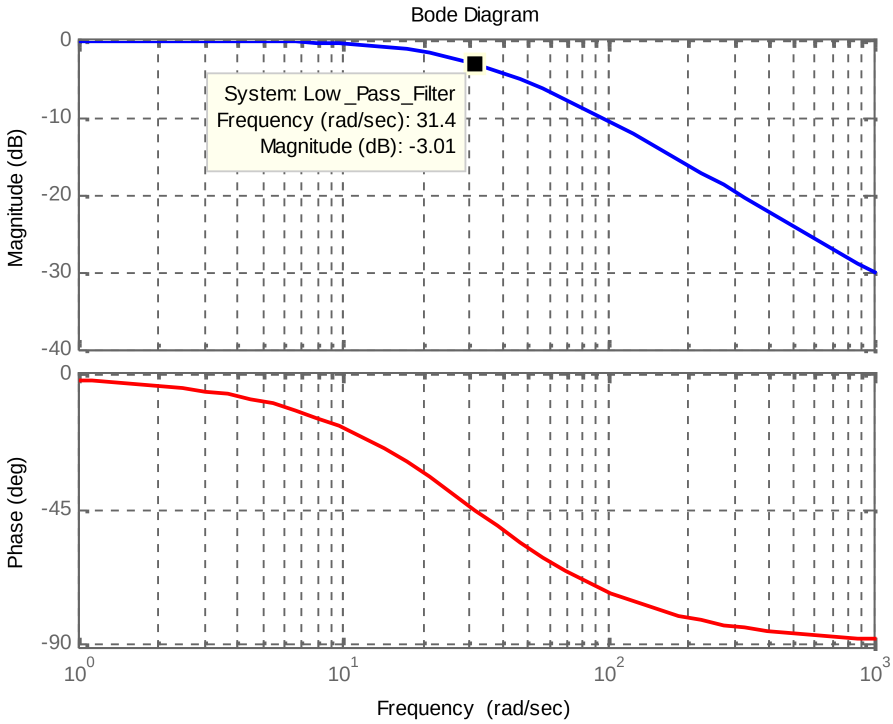


Figure (3.9) frequency response of a low pass filter with a cut off frequency of 5 HZ

High Pass Filter

The pass band in a high pass filter consist of all frequencies above cut off frequency, and stop band consist of those frequencies below

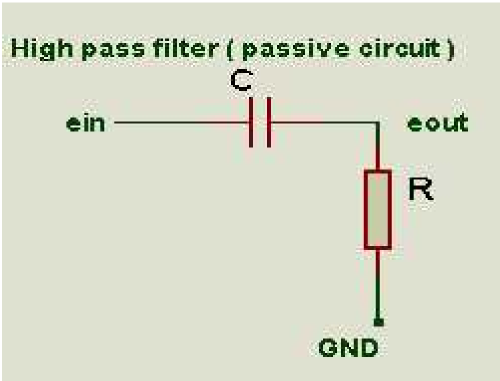


Figure (3.10) passive circuit for a high pass filter

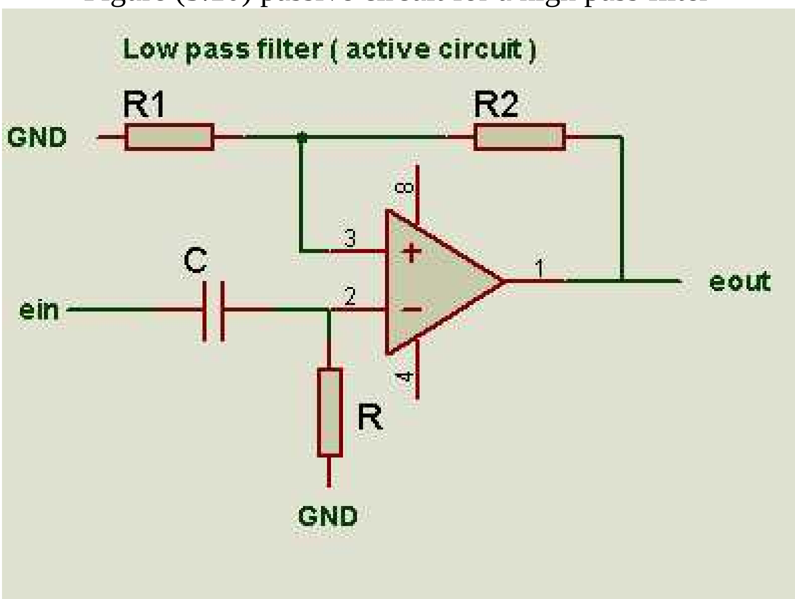


Figure (3.11) active circuit for a high pass filter

For the active high pass filter shown in the figure above, the output voltage is related to the input by the following equation.

for the active network

$$eout = (1 + \frac{R_2}{R_1})(\frac{RCs}{RCs+1})ein$$

for the passive network

$$eout = \frac{RCs}{RCs+1}ein$$

In both network the cut off frequency $f_c = \frac{1}{RC} rad/\sec$

Figure (3.12) shows the frequency response of a high pass filter with a cut off frequency of 100HZ

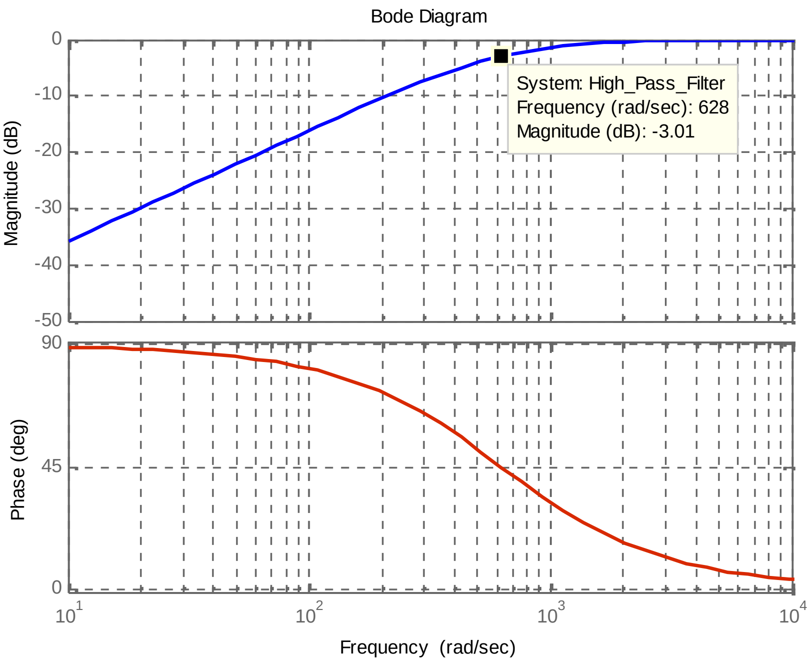


Figure (3.12) frequency response of a high pass filter, cut off frequency =100 Hz

3.5 Analog to digital converter

After measuring the reaction forces on the cutoff or grinding wheel using the load cell and amplify the output voltage and filter it , the voltage had to be converted to the digital form in order to calculate the value of the wheel weight, the unbalance and the unbalance location in the processing unit which consist of the PIC microcontroller . The microcontroller used which is the P18F4550 has 13 channels for the ADC converter with 10 bit resolution for each ,with a reference voltage of 5 volts ,a resolution of 5mv can be achieved if the conversion is done by the converter of the microcontroller but this needs the voltage outputted from the load cell to be amplified to 5 volt at the maximum load and filtered such that the noise peak to peak value be less than 3mv at least if this is done then a maximum weight resolution of 0.5 gram can be achieved which is not adequate for such precise application.

For this reason an external ADC had to be used in order to have a weight resolution of at least 0.1 gram in order for the device to detect small values of unbalance.
The chosen ADC was MCP3553shown in figure(3.13) which is a single channel 22-bit resolution analog to digital converter with differential inputs, external reference voltage and a serial communication protocol.

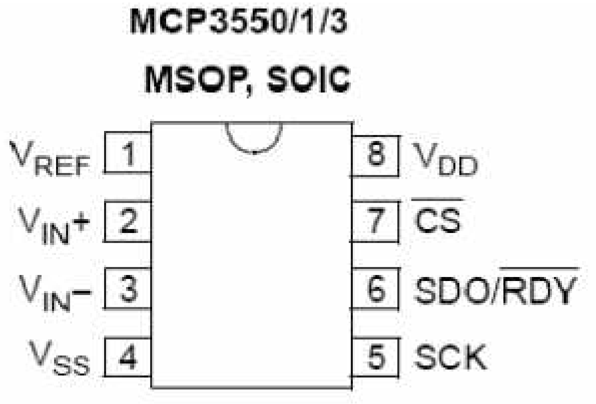


Figure (3.13) MCP3553 ADC

The MCP3553 analog to digital converter is used in high precision weight scales and with its high CMRR of -135dB, its high PSR for 50/60 Hz noises on the reference input of -85dB and its internal filters, it can operate in noisy environments and gives precise results.
An ADC with external reference rather than onboard one was chosen in order to apply the principle of ratio metric measurement, since the output voltage of the load cell depends on the excitation voltage then if this voltage changes the measurement will change for the same load and this will cause gain drift which is very difficult to compensate for in programming.
So in order to have the same digital value outputted from the ADC if the excitation voltage of the load cell changes, one should connect the reference voltage of the ADC with the load cell's excitation voltage as shown in figure (3.14).

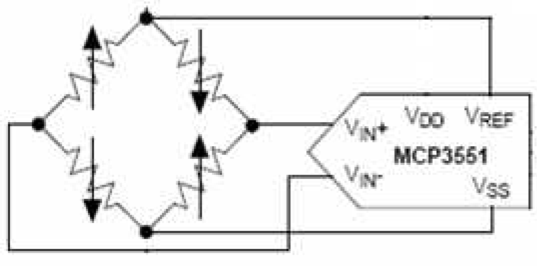


Figure (3.14) Example of Ratiometric Measurements

Some load cell's that are used in very precise applications have six wires ,the two additional wires are called sense wires ,the sense the excitation voltage of the bridge precisely.

Ratio metric measurements are suitable for battery powered devices because the batteries voltage will decrease as it is discharging.

For those devices that are powered directly from the power lines ratio metric principle is of less importance, and actually it was impossible to apply this ratiometric principle because of the difference between the value of the excitation voltage of the load cell which is 8.26 volts and maximum allowable reference voltage which is 6 volts ,putting a voltage divider didn’t solve the problem because the output of this voltage divider will vary according to the current consumption by the ADC.

If Ratiometric measurement principle is not applied for battery powered devices then these devices will be poor repeatable due to the gain drift caused by the variation of the load cell's excitation voltage.

But actually 22-bits was much resolution than needed because after using this ADC it was reasonable to neglect the most least 8 bits from the 22 bits to have a 14bit noise free resolution which can give a weight resolution of 0.0382 gram.

The time conversion of the MCP3553 ADC is 17 ms and it communicates with the MCU through SPI (Serial Peripheral Interface) serial protocol.

More about the MCP3553 ADC can be found in the datasheet found in the appendix.

The ADC circuit together with the signal conditioning circuit is shown in figure (3.15)

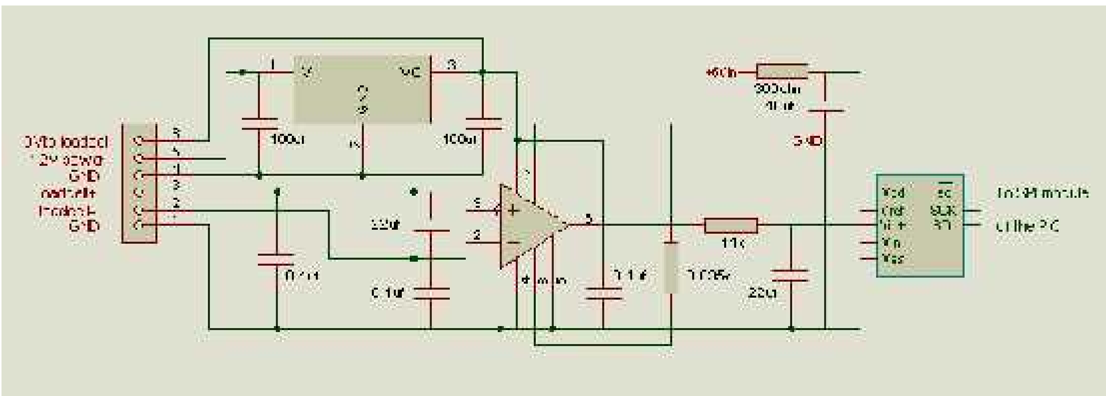


Figure (3.15) Signal conditioning circuit

3.6 PCB design

PCB design is used for circuits that will be manufactured in commercial quantities in the case of this project PCB design is used in order to reduce noise and to provide a design that is suitable for factory environment.

The first step of PCB design is to draw the design using some software package like (Pulsonix) then this design can be implemented on a board using either CNC machine or chemical processing using special acids that removes all copper from the board except the design.

The PCB design of the signal conditioning circuit together with the ADC circuit is shown in figure (3.16)

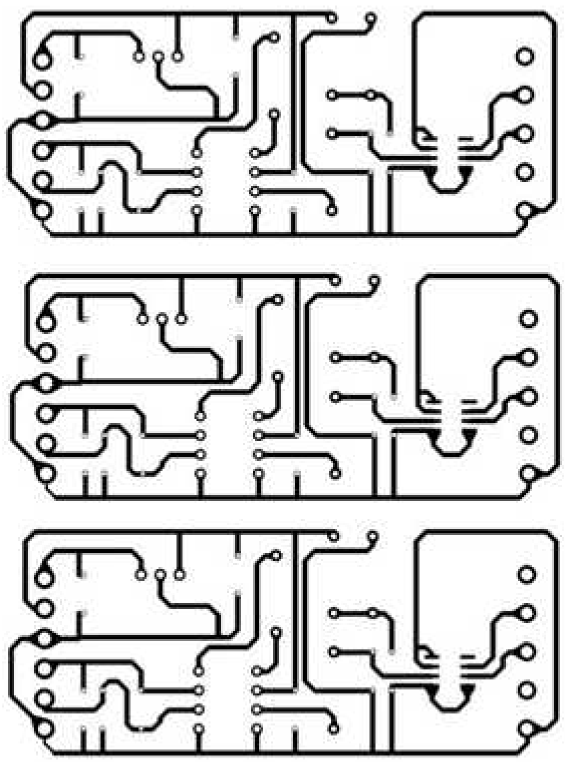


Figure (3.16) PCB design of the signal conditioning circuit

3.7 PIC Microcontroller

The processing unit in the device consists of the PIC microcontroller p18f4550 from Microchip shown in figure (3.16), this microcontroller has so many peripherals like timers, ADC's and PWM modules in addition to many digital I/O's and it supports different serial communication protocols like SPI, I2C and USB, in addition to that it has large program and data memory, in addition to that it is easy to program.

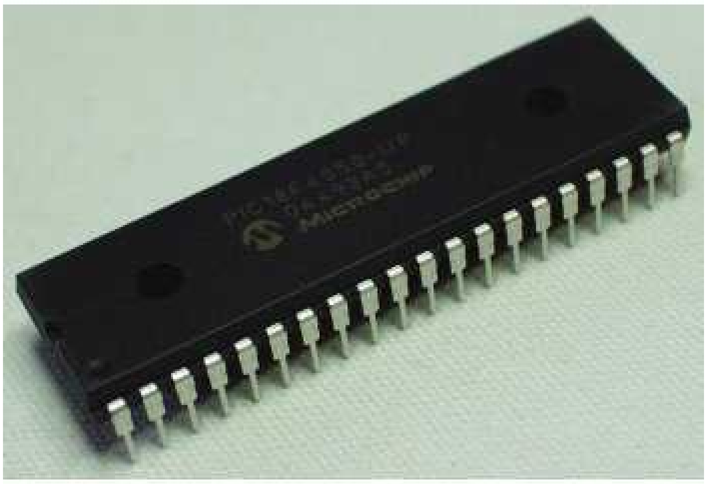


Figure (3.17) P18f4550 microcontroller

3.8 Human machine interface

For the unbalance measuring device there exist three components for interfacing human with the device the first is the LCD for outputting the wheel weight, the Unbalance mass and the angle of compensation.

The second is the key pad which is used by the worker to choose from cutoff, grinding and custom modes and to reset the device when needed.

The third are the lights that are used to turn on the sector at which the material must be compensated in order to remove the unbalance.

3.8.1 LCD

LCD display used is a 2X16 lcd shown in figure (3.18), one can write up to 32 character on this lcd.

The LCD has an onboard controller the interfaces the LCD with the microcontroller and controls the process of displaying.

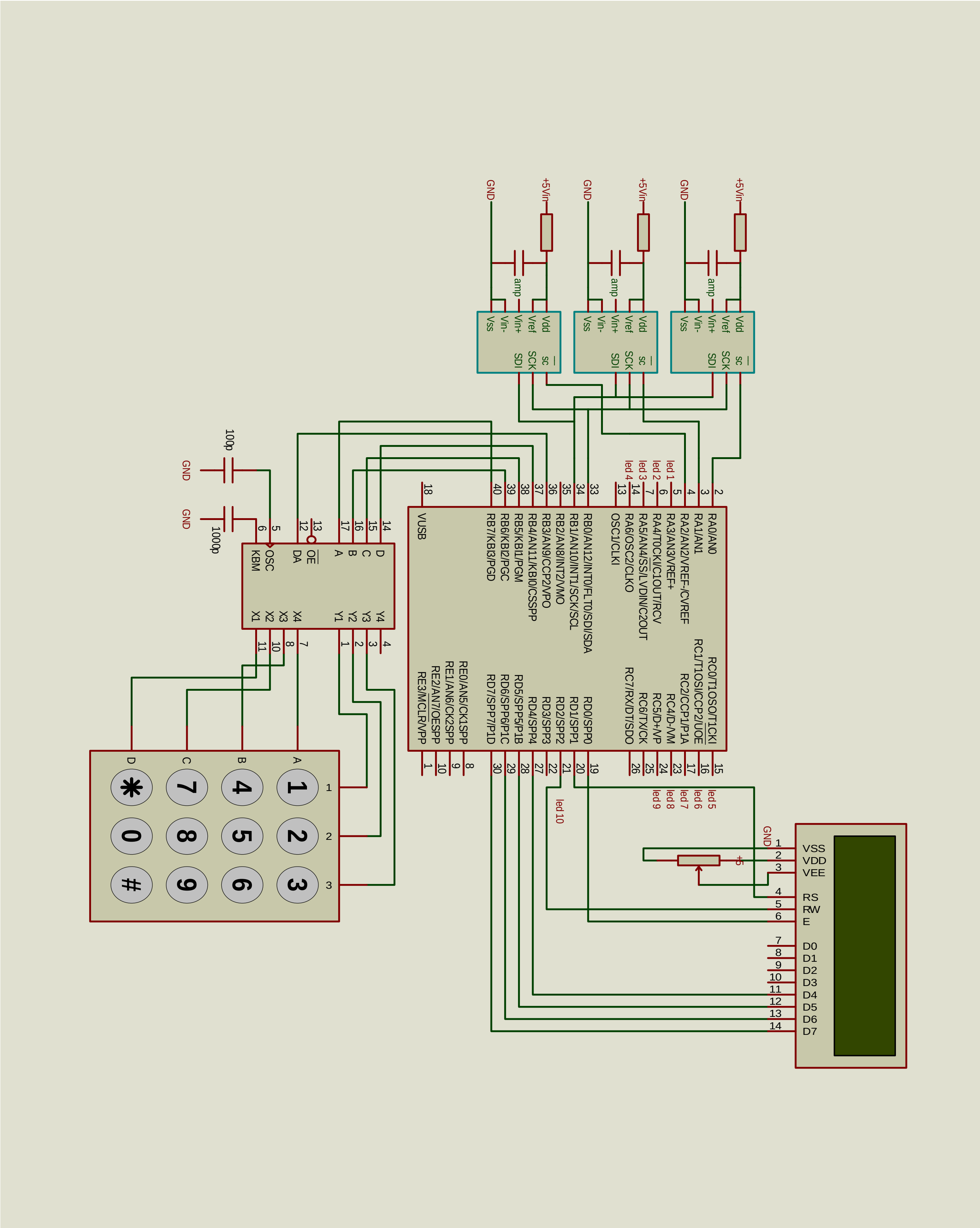
Due to the existence of previously made libraries, it becomes very easy to display results on the LCD without caring how the process of displaying occurs.

Figure (3.18) Liquid crystal display (LCD)

3.8.2 Keypad

The input device used in the project is the keypad which consists of a set of push button that are connected in a matrix form, when a button is pressed it forms a connection between the corresponding row and column a keypad encoder is used to scan the keypad matrix and detects if a button is pressed and outputs a binary value that corresponds to the button pressed The keypad used in the project is 4X4 keypad shown in figure (3.19) The encoder used is the (MM74C922)

Figure (3.19)Keypad



figure(3.20)PIC microcontroller connection diagram

3.8 Program Flow Chart

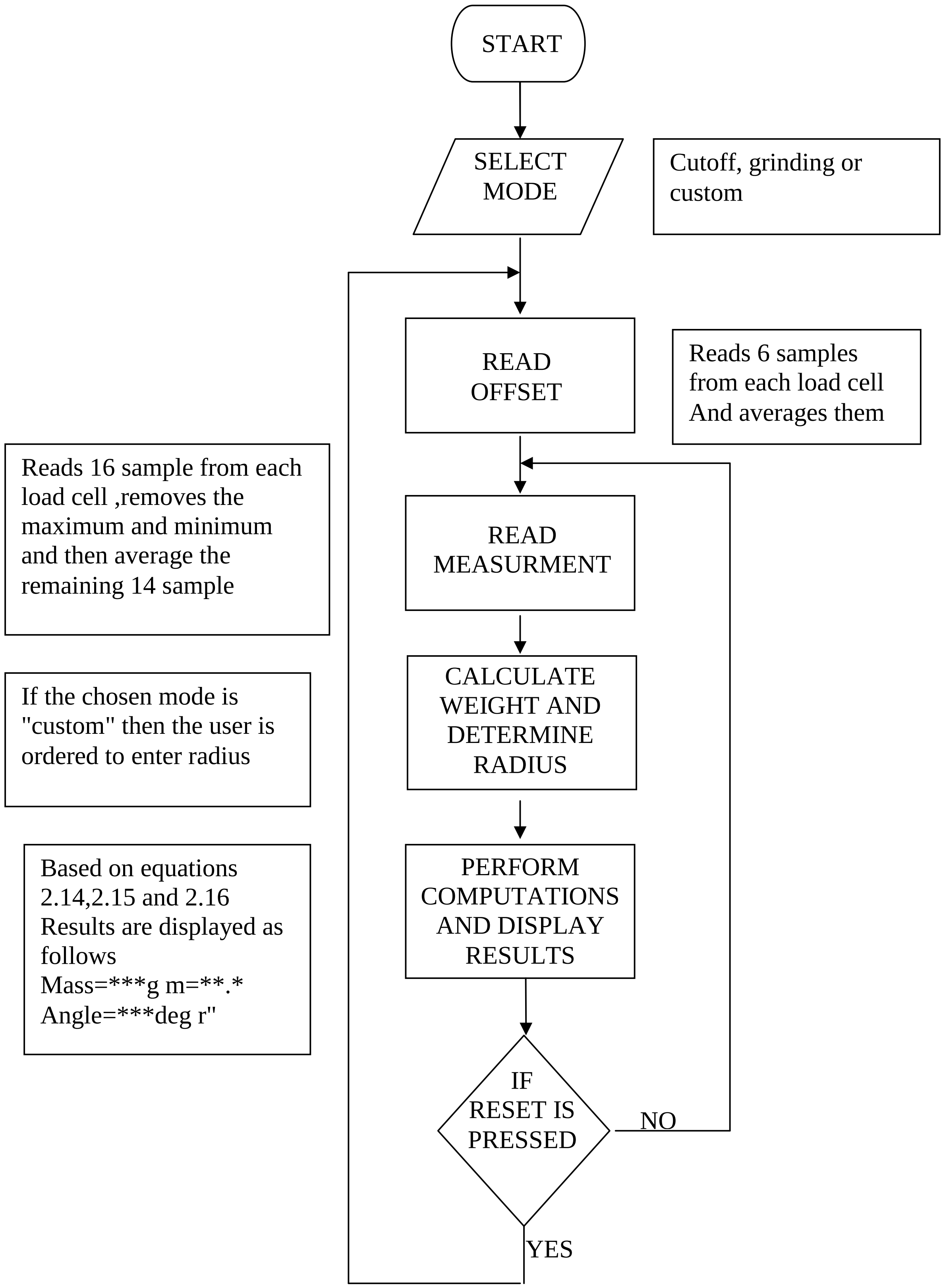


Figure (3.21) Program Flow chart

The flow chart of the device program is shown in figure (3.20) , the device program consists of three modes : cutoff, Grinding and custom modes.
In cutoff and grinding modes the radius of the disc is determined automatically by knowing the weight of the disc and comparing it to preprogrammed table, as shown in table (3.1)
if the worker want to measure the unbalance in cutoff or grinding wheels he choose the corresponding mode, these modes differ only in determining the radius because each of grinding .
if the worker want to test a disc that doesn't exist in the table programmed in it then he choose the custom mode and then he is ordered to enter the radius of the disc .
the results that are displayed include weight of the disc ,compensation mass ,compensation angle ,and the radius of the disc.
The disc perimeter is divide into 10 sectors of equal angle (36 degree) and on each sector there exist an LED that lights if the compensation angle located in that sector .
If the unbalance mass is smaller than 1g then the massage "DISC IS BALANCED" is displayed and no light turns on.
Complete code of the device program is shown in the appendix

Number	Type	Radius	Weight(gram)
1	Cutoff _steel	4.5"	70
2	Cutoff _ stone	4.5"	60
3	Grinding _steel	4.5"	135
4	Grinding _stone	4.5"	150
5	Cutoff _steel	7"	180
6	Cutoff _stone	7"	160
7	Grinding _steel	7"	370
8	Grinding _stone	7"	340
9	Cutoff _steel	9"	280
10	Cutoff _stone	9"	250
11	Grinding _steel	9"	550
12	Cutoff _steel	12"	670
13	Cutoff _steel	14"	770
14	Cutoff _steel	16"	900

Table (3.1) weights and radiuses of different discs manufactured in JELANCO factory

Chapter Four

Experimental results

introduction

Repeatability test

Accuracy test

Conclusion

4.1 Introduction

For the device to be suitable for testing cutoff and grinding wheels in the factory it must pass the repeatability and accuracy test , as mentioned in the requirement in chapter one .

Less of repeatability and accuracy characteristics affect to a large values the quality of the product being produced by the factory.

The unbalance measuring device can be accurate but unrepeatable or repeatable but inaccurate because the accuracy is decoupled from the repeatability .

4.2 Repeatability

The unbalance measuring device must be repeatable in measuring the weight of the disc being measured and also in measuring the unbalance mass and its location (the angle of unbalance).

Unrepeatability can be caused by zero drift variation due to thermal effects on the electrical components specially resistors and due to the variation in the gain that relates the load cell voltage to the measured force due to the variation of gain resistors and due to the variation of the excitation voltage of the load cell and the reference voltage of the analog to digital convertor , also the unrepeatability can be affected by changing of test conditions such as vibrations , temperature and noises .

Due to the large sensitivity if the device (less than 0.03 gram) small eccentricity of the disc hole from the fixture shaft or small tilt (the load cells are not in the same altitude from the ground) will cause variations in the measurement which decreases the repeatability.

In order to test the repeatability ,the same disc is put on the device with the same orientation and unbalance mass 10 times and the results are shown in table (4.1)

# of trial	Weight(gram)	Unbalance(gram)	Angle(degree)	Sector
1	290	1.8	58	3
2	291	1.7	68	3
3	291	1.7	67	3
4	291	1.7	58	3
5	291	1.8	71	3
6	291	1.9	59	3
7	291	1.8	60	3
8	291	1.7	65	3
9	291	1.6	80	3
10	291	1.6	82	3

Table (4.1) : reputability test result.

As shown in the table the device is approximately 100% repeatable in the weight measurement and repeatable to a value of less than 0.3 gram in the unbalance mass measurement.

During the test the disc cannot be guaranteed to be in the same previous location , this may be responsible for the variation in the angle measurements .

The same experiment was done, but with a period of approximately 10 minutes between each trial and a one shakel was put on the disc.

# of trial	Weight(gram)	Unbalance(gram)	Angle(degree)	Sector
1	294	4.5	104	4
2	294	4.2	107	4
3	295	4.1	103	4
4	295	4.9	117	4
5	294	4.3	111	4
6	295	4.5	119	4
7	295	4.8	108	4
8	295	4.9	102	4
9	295	4.4	104	4
10	295	4.9	96	4

Table(4.2) repeatability test results

4.3 Accuracy test

Accuracy is the most important characteristic in any measuring device and specially in unbalance measuring devices because of the large effect of small values of unbalance due to the huge rotational speeds.

The device should be accurate in measuring the weight of the disc, the angle of unbalance and the value of unbalance mass.

In order to test the accuracy a cutoff wheel of mass 74 and radius 4" is balanced then a mass of 3.2 gram is put on the disc (one shekel) ,the disc is also rotated around the whole sectors and the results is as in table(4.3).

# of trial	Weight(gram)	Unbalance(gram)	Angle(degree)	Sector
1	79	3	13	1
2	80	3.5	50	2
3	79	3.6	72	3
4	79	3.5	110	4
5	80	3.4	143	5
6	79	3.2	172	6
7	79	3	219	7
8	79	2.8	253	8
9	79	3	290	9
10	79	3	331	10

Table(4.3) :accuracy test results

4.4 Conclusion

The device is repeatable and accurate as long as the test is done in optimal conditions which include:

1)minimum eccentricity of the disc hole from the fixture shaft

2)minimum vibrations

3)minimum tilt of the device from vertical axis .

Chapter Five

Problems, Recommendations and Conclusions

5.1 Problems

1) The main problem that affects the accuracy of the device is its large sensitivity to very small eccentricity of the disc's hole from the fixture shaft (variation of 1 mm can cause a drift of 1 gram in the measurement and can cause a large variation in the angle), also the device is very sensitive to the non parallelism of the disc to the ground so a tilt very small will cause different and may be wrong measurements , also small vibrations on the device can cause wrong measurements ,this problem affects measuring small values of unbalance but it has small effect when the unbalance is large (575 gram. mm and above).

2) The absence of a graduation project for Mechatronics

This is one of the major problems that we faced during our work, although the computer control lab includes all equipment need and the lab supervisor does not hesitate to help graduation students by his experience, working in the this lab is not so comfortable because there exist no enough time, only six hours per week, so if mo strikes happen during the year, students have to finish there projects only in approximately 90 hours which is completely not enough.

So in order for the Mechatronics student to be able to produces valuable graduation project, the must have a graduation project that is always open for them.

3) Needed components

Due to the conditions in which we are living students have to wait a long time (usually a month or larger) in order to get the components they order because of the existence of these components outside the country and because of the late from electronic components sellers.

5.2 Recommendations

Since the noise problem is fully solved and the device has good resolution, the remaining problem in the face of using the device in the factory is it's large sensitivity to very small effects that may be caused by human error, small tilt of the device and vibrations, these problems can be solved by treating the device carefully such that the disc is put on the fixture with minimum eccentricity as possible, avoid vibrations, setup the device such that it has minimum tilt as possible and testing the disc more than once time.

This may increase the test time but it will solve the problem and give good results

5.3 conclusions

The unbalance measuring device has an advantage of being static test (non rotating) which means that it will measure unbalance with small time comparable to rotating test devices and it is suitable for testing cut-off and grinding wheels which are brittle during manufacturing but it has a disadvantage of being sensitive to small conditions that cannot be guaranteed to be optimal during the test , but if the solutions proposed in the recommendations are followed then the device will be accurate and suitable .

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Appendix (B): Microcontroller program

In order to simplify fault diagnoses and due to calling several functions many times These functions are put on a library called load_cell.h

```
//*****************************************************************
// load_cell library
#include<p18f4550.h>
#include<spi.h>
#include<math.h>
#include"gamelcd_v3.h"
 int data,data1,data2,b,i,k,f,d,v;
unsigned char DATA1,DATA2,DATA3,n,N;
float result,max,min,sum=0,aver=0,off,g,c;
float read_loadcell(char s);
float read(char s,int u)
{
sum=0;
aver=0;
  for(i=0;i<u;i++)
{
result=read_loadcell(s);
if(i==0)
{
max=result;
min=result;
}
if(result>max)
{
max=result;
}
if(result<min)
{
min=result;
}
sum+=result;
}
sum=sum-max-min;
aver=sum/(i-2);
return aver;
}
float read_loadcell(char s)
{
switch(s)
{
case '1':PORTAbits.RA0=0;g=0.03820;break;
case '2':PORTAbits.RA1=0;g=0.03820;break;
case '3':PORTAbits.RA2=0;g=0.03820;break;
```

```
}
  for(n=0;n<100;n++);
while(PORTBbits.RB0==      1);
DATA1 = ReadSPI();
DATA2= ReadSPI();
DATA3= ReadSPI();
PORTA=PORTA|0B00000111;
DATA1=DATA1&0b00111111;
data2=DATA2&0b11111111;
data1=DATA1;
data=(data2+data1*256);
off=data*g;
return off;
}
float find_radius_cutoff(float Mass,char k)
{
float radius;
if(Mass>30.0&Mass<100.0)
{
radius=4.5*25.4/2.0;
k='a';
}
else if(Mass>140.0&Mass<220.0)
{
radius=25.4*7.0/2.0;
k='b';
}
else if(Mass>220.0&Mass<350.0)
{
radius=9.0*25.4/2.0;
k='c';
}
else if(Mass>600.0&Mass<710.0)
{
radius=12.0*25.4/2.0;
k='d';
}
else if(Mass>720.0&Mass<840.0)
{
radius=14.0*25.4/2.0;
k='e';
}
else if(Mass>850.0&Mass<1000.0)
{
radius=16.0*25.4/2.0;
k='f';
}
else
{k='g';
radius=0.0;
```

```
}
return radius;
}
void print_mass(float result)
{
if(result>=999.0)
result=999.0;
b=result;
c=result-b;
if(c>=0.5)
b+=1;
if(b<100&b>=10)
lcd_putrs("0");
else if(b<10)
lcd_putrs("00");
lcd_puti(b);
}
void print_mc(float input)
{
if(input>=99.9)
input=99.5;
c=input;
b=input;
c=c-b;
//if(c>=0.25&c<0.75)
//v=5;
//else if(v>=0.75)
//{
//v=0;
//b=b+1;
//}
//else v=0;
c=c*10.0;
v=c;
if(b<10)
lcd_putrs("0");
lcd_puti(b);
lcd_putc('.');
lcd_puti(v);
}
void print_phi(float result)
{
b=result;
if(b<0)
{
b=b+360;
}
if(b<10)
lcd_putrs("00");
else if(b<100&b>=10)
```

```
lcd_putrs("0");
lcd_puti(b);
lcd_putrs("deg");
}
void led(float phi)
{
if(phi>-18.0&phi<=18.0)
PORTC=0b00000001;
else if(phi>18.0&phi<=54.0)
PORTAbits.RA4=1;
else if(phi>54.0&phi<=90.0)
PORTC=0B00000010;
else if(phi>90.0&phi<=126.0)
PORTAbits.RA5=1;
else if(phi>126.0&phi<162.0)
PORTC=0B00000100;
else if(phi>162.0|phi<=-162.0)
PORTE=0B00000001;
else if(phi>-162.0&phi<=-126.0)
PORTE=0B00000010;
else if(phi>-126.0&phi<=-90.0)
PORTAbits.RA3=1;
else if(phi>-90.0&phi<=-54.0)
PORTDbits.RD3=1;
else PORTC=0B01000000;
}
void turn_off(void)
{
PORTC=0;
PORTE=0;
PORTA=PORTA&0B00000111;
PORTDbits.RD3=0;
}
int read_keypad(void)
{
k=PORTB&0b11110000;
switch(k)
{
case 0: d=1;break;
case 128:d=2;break;
case 64:d=3;break;
case 32:d=4;break;
case 160:d=5;break;
case 96 :d=6;break;
case 16 :d=7;break;
case 144 :d=8;break;
case 80 :d=9;break;
case 176 :d=0;break;
case 48 :d=11;break;
case 112 :d=12;break;
```

```
}
return d;


}
float find_radius_grinding(float M,char h)
{
float radius1;
if(M>=100.0&M<=210.0)
radius1=4.5*25.4/2.0;
else if(M>300.0&M<450.0)
radius1=7.0*25.4/2.0;
else if(M>=500.0&M<700.0)
radius1=9.0*25.4/2.0;
else radius1=0.0;
return radius1;




}
void turn_on(void)
{
PORTC=0xff;
PORTE=0xff;
PORTA=PORTA|0B11111000;
PORTDbits.RD3=1;
}


//*****************************************************************
//*                 PALESTINE POLYTECHNIC UNIVERSITY
//*                    UNBALANCE MEASURING DEVICE
//*          MOHAMMAD AMAYREH AND MOHAMMAD ALBAKRI
//*                 SUPERVISOR DR YOUSIFE AL SWEITTI
//*                                2009-2010
//*
//*****************************************************************
//LIBRARY CALLING AND FUNCTION PROTOTYPING
// these functions are found in the "load_cell.h" library
//--------------------------------------------------------------------------------
#include<p18f4550.h>
#include<spi.h>
#include<math.h>
#include<delays.h>
#include"gamelcd_v3.h"
#include "load_cell.h"

void Delay10KTCYx(PARAM_SCLASS unsigned char);
void turn_off(void);      // TURINING ALL LIGHTS OFF
```

```
float read(char s,int u); // READS THE LOAD CELL 'S' WITH U SAMPLES AND
AVERAGE THEM
float read_loadcell(char s);// READS ONE SAMPLE FROM THE LOAD CELL 'S'
float find_radius_cutoff(float Mass,char k);// BASED ON THE MASS THIS
FUNCTION DETERMINES THE RADIUS FOR CUTOFF WHEELS
void print_mass(float result);// DISPLAY THE MASS IN 3 DIGITS FORMAT
void print_phi(float result);//DISPLAYS THE ANGLE IN 3 DIGIT FORMAT
void print_mc(float result);// DISPLAYS THE UNBANACE MASS WITH TWO
INTEGERS AND ONE FLOATING POINT
void led(float phi);// TURNS THE LIGHT THAT CORRESPOSDS TO THE
SECTOR OF ANGLE PHI
int read_keypad(void);//  READS THE BINARY VALUE FROM THE KEY PAD
ENCODER AND DETERMINES THE DEICMAL VALUE
float find_radius_grinding(float M,char h);// BASED ON THE MASS THIS
FUNCTION DETERMINES THE RADIUS FOR GRINDING WHEELS
void turn_on(void);// TURN ALL LIGHTS ON
void main(void)
{
//------------------------------------------------------------------------------
//VARIABLES DEFINITION
float fmin,
f1=0.0,f2=0.0,f3=0.0,M=0.0,m=0.0,r,phi=0.0,phic=0.0,o1=0.0,o2=0.0,o3=0.0,me1=0.
0,me2=0.0,me3=0.0;
float u=0.0,M_1=0.0;
int b=0,t,i=1,k1,k,d=1,a,l,j;
char key=0,h;

//-----------------------------------------------------------
//IO configurations
ADCON1=0X0F;
TRISC=0;
TRISE=0;
TRISA=0;
TRISDbits.TRISD3=  0;
TRISAbits.TRISA0=  0;
TRISAbits.TRISA1=  0;
TRISAbits.TRISA2=  0;
PORTAbits.RA0=      1;
PORTAbits.RA1=      1;
PORTAbits.RA2=      1;
PORTDbits.RD3=0;
OpenSPI(SPI_FOSC_64, MODE_11, SMPMID);
 TRISBbits.TRISB0 = 1;   //SDI
  TRISBbits.TRISB1 = 0;   //SCK
lcd_init();
o1=read_loadcell('2');
o2=read_loadcell('3');
o3=read_loadcell('1');
turn_on();
lcd_gotoyx(1,0);
```

```
lcd_putrs(" UNBALANCE TEST ");
lcd_gotoyx(2,0);
lcd_putrs("----------------");
for(i=1;i<=10;i++)
{
Delay10KTCYx(200);
}
/*
o1=read('2',20);
o2=read('3',20);
o3=read('1',20);*/
//----------------------------------------------------------------
//MAIN PROGRAM
while(1)
{
j=1;
u=0.0;
lcd_gotoyx(1,0);
lcd_putrs("Mode:1-Cutoff   ");
lcd_gotoyx(2,0);
lcd_putrs("2-Grind 3-Custom");
while(PORTBbits.RB2==0);//IF BUTTON IS PRESSED
while(PORTBbits.RB2==1);//IF BUTTON IS RELEASED
key=read_keypad();
if(key!=1)
if(key!=2)
if(key!=3)
j=0;
if(key==3)
{
lcd_gotoyx(1,0);
lcd_putrs("Enter Radius    ");
lcd_gotoyx(2,0);
lcd_putrs("                ");
lcd_gotoyx(2,0);
while(1)
{
while(PORTBbits.RB2==0);
while(PORTBbits.RB2==1);
k=read_keypad();
if(k<=9)
{
u+=100.0*k;
lcd_puti(k);
break;
}
}
while(1)
{
while(PORTBbits.RB2==0);
```

```
while(PORTBbits.RB2==1);
k=read_keypad();
if(k<=9)
{
u+=k*10.0;
lcd_puti(k);
break;
}
}
while(PORTBbits.RB2==0);
while(PORTBbits.RB2==1);
k=read_keypad();
lcd_puti(k);
u+=k;
a=1;
while(a)
{
if(PORTBbits.RB2==1)
{
while(PORTBbits.RB2==1);
k=read_keypad();
if(k==11)
a=0;
}
}
}
while(j)
{
lcd_gotoyx(1,0);
lcd_putrs("MASS=000g m=00.0");
lcd_gotoyx(2,0);
lcd_putrs("Angle=000deg    ");
turn_off();
a=1;
i=1;
o1=read('2',6);
o2=read('3',6);
o3=read('1',6);

l=1;
a=1;
M=1000.0;
while(a)
{
M_1=M;
me1=read('2',16);
f1=(me1-o1);
if(PORTBbits.RB2==1)
{
while(PORTBbits.RB2==1);
```

```
k=read_keypad();
if(k==0|k==12)
{
if(k==12)
j=0;
break;
}
}
me2=read('3',16);
f2=(me2-o2);
if(PORTBbits.RB2==1)
{
while(PORTBbits.RB2==1);
k=read_keypad();
if(k==0|k==12)
{
if(k==12)
j=0;
break;
}
}
me3=read('1',16);
f3=(me3-o3);
if(PORTBbits.RB2==1)
{
while(PORTBbits.RB2==1);
k=read_keypad();
if(k==0|k==12)
{
if(k==12)
j=0;
break;
}
}
M=(f1+f2+f3);
switch(key)
{
case 1:
r=find_radius_cutoff(M,h);
break;
case 2:
r=find_radius_grinding(M,h);
break;
case 3: r=u;break;
}
if(f1>f2&f3>f2)
fmin=f2;
else if(f1>f3&f2>f3)
fmin=f3;
else fmin=f1;
```

```
f1=f1-fmin;
f2=f2-fmin;
f3=f3-fmin;
m=50.0*sqrt(pow(f1,2.0)+pow(f2,2.0)+pow(f3,2.0)-(f1*f2+f1*f3+f2*f3))/(r);
phi=atan2(2.0*0.866*(f2-f3),((2.0*f1)-f2-f3))*180.0/3.142;
phic=phi+180.0;
lcd_gotoyx(1,6);
if(M>=0.0)
{
print_mass(M);
}
lcd_gotoyx(1,13);
if(r!=0.0)
{
print_mc(m);
}
else lcd_putrs("----");
lcd_gotoyx(2,7);
if(M>=5.0)
{
print_phi(phic);
}
else lcd_putrs("---");
lcd_gotoyx(2,14);
r=r*2.0/25.4;
b=r;
lcd_puti(b);
lcd_putc('"');
lcd_putc(' ');
if(phic>180.0)
phic=phic-360.0;
turn_off();
if(M>=5.0)
{
led(phic);
}

}
}

}
}
```

Appendix (C) Matlab program

```
%% this program is used to read data from the data acquisition card
%% Define the Analog input Object
ai=analoginput('nidaq','Dev3');
set(ai,'InputType','Differentail')
addchnnel(ai,0)
set(ai,'SampleRate',1000)
set(ai,'SamplesPerTrigger',10000)
start(ai)


%% Determine the offset values
[data time]=getdata(ai);
offset=mean(data)
%% averaging
i=1;
while(i<1000)
y=data(1,i:i+5);
[ymax Imax]=max(y);
y(Imax)=[];
[ymin Imin]=min(y);
y(Imin)=[];
ymean=mean(y);
data_mean(1,i:i+5)=ymean;
i=i+6;
end



%% Now put the load and read the measurements
start(ai)
[data time]=getdata(ai);
measurment=mean(data)
%% calculate the forces
gain=1000;
force=(measurment-offset)/gain
%% calcuate the Unbalance mass and angle
theta=atan((2*cos(30*pi/180)*(force(2)-force(3)))/(2*force(1)-
force(2)-force(3)))*180/pi
R=0.1;
g=9.81;
r=.05;
mass=r*sqrt(sum(force.^2)-
(force(1)*force(2)+force(1)*force(3)+force(2)*force(3)))/(g*R)
```

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