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BUILDING SIGNAL CONDITIONING FOR STRAIN GAUGE SENSORS

By

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صفحة نتيجة الحكم على البحث (نتيجة الحكم من قبل لجنة المناقشة)

ABSTRACT

Strain gauge sensors are used extensively in industrial machines, testing equipments, and weighing indicators. The output signal of these sensors is basically an analog voltage in the millivoltage range, and it needs to be monitored, measured, or analyzed. It is not suitable for direct input to popular analog to digital converters because of its low level, so it needs to be amplified using a suitable signal conditioner which is characterized by its precision, reliability, low power consumption, low price, and noise reduction. Interfacing these sensors to a computer system is a challenging problem. There are many popular solution strategies; therefore, designers must always deal with trade off among cost, accuracy, and reliability. In this research, a real design problem is presented. It is a rehabilitation of a *Materials Testing Machine* that was partially destroyed during the last war on Gaza. Many possible solution strategies are described and the most suitable one to the case study is adopted. We amplify the output signal from a strain gauge sensor using a precise signal conditioner designed circuit. This amplified signal is filtered and input to a microcontroller and the value of the load is then monitored using liquid crystal display .The proposed design has been successfully implemented and the machine is returned back to work properly.

ملخص

"إنشاء نظام تكييف إشارة مجسات قياس الإجهاد"

مجسات قياس الإجهاد تستخدم بكثرة في ماكينات المصانع، أجهزة الفحص، أجهزة قياس الأوزان. الإشارة الخارجة من هذه المجسات هي في الأساس إشارة فولتية متناظرة بمقياس الملي فولت و تحتاج إلى ضبط و قياس و تحليل، وهى ليست مناسبة للإدخال المباشر إلى معظم محولات الإشارات التناظرية إلى إشارات رقمية لأنها إشارة ضعيفة، ولذلك تحتاج إلى تكبير باستخدام دائرة تكييف مناسبة و دقيقة و ذات فاعلية و قليلة استهلاك للطاقة و قليلة التكلفة و تعمل كذلك على إزالة الضجيج. موائمة هذه المجسات مع أنظمة الحاسوب عادة تكون مسألة تحدي. هناك استراتيجيات عامه للحلول، ويحاول المصممين الموائمة بين التكلفة والدقة و الفاعلية. في هذا البحث يتم عرض مشكلة تصميم واقعية هي إعادة تأهيل لماكينة فحص المواد التي دمرت جزئيا خلال الحرب الأخيرة على غزة. عدة استراتيجيات للحل تم وصفها و الحل الأمثل لهذه الحالة تم تبنيه. تم تكبير الإشارة الناتجة من مجسات قياس الإجهاد باستخدام دائرة الكترونية دقيقة تم تصميمها تتعلق بتكييف الإشارة. هذه الإشارة المكبرة تم فلترتها و تم إدخالها إلى معالج دقيق و قيمة الوزن تم عرضها على شاشة عرض. التصميم المقترح تم تنفيذه بنجاح وعادت الماكينة إلى العمل كما ينبغي.

DEDICATION

To all my family members who have been a constant source of motivation, inspiration, and support.

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I thank Allah, the lord of the worlds, for His mercy and limitless help and guidance. May peace and blessings be upon Mohammed the last of the messengers.

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There are no words that describe how grateful I am to my family specially my wife for her support and encouragement through the years. My deepest thanks go to my brothers, my sisters and my daughter for their patience and understanding during my busy schedule.

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ABBREVIATIONS

AC	Alternating Current
A/D	Analog to Digital
ADC	Analog to Digital Converter
C^o	Degree Celsius
CE	Certificate for the Product
Cm	Centimeter
CMRR	Common Mode Rejection Ratio
CMOS	Complementary Metal-Oxide-Semiconductor
COM	Component Object Model
CPU	Central Processing Unit
ECU	Electrical Control Unit
D	Deformation
DC	Direct Current
DIP	Dual In-Line Package
DSC	Digital Strain Gauge to Data Converter
DSCS2ASC	Digital Strain Gauge to Data Converter Industrial Stability RS232 Output ASCII Protocol
DSCS4ASC	Digital Strain Gauge to Data Converter Industrial Stability RS485 Output ASCII Protocol
GLCD	Graphical Liquid Crystal Display
GND	Ground
F	Force
F.S.	Full Scale
HDPE	High Density Polyethylene
I/O	Input/Output

IUG	Islamic University of Gaza
Kg	Kilo Grams
kN	Kilo Newton
Lb	Pound
LC	Load Cell
LCD	Liquid Crystal Display
LDPE	Low Density Polyethylene
LPF	Low Pass Filter
MCU	Micro Controller Unit
MUX	Multiplexer
No.	Number
op-amp	Operational Amplifier
PC	Personal Computer
PGA	Programmable Gain Amplifier
PIC	Peripheral Interface Controller
PLC	Programmable Logic Control
PVC	Polyvinyl Chloride
SH	Shield
SPI	Serial Peripheral Interface
TTL	Transistor-Transistor Logic
UNF	Unified Fine
US$	United States Dollar
USART	Universal Asynchronous Receiver Transmitter
USB	Universal Serial Bus
VDC	Voltage Direct Current

CHAPTER 1 INTRODUCTION

1.1. Research Motivation and Goal

Generally, signal conditioner manipulates an analog signal in such a way that it meets the requirements of the next stage for further processing. These requirements include amplification, filtering and noise reduction. There are many and different types of signal conditioners used for the amplification of a very small strain gage sensors signal (millivolts). For years, we used to rely on expensive monopolized black-box devices for signal conditioning of strain gauge sensors. Therefore, in this thesis the scope of research is selected to study and to experiment with different types of signal conditioner for quick and available solutions and to choose the best one to be used in developing a new weighing controller. This procedure can be used to solve the problems arising in the field of industrial processes that are concerned with the signal conditioners of strain gauge sensors.

Measurement of forces are present at various locations and applications [1]. The Tinius Olson H10K materials testing machine is shown in Figure (1.1). It has a frame capacity of 10 KN allowing it to test a wide range of materials such as PVC pipes, rigid plastics, films, paper, packaging materials, filter material, thin sheet metal, Aluminum, adhesives, foils, food, toys, medical devices, etc. [2].

Figure (1.1): The Tinius Olson H10K materials testing machine

The main purpose of this machine is performing a vast array of tension and compression force tests and the elongation of the tested sample before break down. The machine can be modeled as shown in Figure (1.2). The material under test is fixed between points *a* and *b*. Point *b* is stationary while point *a* is allowed to move up or down using a DC motor screw jack with a user-defined speed. The resultant force (F) on the material and the displacement of point *a* which is called *the material deformation* (D) are calculated by the controller and presented to the user on a graphical display. Material scenes people relies on this test to judge on the quality of the material after sketching the applied force versus the material deformation [3, 4].

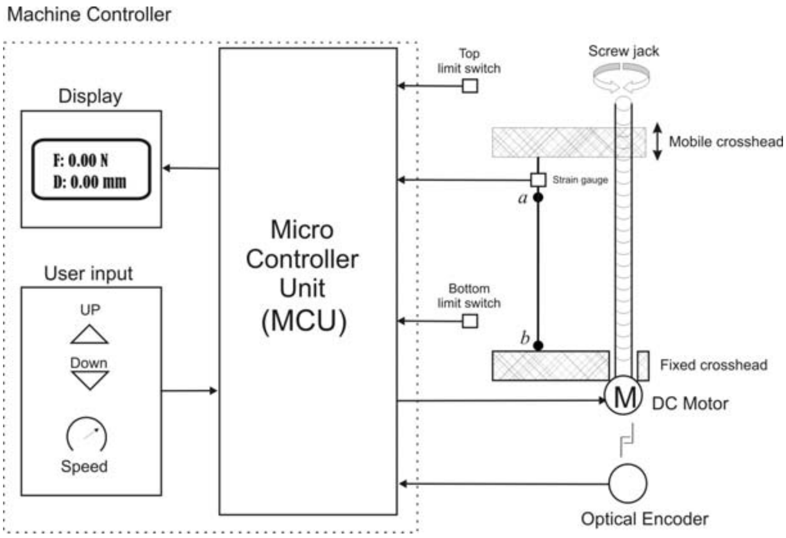


Figure (1.2): Model of the material testing machine

The displacement is detected by a 1000 pulse quadrature optical encoder [5]. On the other hand, the force is measured via a 10 KN S-beam type strain gauge incorporated in the mobile crosshead [6].

The machine under consideration is unique in Gaza. It belongs to the *Materials and Soil Laboratory* at the Islamic University and it is characterized by its precession and long deformation range measurements (up to 83 cm). It is originally controlled via a professional microcomputer system. Unfortunately, this system is totally damaged during the last war on Gaza and ordering a new controller may cost as much as 8000 US$. Due to the siege on Gaza and if this money is available, it is not guaranteed that the machine parts will be allowed to enter Gaza. In addition, it is not guaranteed that the machine will work properly. Therefore, we have to rely on viable solutions to return the machine back to work quickly. It is the aim of this work to describe our approach to resolve the problem.

Figure (1.3) depicts a typical interface of a strain gauge sensor to a digital system [7]. Filtering the signal is an essential process that will separate the main effective part of signal from extraneous and undesirable components which are generally referred to a noise. Noise can be interference noise from external sources or inherent noise from the device itself such as thermal noise, operational amplifier noise and quantization noise. The signal is then applied to a microcontroller to be analyzed, compared and measured. Then the MCU will display the data on LCD and also use this data to control the desired electrical and mechanical operations.

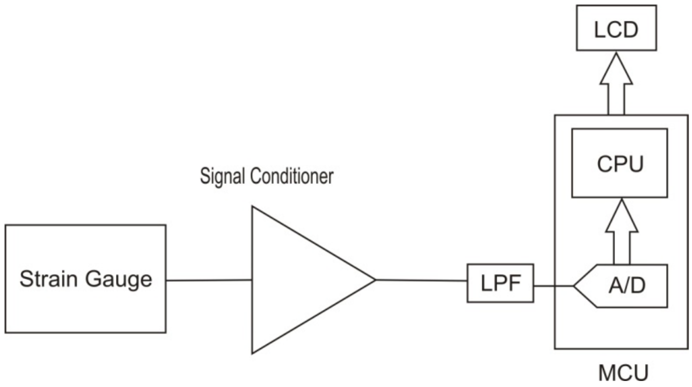


Figure (1.3): Strain gauge interfacing

For signal conditioning at the measurement point, a compromise must be made between signal integrity and system cost [8]. In this research, different experimental circuits have been built concerning with the signal conditioning of strain gauge sensors. These circuits were designed, simulated, built, and tested. Printed circuit boards (PCBs) were designed for each circuit using PROTEUS computer program then these boards were developed. The electronic components are mounted and soldered on them and tested. Results were very good and matched our expected requirements. According to these experiments, we could achieve our goals using available, low cost and easy maintenance components. We used these techniques to rehabilitate a destroyed *Material Testing Machine.* This study could be used by engineers and technicians to solve any problem in the industrial fields concerning weighing, filling and testing machines or equipments. Also this study can be implemented for educational fields. The main contribution lies behind the success on interfacing the strain gauge to a PIC microcontroller via a precise and viable signal conditioning circuit. We succeeded in building a reliable low-cost controller (about 300 US$) based on available electronics from the local market.

1.2. Historical Background

The variable resistance strain gage has used the Wheatstone bridge circuit in various forms since its inception [9]. Before strain gauge-based load cells became the method of choice for industrial weighting applications, mechanical lever scales were widely used.

In 1820, the earliest, pre-strain gauge force sensors include hydraulic and pneumatic designs. In 1843, English physicist Sir Charles Wheatstone devised a bridge circuit that could measure electrical resistances. The Wheatstone bridge circuit is ideal for measuring the resistance changes that occur in strain gauges.

In 1940, the first bonded resistance wire strain gauge was developed. It was not until modern electronics caught up that the new technology became technically and economically feasible [10]. It was used in the development of an accurate and reliable load cell or force transducer [11]. In 1960, Art Zias was the person most responsible for bringing sensor technology to the world. He worked for a contract on solid state motion transduction. In 1972, Art Zias and Bill Hare founded National Semiconductor's transducer operation and continued the efforts for automotive applications [12].

Today, except for certain laboratories where precision mechanical balances are still used, strain gauge load cells dominate the weighing industry. Pneumatic load cells are sometimes used where intrinsic safety and hygiene are desired, and hydraulic load cells are considered in remote locations, as they do not require a power supply [10]. The strain gauge and its applications have been one of the most intensely researched fields in recent technological history [11].

Signal amplification began back in the vacuum tube era. An operational amplifier is first found in USA patent "*Summing Amplifier*" filed by Karl D. Swartzel Jr. of Bell laboratories in 1941. This design used three vacuum tubes to achieve to achieve a gain of 90 dB and operated on voltage rails of ±350V.

In May of 1954, Gordon Teal of *Texas Instrument*s developed a grown-junction silicon transistor. These transistors had lower leakage, and were generally amplifying devices. Additional processing refinements were to improve up on the early silicon transistors, and eventually lead the path to the invention of the first integrated circuits in the late fifties. In 1958, Jack Kilby invented the integrated circuit.

Signal Conditioning Solutions company was established in late 2004. It was established to provide focused sales development service for *Analog Devices* line of analog signal conditioning products to the process control market segment in North America.

In 2008, *Integrated Electronic Technologies* company had signal conditioning apparatus circuit patents. These circuits achieve high levels of effective signal isolation and so eliminate common mode interference related to analog signal interconnects. The circuits are inherently stable, place no constraints on circuit input impedance or output impedance, insensitive to large imbalances in source impedance, and can be configured to inherently protect inputs and outputs from short circuit and accidental connection to power supply potentials. The recent trends are low voltage operational amplifiers containing digital logic.

1.3. Problem Statement

In the industry in Gaza, we used to deal with the signal conditioner concerning the weighing, filling and force testing machines as a black box. When it is not working or damaged, we used to buy another one to replace it or we need to bring foreigner expert to solve the problem. Due to the siege on Gaza, it takes time and it is difficult to buy the damaged components. It is not guaranteed to buy these components, so we build a signal conditioner from available components to serve the industrial process. The signal conditioner conditions the load cell signal, then it is amplified and filtered with noise reduction. Interfacing the signal conditioner with the microcontroller must be done.

1.4. Thesis Contribution

In this thesis, a survey for different signal conditioning circuits was made and a suitable one which is applicable to our application was chosen. It has different gain ranges of 1, 10, 100 and 1000 digitally selected by using two transistor-transistor logic (TTL) lines. Also, different signal conditioning printed circuit boards (BCBs) were built. In the first experiment, BCB1 and PCB2 which include signal conditioner with filter, was connected with the load cell to measure the weight of the loads on a graphical liquid crystal display screen (GLCD). In the second experiment, the load cell is connected to a digital strain gauge to data converters (DSCS2ASC and DSCS4ASC) in order to present the weight of the load on the computer using special software called instrumentation explorer program. In the last experiment, BCB3 was designed using signal conditioner to rehabilitate a damaged tensile testing machine. The Force and the elongation distance of the tested material are presented on liquid crystal display screen (LCD).

1.5. Thesis Structure

This section outlines the overall structure of the thesis and provides a brief description for each chapter. Chapter 2 provides some basic knowledge about general sensors, resistive and capacitive strain gauge sensors, the resistive load cells products and the uses of load cells. Chapter 3 addresses the analog signal conditioning issues, introduction to amplifiers and classifications, operational amplifiers, differential amplifiers, instrumentation amplifiers, different integrated circuit amplifiers and a comparison summary table between different types of amplifiers. The chapter also demonstrates experimental work for designing a weighing indicator using PGA204 instrumentation amplifier and load cells with embedded signal conditioning circuit. Chapter 4 addresses the digital load cells, digital processing for sensor's output. It presents a digital load cell from *Tedea Company*, the digital strain gauge to data converter, experimental work on the digital strain gauge to data converter industrial Stability RS232, and RS485 Output using ASCII Protocol and iLoad products of digital load cells. Chapter 5 addresses the rehabilitation of the tensile testing machine. It explains the direction and speed controller of the machine, the force and deformation measurement, the hardware and the software implementation. Finally, in chapter 6 conclusions and suggestions for future work are summarized.

CHAPTER 2 STRAIN GAUGE SENSORS

This chapter describes the details of the electrical output signals from strain gauge sensors. Electrical signals play a crucial role in the operation of electronic devices. In fact, it is hard to imagine a device which does not send or receive some signals. For that reason, signals are the most important and essential objects of any electronic device or system. Physically, an electrical signal is a flow of electrons that are subjected to complex laws of physics.

Without signals transporting information from one circuit to another, there would be no computation. There are two important classifications of signals:

- Analog signals: It is a continuous signal that represent a measured response to changes in physical phenomena, such as sound, light, temperature, position, or pressure, and is achieved using sensor.
- Digital signals: Discrete-time signals that have a discrete number of levels. It is achieved by sampling, quantizing and coding the analog signals.

Machines can communicate by sending and receiving signals. For example, a temperature sensor may inform a circuit when the temperature reaches certain level so that the circuit may turn on an air conditioner.

2.1. Sensors

A sensor is a device that converts a physical phenomenon or quantity into an electrical signal which can be further used to indicate or control the measured variable [8]. Sensors are classified as passive and active sensors. A passive sensor has no power supply and all the energy it delivers to the next stage (the signal conditioning stage) is drawn from the measured. While an active sensor is a modulator and can; therefore, deliver more energy to the next stage than it draws from the measured [13].

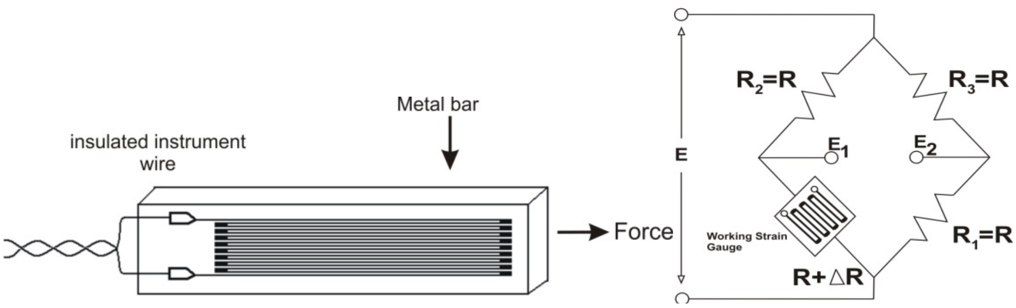
Typical sensors yield low amplitude analog signals, sometimes millivolts like strain gauge sensors. Only a few sensors, such as a position encoders offer a digital output signals that if it has the appropriate voltage levels could be directly connected to the port of a microcontroller [14].

There are many types of sensors such as strain gauge sensors, microphones sensors, velocity sensors, linear position sensors and etc. [15]. A sensor does not function by itself; it is always a part of a larger system that may incorporate many other detectors, signal conditioners, signal processors, memory devices, data recorders, and actuators [16].

2.2. Resistive Strain Gauge Sensors

"The strain gauge is a special adaptation of the resistive motion sensor. It is a conducting wire whose electrical resistance changes by a small amount when it is lengthened or shortened in proportion to the amount of strain or stress in the device. The change in length is small, a few millionths of millimeter. The strain gauge is bonded to structure so that the percent change in length of strain gauge and structure are identical. A *foil-type* gauge is shown in Figure (2.1a). The active length of the gauge lies along the transverse axis. The strain gauge must be mounted so that its transverse axis lies in the same direction as the structure motion that is to be measured. Lengthening the bar by tension lengthens the strain gauge conductor and increases its resistance. Compression reduces the gauge's resistance because the normal length of the strain gauge is reduced.

Strain gauges are made from metal alloy such as Constantan, Nichrome, Dynaloy, Stabiloy, or Platinum alloy. For working at high-temperature they are made of wire. For moderate temperature, strain gauges are made by forming the metal alloy onto very thin sheets by a photoetching process. The resultant product is the so called *"foil-type*" strain gauge" [17].



(a) Strain gauge **(b) Load cell**

Figure (2.1): Strain gauge and resistive bridge structure

The strain gage converts all of the load physical quantities into a changing resistance ΔR by responding to the stress or strain induced in a mechanical member to which it is attached.

In order to measure force using a strain gauge sensor, the change of resistance in the gauge ΔR must be measured. To measure resistance a technique to convert a resistance to a current is needed. The most common technique is to place the strain gauge in one arm of a resistance bridge, as shown in Figure (2.1b). Assume that an excitation voltage E or current is applied, the gauge is unstrained, so that its resistance = R. Under these conditions $E_1=E_2=E/2$ and $E_1-E_2=0$. The bridge is said to be balanced for zero output. If the strain gauge is compressed or stretched, R will change by ΔR, the bridge is unbalanced [18] and the differential voltage E_1-E_2 would be given by:

$$
\begin{aligned}
E_1 - E_2 &= E\,\frac{R + \Delta R}{2R + \Delta R} - E\,\frac{R}{2R} \\
&= E\left[\frac{2R^2 + 2\Delta R \times R - 2R^2 - \Delta R \times R}{(2R + \Delta R)2R} - E\,\frac{R}{2R}\right] \\
&= E\left[\frac{\Delta R \times R}{(2R + \Delta R)2R}\right] = E\,\frac{\Delta R \times R}{4R^2 + 2R\,\Delta R} \\
&= E\,\frac{\Delta R}{4R + 2\,\Delta R} \qquad \cong E\,\frac{\Delta R}{4R} \qquad \text{since } \Delta R << R \qquad (2.1)
\end{aligned}
$$

This can be detected by a sensitive voltmeter connected across the center arms of the bridge. When a strain gauge is arranged in a resistive bridge, the resultant device is called a *load cell*.

2.3. Improving Load Cell Stability Against Temperature Change

"Even if we succeed in balancing the bridge circuit of Figure (2.1b) it will not stay in balance because slight temperature changes in strain gauge cause resistance change equal to or greater than those caused by strain. Load cell manufacturers apply some ideas to improve load cell stability against temperature changes and enhance its gain $(E_1-E_2)/E$. Today's standard load cells have a wide and sufficient range of operating temperature and a gain in the range of 2 or 3 mV/V at full scale [19]. That is if a 10 Kg capacity 2mV/V load cell is excited with 5V supply, then the maximum output voltage (at 10 Kg load) will be 10 mV.

This is done by mounting another identical strain gauge immediately adjacent to the working strain gauge so that both share the same thermal environment. Therefore, as temperature changes, the added gage's resistance changes exactly as the resistance of the working gauge. Thus the added gauge provides automatic temperature compensation.

The *temperature-compensation gauge* is mounted with its transverse axis perpendicular to the transverse axis of the working gauge, as shown in Figure (2.2). This type of standard gauge arrangement is available from manufactures. The new gauge is connected in place of resistor R_1 in the bridge circuit of Figure (2.1b). Once the bridge has been balanced, R of temperature compensation gauge and working gauge track one another to hold the bridge in balance to eliminate the temperature effect. Obviously, these standard load cells require a precise power supply circuit, which is able to provide a stable excitation voltage" [18].

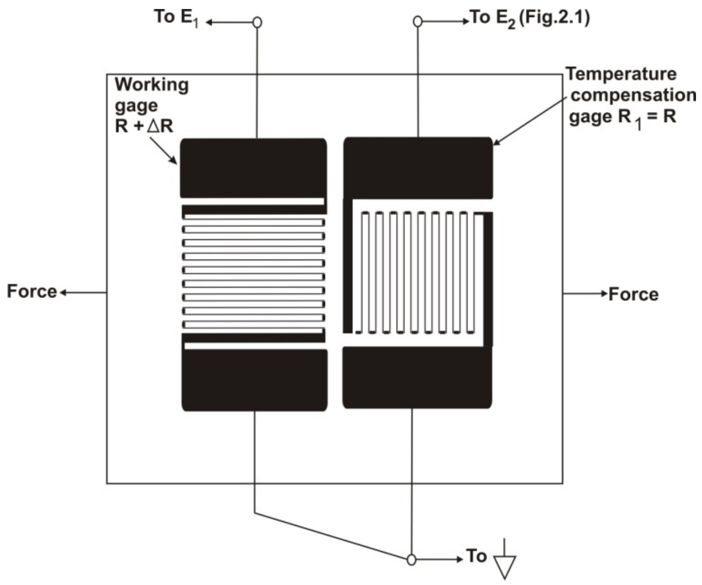


Figure (2.2): The temperature compensation gauge

2.4. Load Cell Sensitivity

A single working gage were shown in Figure (2.3a) to give a differential bridge output of

$$E_1 - E_2 = \frac{E}{4}\left[\frac{\Delta R}{R + \frac{\Delta R}{2}}\right] \tag{2.2}$$

Further sensitivity (more output) results when two of the bridge resistors are *'active'*. Opposing arms are placed in tension and compression (stressed and strained) [8] as shown in Figure (2.3b) to increase sensitivity of the strain gauge.

$$E_1 - E_2 = \frac{E}{2}\left[\frac{\Delta R}{R + \frac{\Delta R}{2}}\right] \tag{2.3}$$

More sensitivity will be gotten for the output by arranging the active gages as shown in Figure (2.3c).

$$E_1 - E_2 = \frac{E}{2}\left[\frac{\Delta R}{R}\right] \tag{2.4}$$

The sensitivity for output of the four-strain-gauge arrangements shown in Figure (2.3d) is quadruped over the single-gauge bridge to

$$E_1 - E_2 = E\left[\frac{\Delta R}{R}\right] \tag{2.5}$$

Figure (2.3) shows that the output voltage sensitivity and linearity of constant voltage drive bridge configurations differs according to the number of active elements.

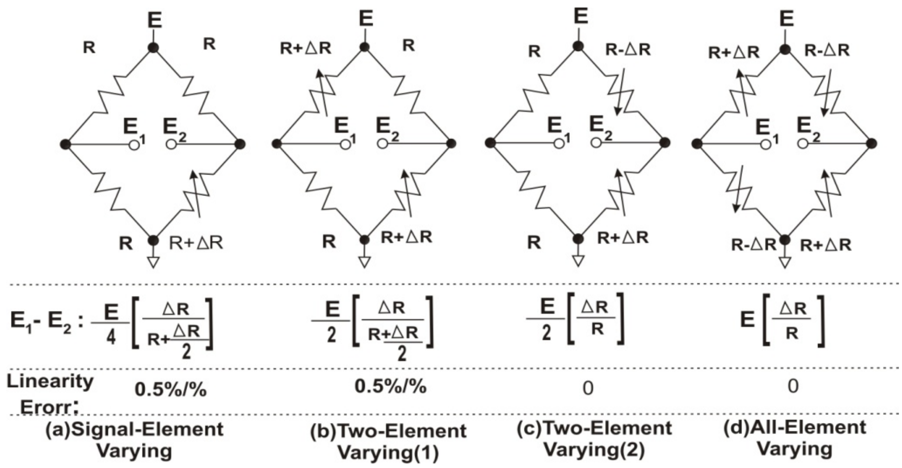
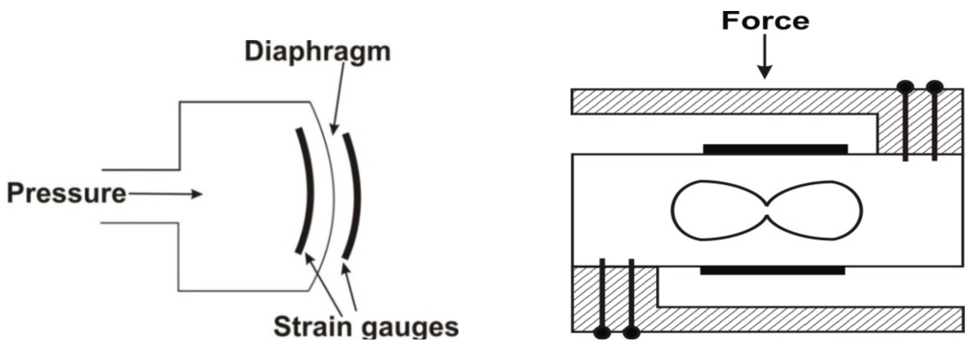


Figure (2.3): The output voltage sensitivity and linearity

To increase sensitivity, double bonded strain gauges are mounted on both sides of a diaphragm to measure pressure of gases and liquids as shown in Figure (2.4a). The same idea is applicable in load cells as shown in Figure (2.4b)



(a) Pressure measurement **(b) Force measurement**

Figure (2.4): Double bonded strain gauge

2.5. Resistive Load Cells Products

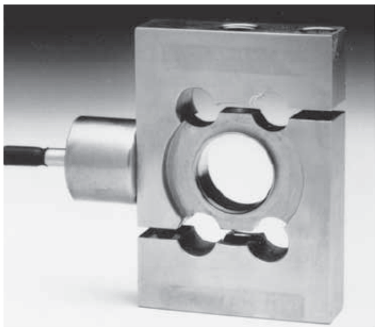
There are many companies producing the load cells which are widely used in our industry such as *Tedea* Company, *Celtron* Company, *Omega Engineering* Incorporation, *Honeywell* Company, *Cooper Instruments and Systems* Company, *Load Cell Central* Company, *Futek Advanced Sensor Technology* Inc., and *ME-Meßsysteme* Company.

Tedea Company produced different model numbers such as:

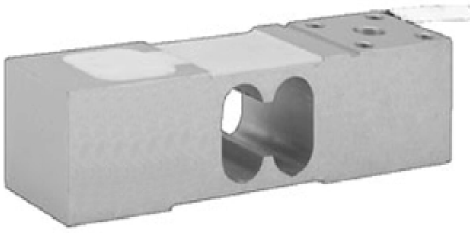
- Model No. 240 fluid-damped analog load cell with capacity 2-50 kg, shown in Figure (2.5a).
- Model No. LFS250 shown in Figure (2.5b) with the following specifications: Capacity range (0−45 kg), accuracy (0.03% F.S.), repeatability (0.01 % F.S.), material stainless steel, temperature range (0−54 degree Celsius), output (3 ± 0.003

mV/V), bridge resistance 350 ohms, excitation 15VDC max., safe overload 150% F.S., thread (3/8-24 UNF), and cable 914 cm [19].

- Model No. 311F with capacity 50,100 and 200 kg [20].
- Model No. 1002 with a capacity rate 0.5−5 kg (single point) as shown in Figure (2.5c).
- Model No. 1042 (single point) with capacity from 0−50 kg [21].
- Model No. 1242 rate (50−250) Kg single point as shown in Figure (2.5d).



(a) Model No.240 **(b) Model No. LFS250**



(c) Model No.1002 **(d) Model No. 1242**

Figure (2.5): Load cells from TEDIA company

CELTRON Company produces different model numbers of load cells such as: LPS-30 Kg. Omega Engineering Inc. produces different model numbers of load cells such as: LCCD S-beam type with capacity range 0−5000 kg and output = 3mV/V ± 0.25% as shown in Figure (2.6) [22].

Figure (2.6): S-beam load cells for compression and tension applications

2.6. Capacitive Strain Gauge Sensors

Capacitance gauges theory and principle is that the capacitance of a pair of electrodes of defined area, which called upper and lower capacitor plates, separated by a defined distance could be changed by changing the separation distance D_i as shown in Figure (2.7). The space between these electrodes is filled with an intermediate array of dielectric material pads that has suitable modulus of elasticity. The pads formed of silicone- impregnated open-cell urethane foam looks like a gel [23]. Therefore, we can relate the change in electrode spacing to the stress applied to the electrodes surfaces [24].

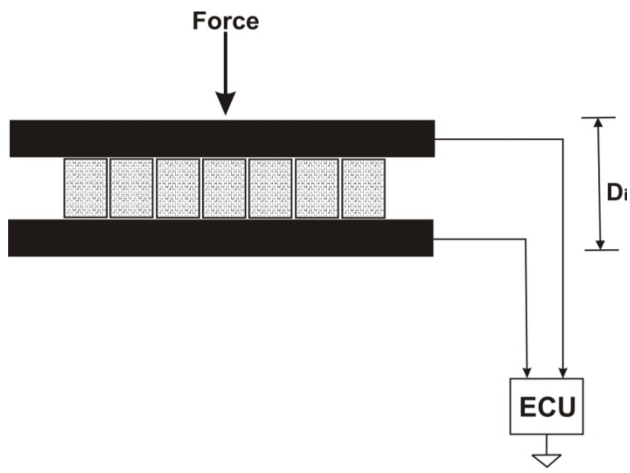
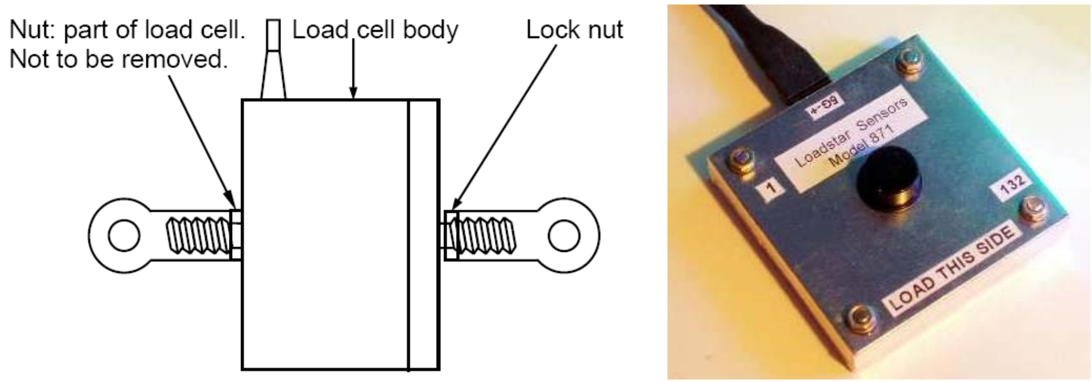


Figure (2.7): Capacitive Sensor

There are many types of capacitive load cells sensors, one type the sensor consists of eight capacitive sensors connected in two full bridges. The capacitive strain gauge sensor structure was designed in order to produce high sensitivity and low dependence with temperature [25].

Figure (2.8) illustrates two different products of capacitive load cells. Figure (2.8a) illustrates a capacitive load cell produced by RDB Electronics Limited with three wires power supply ±15V ±10% at 10mA, the capacity 250, 500 Newton and the resolution limited by electrical noise output (typically 0.01% of full scale) [26]. Figure (2.8b) illustrates a capacitive load cell produced by Loadstar Sensors Company model: 871 measures up to 113 kg. Simply supplying 5 VDC to the load cell, we can read 2000−4000 mVDC output with the voltmeter according to the input load with noise of ±2 mV, enabling 0.1 % sensitivity and 1 % accuracy [27].

From our survey results, we found that the resistive strain gauge sensors are having more accuracy than capacitive strain gauges. Moreover, they are much more popular. Most of our industrial applications in Gaza used the resistive strain gauges. Therefore, our research is focused on that type of strain gauges.



(a) Capacitive load cell form RDB type MC (b) Capacitive LC from Loadstar

Figure (2.8): Capacitive load cells

2.7. Uses of Load Cells

The use of strain gauge load cells in a wide range of weighing applications has grown steadily in the recent years [28]. It is used in retailing scales, postal and shipping scales, crane scales, laboratory scales, onboard weighing for trucks, agriculture and petrochemical applications, in industrial and educational fields, weighing and filling machines and tensile testing machines, medical equipments, force and pressure measurements. Strain gauge applications include thrust measurement on rocket and jet engine test stands, launching pads, and also wind tunnels and other branches of aeronautical research [11].

The weigh and scaling needs in the every day life are very important, so the engineers found many and different digital weighing solutions according to the need of the market. The block diagram of a typical weighing and filling machine is presented in Figure (2.9)**,** and the tensile testing machine is shown in Figure (1.1). GAL PAIL

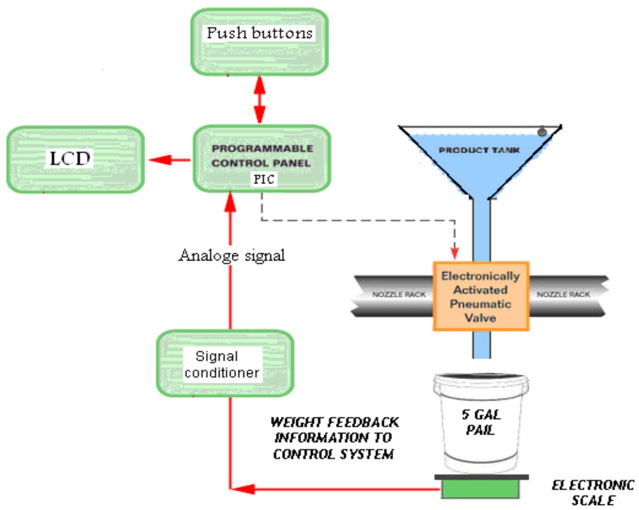


Figure (2.9): Block diagram for the weighing machine

In the industrial field of Gaza Strip, the load cells are mostly used in weighing and filling machines. Filling machines are used in different industrial applications as concrete, flour, nuts, potato chips, and spices industries. Figure (2.10) shows the weighing unit of nuts filling machine widely used in local industry.

Figure (2.10): Nuts and spices filling machine in *Remal* roaster Co.

CHAPTER 3 ANALOG SIGNAL CONDITIONING

For many years, in the local industry, it is dealt with the signal conditioning device for strain gauge sensors as a black-box. It is costly and time consuming to buy and import from abroad, and there are no agencies in Gaza for such devices. In some cases, a foreigner expert must be brought in, to calibrate or repair these devices. In other cases the components were sent abroad to be replaced or repaired. For all of this, this chapter classifies different signal conditioning circuits, which could help for the replacement of these devices. Figure (3.1) illustrates some weighing indicators which are widely used in Gaza [29].

(a) Red Lion product **(b) Shekel product** **(c) Elpack product**

Figure (3.1): Weighing indicators

3.1. Introduction to Amplifiers and Classifications

Before we start dealing with the sensor signal we must:

- Be aware of the characteristics of the signal that is intended to be digitize, such as amplitude, highest frequency component, rising time and etc.
- Choose the data converter that meets the specifications that are most important to us such as static or dynamic specifications, channel count, throughput, power consumption, size and etc.
- Buffer the analog input(s), this presents a stable and known output impedance to the analog to digital (A/D) converter.
- Understand the role that the support circuits can play in achieving optimum performance such as voltage reference, anti-aliasing filter and low-jitter clock.
- Plan PCB fabrication with care such as layout, grounding, shielding and filtering.
- Use the oscilloscope to look at the input and output waveforms.

The output signal from strain gauge sensor, in millivolts, needs amplification, filtering, isolation or other electronic means [8]. There are many types of amplifiers, so we should select the optimal, correct, and suitable type to be used. The amplifiers family classification is illustrated in Figure (3.2) as follows:

- The operational amplifier is one type of differential amplifier.
- The fully differential amplifier is similar to the operational amplifier but with two outputs.
- The instrumentation amplifier is usually built from three op-amps.
- The isolation amplifier is similar to the instrumentation amplifier, but works fine with common-mode voltages that would destroy an ordinary op-amp.
- The negative feedback amplifier also built from one or more op-amps and a resistive feedback network.

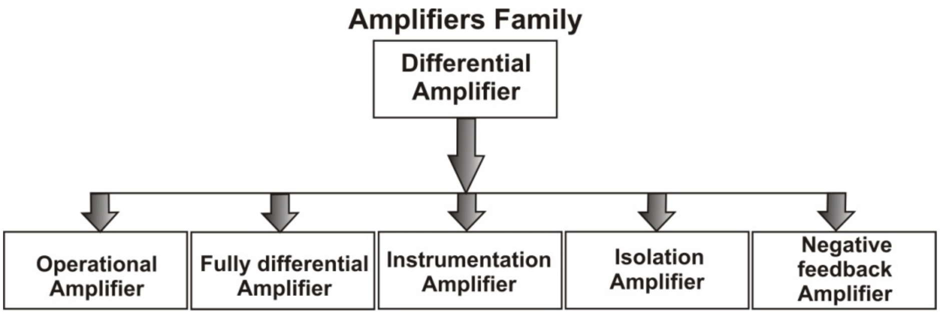


Figure (3.2): Flow chart for amplifiers family

An *operational amplifier* is a DC-coupled high-gain electronic voltage amplifier with a differential input and it is usually a single-ended output. It produces an output voltage that is typically millions of times larger than the voltage difference between its input terminals. Typically, the very large gain of the operational amplifier is controlled by negative feedback, which largely determines the magnitude of its output voltage gain in amplifier applications [30].

A *differential amplifier* is an electronic amplifier that multiplies the difference between two inputs by some constant factor *'Differential gain'*, and its output is given by:

$$V_{out} = A_d (V_{in}^{+} - V_{in}^{-}) + A_{cm} \left(\frac{V_{in}^{+} + V_{in}^{-}}{2} \right), \tag{3.1}$$

where A_d is the differential gain and A_{cm} is the common-mode gain of the amplifier [31]. Differential amplifiers are often used when it is desired to null out noise or bias-voltages that appear at both inputs. A low common mode noise gain is considered good.

The common-mode rejection ratio (CMRR) of a differential amplifier measures the tendency of the device to reject input signals which is common to both input leads. The CMRR is defined as the ratio of powers of the differential gain over the common mode gain, which is measured in positive decibels (thus using the 20 log rule):

$$CMRR = 10\log_{10}\left(\frac{A_d}{A_{cm}}\right)^2 = 20\log_{10}\left(\frac{A_d}{|A_{cm}|}\right) \quad (3.2)$$

As differential gain should exceed common-mode gain, this will be a positive number, and the higher the better.

An *instrumentation amplifier* is a differential circuit, usually a dedicated IC or three operational amplifiers, providing high input impedance with ease of gain variation with a single resistor adjustment. Instrumentation amplifiers are featured with very low noise, very low DC offset, very low drift, very high open loop gain and very high common-mode rejection ratio. The most commonly used instrumentation amplifier circuit is shown in Figure (3.3). The gain of the instrumentation amplifier is given by:

$$G = \frac{V_{out}}{V_2 - V_1} = \left(1 + \frac{2R_1}{R_{gain}}\right)\frac{R_3}{R_2} \quad (3.3)$$

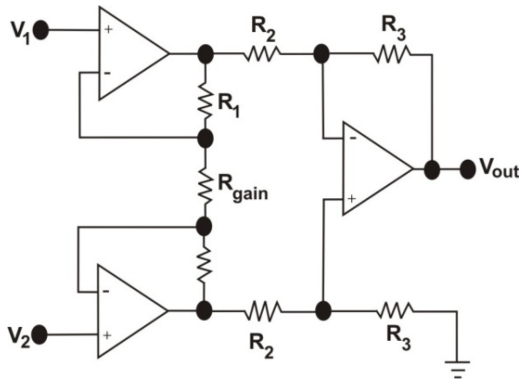


Figure (3.3): Dedicated Instrumentation Amplifier

Figure (3.4) shows another type of instrumentation amplifier circuit that conditions a remote voltage sensor. The input resistors (R_2) provide isolation for the sensor in case of open-circuit failure. The circuit amplifies the input difference voltage between (V_{SEN}^+) and (V_{SEN}^-) and rejects the common mode noise [32].

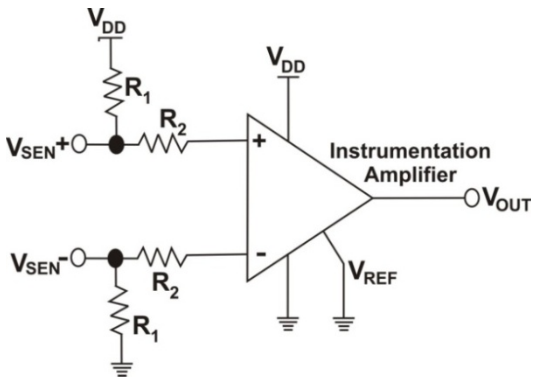


Figure (3.4): Instrumentation amplifier circuit

The instrumentation amplifier illustrated in Figure (3.4) has many *advantages*, like excellent rejection of common mode noise that is large in remote sensors signal. In addition, it provides resistive isolation from any undesired voltage source and makes detection of sensor failure. The *disadvantages* are that it has a resistive load of the source and it may be costly.

3.2. Integrated Circuit Amplifiers

There are many types of amplifiers, but we focus our survey for the most common used amplifiers for signal conditioning of strain gauge sensors that is suitable for our case study as shown in the following subsections.

3.2.1. INA114 Instrumentation Amplifier

INA114 instrumentation amplifier is manufactured by *Texas Instruments* shown in Figure (3.5). It operates with power supplies as low as ±2.25, allowing the use in battery operated. Quiescent current is 3 mA maximum. The Figure illustrates subtraction by means of an instrumentation amplifier circuit. When operating at unity gain, it produces an output voltage equal to the voltage difference between its input terminals (V_{IN}^{+} - V_{IN}^{-}) [9]. The gain is represented as:

$$G = 1 + \frac{50k\Omega}{R_G} \tag{3.4}$$

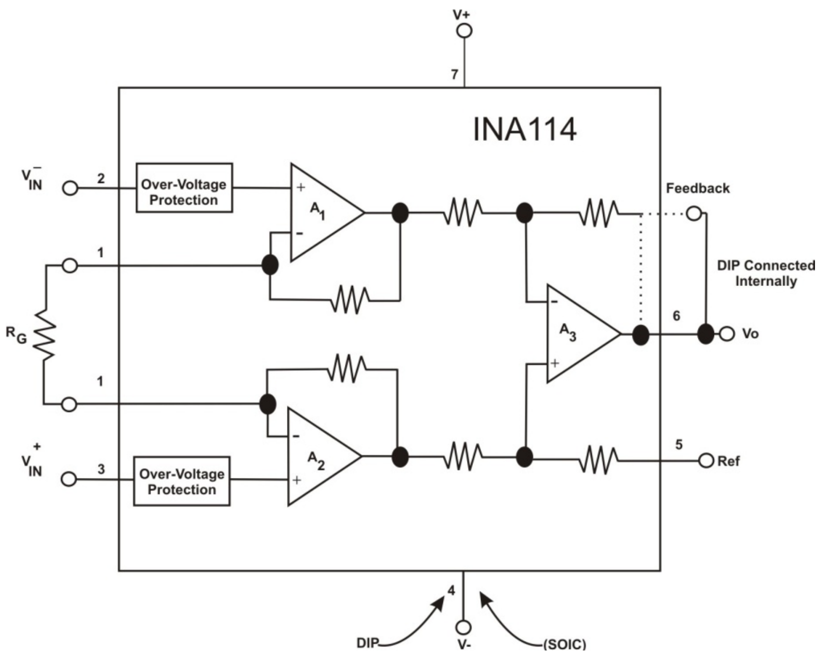


Figure (3.5): INA114 instrumentation amplifier circuit

3.2.2. INA118 Instrumentation Amplifier

INA118 instrumentation amplifier operates with power supplies as low as ±1.35, allowing the use in battery operated. Quiescent current is 350µA maximum. It consists of two parts. The first part is the buffer circuit (one op-amp to buffer each input + and −) that provides a high input impedance which reduce the power of electrodes. The second part is a differential amplifier, which produces desired output. INA118 amplifier also features ease of control over amplification. Amplification factor can be selected by adjusting the value of a single variable gain resistor (R_G) shown in Figure (3.6). Controllable gain of the amplifier is given by:

$$G = 1 + \frac{50k\Omega}{R_G} \tag{3.5}$$

INA118 amplifier has cut-off frequency of 7 kHz. It contains closely matched laser-trimmed resistors and offers excellent common-mode rejection ratio.

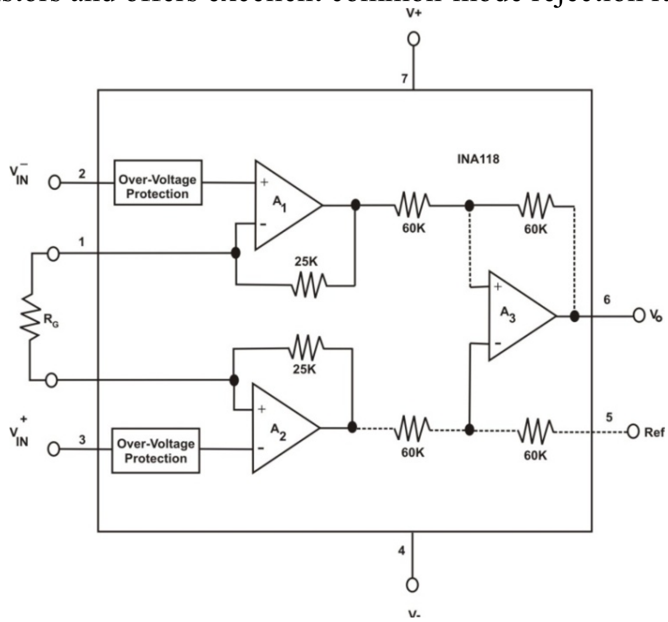


Figure (3.6): INA118 instrumentation amplifier internal design

3.2.3. INA122 Instrumentation Amplifier

INA122 instrumentation amplifier operates with single power supplies from 2.2VDC to 36VDC. Quiescent current is a mere 60µA. Figure (3.7) shows an electrical schematic of the amplifier circuit in conjunction with strain gauge sensors. The four strain gages (SG1 to SG4) are arranged in a "Wheatstone bridge" configuration. The output voltage of the bridge goes to the Vin^+ and Vin^- terminals of the INA122 amplifier chip. The output of the amplifier circuit (V_o and ground) is then connected to an *Analog-to-Digital* (*A/D*) converter (not shown). This particular circuit uses two 9V batteries for the power supplies. The voltage inputs to the INA122 are regulated by +5V and -5V voltage regulators.

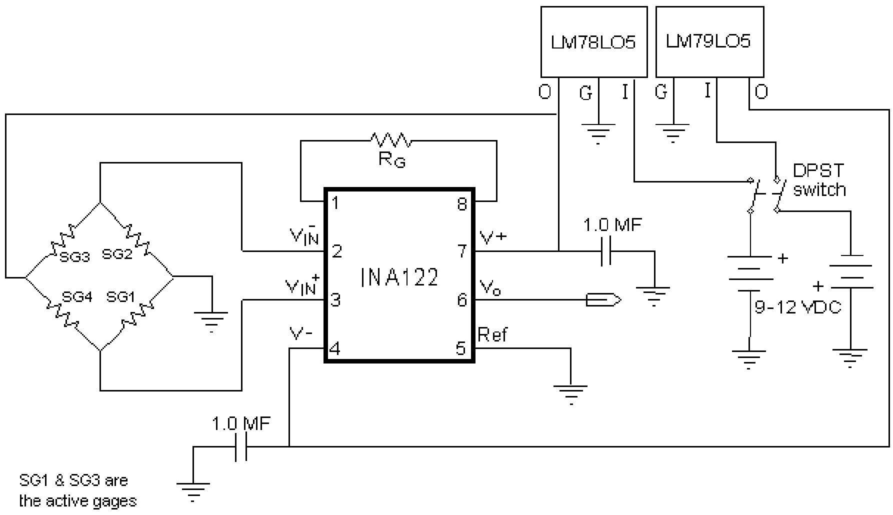
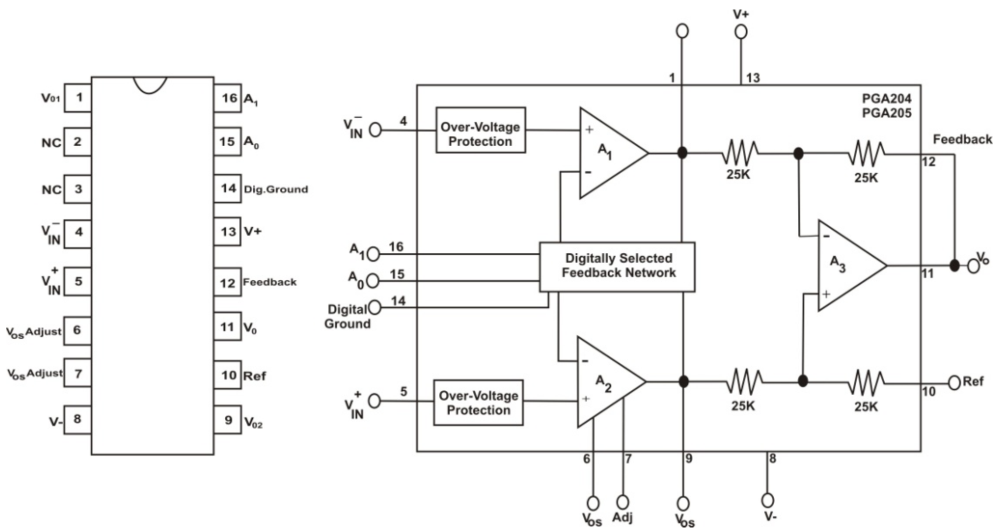


Figure (3.7): INA122 for strain gauge amplifier circuit

3.2.4. PGA204 Programmable Gain Instrumentation Amplifier

The PGA204 programmable gain instrumentation amplifier manufactured by *Burr-Brown Corporation* is low cost, general purpose programmable gain instrumentation amplifier offering excellent accuracy. Gains are digitally selected to 1, 10, 100 and 1000 V/V. The precision, versatility and low cost of the PGA204 make it ideal for wide range of applications. It operates with power supply as low as ±4.5V, allowing use in battery operated system. PGA204 is available in 16-pin plastic dual in-line package (DIP), the pin configuration and internal circuit diagram are illustrated in Figure (3.8a) and (3.8b) respectively [33].



(a) PIN configuration **(b) PGA204, 205 internal circuit diagram**

Figure (3.8): PGA204, 205 PIN configuration and circuit diagram

3.2.5. PGA205 Programmable Gain Instrumentation Amplifier

The PGA205 programmable gain instrumentation amplifier with a gain digitally selected to 1, 2, 4 and 8 V/V. Gain is selected by two TTL or CMOS-compatible address lines A_0 and A_1. Internal input protection can withstand up to ±40V on the analog inputs without damage [34].

3.2.6. AD521 Instrumentation Amplifier

Figure (3.9) shows an AD521 instrumentation amplifier connected to a bridge arrangement of a strain gauge, it is a low cost monolithic IC developed by *Analog Devices Company*. The AD521 is a *gain block* with differential inputs and an accurately input/output gain relationship, it has a tuning gains from 0.1 to 1000, complete input protection for power ON and power OFF and very low internal component noise 0.5 µV peak to peak [35].

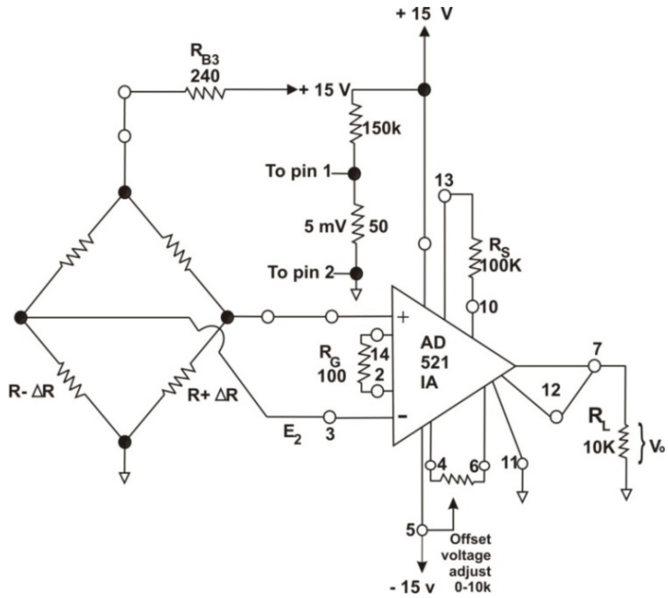


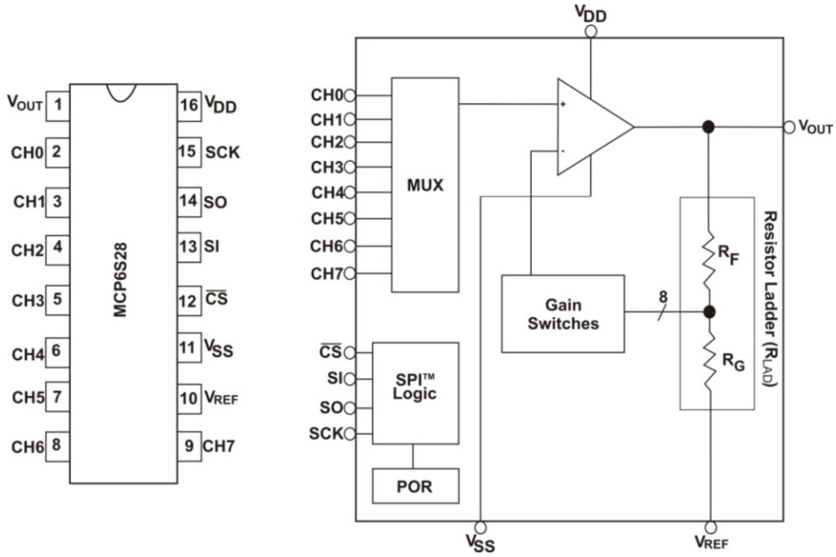
Figure (3.9): The AD521 instrumentation amplifier

3.2.7. MCP6S28 Low Gain Programmable Gain Amplifier (PGA)

The programmable gain amplifier (PGA) used to condition multiple sensors. The PGA allows the user to select an input sensor and gain with the Serial Peripheral Interface (SPI) bus. It can also help to linearize non-linear sensors (e.g. a thermistor). It has 8 gain selections 1, 2, 4, 5, 8, 10, 16 and 32. The input multiplexer can select one of up to eight channels through an SPI port. The pin configuration is shown in Figure (3.10a), and the internal circuit diagram is shown in Figure (3.10b).

Advantages: Multiple sensors (input MUX), CMOS input (high impedance and low bias current), digital control (SPI) of input and gain and linearization of non-linear sources.

Disadvantages: Input stage distortion, amplifies common mode noise and needs microcontroller unit (MCU) and firmware [32].



(a) MCP pin configuration **(b) MCP Block diagram**

Figure (3.10): Programmable gain amplifier

There are many other types of instrumentation amplifiers, but it is not suitable for our applications. Example, The CLC430 is a low cost, wideband monolithic amplifier for general purpose applications produced by *National Semiconductor Company*. It has a high bandwidth 20-100 MHz operational amplifier. It is general purpose current feedback amplifier shown on Figure (3.11), and its gains are represented by:

$$\text{Non Inverting Gain} = 1+\frac{R_f}{R_g} \tag{3.6}$$

$$\text{Inverting Gain} = -\frac{R_f}{R_g} \tag{3.7}$$

Gain for this amplifier is low ranging from 1 to 2 suitable for video signals.

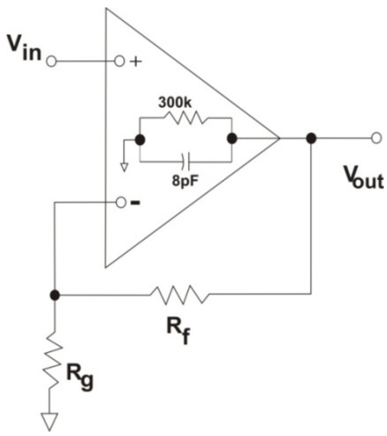


Figure (3.11): CLC430 operational amplifier circuit

3.2.8. Comparison Summary

Some laboratory experimentation is made on the commonly used integrated circuit amplifiers under consideration. Using the data sheets available and the results of these experiments we could summarize the main characteristics of the amplifiers in Table (3.1).

Table (3.1): Survey summery of commercial integrated circuit amplifiers.

Model	Voltage Gain	Remarks
INA114	1-10000	• Gain is set using a variable resistor (R_{min}=5 Ω). • Over voltage protection up to ±40 V. • Cut off frequency of 100 kHz.
INA118	1-1000	• Precision, Low Power. • Gain is set using a variable resistor (R_{min}=50 Ω). • Over voltage protection up to ±40 V. • Cut off frequency of 7 kHz.
INA122	5-10000	• Low quiescent current 60 μA. • Gain is set using a variable resistor (R_{min}=20 Ω). • Wide power supply range. • Single Supply: 2.2V to 36V. • Dual Supply: –0.9/+1.3V to ±18V.
PGA204	1, 10, 100, 1000	• Gain is digitally selected. • Low cost and available in local market. • Excellent accuracy. • Ideal for our application. • Battery operated system.
PGA205	1, 2, 4, 8	• Gain is digitally selected. • Low cost and available in local market. • Excellent accuracy. • Ideal for wide range of applications. • Battery operated system.
AD521	0.1-1000	• The instrumentation can be calibrated. • Gain is set using a variable resistor (R_{min}=100 Ω). • Not recommended for new designs.
AD620	1 – 10000	• Low cost • Gain is set using a variable resistor (R_{min}=100 Ω).
MCB6S28	1,2,4,5,8,10,16,32	• Multiplexed inputs: 1, 2, 6 or 8 channels • Low gain programmable gain amplifier • Inputs and Gain is adjusted through SPI port

We converged on the instrumentation amplifier integrated circuit (PGA204) from *Burr-Brown Corporation* to be the core of a signal conditioning circuit for our strain gauge sensor. It is a low cost, general purpose programmable-gain instrumentation amplifier offering excellent accuracy. Gain is digitally selected (1, 10, 100 and 1000 V/V) by two TTL address lines. It has low offset voltage about 50 μV maximum.

3.3. Experimental Work for Designing a Weighing Indicator Using PGA204

In this experimental work, we design a weighing indicator to measure the weight of the load until 3 kg. A strain gauge (load cell) from *Tedea Company* shown in Figure (3.12) is connected to a signal conditioning (PCB1) which connected to a microcontroller and graphical liquid crystal display (GLCD) mounted on (PCB2).

Figure (3.12): Strain gauge (load cell) from *TEDEA* company

The load cell model No. 240 is a fluid damped to overcome the movement vibrations, designed especially for the industrial environment. The excitation of the strain gauge sensor (Load Cell) must be a very precise and stable voltage source around 10 volts. Standard voltage regulators (such as LM7810) are unsuitable as they may have some voltage drop. Therefore, we designed a 10 V zener diode regulator circuit for this purpose.

3.3.1. PCB1 Design for Signal Conditioning

PCB1 is the first printed circuit board designed during this research. It contains the signal conditioner PGA204 that amplifies the signal from the strain gauge 1000 times. At the output stage, a simple RC filter was implemented to suppress any possible high frequency noise. The signal conditioning circuit diagram along with its layout and implementation are shown in Figures (3.13, 3.14, 3.15) respectively. The implemented board was just for experimentation purposes. Later in this work (chapter 5), it will be integrated within a larger printed circuit for the tensile testing machine containing regulated power supplies, a microcontroller (MCU), optical encoder interface, a Liquid Crystal Display (LCD), and other components.

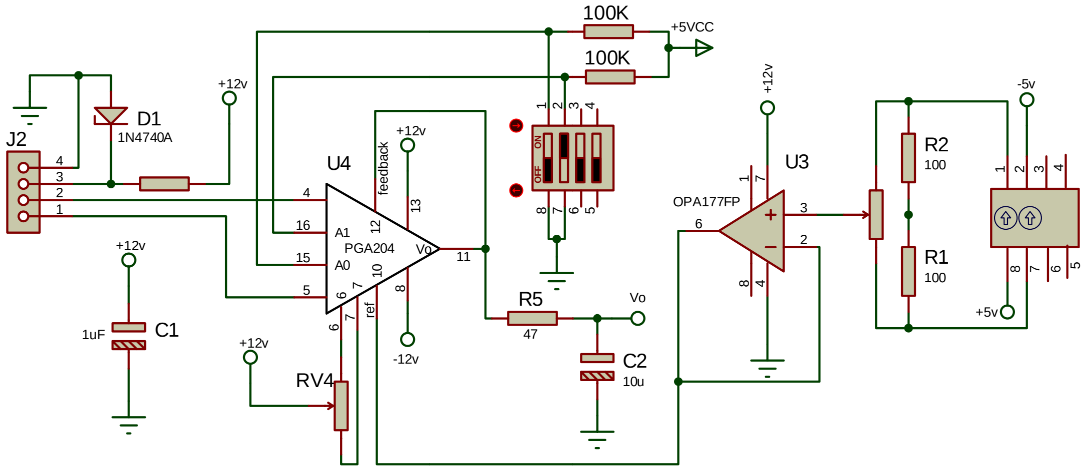


Figure (3.13): Schematic circuit diagram

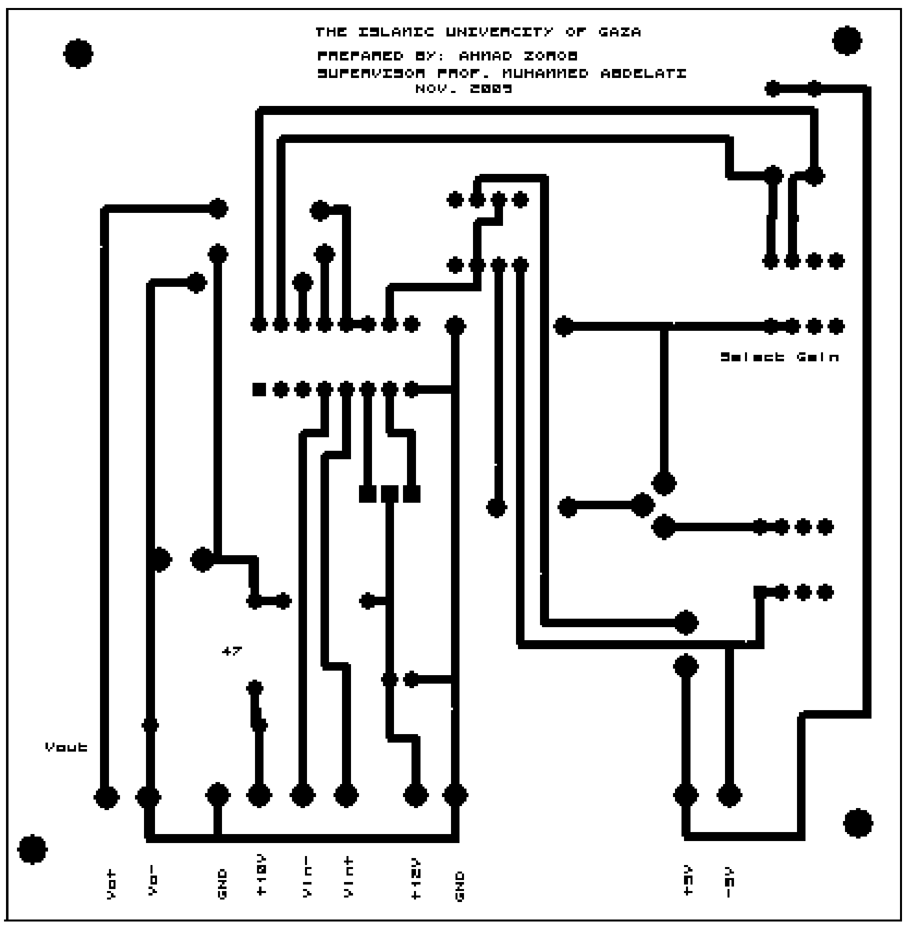


Figure (3.14): Printed Circuit layout

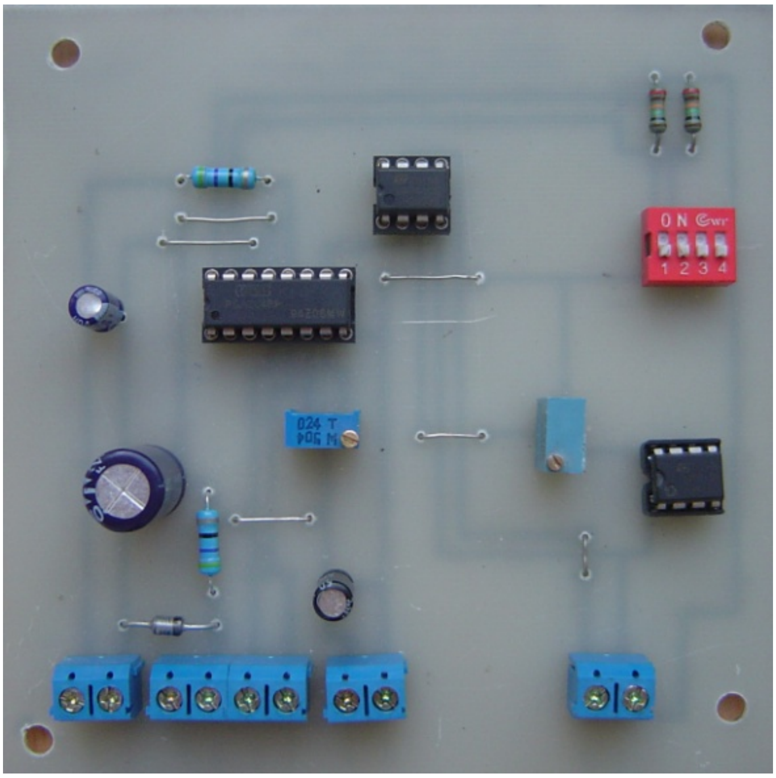


Figure (3.15): The implemented signal conditioning PCB

3.3.2. Analog Signal Filtering

Filtering is the process by which the essential and useful part of a signal, is separated from extraneous and undesirable components that are generally referred to as a noise. Noise refers to either the undesired part of the signal, as in the case of amplitude modulation [36], or undesirable but inevitable interference signals generated by the electronic devices and components. The shorter interconnection from sensor to signal conditioner is less likely to pick up noise, and the high-level output signal offers better immunity against induced pickup from natural or man-made sources. Instrumentation amplifier must feature very low noise like all the components of the designed system [37].

Noise sources can be classified as follows:

- Interference noise from external sources which is not easily controlled.
- Inherent noise such as thermal noise, operational amplifier noise, quantization noise and aperture noise.

Any noise component with a frequency higher than (Example 32 Hz) is cut using low pass filter. With cut off frequency fc = 32 Hz, a passive filter shown in Figure (3.16) is used with R = 5 kΩ and C = 1 μf to meet the cut off frequency.

$$f_c = \frac{1}{2\pi RC} = 32 \text{ Hz} \tag{3.8}$$

Practically, the range of the frequencies of the signal at the LPF output was 32 Hz and the signal vanished at the higher frequencies.

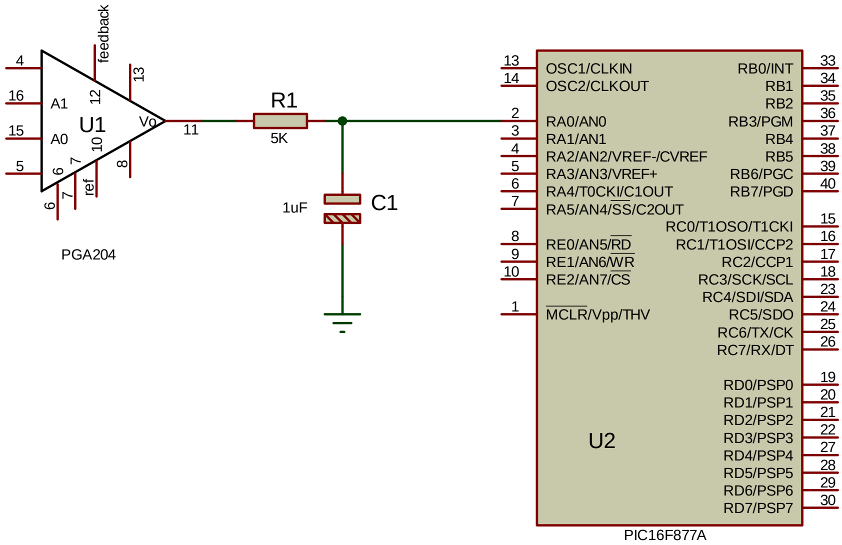


Figure (3.16): Instrumentation amplifier and LPF design

3.3.3. PCB2 Design for Microcontroller and GLCD

PCB2 is the second printed circuit board which has been developed. In this board the amplified analog signal was converted to digital signal using microcontroller PIC16F877A, then measured, calibrated and displayed. A graphical liquid crystal display (GLCD) is used to monitor the weight of the load in grams. The circuit diagram along with its layout and implementation are shown in Figures (3.17, 3.18, 3.19) respectively.

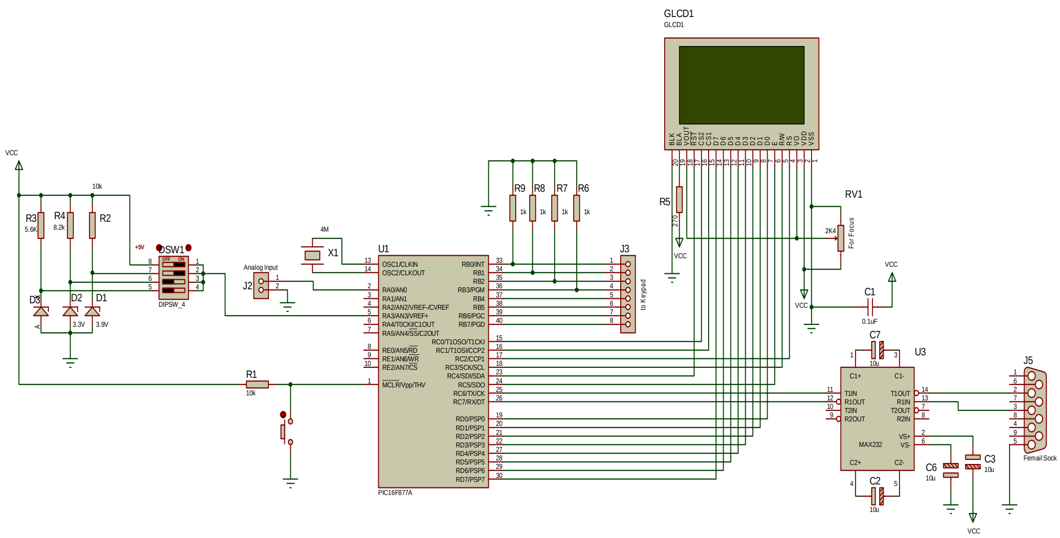


Figure (3.17): Schematic circuit diagram

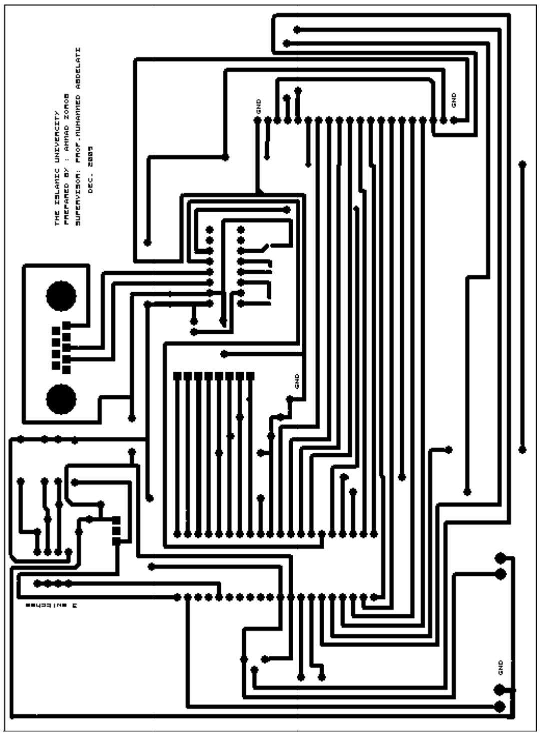


Figure (3.18): Printed circuit layout

Figure (3.19): The implemented signal conditioning circuit (PCB2)

Figure (3.20) shows the working stages for the designed weighing indicator that can be used for many applications. The MicroC program is imbedded inside the microcontroller. This program is required for the system operation and presented in appendix A. The MicroC code for moving window average filter is illustrated in Figure (3.21). This filter takes 10 consecutive readings and calculates the average to be displayed on the GLCD.

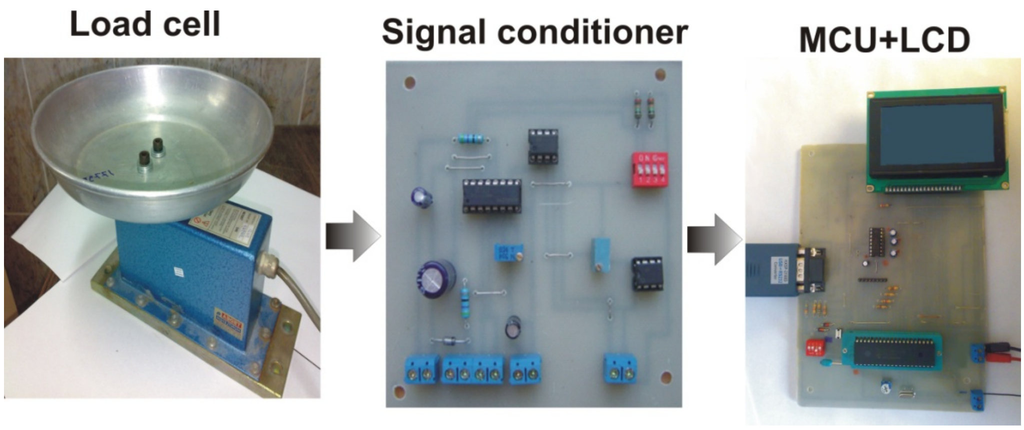


Figure (3.20): Weighing indicator system

```
Make a loop to take 10 different readings
{
Digital_Value  = The digital reading from the ADC;
                         //   The reading is  =10 bit
The reading= 2.823*Digital_Value/1023.0;

//############# Moving window Average filter##################
Reading No.10= Reading No.9;
                 // The Reading is the integer value of the weight
Reading No.9 = Reading No.8;
Reading No.8 = Reading No.7;
Reading No.7 = Reading No.6;
Reading No.6 = Reading No.5;
Reading No.5 = Reading No.4;
Reading No.4 = Reading No.3;
Reading No.3 = Reading No.2;
Reading No.2 = Reading No.1;
Reading No.1 = Reading No.0;

}
Average Reading = (Reading No.0+Reading No.1+……..…Reading No.9)/10;

//############################################################
```

Figure (3.21): MicroC code for moving window average filter

The main results of this experiment; the accuracy of this measurement system is the degree of closeness of measurements of a quantity to its actual (true) value was found 0.1 %.

3.4. Load Cells with Embedded Signal Conditioning Circuit

3.4.1. The iLoad Analog

The *iLoad* analog which is shown in Figure (3.22), is a series of load cells integrates signal conditioning electronics into the load cell, eliminating the need to attach any external equipment to use the sensor. The small size, ruggedness, and low power requirements of the *iLoad Analog Series* makes it an ideal choice for a wide range of applications. The *iLoad* analog load cell has signal conditioning electronics built into the sensor itself, and does not need specialized external equipment for output measurement. The sensor itself is thin and provides high reliability as well as space-saving benefits to manufacturers. It mounts easily on commonly available fixtures.

The sensor accepts a 5 VDC input signal and output is a linear analog 0.5 to 4.5 VDC signal proportional to the applied load. The full-scale output range is 4,000 mV. This signal can be easily measured using commonly available *Digital Multi-meters* or with programmable logic controller (PLC) [38].

Unfortunately, those load cells with embedded signal conditioning circuits are of compression type. Therefore, they are not suitable for our applications. We need S-beam type load cell for our material testing machine application.

Figure (3.22): iLoad analog load cell

3.4.2. Honeywell Load Cell with Internal Amplifier

The *Honeywell* model 41 shown in Figure (3.23) is a high precision low-profile load cell with internal amplifier. These bonded foil, strain gage load cells are engineered to measure a wide range of loads. It has the following features:

- 0.1 % accuracy.
- 2.27 to 227000 Kg range of measurement.
- mV/V output (standard); 0 to 5 VDC.
- Certificate for the product (CE) approved.
- Double diaphragm design and intrinsically safe available [39].

Figure (3.23): Honeywell load cell

CHAPTER 4 DIGITAL LOAD CELLS

4.1. Digital Processing for Sensor's Output

Digital techniques have become more and more popular in processing sensors outputs in data acquisition, process control and measurement. Digital signal processing (DSP) is a technique that converts signals from real world sources (usually in analog form) into digital data that can then be analyzed. Analysis is performed in digital form because once a signal has been reduced to numbers; its components can be isolated, analyzed and rearranged more easily than in an analog form.

Eventually, when the DSP has finished its work, the digital data can be turned back into an analog signal, with improved quality as shown in Figure (4.1). For example, by DSP, we can filter noise from a signal, remove interference, amplify frequencies and suppress others, encrypt information, or analyze a complex waveform into its spectral components.

Figure (4.1): Digital signal processing

Reasons to go digital:

- Flexibility: can easily change, modify and upgrade through software.
- Perfect reproducibility: Identical performance from unit to unit is obtained since there are no variations due to component tolerance. For example, using DSP techniques, a digital recording can be copied or reproduced several times without any degradation in the signal quality.
- Reliability: For signal storage application, memory and logic do not slowly 'go bad' with time and\or not affected by temperature.
- Complexity: complex algorithms can be implemented on lightweight and low power portable devices.
- Suitable for some algorithms, which can only be done in the digital domain: linear phase filters, adaptive filters, data compression, and error correcting codes.
- Low overall cost.

An 8-bit microcontroller generally has sufficient speed and processing capability for most applications. By including A/D conversion and the microcontroller programmability on the sensor itself, a "smart sensor" can be implemented with self-contained calibration and linearization features as shown in Figure (4.2).

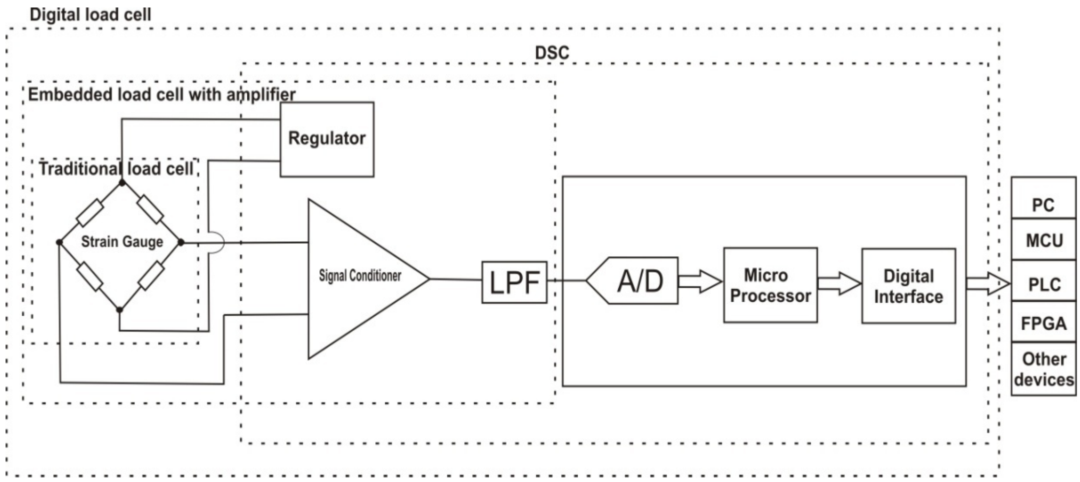


Figure (4.2): Block diagram for DSP for strain gauge O/P

4.2. Tedea Digital Load Cells

Using digital load cells from *Tedea Company* model 204D, a typical digital weighing system results. Installation will consist of a host device (e.g. PC, digital indicator, PLC) and additional load cells connected over a single cable as illustrated in Figure (4.3). Over this connection, commands are issued by the host and the load cells respond with readings and status information. It has the following specifications:

- Fully calibrated and filtered digital output.
- High A/D update rates adjustable from 50 to 800 sample readings per second.
- Host communications interface RS232/485 [4.8 to 11.5 kbaud] using ASCII protocol.
- Many Load cells can be connected through one cable.

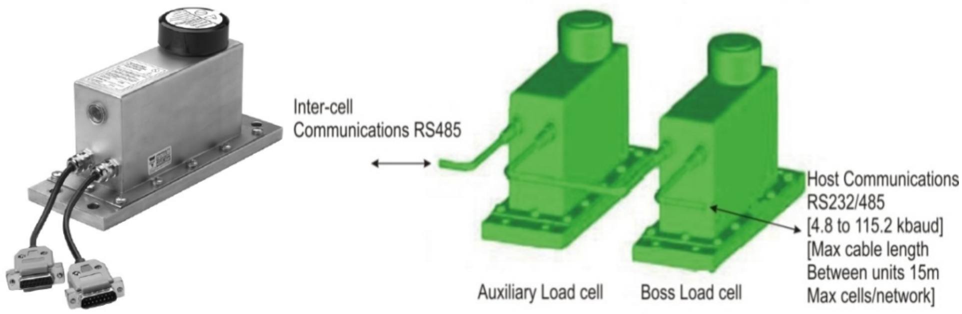


Figure (4.3): Digital load cell from TEDEA Company model 240D

It was ordered with a price arround 1500 US$ but unfortunately, we could not get it in due to the siege imposed on Gaza.

4.3. Digital Strain Gauge to Data Converter (DSC)

The digital strain gauge to data converter (DSC) shown in Figure (4.4) and Figure (4.6) are high performance digital signal conditioners with a host of additional features for the precision measurement of a strain gauge based transducer. The DSC is available with RS232 or RS485 output format making it suitable for "one-to-one" or multi-drop systems. Including the DSC into the load cell based applications enable the building of very high accuracy load cells, using the built in linearization and temperature compensation facility as shown later in our experimental work.

The DSC has a high speed to 500 readings/second, very high stability, noise immunity 5x heavy industrial level, real mV/V calibration, diagnostics light emitting diodes (LEDs), programmable dynamic filter, peak and trough recording, and operating voltage (5.6 - 18VDC) [40].

4.3.1. Experimental Work on the Digital Strain Gauge to Data Converter (DSCS2ASC)

Figure (4.4): The digital strain gauge to data converter with an RS232 output

The digital strain gauge to data converter industrial stability with an RS232 output using ASCII protocol (DSCS2ASC) shown in Figure (4.4) has 18-bit resolution accuracy. It can be easily mounted on a locally designed PCB3. The designed board has connectors for power supply unit ±10 VDC, connectors for the external load cell, connectors for RS485, and a 9 pin special serial connector for RS232. It is shown in Figure (4.5). The header pins of DSCS2ASC are plugged into connectors of the PCB3. Using the instrumentation explorer computer program, we could measure the weight of load on the computer screen after a suitable and precise calibration of the load cell. Calibration is a very easy process using this program. The RS232 output is simpler to be used because our system contains only one load cell and one DSCS2ASC.

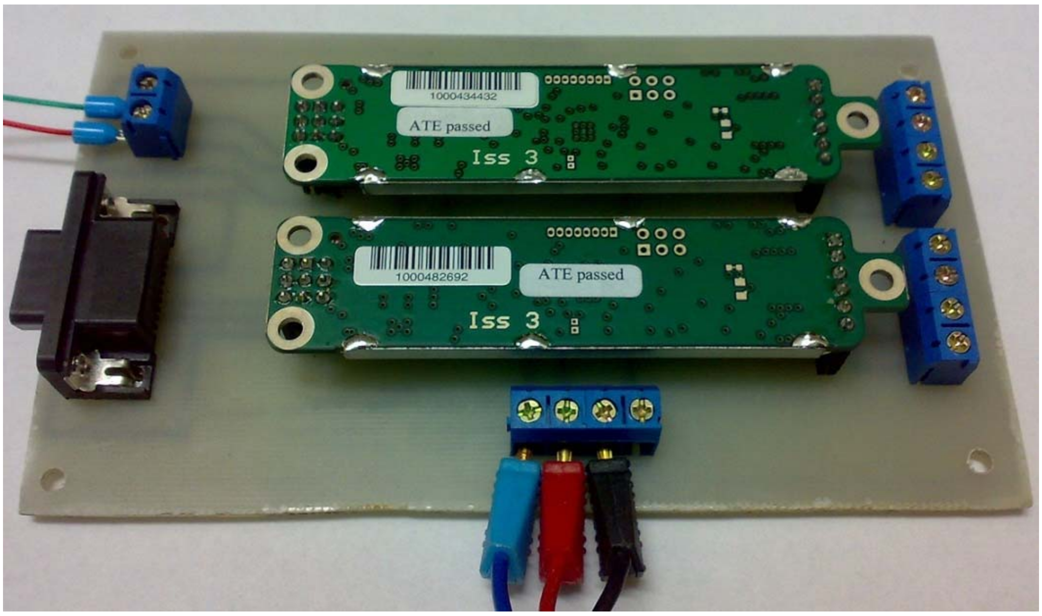


Figure (4.5): BCB3 for DSCS2ASC and DSCS4ASC

4.3.2. Experimental Work on The Digital Strain Gauge to Data Converter DSCS4ASC

The digital strain gauge to data converter industrial stability using RS485 output and ASCII protocol (DSC4ASC), is illustrated in Figure (4.6). It has the same features as DSC2ASC, but its output is RS485 connected to special converter *Delta* type. It converts the output from RS484 to USB, then to the computer to measure the load from the connected load cell as illustrated in the block diagram of Figure (4.7).

Figure (4.6): The digital strain gage to data converter RS485

The DSCS4ASC products are miniature, high-precision strain gauge converters, converting a strain gauge sensor input to a digital output. They allow multiple high precision measurements to be made over a low-cost link. Outputs can be accessed directly by PLCs or computers, or connected via various types of network, telephone or radio modem, all without compromising accuracy. The device addressing allows up to 253 devices with 253 load cells (multi-channel) on a single bus, drastically reducing cabling cost and complexity.

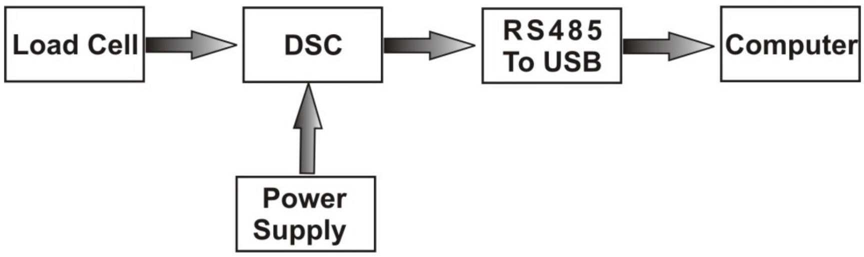


Figure (4.7): The digital strain gage to data converter working method

4.4. The iLoad Digital

The *iLoad* Digital USB load cell which is shown in Figure (4.8) and produced by *Loadstar Company* offers a direct measurement of loads via the USB port of a PC. Just connect and start measuring. It provides unprecedented integration of sensing and measurement electronics to provide sense simplicity for load and force measurements.

Figure (4.8): Digital load cell, iLoad USB

The *iLoad* has the following features:

- Precise: Accuracies from 1% to 0.15% of full scale.
- True USB: No need for signal conditioning or data acquisition system or special software.
- Rugged: Stainless steel construction and environmentally protected.
- Plug and sense simplicity.

Simply connect the digital load cell to a PC via the USB port. The digital load cell appears on the PC as a virtual COM port. Using a standard terminal emulator, commands are sent to the sensor to display loads on screen. They can either be one at a time or in continuous operation mode [41].

CHAPTER 5 REHABILITATION OF TENSILE TESTING MACHINE

Before making rehabilitation for the damaged *tensile testing machine*, a survey was made to know how the machine works, the internal components such as the DC motor and the encoder characteristics, load cell capacity and specifications, and every available parts of the machine. With the help of machine's operator engineers and the information from the datasheet, we could understand the working principle of the machine.

The plan for the rehabilitation of the machine was started by designing a block diagram shown in Figure (5.1). It presents that the weak output signal from the strain gauge sensor need to be amplified by the signal conditioner circuit then digitized by means of an analog to digital A/D converter using a microcontroller PIC 16F877A to present the force and deformation of the tested materials on LCD.

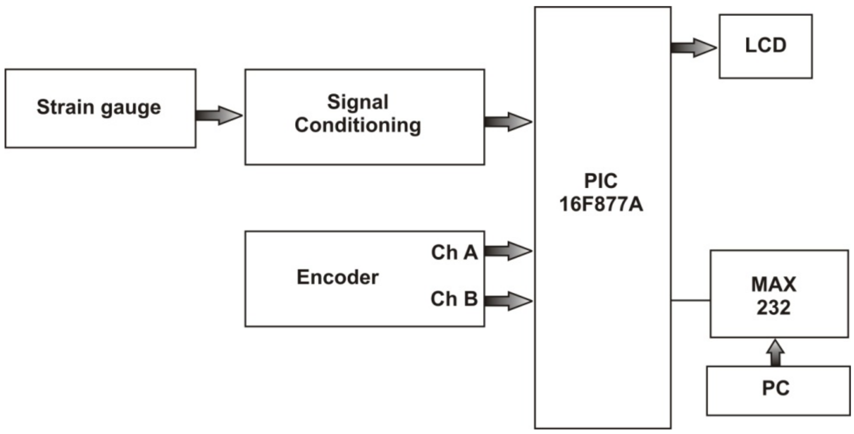


Figure (5.1): Block for designing tensile testing machine F and D measurements

5.1. Direction and Speed Control

The control system may be partitioned to two subsystems as illustrated in Figure (5.2). The lower subsystem is responsible for adjusting the direction and speed of the DC motor. On the other hand, the upper subsystem is responsible for acquisitioning the force and displacement values via the strain gauge and optical encoder respectively.

Moreover, it is responsible for blocking the DC motor in case of excess tension in order to protect the strain gauge against mechanical damage. If the force exceeds 7000 Newton, the *enable* signal from the microcontroller will not allow the operation for the DC motor controller circuit.

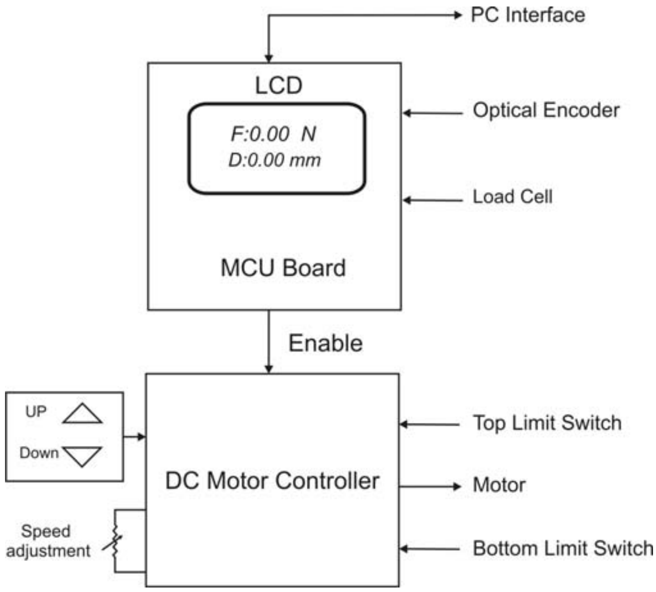


Figure (5.2): Decomposing the controller into two subsystems

The direction and speed controller circuit is shown in Figure (5.3). It is a standard H-bridge relay circuit with a variable DC supply based on SC141D Triac [42]. The circuit consists of the following main parts:

- Fuse 3 amperes and indicator lamp 220 VAC.
- Top and bottom limit switches to protect the motor and the load cell from excessive loads as shown in chapter 1.
- Two electromagnetic relays served as electrical operated switches each having two moving contacts, these four contacts are connected in H-bridge form. The H-bridge circuit enables a voltage to be applied across a load (motor) in either direction. This circuit allows DC motor to run forwards and back words.
- DC permanent magnet DC motor model S663 is used for moving the crosshead to perform the test.
- Dimmer circuit consists of Diac, Triac, variable resistance, resistance, and capacitor to control the AC voltage supply to the transformer from 0−230VAC.
- Transformer 220/35 VAC which supplies a voltage to the bridge rectifier.
- Two push buttons, up and down to control the direction of rotation (clockwise or counterclockwise) of the motor, which controls the direction of the moving crosshead (up or down).

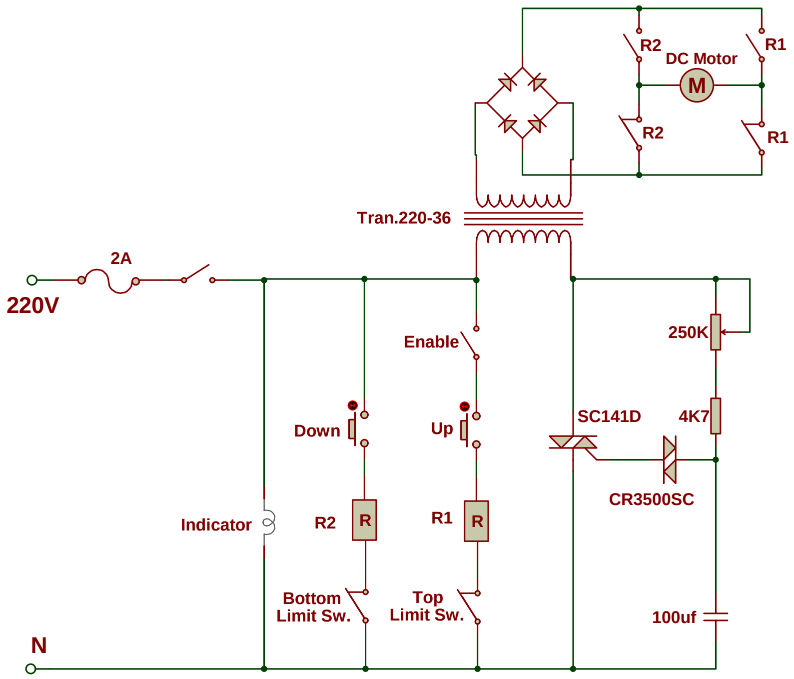


Figure (5.3): Direction and speed controller circuit.

5.2. Force and Deformation Measurement

The force and displacement acquisition unit is designed using a PIC16F877A microcontroller. It features 256 bytes of EEPROM data memory, self-programming, eight channels of 10-bit Analog-to-Digital (A/D) converter, and a *Universal Asynchronous Receiver Transmitter* (USART). All of these features make it ideal for more advanced level A/D applications in automotive, industrial, appliances and consumer applications [14].

We could measure online the peak load and the deformation of the tested material till it breaks down. We have built an active force and elongation displacement parameters readings on LCD, and a protection for the system from extreme force over 7000 Newton.

5.2.1. Hardware implementation

The electronic circuit diagram was designed, simulated using PROTEUS computer program as illustrated in Figure (5.4). We integrate the power regulators (+12V, +10V, −12V, +5V), signal conditioner (PGA204), RC filter, microcontroller, encoder interface and LCD, all in one printed circuit board (PCB3). The DC power supply circuit consists of a 220/12 volts center tapped transformer connected to the bridge rectifier. The bridge connected to two large filter capacitors 2200 μf before the +12 VDC regulator LM7812 and the −12 VDC regulator LM7912.

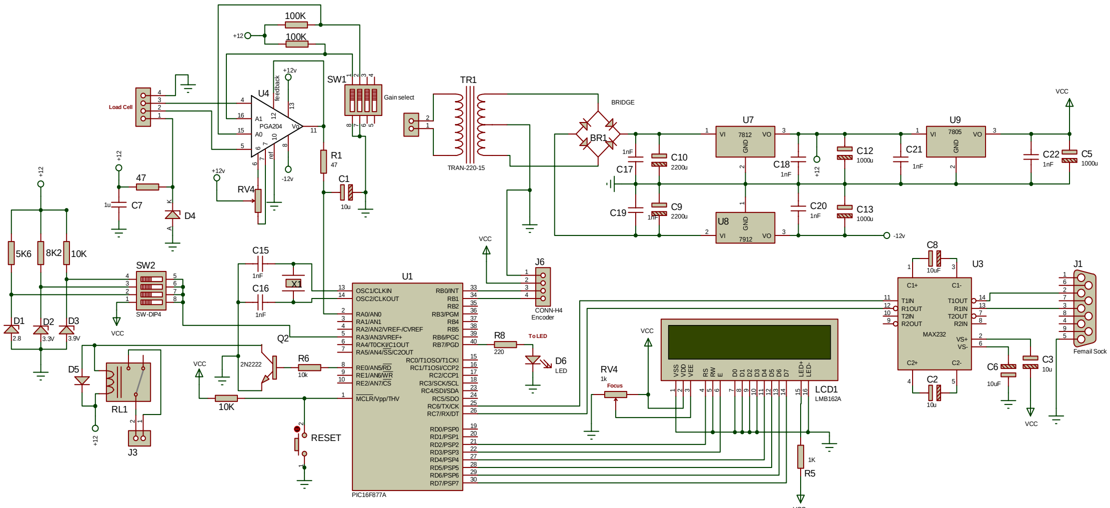


Figure (5.4): Schematic for the force and displacement acquisition unit.

An optical encoder from *Heidenhain* company model number ROD 426 is basically an instrumented mechanical light chopper. It produces a certain number of square pulses for each shaft resolution. Figure (5.5) depicts a 1000 pulse resolution for this optical encoder and its internal structure.

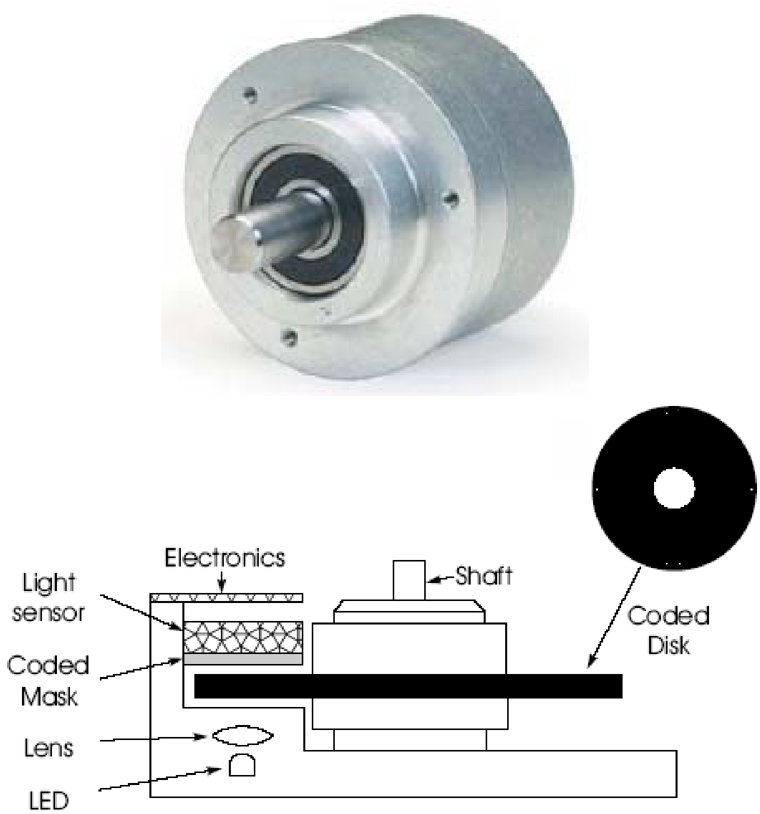


Figure (5.5): Optical encoder for the tensile testing machine

Single channel type encoder has one output only while phase quadrature type has two channels whose pulse trains are 90 degrees out of phase as illustrated in Figure (5.6). Unlike single channel encoders, the phase-quadrature encoders are able to detect the direction of the rotation. A microcontroller circuit determines which channel is leading the other and hence ascertains the direction of rotation. In order to provide a reference for the angular position information, most encoders incorporate an index output that goes high once for each complete revolution of the shaft.

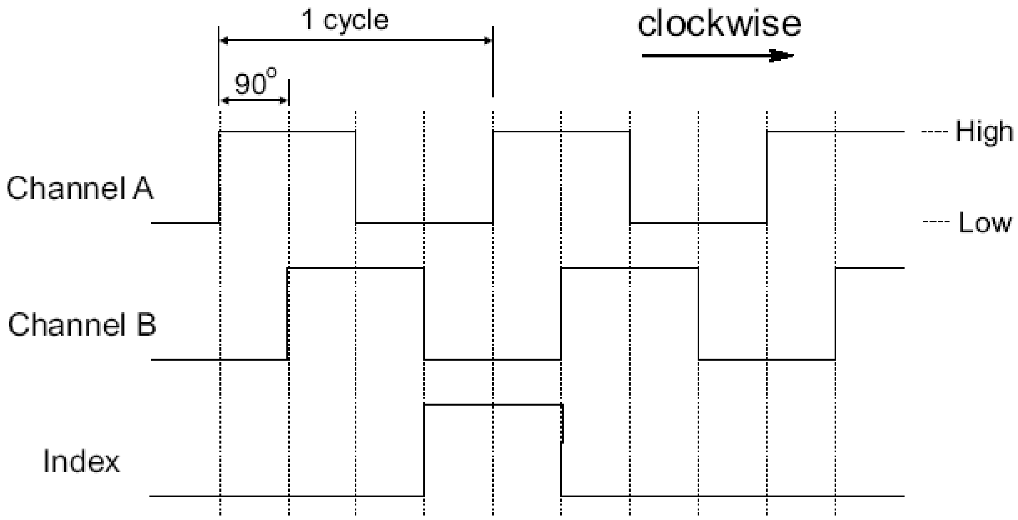


Figure (5.6): Encoder output wave forms

PIC microprocessors made by microchip, called peripheral interface controllers, are increasingly popular for developing inexpensive and reliable mechatronic systems. The microcontroller has analog-to-digital (A/D) and digital-to-analog (D/A) converters provide the link between the analog world of transducers and the digital world of signal processing, computing, digital data collection, data storage on magnetic material or optical disks and data processing systems.

The design features a selectable precise reference voltage for the A/D converters of the microcontroller. Moreover, the MCU is loaded with a boot loader in order to allow in-circuit programming of the MCU via the USART port [43].

The LCD displays the values of the desired input signal from the strain gauge sensor (Force in Newton) and the deformation distance of the material in millimeter. The layout of the designed PCB and the manufactured one are shown in Figures (5.7, 5.8) respectively.

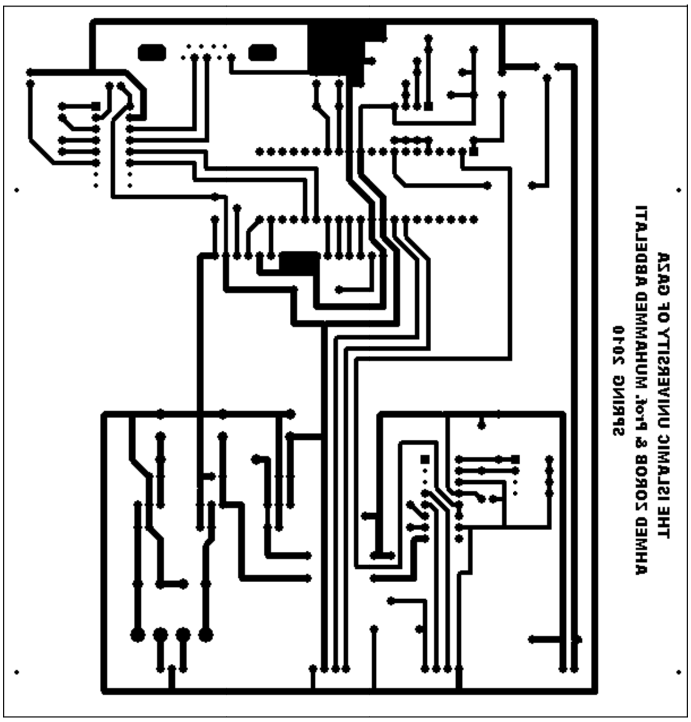


Figure (5.7): The MCU board layout

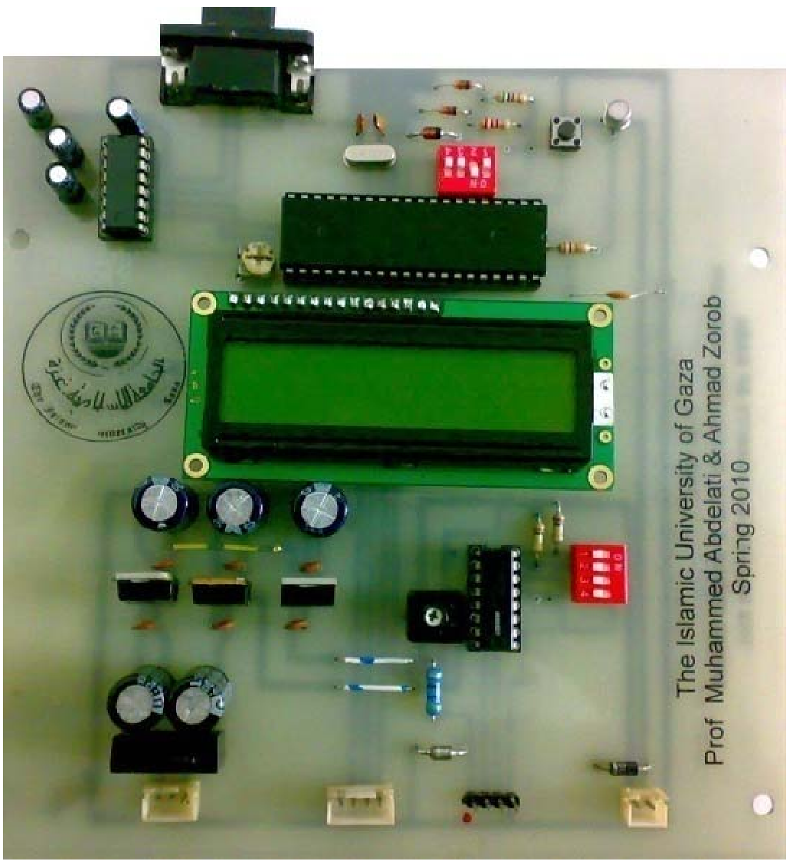


Figure (5.8): The Manufactured MCU board

5.2.2. Software Implementation

The sensors need to have their output signals amplified and then digitized by means of an A/D converter. To adapt the analog signal to the range of expected amplitude at the input of the A/D converter, a signal conditioner is used. In most of the digital systems, there is a frequent need to convert analog signals generated by peripheral devices such as strain gauge sensors, temperature sensors, microphones, analog cameras, and etc. into digital values that can be stored and processed. There are various types of A/D converters: high speed ones, precise ones, and commercial ones and so on. Most of them can be directly connected to any processor [44].

The basic A/D conversion blocks are sampler, quantizer and coder as illustrated in Figure (5.9).

- The sampler samples the signal into a defined rate of digital values. The rate of new values is called sampling rate or sampling frequency of the converter.

- The quantizer makes all signal levels represented using *n*-bit binary number via rounding or truncation. Increasing *n* decreases the quantization error size and increases the complexity and cost of the A/D converter. Cheep converters have 8 or 10 bits while professional converters have more than 16 or 20 bits.
- The encoder encodes the measurement in a convenient format for communication or processing.

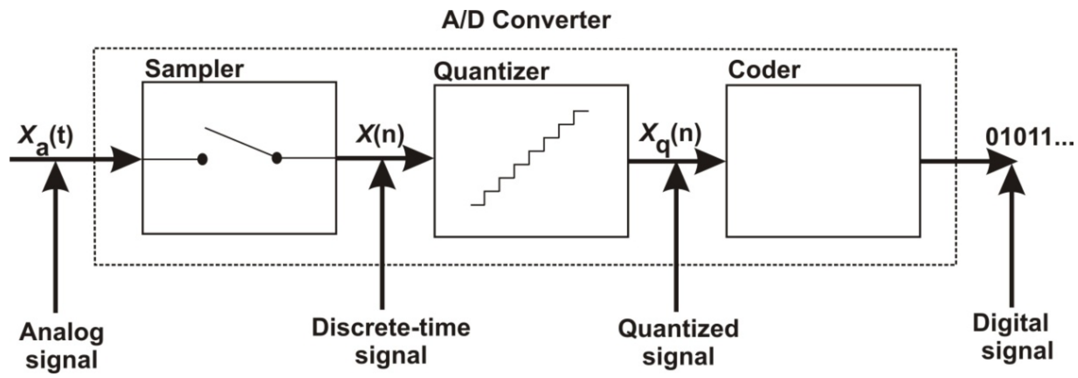


Figure (5.9): Basic A/D conversion blocks

The PIC16F877A converts the input analog signal (to pin two RA0) into digital format. Its analog input is 10 bit resolution, and accepts analog signals in the −5V to +5V range. The fundamental difference between the analog and digital implementations is that the digital system operates on *samples* of the signal rather than on the continuous signal. Doubling the signal bandwidth, then no information will be lost. In other words, all the signal information is included in the samples given they are taken at a rate greater than the Nyquist rate. However, there are three sources of errors associated with digital controllers; quantization error, delay and numerical approximation [42].

The desired reference voltage was selected using 4 DIP switches. It is input to the microcontroller at pin 5 *VREF+*. The MicroC code used to implement the reference voltage for comparison with the input analog signal is illustrated in Figure (5.10).

```
Configure pin No. 3 of the PIC as positive reference voltage;
               // configure AN3 Vref+, and Vref - as Vss
Initial Force = Initial reading from the ADC
              //  Read the first value of the force
Force =0;
Force_max=0;

Make loop
  {

   Delay 10 microseconds;
   Force integer= The reading from ADC – Initial Force

  :
  :
  }
```

Figure (5.10): MicroC code for load cell output handling

During the operation of the tensile testing machine, there was sometimes a glitch of the LCD output. To avoid this glitch and noise, the output from the signal conditioning circuit was connected to RC low pass filter and we made unused port pins of the microcontroller PIC as outputs using MicroC programming code as illustrated in Figure (5.11). Another approach to avoid noise is that the unused pins are pulled to *V+* through resistors around 10 K ohms, or grounded but in the case of grounding them, one must be careful that an inadvertent command sending these ports high, will damage the PIC.

```
//TO avoid noise make unnecessary (unconnected) pins as outputs

Configure PORT A= 001101;   // 0 means output and 1 means input
Configure PORT B= 10000011; // 0 means output and 1 means input
Configure PORT C= 11000000; // 0 means output and 1 means input
Configure PORT E= 000;      // 0 means output and 1 means input
```

Figure (5.11): MicroC code for noise interference reduction

Figure (5.12) illustrates interfacing an optical encoder to a microcontroller PIC16F877A. The MCU helps decoding the encoder signals and provides an absolute value for the deformation of the tested materials used in our machine.

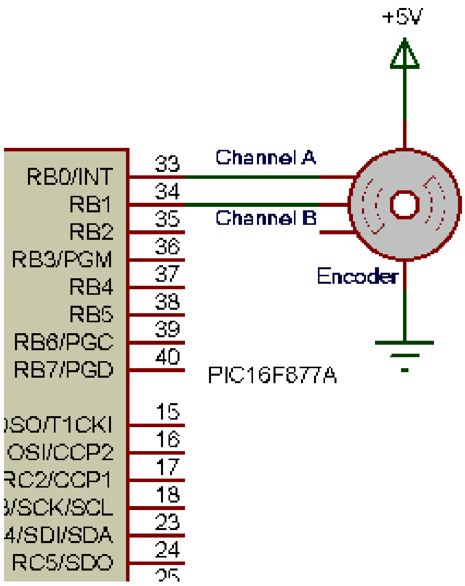


Figure (5.12): Optical encoder interface

At the rising edge of *Channel A* signal the value of *Channel B* is monitored. If it is found logic low, then clockwise rotation is concluded and the value of the *Counter Register* is incremented by one. On the other hand, if *Channel B* is found logic high, counterclockwise rotation is inferred, and hence, the value of *Counter Register* is decremented by one [42]. The Micro C computer programming language code implemented inside PIC to measure the deformation is shown in Figure (5.13).

```
Interrupt loop
 {
if <Pin No. RB2 is high> then increase Counter_Register by 1;
else
Decrease Counter_Register by 1;
Reset the interrupt Register <INTCON.INTF>;
 }
Main loop ()
 {
Configure pin No. RB0 as input;
                    // encoder pin RB0 as input Channel A
Configure pin No. RB1 as input;
                    // encoder pin RB1 as input Channel B
Configure interrupt register <INTCON> for interrupt;
 :
 :
}
```

Figure (5.13): MicroC code for the optical encoder interface

Inside the microcontroller a digital filter was implemented using MicroC programming language to get stable readings of the tension force on LCD. The programming code for the filter is presented in Figure (5.14).

```
Loop;
        {
   Delay 10 microseconds;
   Force integer =First Reading from ADC;  //get ADC value
   Force = 0.9*Force + 0.1*Slope_Force * Force integer;

   if Force_max less than Force then Force_max = Force;
   Convert the integer  value of Force_max to Force_string;
   Show Force_string on LCD starting from Row 1  column 4;
        }
```

Figure (5.14): MicroC code for digital filter

When the load cell gets an excessive force more than 7000 Newton, the MicroC program will give a disable signal to the microcontroller pin 8 to disconnect the relay to stop the motor from applying this force. This excessive force could damage the load cell. The code is shown in Figure (5.15). The MicroC program for the system operation, which was impeded in the microcontroller, is presented in appendix A.

```
Loop
  }
   Force_integer = The reading from ADC- Initial Force Reading;
                             // get ADC value,  10 bit =1023
   Force= 0.9*Force + 0.1*Slope_ Force_integer;
   If Force_max less than Force then Force_max = Force;
   If Force_max less than 7000 Newton then make PORTE low;
            // This makes the operating relay off so the power is off
 :
 :
  }
```

Figure (5.15): MicroC code for excessive force protection

The tensile testing machine was calibrated to ensure its accuracy. This calibration procedure must be done at regular time intervals. Accurate force calibration was implemented using a special calibrated instrument having the range up to 10 K Newton similar to the maximum force applied to the machine.

Each material has different characteristics curve. Figure (5.16) illustrates the characteristics curve of stress versus strain relationship for polyamide thermoplastic material. This curve could be drawn from the test results using a tensile testing machine. The tensile testing machine is used for testing the irrigation polyethylene pipes. These pipes could be low density polyethylene (LDPE) pipes with diameter 16,25 mm/2.5 bar or high density polyethylene (HDPE) pipes with diameter 63,100,100 mm/25 bar. The test results for strain versus stress of the standard sample HDPE pipe with diameter 63mm/25 bar is illustrated in Figure (5.17). The stress is measured as follows

$$\text{Stress} = \frac{\Delta L}{L} \times 100 \qquad (5.1)$$

where ΔL is the elongation of the tested sample and L is the original length of the sample (50mm). This result is drawn using the rehabilitated tensile testing machine in the IUG. Many different readings were taken for different time intervals for the same machine and the repeatability error was found to be ± 0.03% of the full scale.

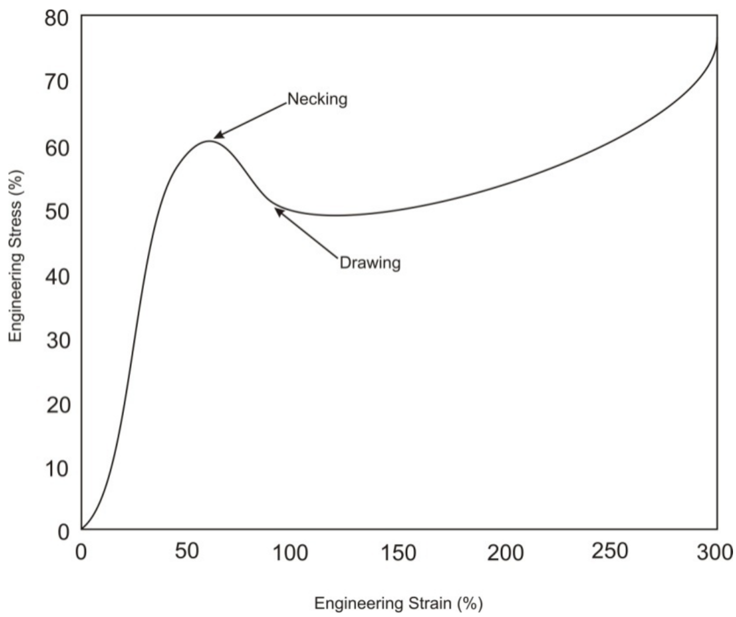


Figure (5.16): Stress-strain curve for polyamide thermoplastic

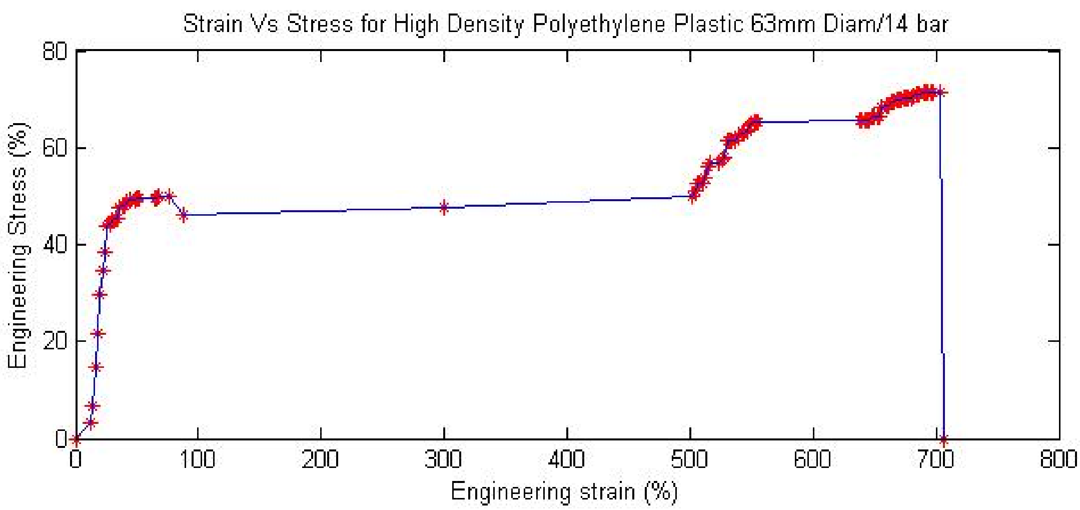


Figure (5.17): Stress-strain curve for HDPE pipe with 63mm/4 bar

The resultant rehabilitated machine is shown in Figure (5.18). In the left hand side of the machine a plastic box contains the speed and direction controller circuit with push buttons switches and indicator lamp. In the right hand side the box containing the manufactured PCB4 with reset external button and the LCD to present the force and the elongation of the tested sample.

Figure (5.18): The rehabilitated machine

CHAPTER 6 CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

The main objectives of this research are to end up with a precise signal conditioning device for strain gauge sensors, which are widely used in commercial, industrial, educational and medical fields. For years, we used to rely on expensive monopolized black-box devices for that purposes.

A process to rehabilitate any weighing machines with low cost and available components is developed through this thesis. A tensile testing machine is rehabilitated and it is used now effectively at the IUG Materials and Soil Laboratory. The recommended signal conditioning circuit, which has been chosen and built, serves the educational and industrial fields in the Gaza Strip.

The results of this research are expected to help the local engineers to build their own solutions depending on tremendously cheap and available components. We believe that young research and development people (R&D) in Gaza will combine the results of this research with their good experience in microcontrollers as well as Programmable Logic Controllers (PLCs) and they will contribute significantly to the development of the local industry. It has been demonstrated through a real case problem the significance of this contribution, which can not be denied under the present siege on Gaza.

In a future work, we plan to build a commercial multi-channel weighing indicator with digital interface suitable for both PLCs and general purpose computers.

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APPENDIX A

1. MicroC Software Code Implemented Inside PIC to Measure the Weight Using *TEDIA* Load Cell and Graphical LCD

```
Int Digital_Value;
Double t;
Char table[17]={0,1,2,3,0,4,5,6,0,7,8,9,0,10,0,11,0};
Char txt[4] ;
Char volt1[13];
Unsigned float tint,tint1,tint2,tint3,tint4,tint5,tint6,tint7,tint8,tint9;
Unsigned float tint10;
Unsigned float slope,wight,tavgfloat;   // t must be defined as float or int
Unsigned char var1, var2, Kp, Kp1,i;
Unsigned int tavg,tavg1;
Char attempts=0;

Void main()  {

GLCD_Init (&PORTC,0,1,2,3,4,5,&PORTD);
Glcd_Set_Font(FontSystem5x8, 5, 8, 32);
Glcd_Fill(0);  // Clear screen
Usart_Init(2400);

INTCON = 0;

Keypad_init(&PORTB) ;
GLCD_Write_Text("ISLAMIC UNIVERCITY",1,1,1);
GLCD_Write_Text("WEIGHT:",1,11,1);

OPTION_REG  = 0x80;
ADCON1     = 1;            // configure AN3 Vref+, and Vref - as Vss
TRISA      = 0b110110;     // 0 means input

while (1)
  {

    while(!keypad_Read())
     {
      delay_ms(10);

 for(i=0;i<10;i++)
 {
   Digital_Value  = ADC_read(0); // get ADC value 8 bit =255
   t=2.823*Digital_Value/1023.0;
   t=(t-0.658)/1.362;            // becomes x (weight)
   tint=t*1000;
   tint10=tint9;
   tint9=tint8;
   tint8=tint7;
   tint7=tint6;
   tint6=tint5;
   tint5=tint4;
   tint4=tint3;
   tint3=tint2;
   tint2=tint1;
```

```
   tint1=tint;
   delay_us(200);

//@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
if (Usart_Data_Ready())    // If data is received
    {
        b = Usart_Read();         // Read the received data
        Usart_Write(b);           // Send data via USART
    }
//@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
}

tavg=(tint+tint1+tint2+tint3+tint4+tint5+tint6+tint7+tint8+tint9)/10;
tavg1=tavg%10;
tavg=tavg-tavg1;

  if (tavg1>=0 && tavg1<=5)  tavg1=2;
  if (tavg1>=6 && tavg1<=9)  tavg1=7;
  tavg=tavg+tavg1;
  tavgfloat=tavg/1000.0;

//######################################################

       Wight = tavgfloat; // y = ax + b

// ##### eleminate exponential term #################
        if(wight<1.0)
          {
           wight=wight*1000;
           if(wight<2.01)     {wight=1.001;}
           floattostr(wight,volt1);
           volt1[8]='g';
           volt1[9]='m';
           volt1[10]=' ';
          }
        else
          {
          floattostr(wight,volt1);
          volt1[8]='k';
          volt1[9]='g';
          volt1[10]=' ';
          }

       GLCD_Write_Text(volt1,1,21,1);         //y,x
       Delay_ms(500) ;
//############################################

      }

    while(!keypad_Read());             //wait for key 1 press
          Delay_ms(10);                //debounce time
          kp=keypad_Released();        //wait for release
          var1=kp;                     //store var1 into kp
          var1 =table[kp] ;
          ByteToStr(var1,txt);
          GLCD_Write_Text(txt,20,30,1);
          Delay_ms(100);

           }
           }
```

2. MicroC Code Inside PIC to Measure the Force and Deformation of the Tested Materials via the Tensile Testing Machine

```
Int F0, F_int,F1, F_int_old,F1;
Signed Int INC_DEC;
Char txt[12],Dir, F_str[12];
Float Force,Distance, Force_max ;
Long int Height,D1,D2;
Const Slope_Force=5.03;   //factor
Void interrupt ()
{
  if (PortB.F1)
      Height++;
  else
      Height--;

  INTCON.INTF=0;
}

void main()
{
  TRISA.F0 = 1;    // Designate RA0 as input
  TRISA.F2 = 1;    // Designate RA2 as input  Vref-
  TRISA.F3 = 1;    // Designate RA3 as input  Vref+

  TRISD    = 0;    // Designate Port D output to LCD
  TRISB.F0 = 1;    // Encoder,  Port B as input
  TRISB.F1 = 1;    // Encoder,  Port B as input
  TrisB.F7 = 0;    // Pin RB7 input  for led test
  TRISE    = 0;    // Output for relay
  PORTE    = 1;
  PORTB.F7 = 0;    // Designate output for led indication test

  //### TO avoid noise make unnessary (unconnected) pins as outputs######

  TRISA = ob 001101   // 0 means output
  TRISB = ob 10000011 // 0 means output
  TRISC = ob 11000000 // 0 means output
  TRISE = ob 000      // 0 means output

  //####################################################################

  INTCON=0b10010000;    // for interrupt

  Lcd_Init(& PORTD);          // Initialize LCD connected to PORTB
  Lcd_Cmd( Lcd_CLEAR);        // Clear display
  Lcd_Cmd( Lcd_CURSOR_OFF);   // Turn cursor off
  Lcd_Out( 1, 1, "F:");
  Lcd_Out( 1, 14, "N");
  Lcd_Out( 2, 1, "D:");
  Lcd_Out( 2, 14, "mm");

  Height=0;
  OPTION_REG  = 0x80;
  ADCON1     = 1;           // configure AN3 Vref+, and Vref - as Vss
  F0 = ADC_read(0);
  Force=0;
  Force_max=0;
  F_Int_Old=0;

  while (1)
     {

  //####################### Flasher to test The PIC #################
  PORTB.F7=~PORTB.F7;
  DELAY_MS(10);
  //###################################################################
```

```
INC_DEC=F_int – F_int_old
F_int_old= F_int;

If INC_DEC<0 && (F_int>=(F0 - F0/10)&& F_int<=(F0 + F0/10))) PortE=0;

F_int  = ADC_read(0)-F0;  // get ADC value 8 bit =255

Force_max  = 0.9*Force_max + 0.1*Slope_Force*F_int;

If (Force_max>7000.0)   PortE=0; // To protect the Load Cell

IntToStr(Force_max,F_str);
Lcd_Out( 1, 4, F_str);

Distance=(Height/2474.96);   // each 1mm =2474.96 pulses from encoder
D1 = Distance*100;
LongToStr(D1,txt);

Lcd_chr(2,3,txt[2]);
Lcd_chr(2,4,txt[3]);
Lcd_chr(2,5,txt[4]);
Lcd_chr(2,6,txt[5]);
Lcd_chr(2,7,txt[6]);
Lcd_chr(2,8,txt[7]);
Lcd_chr(2,9,txt[8]);
if (D1==0) LCD_chr(2,10,' ');  else LCD_chr(2,10,'.');
Lcd_chr(2,11,txt[9]);
Lcd_chr(2,12,txt[10]);

  }
  }
```