

# **Palestine Polytechnic University**



**College of Engineering & Technology**

**Mechanical Engineering Department**

**Graduation Project**

**Computerized Impact Test Machine**

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**Hebron – Palestine**

**July, 2013**

**Palestine Polytechnic University**  
**Collage of Engineering and Technology**  
**Departments of Mechanical Engineering**

**Pendulum Impact Test Machine**

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According to the directions of the project supervisor and by the agreement of all examination committee members, this project is presented to the Departments of Mechanical Engineering, for partial fulfillment of Bachelor of engineering degree requirements.

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# Abstract

The pendulum impact test machine is a device used to measure material's toughness by measuring the energy absorbed to fracture the specimen, the importance of this kind of test appears in many fields such as ship design, automotive design and heavy duty industries.

The machine consists of a hammer raised to an initial height ( $H_1$ ), then released in free fall and hits the test specimen to be fractured; the hammer rise ( $H_2$ ) after impact is measure by a rotary encoder attached to the hammer axis of rotation, the microcontroller computes the impact energy by subtracting the potential energy before and after impact.

Since material's toughness change with temperature, an electronic controlled electrical furnace is designed to accompany the machine in order to allow the user to test the effect of temperature on toughness of the material under consideration.

The overall machine is controlled and monitored by a control panel that includes an arduino microcontroller to execute the mathematical operations for computing the impact energy and controlling the furnace temperature, a keypad to allow the user to set the parameters of the experiment, and an LCD to display the set parameters and experimental results.

# **ACKNOWLEDGEMENT**

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# DEDICATION

First of all thanks and praise to god, for patronizing us work on this project.

This project is dedicated to wonderful parents, who have raised us to be the persons we are today.

You have been with us every step of the way ,through good times and bad.

Thank you for all unconditional love ,guidance , and support that you have always given us, help us to succeed and instilling in us the confidence that we are capable of doing anything we put our mind to .thank you for everything.

Thanks for our families for their continued support, encouragement and patience from the first step till end, and their best wishes to us.

To our teacher for their advices and to our friends.

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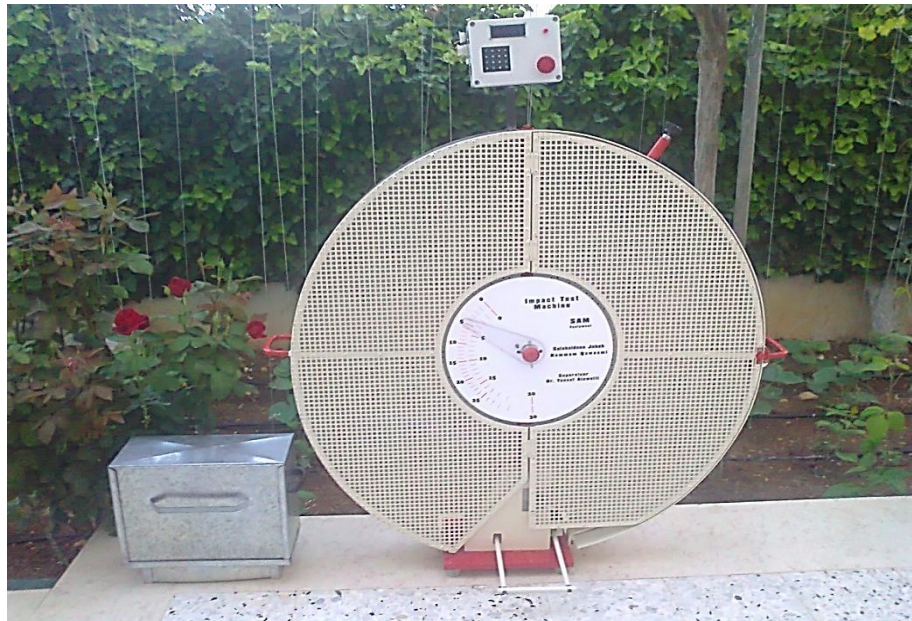
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# Chapter 1

## Introduction

### 1.1 General View

Impact test machine is used for measuring impact energy of material, And to study the effect of many factors on the impact energy like temperature, dampness, type of material on the impact energy, our device can measure the impact energy and explain relationship between impact energy and temperature of material.



*Figure (1-1): Impact test machine.*

The basic principle of this device is to calculate the loss of energy before and after impact, this difference in energy equal to energy absorbed by the specimen to fracture.

In other hand a small heater box is design for (furnace) increasing temperature of samples.

Many companies that produce impact test machine (like: TQ and GUNT), machine is designed for same purpose, but in different design and with higher reliability and more advanced interface.

The factor effect on impact energy sample, hammers weight, hammers height (angle of axis rotation) and samples temperature, this data are required to study the impact energy (toughness) of the test material for different temperature.

The machine calculate energy before impact from the height of hammer, then hammer goes under free fall to break the sample and continue motion to a new height after impact, by using height before and after impact we can calculate impact energy, furnace is provided separately to increase temperature of the sample, machine plot a graph explaining relationship between impact energy and temperature.

## **1.2 Recognition of the need & importance of the project:**

Impact testing is a test designed to gain information on how a material would respond to a sudden applied stress or load. This test is related to the toughness which is the ability of a certain material to deform plastically and to absorb energy in the process before fracture. Toughness can be measured by Charpy test or Izod test.

The Charpy test provides a standard method of studying the impact strength of a component containing a stress concentration. A rectangular beam of metal is notched in the center. It is then placed between two anvils and broken by a swinging pendulum. By measuring the height to which the pendulum raise after impact compared to the height from which it was dropped, one can find the total energy absorbed by the sample.



Fracture in materials was widely investigated especially during the industrial revolution where extraction processes of iron and steels led to the wide-spread uses of iron and steels for structural and transportation applications. The Liberty ships fracturing into two halves, brittle fracture has then been investigated in great details whereas ductile fracture was however studied in a lower extent.

The importance of this project which added new laboratory equipment at Palestine polytechnic university is to allow a connection between the theoretical part of different courses with the actual and real behavior of materials. Also this project will reduce the cost of buying such a device because its price is very expensive.

In other words, courses such as material science, strength of materials, machine design and other courses are concerned on materials specifications, and material behavior under different loads. At the same time a small furnace will be built and attached to the project to test the same material behavior under different temperature degrees.

Students can explain the meaning and use of Ductile-to-Brittle-Transition-Temperature Curve (DBTT) and explain the relationship between the absorbed energy of the specimen and its fracture surfaces. Identify the transition temperature of the tested materials.

Impact test machine will be connected to Arduino microcontroller, in many ways the machine will introduce the information in modern method on LCD, in a way that gives students or laboratory supervisor accurate readings and can plot curve in impact energy versus temperature.

Students of Mechanical Engineering Department, civil engineering and students in applied college may have a serious interaction with Impact Test Machine. A broader

view to the project, peoples outside the university can use the machine to test their materials in industry world.

### 1.3 Time schedule:

The time plane explains the stages in designing and building the system components. The section includes the first one show what is done in the first semester while the second semester shows the tasks scheduling for the second semester. Table1-2 shows the first semester and Table

**Table 1-1:** Time table for the first semester time (week).

Activity	week														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
project selection	■	■													
collecting general information			■	■	■										
previous studies					■	■	■	■							
Mechanical Design & Mathematical calculation							■	■	■	■	■	■			
evaluating and reviewing										■	■	■	■		
final calculation												■	■	■	
writing													■	■	■

**Table 1-2:** Time table for the second semester time (week).

<b>Activity</b>	<b>week</b>	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
buying electrical components		■	■	■	■											
reviewing hardware design				■	■	■										
Lathing operation						■	■	■	■							
microcontroller programming					■	■	■	■	■	■	■	■				
painting													■			
reviewing programming													■	■	■	
writing														■	■	■

#### 1.4 Project Coast

**Table 1-3:** Project total cost.

component	price
arduino	70
LCD	20
Encoder	100
lath machining	600
electronics	100
painting	90
furnace	50
	1030

Notice that comparing total coast of project is less than buying this machine from abroad, even that this device is more advanced and connected to electronic parts.

## **Chapter 2**

### **Previous Studies and Project Definition**

#### **2.1 Material properties**

The mechanical properties of materials are ascertained by performing carefully designed laboratory experiments that replicate as nearly as possible the service conditions. Factors to be considered include the nature of the applied load and its duration, as well as the environmental conditions. It is possible for the load to be impact, tensile, compressive, or shear, and its magnitude may be constant with time, or it may fluctuate continuously. Application time may be only a fraction of a second, or it may extend over a period of many years. Service temperature may be an important factor.

##### **2.1.1 Materials failure**

The loss of load carrying capacity of a material unit. This definition per se introduces the fact that material failure can be examined in different scales, from microscopic, to macroscopic. In structural problems, where the structural response may be beyond the initiation of nonlinear material behavior, material failure is of profound importance for the determination of the integrity of the structure. On the other hand, due to the lack of

globally accepted fracture criteria, the determination of the structure's damage, due to material failure, is still under intensive research. <sup>[1]</sup>

### **2.1.2 Ductility**

A solid material's ability to deform under tensile stress; this is often characterized by the material's ability to be stretched into a wire. Malleability, a similar property, is a material's ability to deform under compressive stress; this is often characterized by the material's ability to form a thin sheet by hammering or rolling. Both of these mechanical properties are aspects of plasticity, the extent to which a solid material can be plastically deformed without fracture. Also, these material properties are dependent on temperature and pressure (investigated by Percy Williams Bridgman as part of his Nobel Prize winning work on high pressures).

Ductility and malleability are not always coextensive – for instance, while gold is both ductile and malleable, lead is only malleable. The word *ductility* is sometimes used to embrace both types of plasticity. <sup>[1]</sup>.

### **2.1.3 Toughness**

In materials science and metallurgy, toughness is the ability of a material to absorb energy and plastically deform without fracturing.<sup>[1]</sup> Material toughness is defined as the amount of energy per volume that a material can absorb before rupturing. It is also defined as the resistance to fracture of a material when stressed.

Can be determined by measuring the area (i.e., by taking the integral) underneath the stress-strain curve and its energy of mechanical deformation per unit volume prior to fracture. The explicit mathematical description is:

$$\frac{\text{energy}}{\text{volume}} = \int_0^{\epsilon^f} \sigma d\epsilon \quad \dots (2.2)$$

Where:

- $\epsilon$ : is strain.
- $\epsilon^f$  : is the strain upon failure.
- $\sigma$ : is stress.

Another definition is the ability to absorb mechanical (or kinetic) energy up to failure. The area covered under stress strain curve is called toughness.

If the upper limit of integration up to the yield point is restricted, then the energy absorbed per unit volume is known as the modulus of resilience. Mathematically, the modulus of resilience can be expressed by the product of the square of the yield stress divided by two times the Young's modulus.

Tests can be done by using a pendulum and basic physics to measure how much energy it will hold when released from a particular height. By having a sample at the bottom of its swing, a measure of toughness can be found, as in the impact tests.

Toughness is measured in units of joules per cubic meter ( $\text{J/m}^3$ ) in the SI system and inch-pound-force per cubic inch ( $\text{in}\cdot\text{lbf/in}^3$ ) in US customary units.

## **2.2 Materials testing:**

Measurement of the characteristics and behavior of such substances as metals, ceramics, or plastics under various conditions.

The data thus obtained can be used in specifying the suitability of materials for various application, for example: building or aircraft construction, machinery, or

packaging. A full- or small-scale model of a proposed machine or structure may be tested. Alternatively, investigators may construct mathematical models that utilize known material characteristics and behavior to predict capabilities of the structure.

Materials testing breaks down into five major categories:

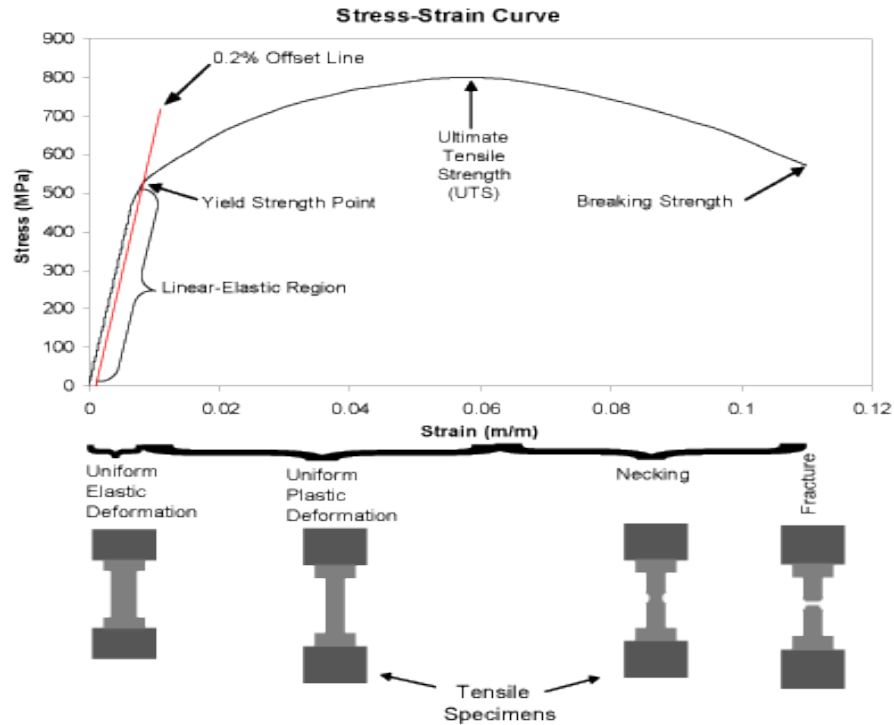
1. Mechanical testing.
2. Testing for thermal properties.
3. Testing for electrical properties.
4. Testing for resistance to corrosion, radiation, and biological deterioration.
5. Nondestructive testing.

Standard test methods have been established by such national and international bodies as the International Organization for Standardization (ISO), with headquarters in Geneva, and the American Society for Testing and Materials (ASTM), Philadelphia.<sup>[9]</sup>

### **2.2.1 Measures of ductility:**

Ductility is the capacity of a material to deform permanently in response to stress. When a material specimen is stressed, it deforms elastically (for example: recoverably) at first; thereafter, deformation becomes permanent. A cylinder of steel, for example, may “neck” (assume an hourglass shape) in response to stress. If the material is ductile, this local deformation is permanent, and the test piece does not assume its former shape if the stress is removed. With sufficiently high stress, fracture occurs.

Ductility can be expressed as strain, reduction in area, or toughness. Strain, or change in length per unit length, was explained earlier. Reduction in area (change in area per unit area) may be measured,



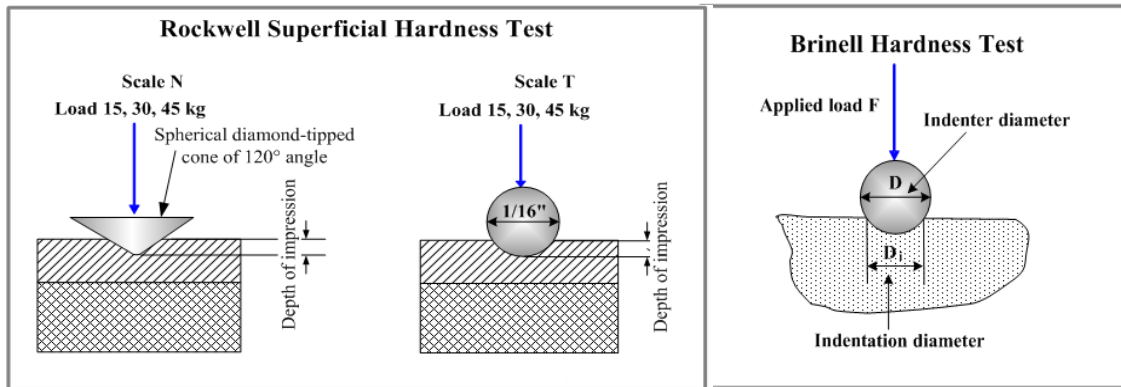
**Figure (2-1):** Stress strain curve.

Toughness measures the amount of energy required to deform a piece of material permanently. Toughness is a desirable material property in that it permits a component to deform plastically, rather than crack and perhaps fracture. <sup>[3]</sup>

### 2.2.2 Hardness testing:

Based on the idea that a material's response to a load placed at one small point is related to its ability to deform permanently (yield), the hardness test is performed by pressing a hardened steel ball Brinell test explain in figure (2.3), or a steel or diamond cone Rockwell test explain in figure (2.2) into the surface of the test piece.





**Figure (2-2):** Rockwell superficial hardness test

**Figure(2-3):** Brinell Hardness

Most hardness tests are performed on commercial machines that register arbitrary values in inverse relation to the depth of penetration of the ball or cone. Similar indentation tests are performed on wood. Hardness tests of materials such as rubber or plastic do not have the same connotation as those performed on metals. Penetration is measured, of course, but deformation caused by testing such materials may be entirely temporary. [4]

### 2.2.3 Impact test:

Impact: is a high force or shock applied over a short time period when two or more bodies collide. Such a force or acceleration usually has a greater effect than a lower force applied over a proportionally longer time period of time. The effect depends critically on the relative velocity of the bodies to one another.

Impact tests are used in studying the toughness of material. A material's toughness is a factor of its ability to absorb energy during plastic deformation. Brittle materials have low toughness as a result of the small amount of plastic deformation that they can endure. The impact value of a material can also change with temperature.

Different materials can behave in quite different ways in impact when compared with static loading conditions. Ductile materials like steel tend to become more brittle at high loading rates, and spalling may occur on the reverse side to the impact if penetration doesn't occur. The way in which the kinetic energy is distributed through the section is also important in determining its response. Projectiles apply a Hertzian contact stress at the point of impact to a solid body, with compression stresses under the point, but with bending loads a short distance away. Since most materials are weaker in tension than compression, this is the zone where cracks tend to form and grow. <sup>[1][6]</sup>

#### **2.2.3.1 Impact test (Charpy):**

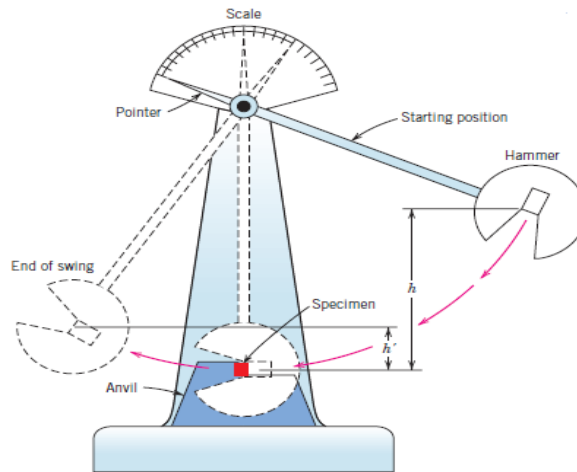
The test was developed around 1900 by S. B. Russell (1898, American) and G. Charpy (1901, French). The test became known as the Charpy test in the early 1900s due to the technical contributions and standardization efforts by Georges Charpy. The test was pivotal in understanding the fracture problems of ships during WWII.

Two type of impact test has a hammer held at a specific height (constant potential energy) is released. The hammer hits the sample and breaks it. From the energy absorbed by the sample, its impact strength is determined, but differs in that the sample is held in a cantilevered beam configuration as opposed to a three-point bending configuration; this test can also be used to determine the notch sensitivity.

#### **2.2.3.2 Izod impact testing:**



The test is named after the English engineer Edwin Gilbert Izod (1876–1946), who described it in his 1903 address to the British Association, subsequently published in Engineering.

The Izod impact test differs from the Charpy impact test in that the sample is held in a cantilevered beam configuration as opposed to a three-point bending configuration, this test can also be used to determine the notch sensitivity. <sup>[1]</sup>



*Figure (2-4): Impact test device.*

*Table 2-1: specimen installation.*

Name	Test Description	Diagram
Notched Izod Impact Strength	Specimen held as vertical cantilevered Beam and is broken by a pendulum. Impact is on the notched side of the Specimen.	
Charpy Impact Strength	Specimen held as a simply supported Beam and impact is on the side Opposite to the notch.	

### 2.3 Impact test sample:

The notch in the sample affects the results of the impact test, thus it is necessary for the notch to be of regular dimensions and geometry. The size of the sample can also

affect results, since the dimensions determine whether or not the material is in plane strain. This difference can greatly affect conclusions made.

The North American standard for Impact testing of plastics is ASTM D256. The results are expressed in energy lost per unit of thickness (such as ft-lb/in or J/cm) at the notch. Alternatively, the results may be reported as energy lost per unit cross-sectional area at the notch ( $J/m^2$  or ft-lb/in<sup>2</sup>). In Europe, ISO 180 methods are used and results are based only on the cross-sectional area at the notch ( $J/m^2$ ).<sup>[10]</sup>

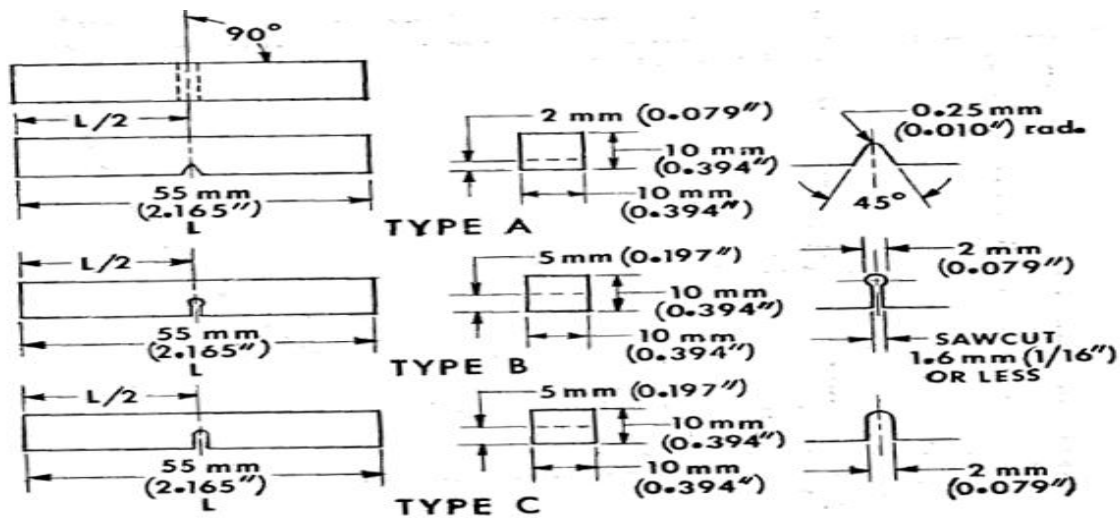


Figure (2-5): Charpy impact test specimen.<sup>[10]</sup>

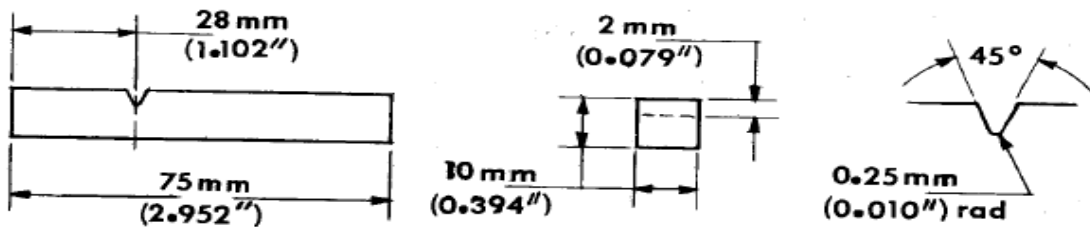


Figure (2-6): Izod impact test specimen.

**Table (2-2): Specimens standard impact test.**

specimen standard		Width (mm)	Thickness (mm)	Length (mm)
ASTM	Standard	10	10	55
	Subsize	10	7.5	55
		10	6.7	55
		10	5	55
		10	3.3	55
		10	2.5	55
ISO	Standard	10	10	55
	Subsize	10	7.5	55
		10	5	55
		10	2.5	55

## 2.4 Impact testing machines:

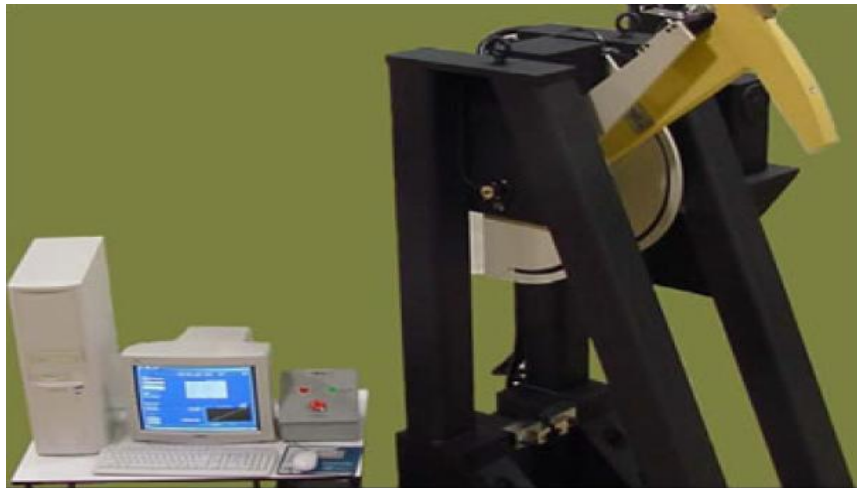
Team project went to Nablus to visit Hisham Hijawi College, the college has impact test machine (gunt), specimens attached with device has (10 x 5 mm) cross section area, with length of (55 mm), and a square notch at middle (2mm) width and (5 mm) depth at the middle.

Impact test machines are distributed around the over the entire world, and many companies are producing such impact test machine, by the way we hope that this project will be in more advanced mode, with electronic interfacing with PC and more accurate. And here there are some examples about Impact Test machine examples. <sup>[9]</sup>

### 2.4.1 MPM Charpy/Izod 9000 series impact test machine

The MPM Charpy/Izod 9000 Series impact test machines can be used with pendulums in the 100 ft-lb to 700 ft-lb energy capacity ranges. Since the machine frame

has been designed for up to 700 ft-lbs, any lower capacity can be accommodated. Therefore, you can upgrade your machine capacity later by purchasing a higher capacity pendulum without the need to buy an entire test machine. MPM will provide the test machine with the customer-specified energy capacity at the time of purchase. As discussed later, the accuracy of the energy measurement for higher capacity machines is equivalent to that for low capacity machines through the use of advanced encoder technology.<sup>[7]</sup>



*Figure (2-7): MPM Impact test machine.*

#### **2.4.2 TQ Energy absorbed at fracture**

A small-scale, bench-mounting, notched-bar impact tester. The equipment provides an effective, convenient and safe introduction to the principles of common impact testing techniques, enabling investigations into the resistance of materials to crack propagation and the influence of temperature on fracture properties.

The apparatus consists of a main unit, an instrumentation unit and a power supply. The main unit consists of a pendulum supported in a rigid frame by low-friction bearings. The pivot arrangement includes an angular encoder to measure the angular position of

the pendulum over its range of movement. The apparatus is fully enclosed with an interlocked guard covering all moving parts. Adjustable feet on the base of the unit enable accurate leveling of the equipment.

To perform a test, students raise the pendulum to the start position, where it is held. They then clamp a specimen in a holder, which safely slots into the base of the frame at the lowest point of the pendulum swing. The separate instrumentation unit controls the release of the pendulum and measures and displays its angular position before and after the impact. The unit also directly displays energy absorbed by the impact in Joules.

As well as comparing impact properties of each material, by heating and cooling specimens before testing, students can investigate the brittle-ductile transition in steel.

Note: Separate heating and cooling vessels (not included) are required for tests at different temperatures. A pair of specimen tongs is included for safe handling of hot or cold specimens.<sup>[8]</sup>



**Figure (2-8):** TQ energy absorbed at fracture

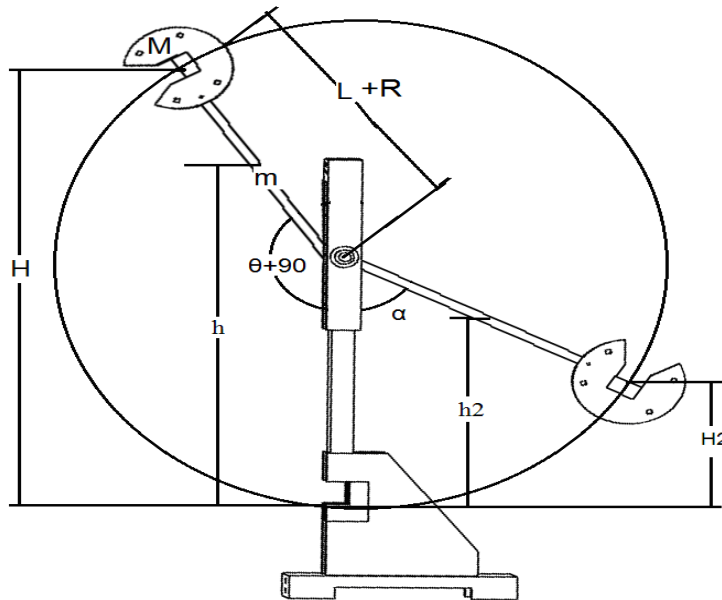
# Chapter 3

## Mechanical Components

### 3.1 Mathematical calculation.

#### 3.1.1 General description:

The machine designed with different energy capacity, (30-20) joules Rang of energy in this equipment, these flexibility in the design can be obtained by mean of four additional weight that can be added or removed easily by two screws one each additional weight.



*Figure (3-1): Machine sketch*



To find energy absorbed at impact:

Energy before impact = energy at impact = energy after impact

$$\text{Potential energy (before impact)} = M g H + m g h \quad \dots (3.1)^{[3]}$$

$$\text{Energy at impact (kinetic energy)} = \frac{1}{2} M V_H^2 + \frac{1}{2} J \omega^2 \quad \dots (3.2)^{[3]}$$

$$\text{Energy after impact} = M g H_2 + m g h_2 \quad \dots (3.3)^{[3]}$$

$$J = \frac{m l^2}{2 g} \quad \dots (3.4)^{[2]}$$

Where:

E: System energy.

$V_H$ : Instantaneous hummer velocity just before impact.

$V_c$ : Instantaneous connecting rod velocity just before impact

M: Hummer mass.

m: connecting rod mass.

H: Hummer center gravity elevation before impact.

h: distance between center of gravity for rod and the bottom before impact.

H2: Hummer elevation after impact.

h2: distance between center of gravity of rod and the bottom after impact.

$g$ : acceleration of gravity.

$L$ : connecting rod length.

$R$ : Hammer radius.

### 3.1.2 Numerical Calculations

$$E = M g H + m g h$$

$L = 0.35$  [m] (Length of connecting rod)

$D_c = 17$  [mm] (connecting rod diameter)

Hammer Radius ( $R$ ) = 75 [mm]

Let rod angle = 60

$$H = (L + R) (1 + \sin 60)$$

... (3.5)

$$H = (0.35 + 0.075) (1 + \sin 60)$$

$$H = 0.793 \text{ [m]}$$

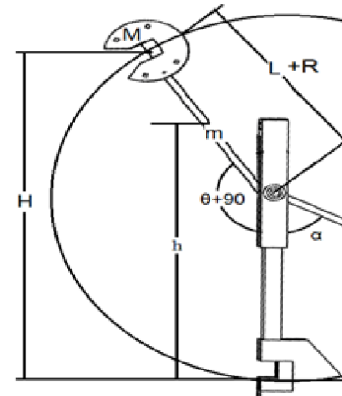
- For Connecting rod:

Connecting rod mass has been calculated by Catia software

$$m = 0.55 \text{ [kg]}$$

$$h = (L/2) (1 + \sin 60) \quad \dots (3.6)$$

$$h = 0.65 \text{ [m]}$$



- Calculation of the hummer mass

In order to make the hummer flexible and able to work at 20 & 30 joules, hummer mass should be variable, at 20 joules without additional masses, and at 30 joules with additional required masses.

a) Hummer mass to produce  $E = 20$  [J]

$$20 = M (9.81) (0.793) + (0.55) (9.81) (0.65)$$

$$M = 2.118 \text{ [Kg]} \text{ (for hummer and hummer tip)}$$

- Hummer Tip:

$$\text{Volume} = 9.185 \cdot 10^{-6} [m^3]$$

$$M_{\text{tip}} = 0.0721 \text{ kg}$$

$$\text{Note: } M = M_{\text{hummer}} + M_{\text{tip}} \quad \dots (3.7)$$

$$M_{\text{hummer}} = 2.118 - 0.0721 = 2.046 \text{ [Kg]} \text{ (to produce 20 J)}$$

B) Hummer mass to produce  $E = 30$  [J]

$$30 = M (9.81) (0.793) + (0.55) (9.81) (0.65)$$

$$M = 3.4 \text{ [Kg]}$$

- The same Hummer Tip:

$$M_{\text{hummer}} = 3.4 - 0.0721 = 3.33 \text{ [Kg]} \text{ (to produce 30 J)}$$

$$\text{So: } M_{\text{add}} = 3.4 - 2.118 = 1.282 \text{ [Kg]}$$

$M_{\text{add}}$ : additional masses to hummer.

Addition masses will be divided to four parts, every part mass can be calculated by:

$$M_{\text{extra}} = M_{\text{add}}/4 = 1.282/4 \quad \dots (3.8)$$

$M_{\text{extra}}$ : extra masses added on hummer (at right up and down, at left up and down).

$$M_{\text{extra}} = 0.3205 \text{ [kg]}$$

Hummer volume depend on the mass, the mass shouldn't be change, so it's required to calculate the volume of the Hummer depending on the mass, so that the thickness of the parts (hummer and hummer extension) could be found.

$$V = \frac{M}{\rho} \quad \dots (3.9)^{[1]}$$

$$V = \frac{2.118}{7850}$$

$$V = 2.7 \cdot 10^{-4} \text{ [m}^3\text{]}$$

Hummer thickness could be found using:

$$t = \frac{V}{A} \quad \dots (3.10)$$

$A = 0.012 \text{ [m}^2\text{]}$  (calculated by Catia software)

$$t = \frac{2.54639 \cdot 10^{-4}}{0.012} = 20.535 \text{ [mm]}$$

Hummer extension thickness can be calculated by the same equation:

$$V = \frac{M_{\text{add}}}{\rho} = \frac{0.47175}{7850} = 4.08 \cdot 10^{-5} \text{ [m}^3\text{]}$$

Hummer extension thickness could be found using:

$$t = \frac{V}{A} = \frac{6.0096 \cdot 10^{-5}}{0.005} = 12.02 \text{ [mm]}$$

- Its required find shear force and tension force in order to be able to calculate the required diameter of the connecting rod and pin.

Calculation has been done at maximum force, to avoid any permanent deflection in beam, and to make the design more reliable and more safety. The maximum force appears when the hummer can't break the specimen and return in the same velocity in the opposite direction.

- Calculation of axial force:

At maximum energy  $E=30$  [joule], At impact point, It's required to calculate the axial force on connecting rod. See figure (3.2) that shows forces on the connecting rod.

At impact point:

$$M_{\text{Hummer}} = 3.2 \text{ [Kg]}$$

$$T_c - M_{\text{Hummer}} g = M_{\text{Hummer}} W^2 (L+R) \quad \dots (3.11)^{[3]}$$

$$V_H = 4.38 \text{ [m/s]}$$

$$W = \frac{VH}{(L+R)} \quad \dots (3.12)^{[3]}$$

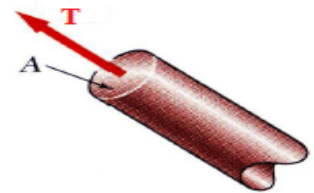
$$V^2 = \sqrt{2g(L + R)(1 + \sin 60)}$$

$$V = 4.38 \text{ [m/s]}$$

$$W = \frac{4.38}{0.4+0.0074} = 9.24 \text{ [rad/s]}$$

$T_c$ : Tension in connecting rod.

$$T_c = M_{\text{Hummer}} g + M_{\text{Hummer}} W^2 (L+R)$$



**Figure (3-2):** axial force

$$T_c = 3.2 \cdot 9.81 + 3.2 \cdot 9.24^2 \cdot 0.474$$

$$T_c = 161 \text{ [N]}$$

$$\sigma = \frac{T}{A}$$

$$\dots (3.13)^{[5]}$$

$\sigma$ : shear stress.



**Figure (3-3):** pin shear force.

$$\text{Diameter}_{\text{connecting rod}} = \sqrt{\frac{(T)(4)(S.F)}{\pi\sigma}}$$

$$\text{Diameter}_{\text{connecting rod}} = \sqrt{\frac{(161)(4)(1)}{\pi(250 \cdot 10^6)}} \quad (\text{at safety factor} = 1, \sigma = 250 \text{ MP})$$

$$\text{Diameter}_{\text{connecting rod}} = 0.91 \text{ [mm]}$$

This is the needed diameter dimension, the designed diameter = 12 [mm],

- Calculation of Pin shear stress (figure 3.4):

$$\tau = \frac{2T}{A}$$

$$T = T_c / 2$$

$$\text{Diameter}_{\text{pin}} = \sqrt{\frac{(2T)(4)(S.F)}{\pi\sigma}}$$

$$\text{Diameter}_{\text{pin}} = \sqrt{\frac{(161)(4)(1)}{\pi(250 \cdot 10^6)}}$$

$$\text{Diameter}_{\text{pin}} = 0.91 \text{ [mm]}$$

This is the needed diameter dimension, the designed diameter = 4 [mm],

$$\text{Diameter}_{\text{pin}} = \sqrt{\frac{(2 * 977.18)(4)(1)}{\pi(250 * 10^6)}}$$

It's required to be sure that the machine at all will not flip, so the moment should be taken about the center of gravity of machine.

$CG_M$ : Center of gravity of machine at all measured from the edge of ground base in the hummer side.

$$CG_M = 0.118 \text{ [m]}$$

$$M_s = F d = m g d = \rho V g d \quad \dots (3.14)$$

$$M_s = (7850) (0.005) (9.81) (0.118)$$

$$M_s = 45.5 \text{ [N.m]}$$

$$M_{H+C} = \rho V g d$$

$$M_{H+C} = (7850) (4.661 * 10^{-4}) (9.81) (0.5115)$$

$$M_{H+C} = 18.4 \text{ [N.m]}$$

Where:

$M_s$ : Mass of system without hummer and connecting rod.

$M_{H+C}$ : Mass of connecting rod and hummer.

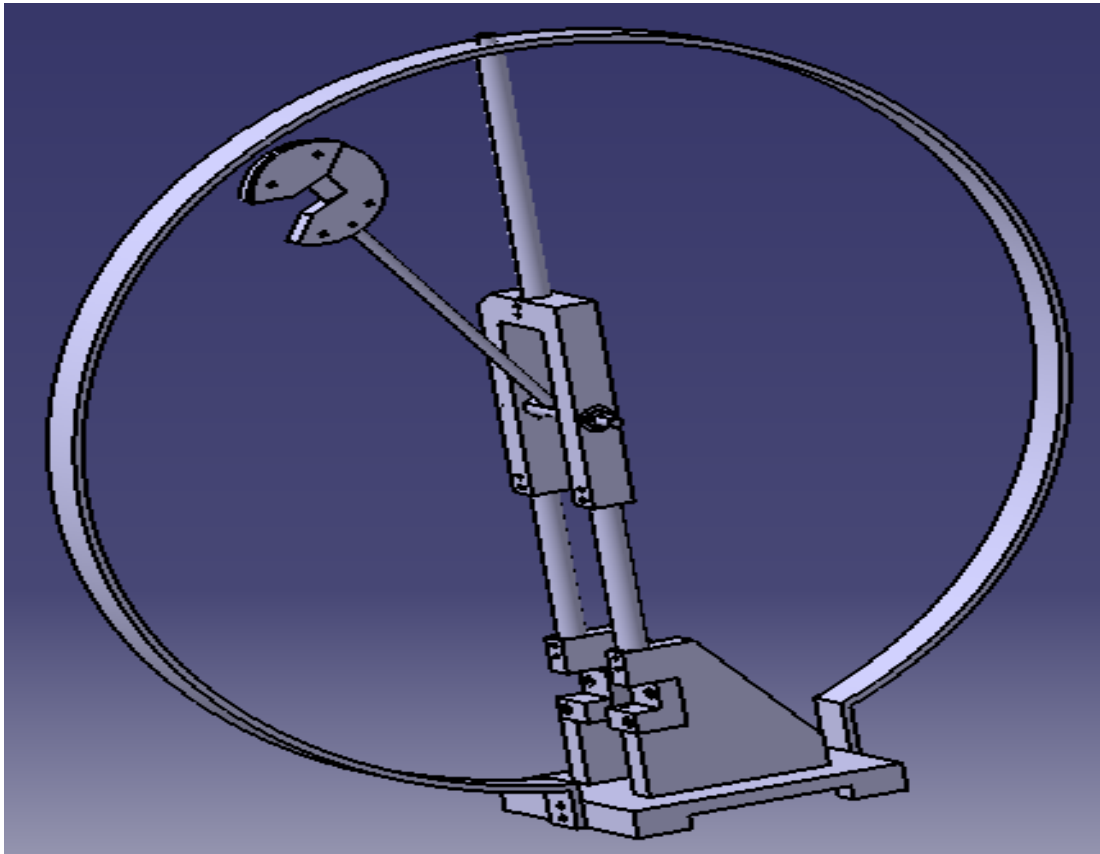
$\rho$ : A36 steel density.

$d$ : distance between center of gravity and line of force.

$g$ : gravity acceleration.

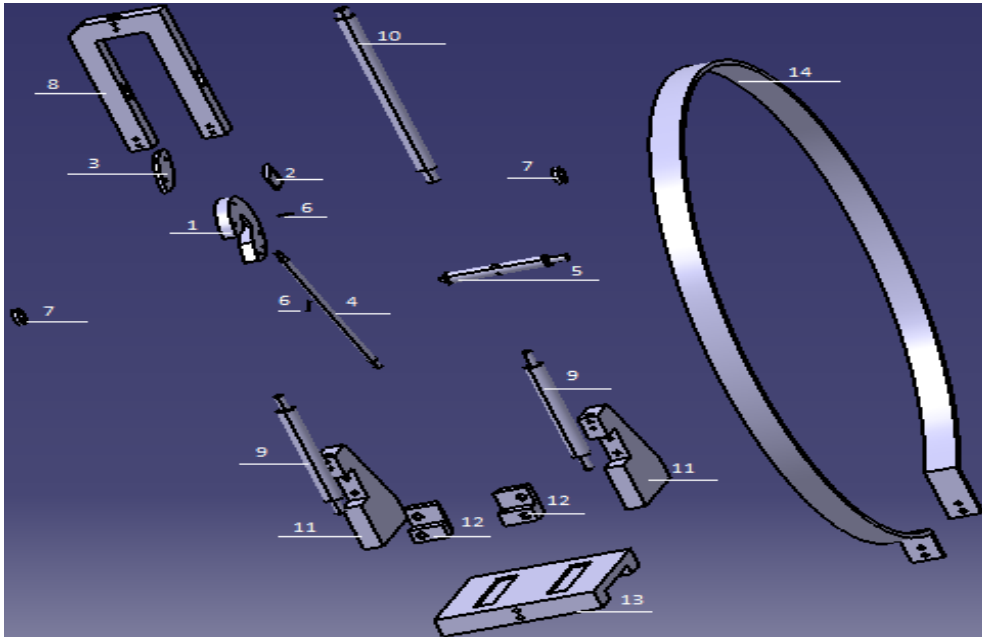
### 3.2 Projects mechanical parts:

Systems parts designed and plotted individually, after that all parts assembled together to build the final structure design.



*Figure(3-4):Final structure design.*





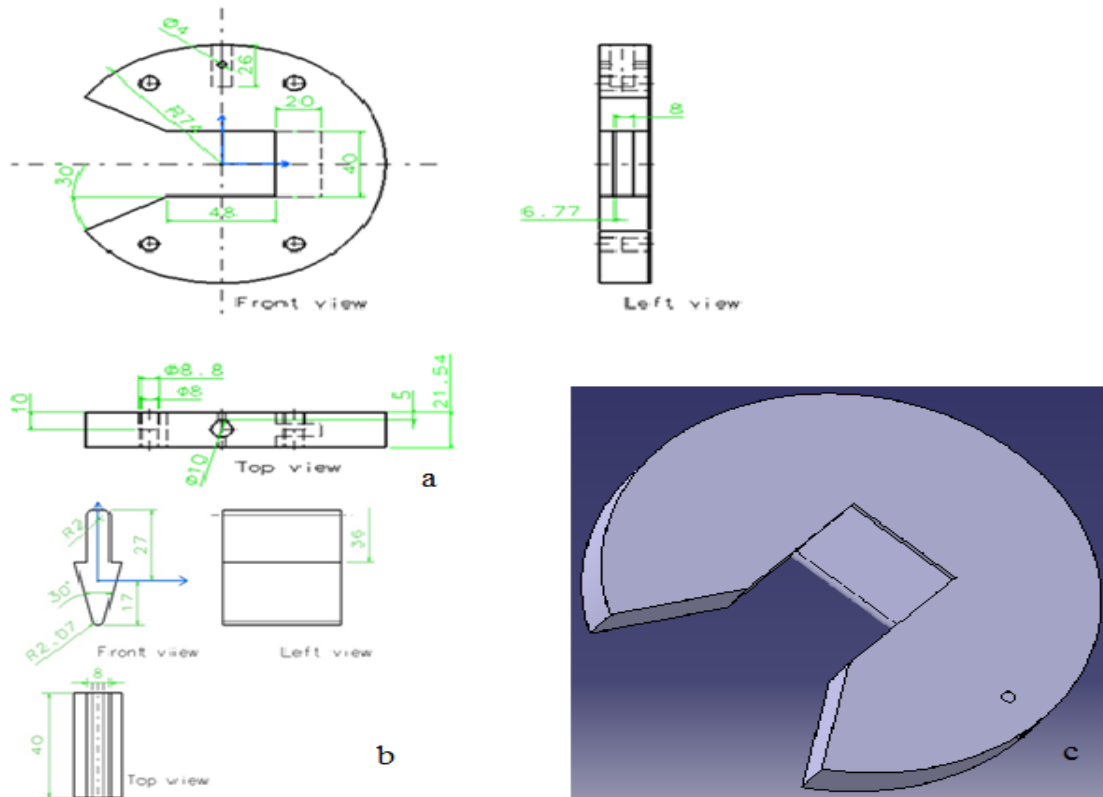
*Figure (3-5): Machine explodes.*

1. Hummer.
2. Hummer tip.
3. Hummer additional.
4. Connecting rod.
5. Shaft on bearing.
6. Pins.
7. Ball bearing.
8. U part.
9. U shaft.
10. Shaft over U part.
11. Carrier base.
12. Specimen carrier.
13. Ground base.
14. Outer shell.

### 3.2.1 Hammer and hammer tip:

Hammer figure (3.6.a) is the main part of the project, since its potential energy will convert to kinetic energy when it strikes the specimen. The hammer calculation has been described previously in this chapter.

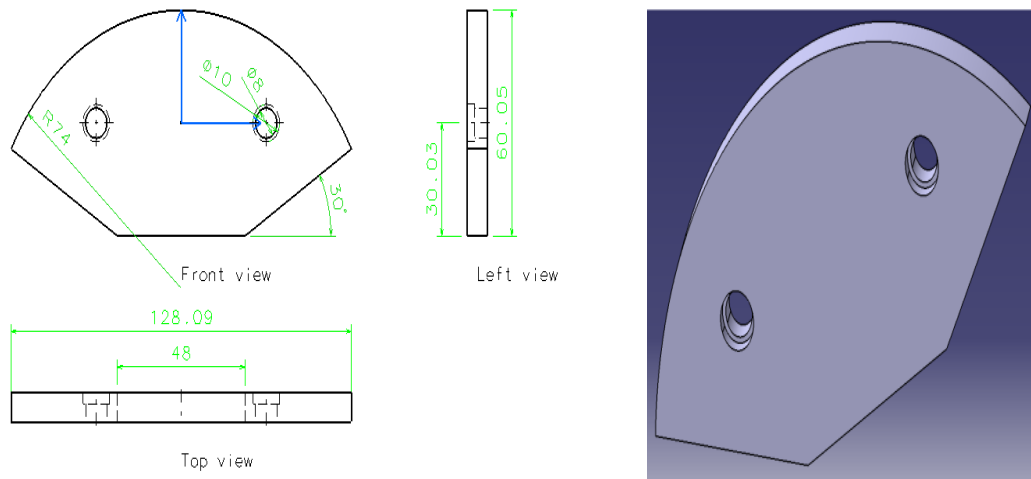
Hammer Tip figure (3.6.b), is the part that strikes the specimen, however the hammer tip is made from the regular steel (A36), but then goes to process of strain hardening.



**Figure (3-6):** hammer

### 3.2.2 Hummer additional:

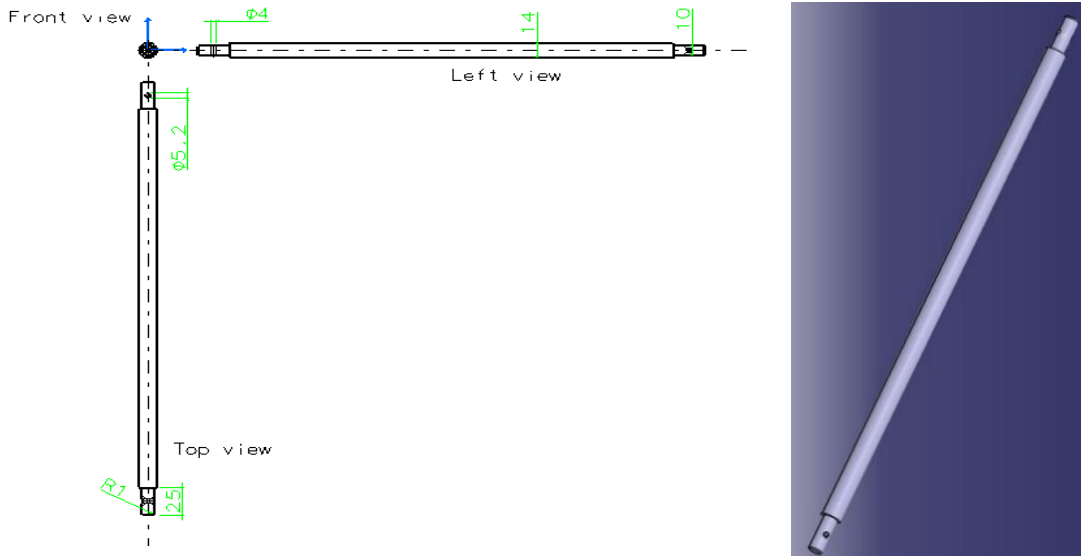
Hummer additional figures (3.7) is composed of four parts, used to increase the potential energy of the hummer, this gives flexibility to the machine to increase of its potential energy capacity from 20 to 30 joules, hummer extensions could be added or remove by two screws on each one.



**Figure(3-7.a):** Hummer additional perspective. **Figure(3-7.b):** Hummer additional 3D.

### 3.2.3 Connecting rod:

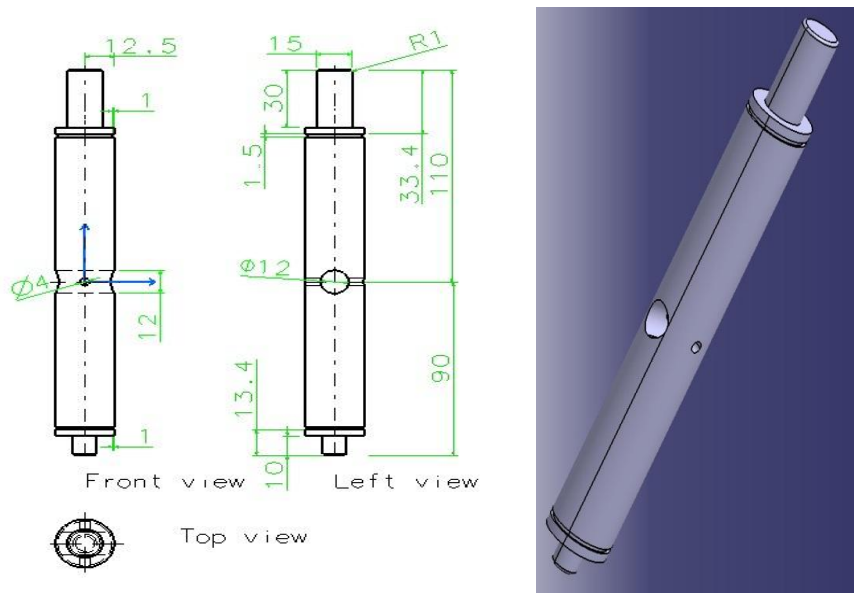
Connecting rod figure (3.8) used to connect the hummer with the rotational axis. Since the connecting rod has mass affect to the potential energy, mass calculation should take seriously.



**Figure (3-8.a):** Connecting rod perspective. **Figure (3-8.b):** Connecting rod 3D.

### 3.2.4 Shaft on bearing:

Shaft on Bearing figures (3.10) will carry the connecting rod, and also it will carry the encoder that measure the angle and by mean the elevation of the hummer, and from its another end it carry part that will cause the rotation of the cursor.

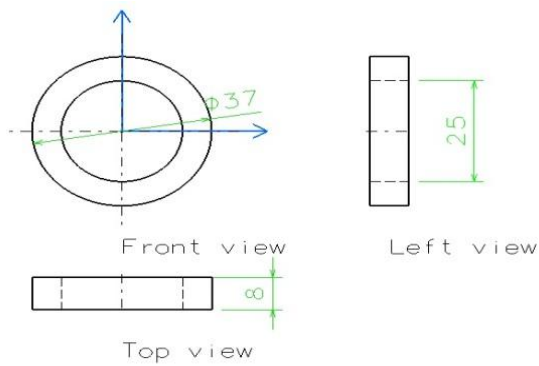


**Figure (3-9.a):** Shaft on bearings.

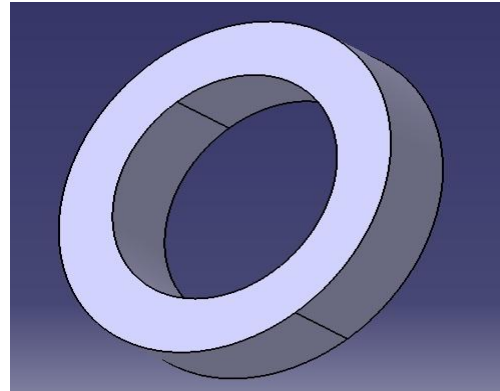
**Figure (3-9.b):** Shaft on bearing 3D.

**3.2.5 Ball bearings:**

Bearings figures (3.11) used to hold shaft and to provide a low friction as possible, also the bearing chosen to thick as possible so will not cause minimum thickness of U part.



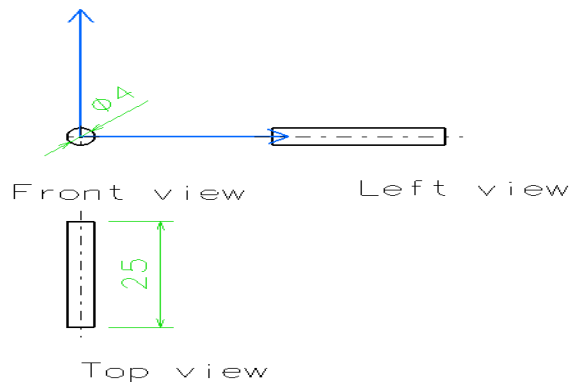
**Figure (3.11.a):** Ball bearings



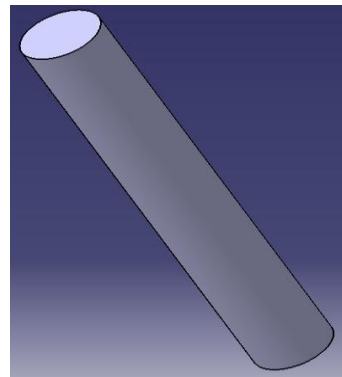
**Figure (3.11.b):** Ball bearings 3D.

### 3.2.6 Pins:

Pins figures (3.12) will be used to make coupling between different parts, pins is very useful to prevent rotating, first pin to couple the hummer with the connecting rod, and the second pin will be used to make connection between the connecting rod and the Shaft on bearing.



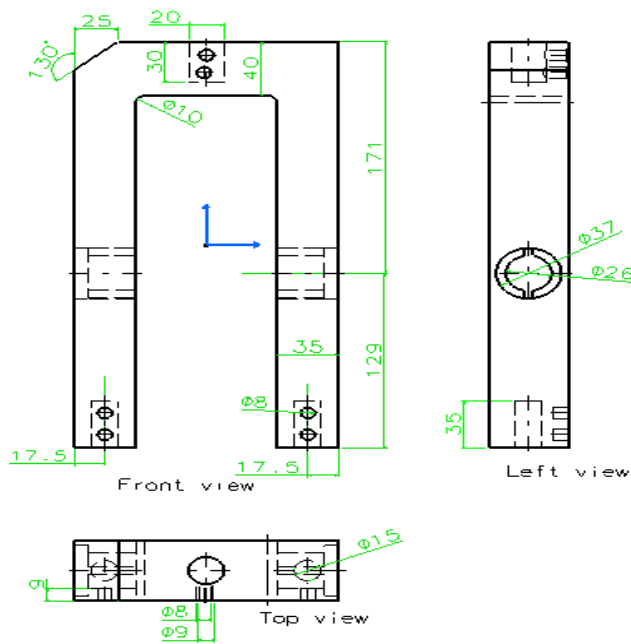
**Figure (3.12.a):** Pin perspective.



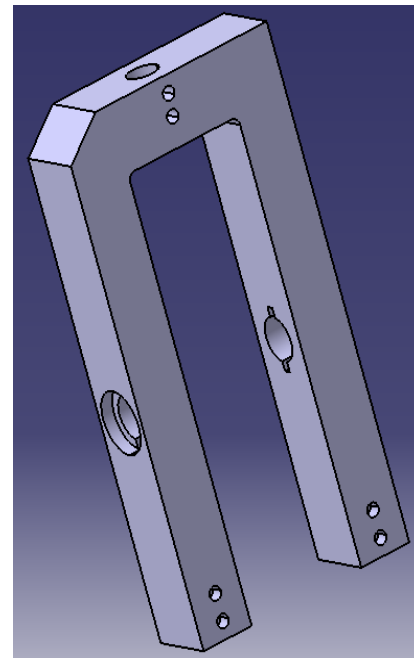
**Figure (3.12.b):** Pin 3D.

### 3.2.7 U Part:

The U Part figures (3.13) is an important part, it carry bearing and connect the upper parts of the project and the lower parts. To connect the shafts, screws will be use.



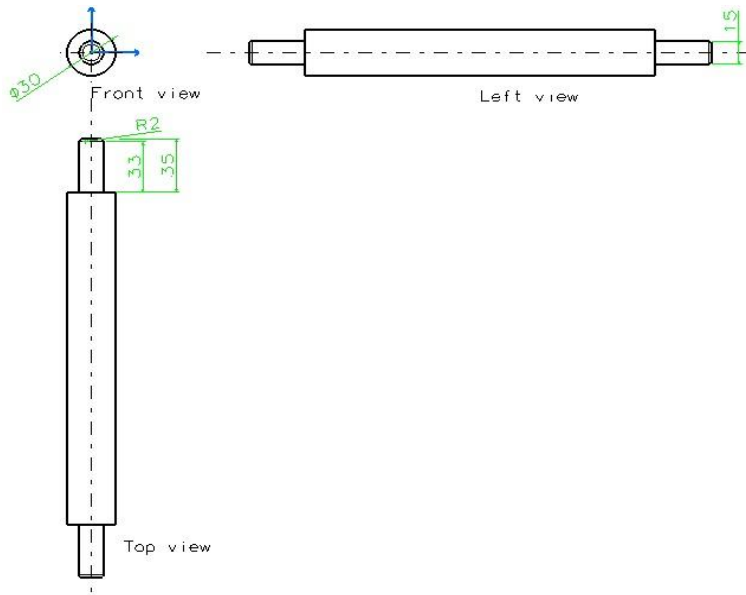
*Figure (3.13.a): U Part perspective.*



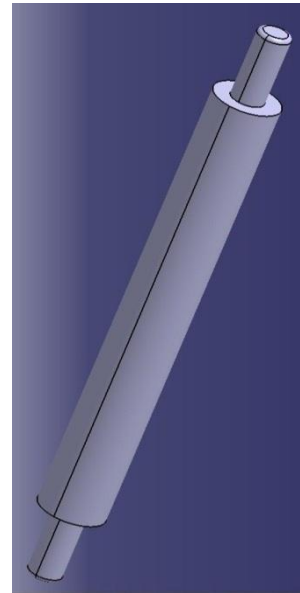
*Figure (3.13.b): U Part 3D.*

### 3.2.8 U Shafts:

U Shafts figures (3.14) are shafts under the U; these shafts connect between the U and the base.



**Figure (3.14.a):** U Shaft perspective.

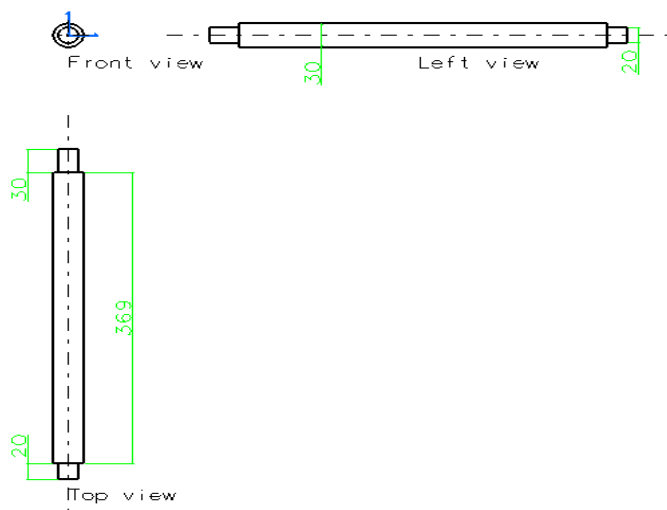


**Figure (3.14.b):** U Shaft 3D.

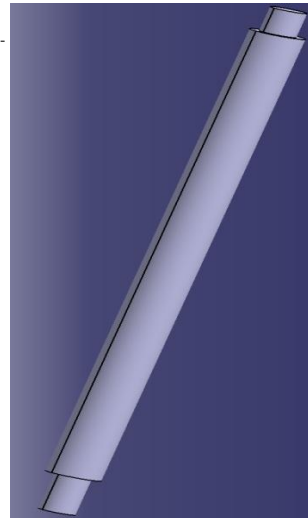
### 3.2.9 Shaft over U:

Shaft over U figures3.15) is fixed above the U Part, and hold the outer shell in its appropriate place.





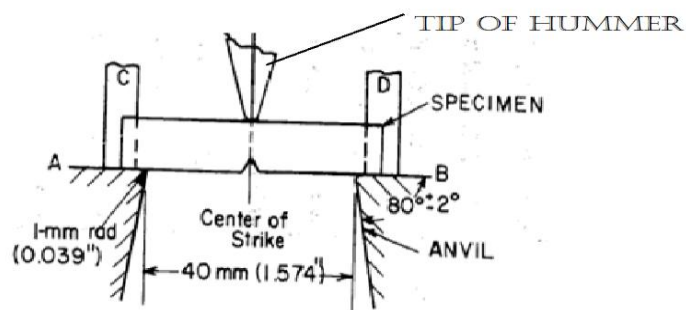
**Figure (3.15.a):** Shaft over U perspective.



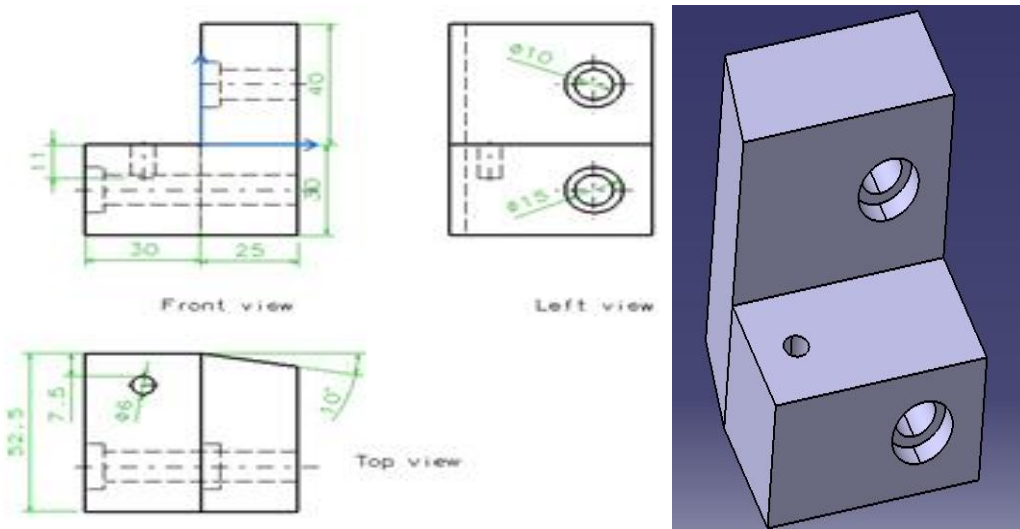
**Figure (3.15.b):** Shaft over U 3D.

### 3.2.10 Specimen carrier:

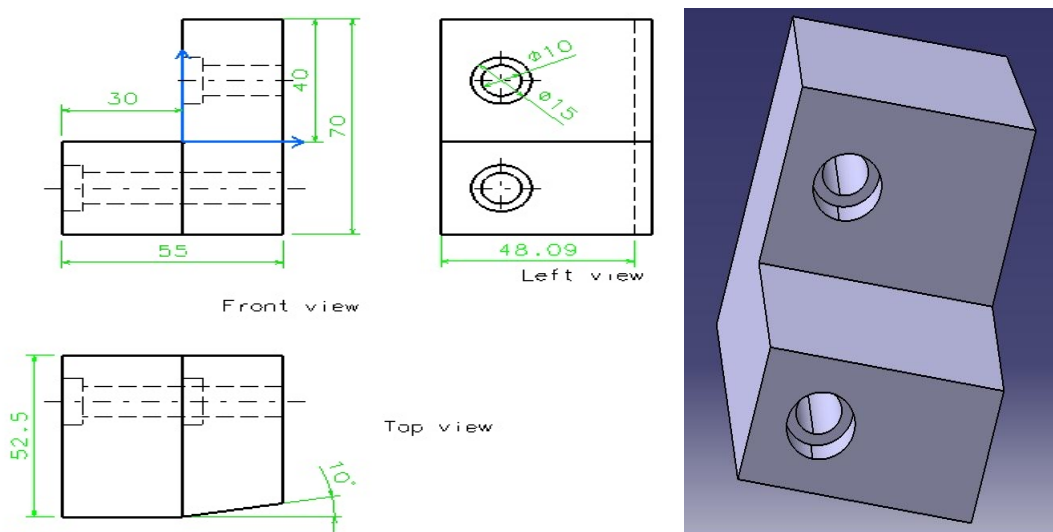
Specimen carrier figures (3.16) holds the specimen, the specimen carrier are designed according the ASTM, the distance between them and the angle.



**Figure (3.16.a):** ASTM standard for carrier.



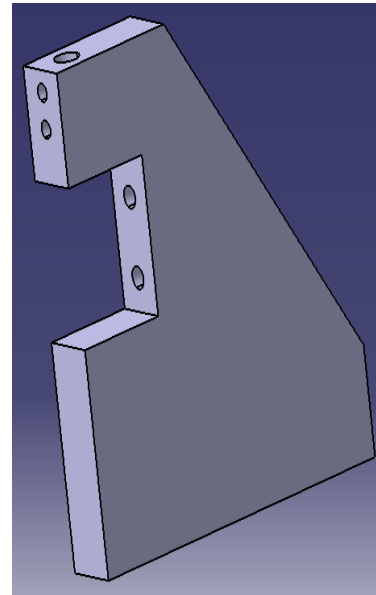
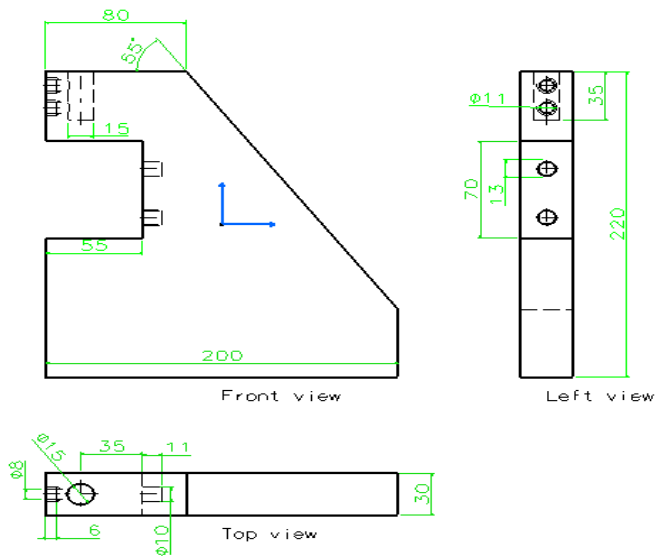
**Figure (3.16.b): Specimen carrier right**     **Figure (3.16.c): Specimen carrierright 3D.**



**Figure (3.16.d): Specimen carrier left.**     **Figure (3.16.e): Specimen carrier 3D.**

### 3.2.11 Carrier base:

Base carrier figures (3.17) hold the carrier, and lies under the U shafts and above the ground base.

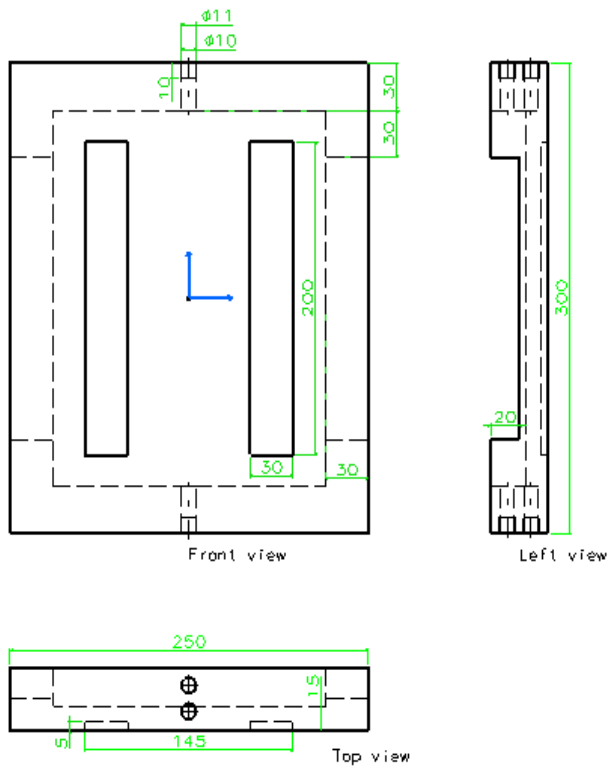


*Figure (3.17.a): Carrier base perspective.*

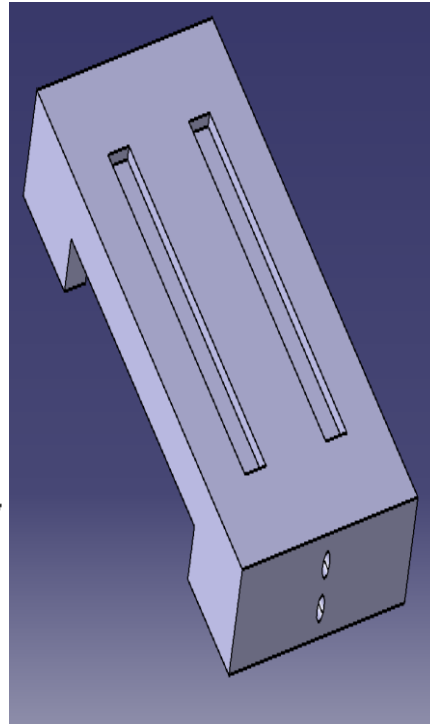
*Figure (3.17.b): Carrier base 3D.*

### 3.2.12 Ground base:

The ground base figures (3.18) is an important part of the project, since it carry the hall machine, however it has two pocketing rectangles to place the two bases inside them, and at the end of every width side, two halls to fix the outer shell. Each base has two Screws to fix them with ground base.



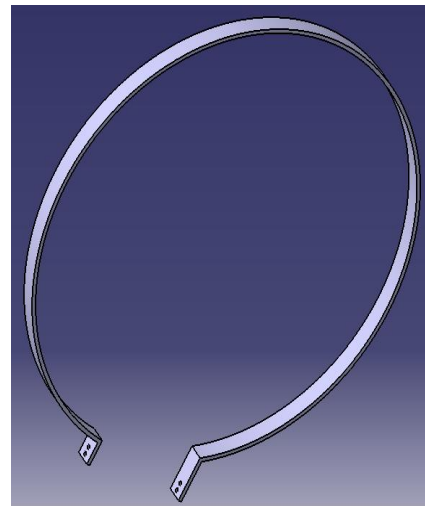
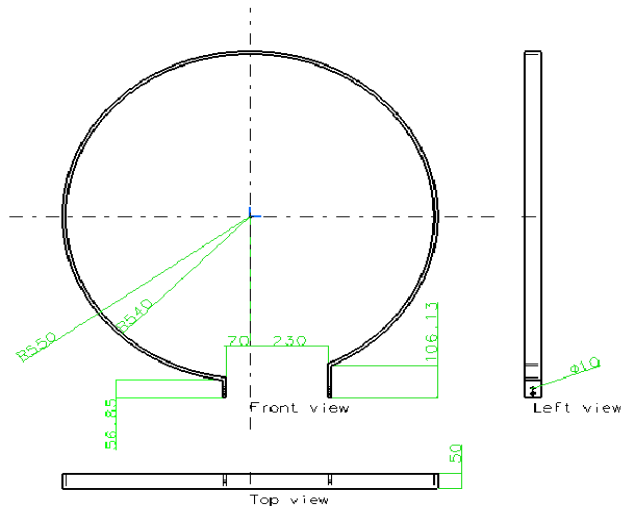
**Figure (3.18.a):** Ground base perspective.



**Figure (3.18.b):** Ground base 3D.

### 3.2.13 Outer shell

Outer shell figures (3.19) used to protect students from accidents, either when the specimen is broken or when the hummer fall down.

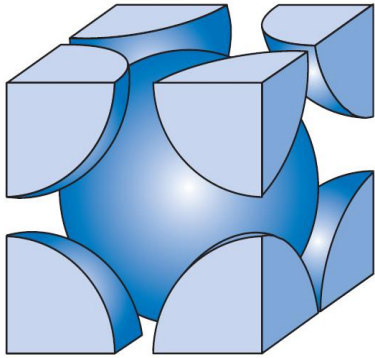


**Figure (3.19.a):** Outer shell perspective. **Figure (3.19.b):** Outer shell 3D.

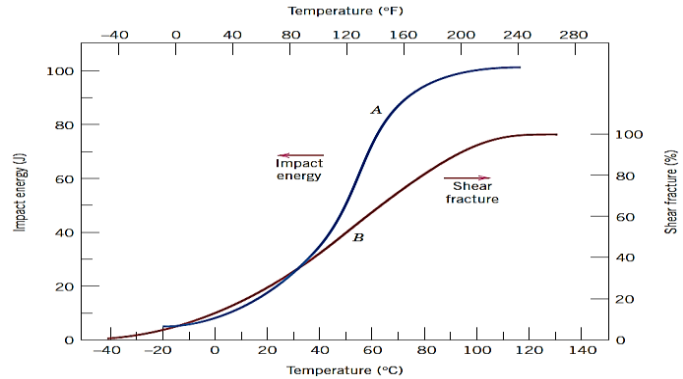
### 3.3 Furnace:

#### 3.3.1 Temperature affects:

Generally, fracture behavior of BCC Fig (3.3.1) structured metals such as mild steels vary with temperature. At low temperature, BBC metals fracture in a brittle mode and becomes more ductile as the temperature increases. FCC structure metals such as stainless steels, copper and aluminum however do not show a dramatic change in fracture behavior with increasing temperature. Therefore, an investigation of fracture behavior in BCC structure metals is concerned with the ductile to brittle transition temperature (DBTT) curve Fig (3.3.2).<sup>[11][9]</sup>



**Figure (3.3.1):** BCC crystal structure.



**Figure (3.3.2):** ductile to brittle transition temperature

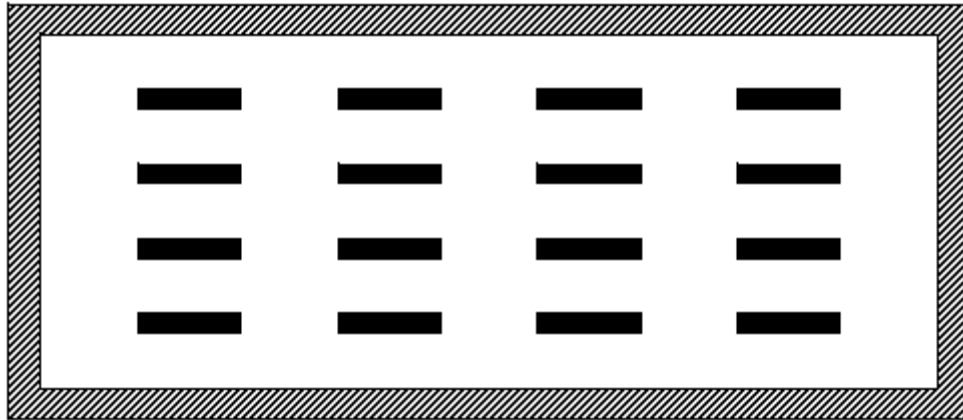
Therefore, the use of structural materials especially BCC metals should concern about their service temperatures such that brittle fracture can be avoided. Temperatures at which material fracture appear fully ductile are considered to be safe whereas the application in the transition temperature involves certain degrees of risk.

### 3.3.2 Furnace specifications:

Furnace Fig (3.3.3) designed to carry 16 specimens at the same time. Specimen will be carried and placed through the two holders from the left and to the right, and the same time an enough space between the specimens take in the design.

Furnace temperature sources are resistance heaters, 220V ac voltage should supply to the heaters. Heaters are distributed in the furnace to ensure the maximum temperature distribution.

Temperature sensor that will be used in the furnace is LM35 that has linear output voltage proportional to the furnace temperature. Temperature range is (25–130) C, and controlled from PC.



*Figure (3.3.3): Furnace schematic.*

### 3.3.3 30[J] angle identification:

It is important to note that the relation between the angle rotation of pendulum and its potential energy is nonlinear, so points has been found between the energy and angle and by using matlab; relation has been found and implemented.

ANGLE	0	5	10	15	20	25	30
ENERGY	0	0.0633141	0.2527741	0.5669369	1.0034096	1.5588679	2.2290808

30	35	40	45	50	55	55
2.2290808	3.0089435	3.8925161	4.8730686	5.9431325	7.0945572	7.0945572

60	65	70	75	80	85	90
8.3185728	9.6058563	10.946603	12.3306	13.747307	15.185932	16.635518

95	100	105	110	115	120	125
18.085024	19.52341	20.939719	22.323165	23.663209	24.949645	26.172674
130	135	140	144			
27.322982	28.391806	29.371005	30.084799			

This values has been implemented from matlab curve fit, 3<sup>rd</sup> order equation has been obtained obtained.

$$y = p1*x^3 + p2*x^2 + p3*x + p4$$

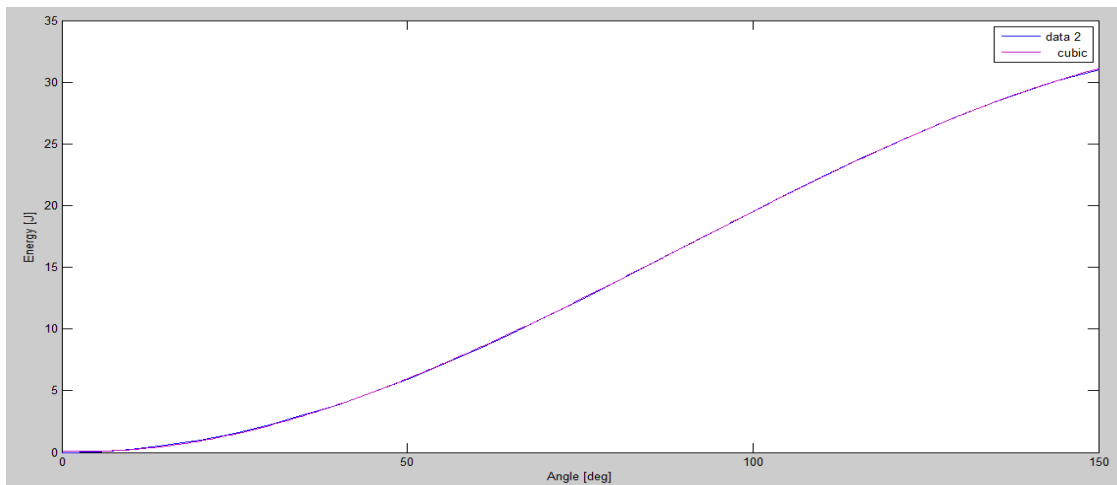
Coefficients are:

$$p1 = -1.2863e-05$$

$$p2 = 0.003468$$

$$p3 = -0.02445$$

$$p4 = 0.13102$$



**Figure (3.19):** Curve between angle and energy impact.



### 3.3.4 20 [J] angle identification:

ANGLE	0	5	10	15	20	25	30
ENERGY	0	0.0420915	0.1680455	0.3769025	0.6670717	1.0363431	1.481904

30	35	40	45	50	55	30
1.481904	2.0003606	2.5877641	3.2396403	3.9510241	4.716497	1.481904

60	65	70	75	80	85	90
5.5302286	6.3860211	7.277356	8.1974442	9.1392778	10.095683	11.059375

95	100	105	110	115	120	125
12.023014	12.97926	13.92083	14.840551	15.731419	16.586648	17.399724

130	135	140	144			
18.164454	18.875014	19.52599	20.000524			

This values has been implemented from matlab curve fit, 3<sup>rd</sup> order equation has been obtained obtained.

$$y = p1*x.^3 + p2*x.^2 + p3*x + p4$$

p1 = -8.4948e-06;  
p2 = 0.0022948  
p3 = -0.01574  
p4 = 0.082634

## Chapter 4

### Electronic and Electrical Component

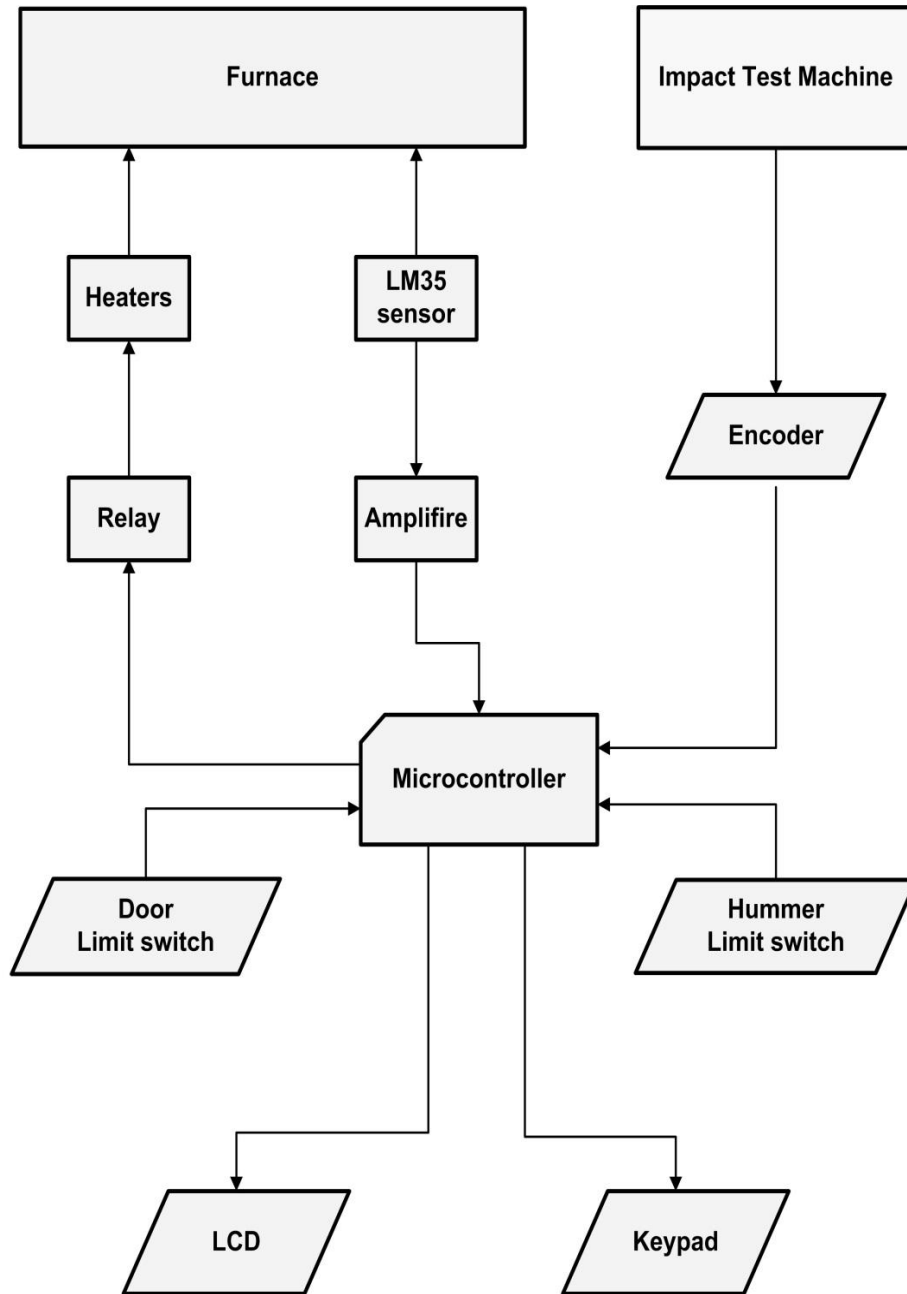
#### 4.1 Introduction and block diagram:

Machine designed to make as much as possible accurate reading, safety and easy usage, electrical and electronics parts are used for this purpose. Because materials' properties changes with temperature; separately furnace will be attach, encoder is used to measure the angle before and after the impact, an encoder and sensor are connecting to Arduino microcontroller in order.

An Interface LCD above the machine describes the situation of the furnace and the machine, this window contains the actual temperature, button to manually enter the reference temperature, also will contain energy absorbed by the specimen.

Values of the absorbed energy for each specimen at specific temperature appear on the LCD, after several tests, students can obtain several points as temperature versus impact energy and they can draw (DBTT) –ductile to brittle transition curve- graph between temperature of specimen [T] and energy absorbed [C].

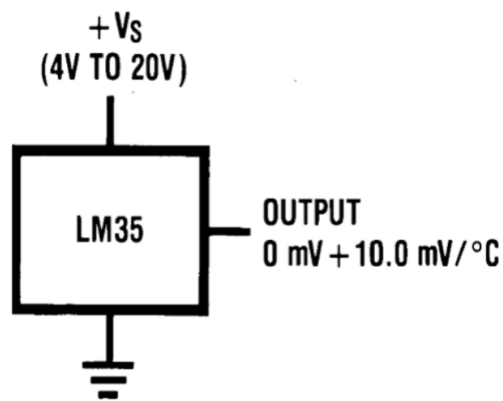
Project block diagram figure (4.1) describes the integration of every components with the other components.



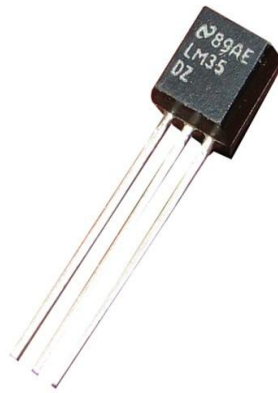
*Figure (4.1): project block diagram.*

## 4.2 Temperature sensor:

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling.

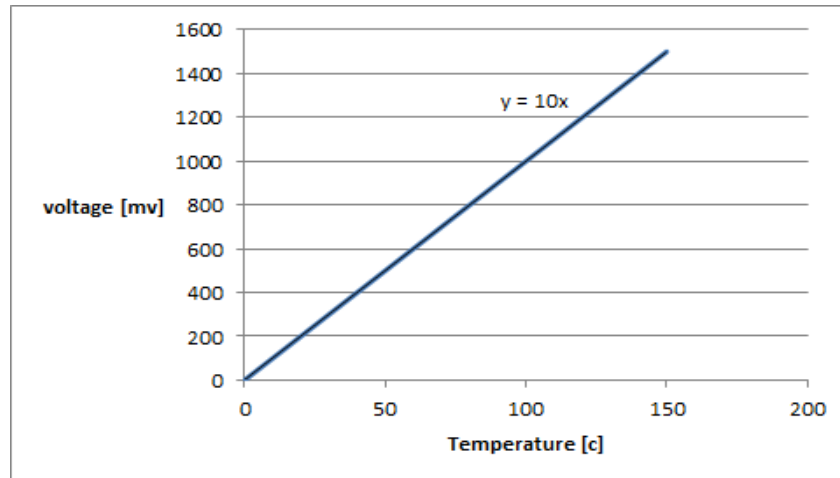


*Figure (4.2): Pin connection of LM35.*



*Figure (4.3): LM35.*

The LM35 does not require any external calibration or trimming to provide typical accuracies of  $\pm 1/4^\circ\text{C}$  at room temperature and  $\pm 3/4^\circ\text{C}$  over a full  $-55$  to  $+150^\circ\text{C}$  temperature range. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies.



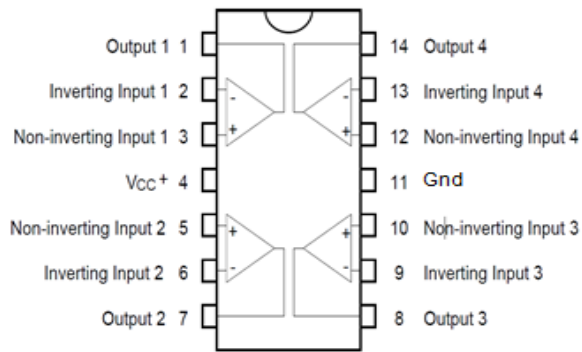
**Figure (4.4):** LM35 specifications.

In the beginning of searching for the most appropriate temperature sensor, many choices are available like thermocouple, IC temperature sensor. The LM35 was the most appropriate one according to the range needed and its linear behavior.

### 4.3 Operational amplifiers:

The TS324 contains four independent high gain operational amplifiers with internal frequency compensation. The four op-amps use a split power supply. The device has low power supply current drain, regardless of the power supply voltage. The low power drain also makes the TS324 a good choice for battery operation. When your project calls for a traditional op-amp function, now you can streamline your design with a simple single power supply. Use ordinary +5V common to practically any digital system or personal computer application, without requiring an extra 15V power supply just to have the interface electronics you need.

The TS324 variety of transducers to dc gain blocks, or any op-amp function. The attached pages offer some recipes that will have your project cooking in no time.

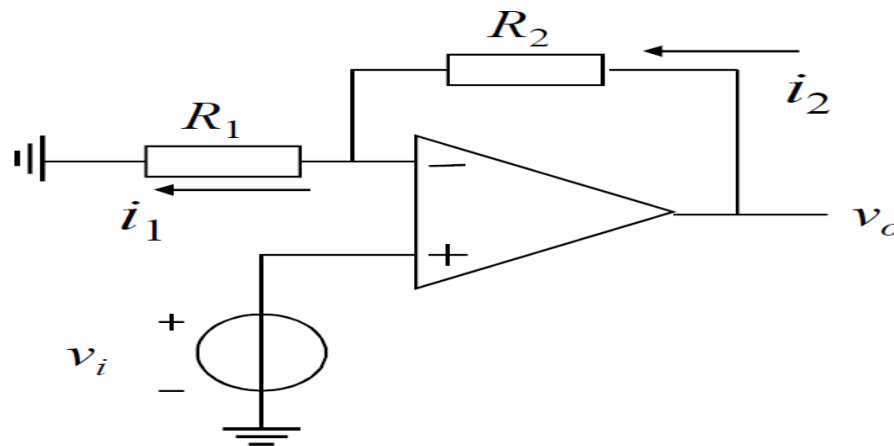


**Figure (5.7):** TS324 pin connection.



**Figure (5.8):** TS324.

The LM35 gives 10mv/C; this small value can lose or change through the wire and electrical component disturbances. TS324 is used to multiplication voltage of temperature sensor, so that the scale becomes higher and therefore more accurate temperature can be obtain, non-inverting amplifier type used in this project. See figure (4.9).



**Figure (4.9):** non-inverting amplifier.

#### 4.4 Numerical calculations:

The Arduino (microcontroller) maximum input voltage is 5 [V] , so the input voltage from the sensor should be less than 5 [V], in addition amplification voltage should added after temperature sensor to increase the voltage operation rang to increase the accuracy, the following calculation determines the appropriate resistances needed in the non-inverting amplifier.

- To find gain in non-inverting connection:

$$\text{Gain} = \left( \frac{R_2}{R_1} + 1 \right) \quad \dots (4.1)$$

Where:

Gain: value of multiplication voltage.

$R_1, R_2$ : resistance (see figure 4.9)

$$R_1 = 4.7[\text{k}\Omega], R_2 = 2[\text{k}\Omega]$$

$$\text{Gain} = \left( \frac{4.7\text{k}}{2\text{k}} + 1 \right) = 3.35$$

- To find  $V_o$  :

$$V_o = \text{Gain} * V_i \quad \dots (4.2)$$

Where:

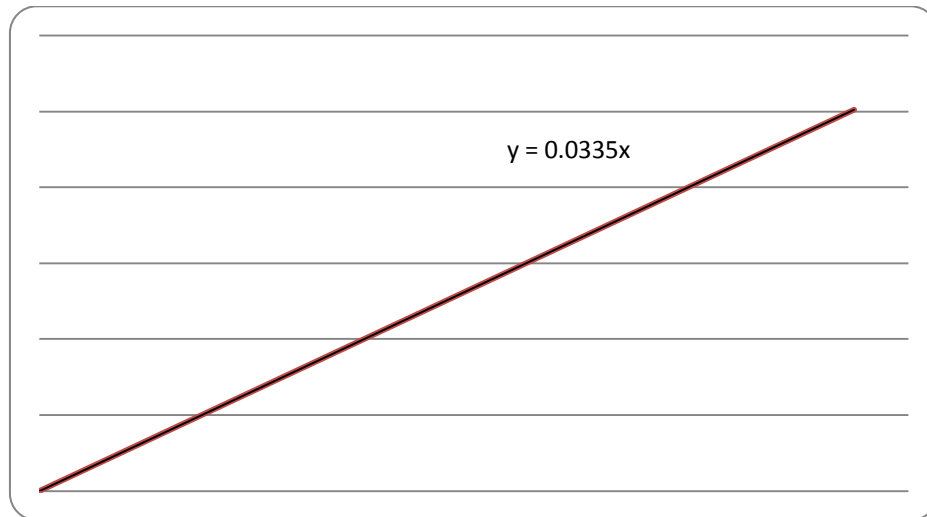
$V_o$ : Output voltage after non-inverting amplifier (see figure 4.9).

$V_i$ : Output voltage from sensor and the input voltage for amplifier (see figure 4.9).

$$V_o = (3.35) * V_i.$$

- At maximum  $V_i$ :

$$V_o = (3.35) (1.5) = 5.025\text{volt} = \text{max. volt input.}$$



*Figure (4.8): Output voltage after amplifications.*

## **4.5 Encoder:**

### **4.5.1 Encoder definition:**

An encoder is a device, circuit, transducer, software program, algorithm or person that converts information from one format or code to another, for the purposes of standardization, speed, secrecy, security, or saving space by shrinking size. A rotary encoder, also called a shaft encoder, is an electro-mechanical device that converts the angular position or motion of a shaft or axle to an analog or digital code.



#### **4.5.2 Encoder type:**

There are two main types: absolute and incremental (relative). The output of absolute encoders indicates the current position of the shaft, making them angle transducers. The output of incremental encoders provides information about the motion of the shaft, which is typically further processed elsewhere into information such as speed, distance, and position.

An incremental encoder works differently by providing an A and a B pulse output that provide no usable count information in their own right. Rather, the counting is done in the external electronics. The point where the counting begins depends on the counter in the external electronics and not on the position of the encoder. To provide useful position information, the encoder position must be referenced to the device to which it is attached, generally using an index pulse. The distinguishing feature of the incremental encoder is that it reports an incremental change in position of the encoder to the counting electronics.

An incremental rotary encoder provides cyclical outputs (only) when the encoder is rotated. They can be either mechanical or optical. The fact that incremental encoders use only two sensors does not compromise their accuracy. One can find in the market incremental encoders with up to 10,000 counts per revolution, or more.

There can be an optional third output: reference or "index", which happens once every turn. This is used when there is the need of an absolute reference, such as positioning systems. The optical type is used when higher speeds are encountered or a higher degree of precision is required.

Incremental encoders are used to track motion and can be used to determine position and velocity. This can be either linear or rotary motion. Because the direction can be determined, very accurate measurements can be made.

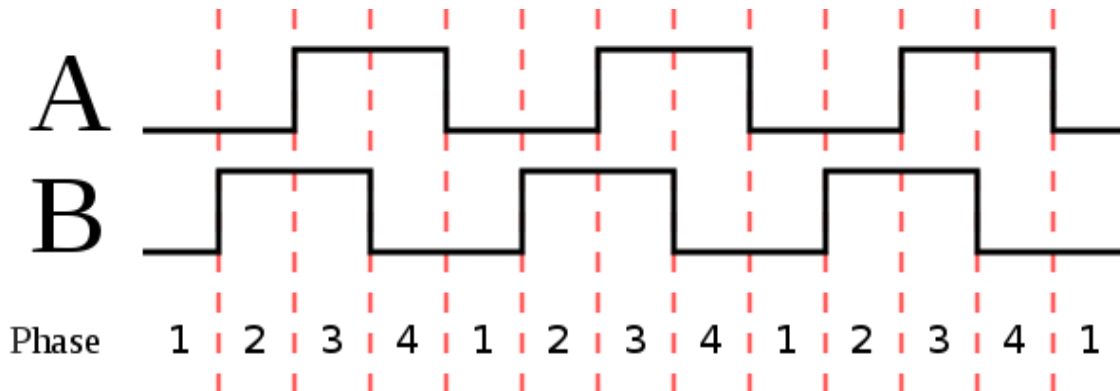
### 4.5.3 Encoder operating principle:

They employ two outputs called A & B, which are called quadrature outputs, as they are 90 degrees out of phase. The state diagram in Table (4.1):

Phase	A	B
1	0	0
2	0	1
3	1	1
4	1	0

Phase	A	B
1	1	0
2	1	1
3	0	1
4	0	0

*Table (4.1) a) Coding for clockwise rotation. b) Coding for counter-clockwise rotation.*



*Figure (4.11): Two square waves in quadrature (clockwise rotation).*

The two output wave forms are 90 degrees out of phase, which is all that the quadrature term means. These signals are decoded to produce a count up pulse or a

countdown pulse. For decoding in software, the A & B outputs are read by software, either via an interrupt on any edge or polling, and the above table is used to decode the direction. For example, if the last value was 00 and the current value is 01, the device has moved one half step in the clockwise direction. The mechanical types would be debounced first by requiring that the same (valid) value be read a certain number of times before recognizing a state change.

On encoders with detents there are different ways to switch states. In some, both A and B are always open circuit at the detents, and an entire 00 → 00 switching cycle occurs while transitioning from one detent to the next. Others have detents of alternating 00 and 11 value, with staggered switching times during the transition between detents

If the encoder is turning too fast, an invalid transition may occur, such as 00 → 11. There is no way to know which way the encoder turned; if it was 00 → 01 → 11, or 00 → 10 → 11. If the encoder is turning even faster, a backward count may occur.

#### 4.5.4 Encoder specifications:

The encoder specifications chosen as follows: 5 [V], 1024 [pulse per revolution].

$$F = N/360 \quad \dots (4.4)$$

$$F = 1024/360 = 2.844 \text{ [Pulse/Degree]}$$

- Number of pulses just before the hummer strikes the specimen (N1)

$$N1 = f(\theta + 90) \quad \dots (4.5)$$

$$N1 = 2.844 \text{ (pulse/degree)} * 150 \text{ (degree)} \quad , (\theta = 60)$$

$$N1 = 426 \text{ [pulse]}$$

$$N2 = N - N1 \quad \dots (4.6)$$

$$\alpha = N2 * 1/f \text{ [degree]} \quad \dots (4.7)$$

$$H = CG*(1 -\cos (60)) \quad \dots (4.8)$$

$$H = 0.75 \text{ [m]}$$

$$E = M_{tot} g H - M_{tot} g H2 \quad \dots (4.10)$$

Where:

$M_{tot}$ : Total mass of hummer and connecting rod.

N: Number of pulses from encoder.

F: Degree factor.

N: Total Pulse number from hummer dropping start until hummer reverses its direction.

N1: Number of pulses just before the hummer strikes the specimen.

N2: Number of pulses after hummer strikes the specimen at maximum height.

$\alpha$ : Maximum Elevation angle after the Hummer strikes the specimen.

E: Impact energy absorbed by specimen.

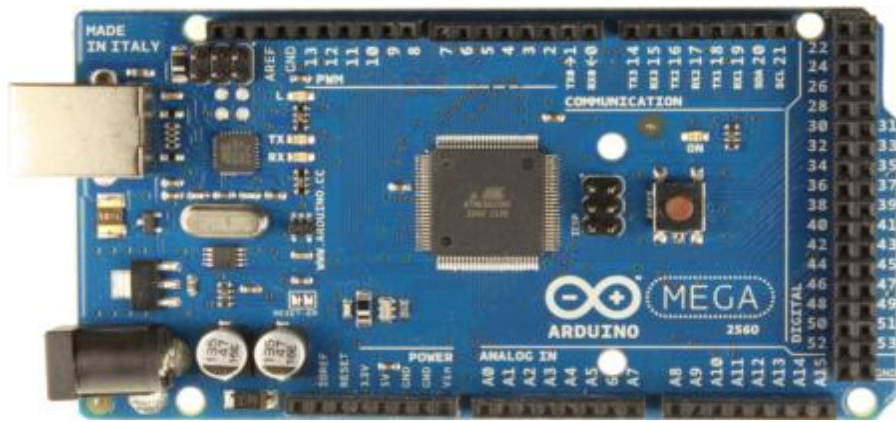
CG: Center of gravity for hummer and connecting rod longitudinal from the rotational axis towards hummer.

H: Hummer elevation before impact.

H2: Hummer elevation after impact.

#### 4.6 Arduino microcontroller:

The Arduino Mega is a microcontroller board based on the ATmega1280 (datasheet). It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila.



*Figure (4.10): Arduino mega.*

#### 4.7 Arduino software:

A SoftwareSerial library allows for serial communication on any of the Mega's digital pin, the Arduino Mega can be programmed with the Arduino software.

The ATmega1280 also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation on the Wiring website for details. To use the SPI communication, please see the ATmega1280 datasheet.

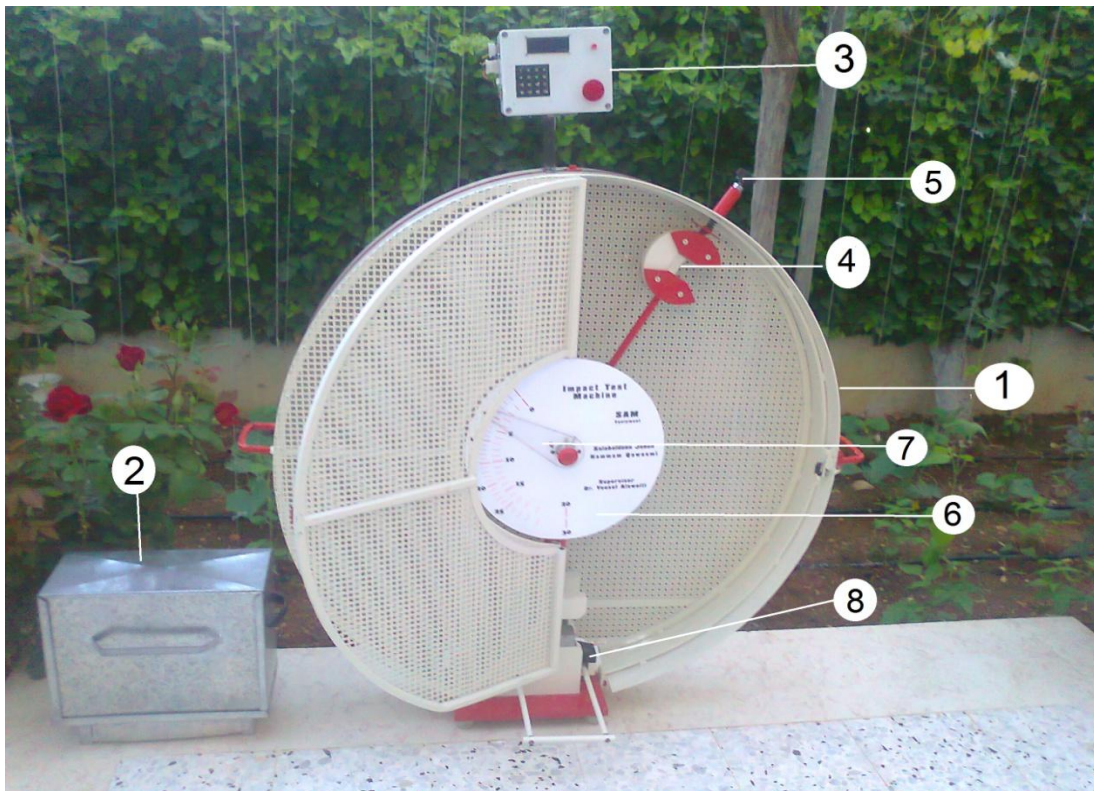
The ATmega1280 on the Arduino Mega comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol.

## Chapter 5

### Impact test machine user manual

#### 5.1 Machine parts

The machine consist of two main parts: **Impact machine** and **Furnace**.



*Figure (5.1): Impact machine parts.*

1. Impact test machine.
2. Furnace.
3. Control panel.
4. Hummer.
5. Lock pin.
6. Impact energy scale.
7. Pointer.
8. Damper.

## 5.2 Automatic modes.

Before start experiment, check the power input and connect to 220 volt to furnace, and 12 volt to impact test machine.

Control panel is an interfacing unit between user an machine, Keypad used to input data and control parameters, LCD displays current situation, parameters and options, emergency button used to disconnect overall power at emergency situation and reset button to restart the microcontroller program.



*Figure (5.2): Control panel.*



### Working technique:

- ✚ A the beginning LCD displays welcome message to user.
- ✚ User has to choose working energy whether it is 20 [J] or 30 [J], choose between them depends on hummer extension is installed or not.
- ✚ Open furnace.



*Figure (5.3): Open furnace.*

- ✚ Insert the specimen in its designated place.



*Figure (5.4): Insert specimen .*

- ✚ After specimen reach its reference temperature, open furnace and by using custom clamp move specimen safety to machine.



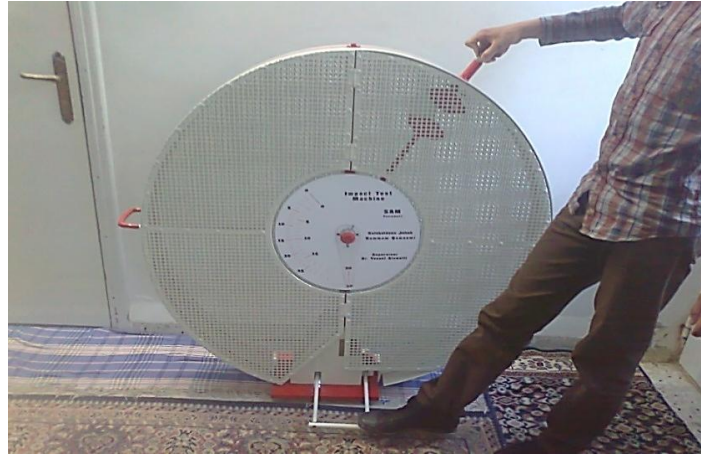
*Figure (5.5): Install specimen in impact machine.*

- ✚ Insert specimen in its designated place in the machine and move it to right side as much as possible.



*Figure (5.1): Suitable way to install specimen .*

- ✚ Close machine's door and press on damper then start experiment by dragging the lock pin.



**Figure (5.7):** Press damper and dragging locking pin.

- ✚ Drag the pointer at 20 [ J ] or 30 [ J ] scale.
- ✚ Impact energy value digitally appears on LCD, and also pointer mechanically moves to the impact energy scale.

### **5.2.1 Change reference temperature:**

- ✚ User can change reference temperature by pressing on 'C' button from keypad.
- ✚ LCD ask user to enter temperature.
- ✚ Range of temperature can entered (15-120) Celsius, if user input value out of the range wrong message appears and user has entered temperature again.
- ✚ 'B' bottom used to clear input temperature.
- ✚ 'A' bottom used to verify temperature.
- ✚ After user press on 'A', LCD display home screen that contains reference temperature and actual temperature.

### 5.3 Manual mode:

This mode used when electric cut off or when any problem happen in microcontroller, note that this mode doesn't support change temperature or digital LCD.

- ✚ User has to choose working energy whether it is 20 [J] or 30 [J], choose by installed hummer extension or not.



*Figure (5.8): Impact machine.*

- ✚ Insert specimen in its designated place in the machine and move it to right side as much as possible.
- ✚ Close machine's door and press on damper then start experiment by dragging the lock pin.
- ✚ Drag the pointer at 20 [ J ] or 30 [ J ] scale.
- ✚ If user installed hummer extinction look at 30[J]scaling, If hummer extension not installed look at 20[J]

## **Chapter 6**

### **Impact Test Report**

#### **6.1 Objectives:**

- 1) Students are required to study the principle of impact testing using metals which are susceptible to brittle fracture such as mild steels.
- 2) Types of fracture in metals are investigated using the fracture energy absorption criterion. Students can explain the meaning and use of Ductile-to-Brittle-Transition.
- 3) Temperature Curve (DBTT) and explain the relationship between the absorbed energy of the specimen and its fracture surfaces. Identify the transition temperature of the tested materials.
- 4) Students are capable of interpreting the obtained experimental data for the selection of engineering materials.

#### **6.2 Theory:**

Charpy impact test is practical for the assessment of brittle fracture of metals and is also used as an indicator to determine suitable service temperatures. To perform the test,

the pendulum set at a certain height is released and impact the specimen at the opposite end of the notch to produce a fractured sample.

The energy is calculated from the difference in initial and final heights of the swinging pendulum.

$$E = M_{\text{tot}} g H - M_{\text{tot}} g H_2$$

E: Energy absorbed by the specimen.

M<sub>tot</sub>: Total mass of hummer and connecting rod.

g: gravity acceleration.

H: Hummer elevation before impact.

H<sub>2</sub>: Hummer elevation after impact.

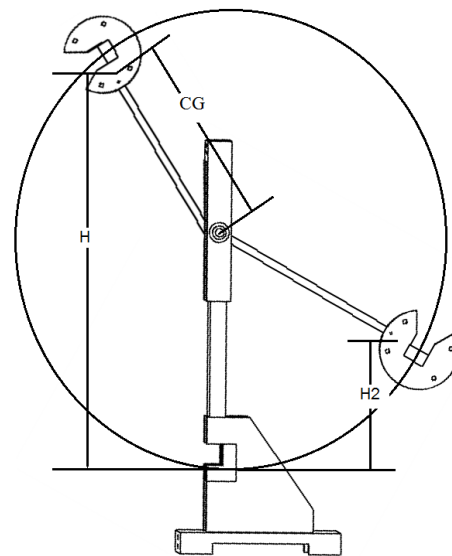
CG: Distance for center of gravity.

$$CG = 0.4014 \text{ [m]}$$

$$H = 0.4014 * (1 + \sin(60))$$

$$H = 0.79102 \text{ [m]}$$

$$g = 9.81 \text{ [m/s}^2\text{]}$$



**Figure (6.1):** Machine sketch.

### 6.3 Procedure:

A) On the Interface screen

- i. Chose the energy capacity (20 or 30) joules.
- ii. Reset the encoder counter.
- iii. Enter the desired temperature.

B) On the Machine

- i. Rise the hammer to its height until the lock pin goes inside the hummer.
- ii. Wait until the specimen temperature settled in.
- iii. Take the specimen from furnace.
- iv. Put the specimen in its place above the carrier.
- v. Release the hummer and save the results.

#### 6.4 Mathematical calculation:

$$E = M_{\text{tot}} g H - M_{\text{tot}} g H_2$$

$$E = (0.4014) (9.81) (0.79102) + (0.4014) (9.81) (H_2)$$

Specimen number	Specimen Temperature [C]	E [N.m]
1	25	
2	50	
3	75	
4	100	
5	125	

*Table (5.1): experiment data table.*

Draw brittle to ductile transition curve, Temperature [C] on the x-axis and energy absorbed [N.m] on y-axis. And comment on the results.

Drawing the brittle to ductile transition curve shows that the energy absorbed by the specimen increase by increase temperature for the same material.

### **6.5 Questions:**

Q1) As the temperature increase, the absorption energy increase or decrease?

As the temperature increase, the energy absorbed by the specimen increase, because of brittle to ductile transition material state.

Q2) for what reasons brittle fracture concerned more than ductile fracture?

- More energy needed in the ductile fracture because it is a tough material.
- Brittle fracture happens quickly without warning while the ductile fracture took a longer time before the whole process to happen.

### **6.6 conclusions:**

Increasing the materials temperature will cause increasing of its ability to absorb energy to fracture, this called brittle to ductile transition.



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# Appendix

# Appendix A

# Appendix A

## Arduino programming

```
#include <Keypad.h>
#include <LiquidCrystal.h>

// initialize the library with the numbers of the interface pins
LiquidCrystal lcd(8, 9, 10, 11,12, 13);

char arr [5] ={}; // used to store the temperature digits while being entered
float DT =15 ; // the final desired temperature
float LM35=0;
float ActTemp=0;
int keyno = 0; // to store the current number of digits that hs been pressed
boolean dots = false; // to know if dot are exist
boolean afterdot = false; // to know if any number after dot enter
boolean no = false; // to chek th pressed key if t no or not
float sensor = A0;
const int relay = 14;

int pinA = 3; //Encoder pin A input
int pinB = 5; //Encoder pin B input
int Pos = 0; //no of counts of encoder
int prev = LOW;
int n = LOW;
int CCWW=0;
int Ocillation =0;
```

```

char key ;
int enval=0;
float angle = 0;
float abenergy = 0;
const float factor = 1024/360;
const int LMD =16;
int LMDstate =0;

// setting up the keypad
const byte ROWS = 4;
const byte COLS = 4;
char keys[ROWS][COLS] = {
  {'1','2','3','A'},
  {'4','5','6','B'},
  {'7','8','9','C'},
  {'.','0','#','D'}
};
byte rowPins[ROWS] = {46,48,50,52}; //connect to row pinouts
byte colPins[COLS] = {38,40,42,44}; //connect to column pinouts

Keypad keypad = Keypad( makeKeymap(keys), rowPins, colPins, ROWS, COLS );

// setting up the LCD
void setup()
{
  lcd.begin(16, 2);

```

```

lcd.print("Welcome.. Impact");

lcd.setCursor(0, 1);

lcd.print("Test Machine");

pinMode(relay, OUTPUT);

pinMode(LMD, INPUT);

digitalWrite (relay, LOW);

// attachInterrupt(2, emergency, CHANGE); // define interrupt no. 2

//function of emergency which located at pin 21

attachInterrupt(3, ENCODER1, LOW); // define interrupt no. 3

//function of emergency which located at pin 20

delay (3000);

lcd.clear();

lcd.print("Energy capacity");

lcd.setCursor(0,1);

lcd.print("2:20J   3:30J");

while ( key!='2' || key !='3')

{

  if (key=='2' || key =='3')

    break;

  key = keypad.getKey();

} //while ( key!='2' || key !='3')

switch (key)

{

  case '3':

    {

```

```

    enval=30;
    break;
}
case '2' :
{
    enval=20;
    break;
}
}////switch (key)
lcd.clear();
lcd.print("Selected Energy");
lcd.setCursor(0,1);
lcd.print("Capacity Is ");
lcd.print(enval);
lcd.print("J");
delay(2000);
} //void setup()

void DOOR ()
{
while (LMDstate==HIGH)
{
    // key=NO_KEY;

    for(int d =0; d<21 ;d++)
    {

```

```

LMDstate = digitalRead(LMD);
if (LMDstate==LOW)
    break;
key = keypad.getKey();
if (key=='C')
{
    LMDstate==LOW;
    Temperature ();
} //if (key=='C')

lcd.clear();
lcd.print("  Error  ");
lcd.setCursor(0,1);
lcd.print(" Close The Door ");
delay(100);
} //for(int d =0; d<41 ,d++)

for(int i =0; i<21 ;i++)
{
    LMDstate = digitalRead(LMD);
    if (LMDstate==LOW)
        break;
    key = keypad.getKey();
    if (key=='C')
    {
        LMDstate==LOW;

```



```

    Temperature ();
  } //if (key=='C')

  LM35 = analogRead(sensor);
  ActTemp = ((LM35/1023)*5)*29.989;

  lcd.setCursor(0,0);
  lcd.print("Ref. Temp ");
  lcd.print(DT);
  lcd.setCursor(15,0);
  lcd.print("C ");
  lcd.setCursor(0,1);
  lcd.print("Act. Temp ");
  lcd.print(ActTemp);
  lcd.setCursor(15,1);
  lcd.print("C ");
  delay(100);

  if (ActTemp <(DT-0.5) )
    digitalWrite (relay, HIGH);
  else
    if(ActTemp>(DT+0.5))
      digitalWrite (relay, LOW);

} //for(int i =0; i<41 ,i++)

```

```

} //while (LMDstate==HIGH)

digitalWrite(LMDstate, LOW);

} //void DOOR

//void(* resetFunc) (void) = 0; //declare reset function @ address 0
//
//void emergency()
//{
// resetFunc(); //call reset
//}

boolean encint = false;
void ENCODER1()
{
  encint = true;
}

void ENCODER()
{
  Pos = 0;
  prev = LOW;

```

```

n = LOW;
CCWW=0;
Ocillation =0;
lcd.clear();
lcd.print ("Waiting... ");
while (CCWW==0)
{
n = digitalRead(pinA);
if ((prev == LOW) && (n == HIGH))
{
if (digitalRead(pinB) == LOW)
{
Pos++;
} // if (digitalRead(encoder0PinB) == LOW)
else
{
if (Pos > 460 && Ocillation >10)
{
CCWW=1;
} // if (Pos >465)
Pos--;
Ocillation ++;
} // else

} // if ((prev == LOW) && (n == HIGH))
prev = n;

```

```

if (CCWW!=0)
{
    key=NO_KEY;
//    Pos = Pos +10;
//    angle = Pos - 430;
//    angle = angle/factor;
//    abenergy = 421-angle;
    lcd.clear();
    lcd.print("Energy absorbed");
    lcd.setCursor(0,1);
    lcd.print(Pos);
    lcd.print("      ");
    while(key != 'D' )
    {
        key = keypad.getKey();
    }
    encint = false;
    loop();
} //if (CCWW!=0)
} //while (CCWW==0)
} //void ENCODER()

void Temperature ()
{

if (keyno==0)

```

```

for (int i=0; i<5; i++)
    arr [i] = 0 ;
lcd.clear();
lcd.print("Enter Temp.");
while (key !='A')
    { // OK
    key = keypad.getKey();
    if (key !=NO_KEY)
    {
    if ( key!='A' && key!='B' && key!='C' && key!='D' && key!='#' && key!='.' )
        no = true;
    else
        no = false;
    switch (no)
    {
    case true:
    {
    if (afterdot == false)
    {
    lcd.setCursor(0, 0);
    lcd.print("Desired temp. is");
    lcd.setCursor(keyno, 1);
    lcd.print(key);
    lcd.setCursor(keyno+1, 1);
    lcd.print("      ");
    arr [keyno]=key;

```

```

keyno++;
} // if (afterdot == false)
if (dots==true)
    afterdot=true;

if (keyno >5)
{
    lcd.clear();
    lcd.print("error input  ");
    delay(1000);
    lcd.clear();
    lcd.print("re-input temp. ");
    delay(1000);
    keyno=0;
    dots = false;
    afterdot = false;
} //if (keyno >5)

break;
} // for case 1 when no is true

case false:
{
    switch (key)
    {
        case 'A': // used for enter

```

```

{

lcd.clear();

DT = atof (arr); //convert array contents to float

if ( DT>120 || DT<15)
{
  lcd.print("error input  ");
  delay(1000);
  lcd.clear();
  lcd.print("Temp. shoulde be");
  lcd.setCursor(0,1);
  lcd.print("Between 15-120 C");
  delay(3000);
  lcd.clear();
  lcd.print("re-input temp. ");
  delay(1500);
  keyno=0;
  dots = false;
  afterdot = false;
  for (int i=0; i<5; i++)
    arr [i] = 0 ;
  //relogToTemp = true;
  key = 'C';
//  Temperature ();
//return ;

```

```

    }// if (DT>120 || DT<20)

else
{
    lcd.print("Entered Temp. Is");
    lcd.setCursor(0, 1);
    lcd.print(DT);
    dots=false;
    afterdot=false;
    lcd.setCursor(keyno, 1);
    lcd.print(" C      ");
    keyno=0;
    dots=false;
    afterdot=false;
    break;
} //elseOpp

} // case 'A':

case 'B': // used for clear
{
    lcd.clear();
    lcd.print("Desired temp. is");
    keyno=0;
    DT=0;
    dots=false;
    afterdot=false;

```



```
break;
} // case 'B':

case 'C':
{

break;
} // case 'C':

case 'D':
{
ENCODER ();
break;
} // case 'D':

case '!':
{
if (key=='.' && dots==false)
{
lcd.setCursor(keyno, 1);
lcd.print(key);
dots=true;
arr[keyno]=key;
keyno++;
}
```

```

    break;
    }// if (key=='.' && dots==false)
}// case '.':

case '#':
{

    break;
}// case '#':

}//switch (key)

break;
}//case false:
}// switch (no)
}//if (key !=NO_KEY)
}//while (key!='A')
}//void Temperature

// Starting the program
void loop()
{
    key = keypad.getKey();
    if (keyno==0)
    for (int i=0; i<5; i++)
        arr [i] = 0 ;

```

```

LM35 = analogRead(sensor);

ActTemp = ((LM35/1023)*5)*29.989;

lcd.setCursor(0,0);
lcd.print("Ref. Temp ");
lcd.print(DT);
lcd.setCursor(15,0);
lcd.print("C ");
lcd.setCursor(0,1);
lcd.print("Act. Temp ");
lcd.print(ActTemp);
lcd.setCursor(15,1);
lcd.print("C ");
// delay(100);

LMDstate = digitalRead(LMD);
DOOR();
digitalWrite(LMDstate, LOW);
delay(100);

if (ActTemp <(DT-0.5) )
    digitalWrite (relay, HIGH);
else

```

```
if(ActTemp>(DT+0.5))  
    digitalWrite (relay, LOW);
```

```
if (encint)  
    key = 'D';
```

```
if (key !=NO_KEY)  
{  
    if ( key!='A' && key!='B' && key!='C' && key!='D' && key!='#' && key!='.')  
        no = true;  
    else  
        no = false;
```

```
if (no == false)  
{  
    switch (key)  
    {  
  
        case 'C':  
        {  
            Temperature ();  
            break;  
        }// case 'C':  
  
        case 'D':
```

```
{  
    ENCODER ();  
    break;  
} // case 'D':  
  
case '#':  
{  
  
    break;  
} // case '#':  
break;  
} //switch (key)  
  
} //if (no == false)  
} //if (key !=NO_KEY)  
} // void loop()
```

# Appendix B

## Appendix B

### M-file

```
% for 30 [J]
angle_30J=[0    5    10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
85   90   95  100  105  110  115  120  125  130  135  140  144  150]

energy_30J=[0    0.063314076  0.252774056  0.566936877  1.003409644  1.558867865
2.229080765  3.008943515  3.892516112  4.873068625  5.943132453  7.09455721
8.318572808  9.605856253  10.94660266  12.33059992  13.74730652  15.18593177
16.63551807  18.08502431  19.52340999  20.93971933  22.32316468  23.66320872
24.94964468  26.17267415  27.32298164  28.39180557  29.371005   30.08479852
31.03143663]

p1 = -1.2863e-05;
p2 = 0.003468
p3 = -0.02445
p4 = 0.13102
y = p1*x.^3 + p2*x.^2 + p3*x + p4

%for 20 [J]
angle_20J=[0    5    10   15   20   25   30   35   40   45   50   55   60   65   70   75   80
85   90   95  100  105  110  115  120  125  130  135  140  144]

energy_20J=[0    0.042091513  0.168045451  0.376902459  0.667071729  1.03634312
1.481903994  2.000360634  2.587764097  3.239640291  3.951024053  4.716496966
5.530228631  6.386021077  7.277355964  8.197444238  9.139277837  10.09568307
11.05937526  12.02301423  12.9792602  13.9208297  14.84055106  15.731419
16.58664804  17.39972412  18.16445427  18.87501374  19.5259904  20.00052388]

p1 = -8.4948e-06;
p2 = 0.0022948
p3 = -0.01574
p4 = 0.082634
y = p1*x.^3 + p2*x.^2 + p3*x + p4
```