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P1A-03: DESIGN, CONSTRUCTION AND TESTING OF A MEAT GRINDING MACHINE

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ABSTRACT
Meat is an essential nutritious food item needed for human consumption from which high quality proteins, minerals and essential vitamins are derived. However, certain categories of consumers such as the children, elderly and sick people might not be able to provide the requisite biting force for chewing of the meat. Thus they would only be able to consume meat in their grinded form. In order to address this problem, it becomes necessary to have a meat grinding machine. Meat grinders are either motorized or manually operated. This paper presents the design, construction and testing of an efficient single meat grinding machine with both manual and motorized mode of operation. To avoid failure of the machine, the calculated working stress of 21MN/m^2 of the machine is kept within the value of the machine ultimate stress of 30MN/m^2 and the calculated factor of safety of 1.4 is within accepted range for factor of safety which indicates that the design is safe. A functional test carried out on the machine shows that it has an efficiency of 69% and 73% for manual and motorized operation respectively. The utilization of this machine would enhance meat processing thereby creating employment. The machine can be used in the urban, rural area and with or without electricity.

Keywords: Design, Construction Assembling, Meat Grinding and Testing.

1.0. INTRODUCTION
The preferred solution to meat processing is to introduce a mechanical and hygienic method of processing meat. The machine is used to force meat by means of rotating shaft under pressure through a horizontal mounted cylinder (shaft housing). At the end of the shaft housing there is a cutting system consisting of a cross-shaped knives rotating with the shaft and a stationary perforated disc (hole plate). The perforation of the hole plate normally range from 1 to 13mm. The meat is compressed by the rotating shaft, forced through the cutting system and extrudes through the hole of the hole plate after being cut by the revolving knives. The degree of grinding is determine by the size of the holes of the hole plate (Principles of Meat Processing Technology, 2014).

This paper presents the design of an efficient single meat grinding machine with both manual and motorized mode of operation, which can be used (in the urban and rural area) and with or without electricity. This design provides the kinematic arrangement of forces, materials selection and proportion of parts to ensure maximum strength and functionality of the machines. Meat grinders are either motorized or manually operated. This paper presents the design, construction and testing of an efficient single meat grinding machine with both manual and motorized mode of operation. The concept of the paper came as a measure to design and construct a machine which can be used for grinding meat into a very smaller piece. This is as to encourage the processing of meat and the establishment of meat processing industries in Nigeria, especially in the northern parts where there is high availability of beef as a raw material.

2.0. METHOD

This work invokes design of a manual and motorized meat grinding machine. Design of individual component of the machine was carried. After the design, various fabrication methods such cutting, welding, grinding, drilling and casting were used for construction of the various components of the meat grinding machine. The individual components of the machine were assembled to form a single meat grinding machine. The manual and motorized operation of the machine was tested using equal mass of meat.

3.0. DESIGN ANALYSIS

The material selection and positioning of components were controlled by the material strength, rigidity, corrosion resistance and the construction method.

3.1. Selection of the V-belt and Calculation of Torque

The machine was designed to use two horse power (2hp) electric motor. Since the power of the electric motor was 1.402kW; a "A" type of V-belt with a power range of 0.7-3.5 kW, a top width (b) of 13mm and thickness (c) of 8mm was selected according to Indian Standard (IS: 2494-1974).

Torque transmitted by electric motor, T_t is given by;

$$T_t = \frac{P}{\omega} \quad 1$$

P = Power transmitted by electric motor, ω = Angular speed of the electric motor

ω = Speed of rotation of electric motor = 1420rev/min

3.2. Calculation of the Tightening Belt Tension T_1 and Slackening Belt Tension T_2,

Figure 1; shows the shaft loading and the power transmission on the manual and motorized meat grinding machine.

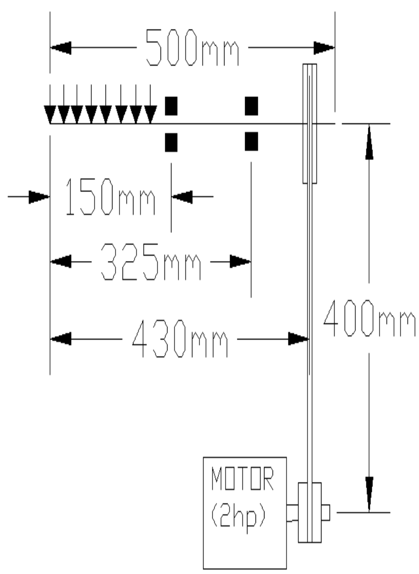


Figure. 1: Meat Grinder Power Transmission

The weight of the pulley W_p is given by;

$$W_P = mg \quad 2$$

Vertical load V_l on the shaft is given by;

$$V_l = (T_1 - T_2)Sin60° \quad 3$$

Horizontal load H_l on the shaft is given by;

$V_l = (T_1 - T_2)Cos60°$ 4

Torque supplied T_t is given by;
$T_t = (T_1 - T_2)r$ 5

r = radius of the smaller pulley

Peripheral Velocity V is given by;

$V = \omega r$ 6
Mass/unit length of belt m is given by;

$m = PgA$ 7
p = Density of the belt = 980kg/m^2

g = Acceleration due to gravity = 9.8m/s^2, A = Cross-sectional area of belt m^2

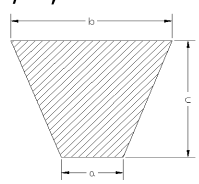


Figure 2: Belt Cross Sectional View

Cross-sectional area A of the belt is given by;
$A = \frac{1}{2}(a + b)c$ 8

Centrifugal Tension T_c is given by;

$T_c = MV^2$ 9
$\frac{T_1 - T_C}{T_2 - T_C} = e^{\frac{\mu\propto_1}{sin\theta/2}}$ 10

μ = Coefficient of friction between belt and pulley = 0.2

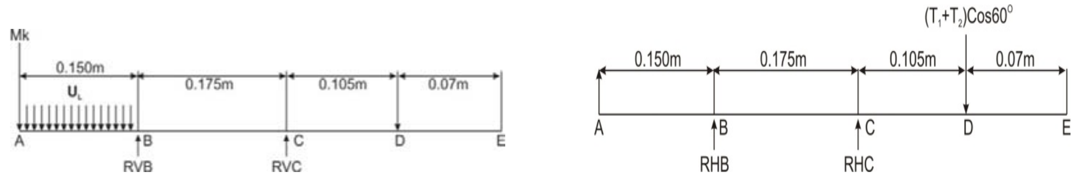
θ = Groove angle for V-belt = 30^O, ρ = Density of belt materials = 980kg/m^3,

$\propto_1$ = Angle of wrap for smaller pulley (rad) = $180^0 - 2Sin^{-1}\frac{R-r}{c}$

C = Centre distance between pulley
R = Larger pulley radius r = Small pulley radius

$But,\ D = \frac{N_1 d}{N_2}.$

N_1 = Speed of the electric motor or small pulpy (r.p.m) N_2 = Speed of the larger pulley (r.p.m)
d = Diameter of the smaller pulley (m) D = Diameter o the larger pulley (m)



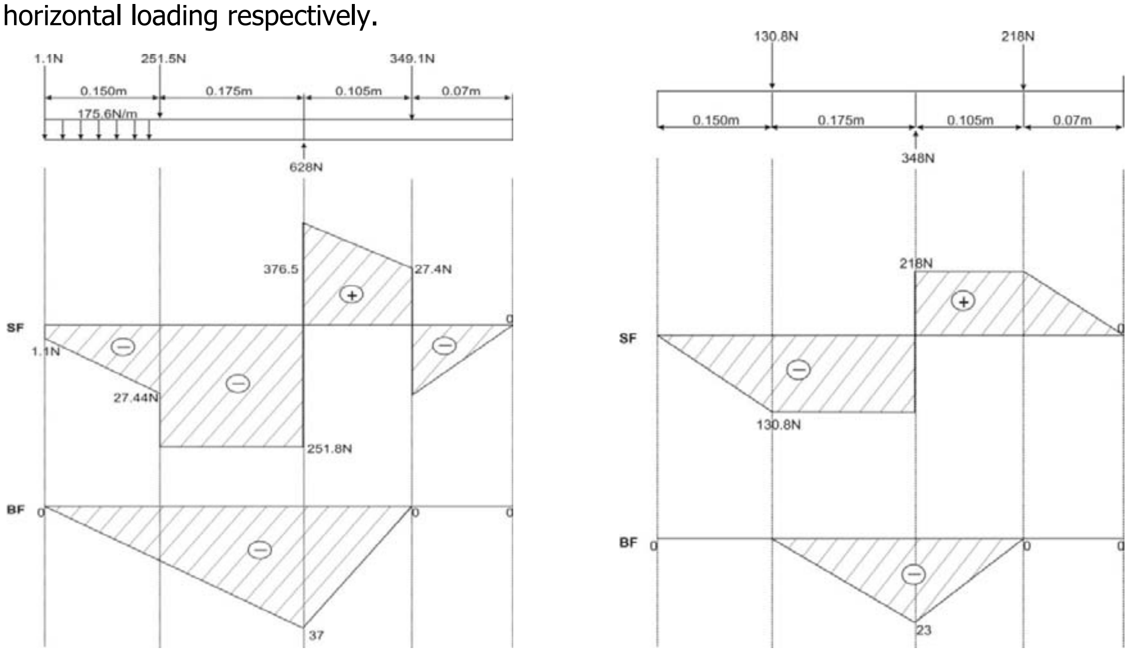
(a) (b)

Figure 3: (a) Vertical Loading on the Shaft. (b) Horizontal Loading on the Shaft

Mk = Weight of the knife U_L = Uniform distributed load

RVB = Reaction of the bearing at B, RVC = Reaction of the bearing at C,

Figure 4.0 shows the hear force and the bending moment diagram for the vertical and horizontal loading respectively.



(a) (b)

Figure 4: Bending Moment and Shear Force Diagram for; (a) Vertical loading. (b) Horizontal Loading.

3.3. Calculation of the Resultant Maximum Bending Moment, Mmax

$$M_{max} = \sqrt{M_h^2 + M_V^2} \qquad 11$$

M_H = Maximum bending moment for horizontal loading
M_v = Maximum bending moment for vertical loading

3.4. Calculation of the Shaft Diameter d_0,

In actual practice shafts are subjected to fluctuating torque and bending moment. For shafts subjected to combine bending and torsion, the shaft diameter, d_o is given by;

$$d_o = \frac{16}{\pi \tau_s} \sqrt{(K_b M_{max})^2 + K_t T_t)^2} \qquad 12$$

The shaft is design to have the maximum allowable shear stress of $\tau_s = 30 \times 10^{-6} N/m$.

T_t = Torque Transmitted by electric motor

K_b and K_t are Combine shock and fatigue factors for bending and torsion. The recommended value for K_t and K_b are 1.5 and 1.0 for steady loading (Khurmi, 2005). π = 3.142.

3.4. Calculation of Belt Length

The belt length is given by;

$$L = \sqrt{4C \quad - (D-d)^2 + \frac{1}{2}(D\alpha_2 + d\alpha_1)} \qquad 13$$

Where;

L = Belt length (m)

D = Diameter of the larger pulley (m)

D = Diameter of the smaller pulley (m)

C = Centre distance between the two pulley (m)

α_1 = Wrap angle of the smaller pulley (rad)

α_2 = Wrap angle of the larger pulley (rad)

3.5. Calculation of the Centre Distance between Pulleys C

The Centre distance between the two pulleys is given by;

$$C = \frac{L}{4} - \frac{\pi(D-d)}{8} + \sqrt{\frac{L}{4} - \frac{(D-d)^2}{8} - \frac{(D-d)^2}{8}} \qquad 14$$

3.6. Bearing Selection,

The resultant radial force (F) and the dynamic loading (C) are calculated.

$$F = \sqrt{F_H^2 + F_V^2} \qquad 15$$

$$F_H = RHC \qquad F_V = RVC$$

3.7. Calculation of the Factor of Safety, F_S,

$$F_S = \frac{Ultimate\ Stress}{Working\ Stress} \qquad 16$$

$$Working\ Stress = \frac{16T}{\pi d^3} \qquad 17$$

T = Twisting Moment (Maximum Bending Moment)

D = Shaft Diameter

According to Sharma and Aggarwal (2006), the Factor of Safety (F_S) is between 1.25 to 1.5 for exceptionally reliable material used under controlled condition and subjected to loads and stresses that can be determine certainly. Therefore since the Factor of Safety of this machine wass within the range (1.25 to 1.5). Therefore the design was safe.

3.8. Key Design

In this design, a round key inform of a bolt was used. The height (h) and the width (b) of the key was determined by using the empirical design code relation for different types of keys.

3.8.1. Calculation of the Width/Diameter of the Key b

b = nd 18

n = Ratio of the key width to the shaft diameter. The recommended value of n is 0.25

d = Shaft diameter

3.8.2. Calculation of the Depth/Height of the Key h

h = mb 19

m = Ratio of height of the key to the key width. The recommended value of m was 1.30
Therefore, a bolt of 6mm in diameter (width) and the more than 7mm height was selected.

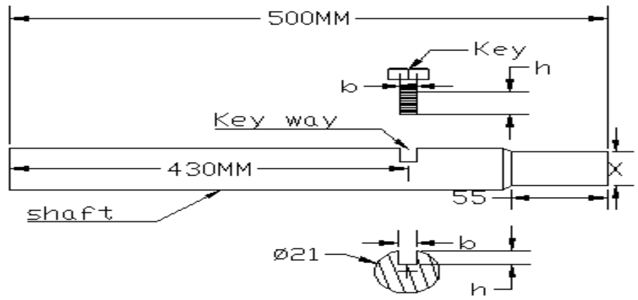


Figure 5: Shaft Design

3.9. Handle Design

The average of 170.6N effort is assigned to operate the machine during the manual operation. The maximum force required for a single person to operate the handle is 400N with the handle length of 300mm, (Khurmi, 2005).

3.9.1. The Maximum Bending Moment of the Handle M_L,

$$M_L = P \times \frac{2l}{3} \qquad 20$$

3.9.2. The Section Modulus of the Handle Z,

$$Z = \frac{\pi}{32} d^3 \qquad 21$$

Where, d = diameter of the handle

The diameter of the handle is proportioned as 25mm for single person with the effort of 400N.

3.9.3. The Constant Twisting Moment T,

$$T = {}^2/_3 \times p \times l \qquad 22$$

3.9.4. The Maximum Bending Moment M_L,

$$M_L = p \times L \qquad 23$$

The length of the lever, L is 86mm

3.9.5. The Width near the Boss B,

$$B = 2t \qquad 24$$

t = Thickness of the lever

The section modulus Z for the level arm is also given by;

$$Z = \frac{1}{6} \times t \times B^2 \quad 25$$

3.9.6. The Dimension or Length of the Square End, of the Handle x

$$x = \sqrt{\frac{D^2}{2}} \quad 26$$

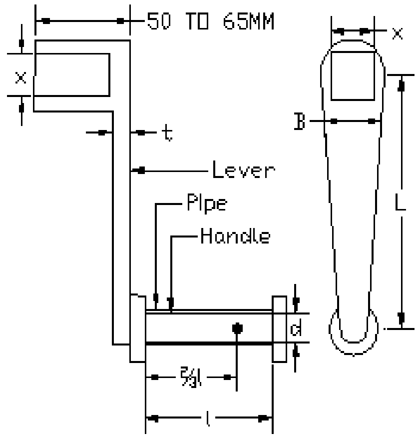


Figure 6: Handle Design

4.0 CONSTRUCTION

The Table 1 summarized the construction process involved with the construction of this machine. The engineering drawing of the individual components and their respective materials are shown in the appendix.

Table 1: Component and Construction Operations

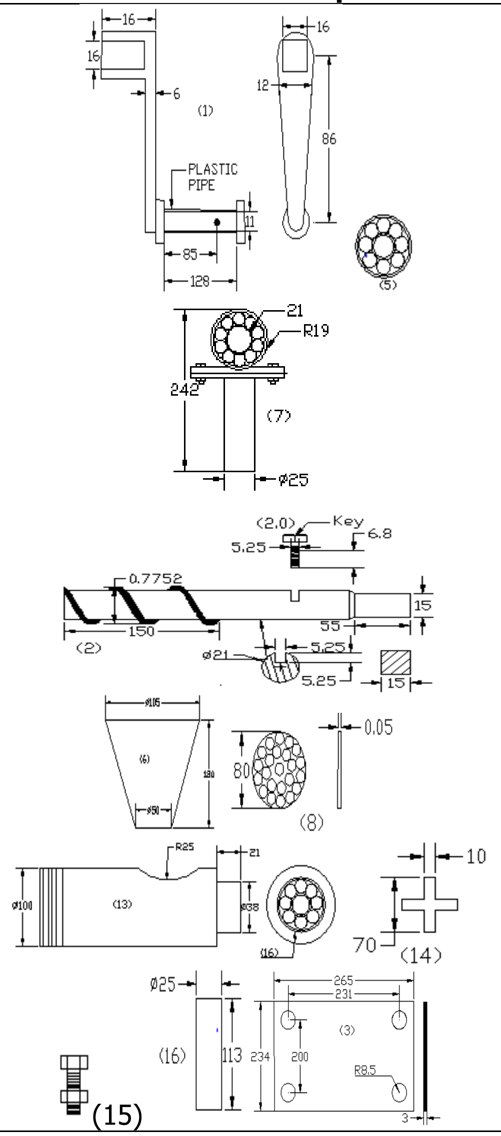
S/N	COMPONENT	MATERIAL	OPERATION
1	Hopper	Mild steel	Cutting to size, folding wielding and grinding
2	Shaft Housing	Galvanized steel	Cutting ti size, threading, wielding, and grinding
3	Hole Plate	Aluminum	Casting and drilling
4	Knife	Stainless steel	Cutting to size, wielding and grinding
5	Shaft	Stainless steel	Cutting to size, turning, wielding, hand forging and grinding
6	Bearing Holder	Mild steel bolts and nuts	Cutting to size. Welding and grinding
7	Ring Screw	Aluminum	Casting and threading
8	Grinder Stand	Mild steel	Cutting to size, welding. Drilling and grinding
9	Handle	Mild steel	Cutting to size, welding and grinding
10	Grinder Stand	Mild Steel Pipe	Cutting to size
11	Grinder Base	Mild Steel Plate	Cutting to size

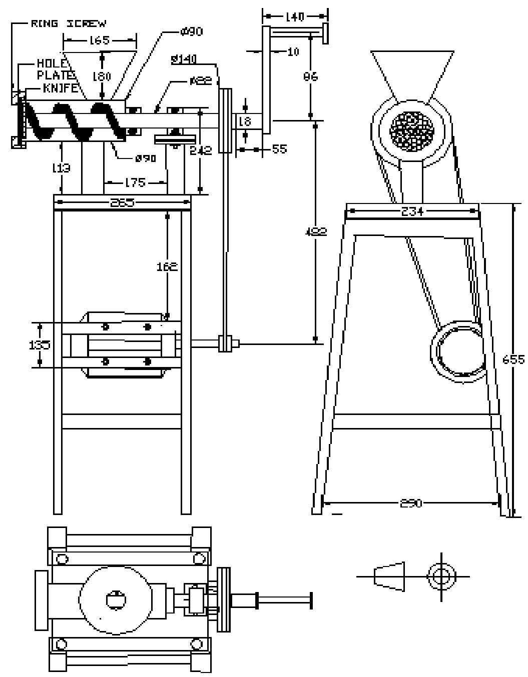
5.0 Assembling

A number of components were permanently joined together using arc welding to form a sub-assembly. The sub-assembly and other components were temporarily joined together using bolts and nuts to form a complete structure of the meat grinding machine. The assembly and individual components drawing are shown in the appendix.

Table 2: Components and Orthographic Drawing

Components and Orthographic drawing



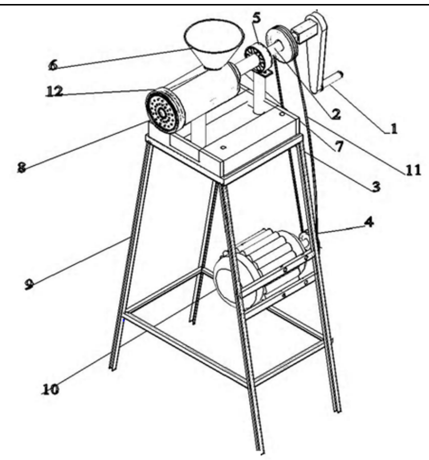


All Dimensions in mm, Scale 1:1

Table 3: Assembling Drawing

The Assembly Drawing

S/N	Component	Material	Qty
1	Handle	MS, P	1
2	Shaft and Key	SS,MS	1
3	Grinder Base	MS	1
4	Motor Pulley	MS	1
5	Bearing	SS	2



6	Hopper	SS	1
7	Bearing Stand	MS	2
8	Hole Plate	A	3
9	Grinder Stand	Ms	1
10	Electric Motor	MS, R	!
11	V-belt	R, C, R	1
12	Ring Screw	A	1
13	Shaft Housing	SS	1
14	Knife	SS	1
15	Bolt and Nut M12x1,25 M16x1,5	 MS MS	 6 4
16	Grinder Leg	MS	1

All Dimensions in mm, Scale 1:1

6.0 TESTING

The machine was tested for performance in terms of Meat Grinding Rate and Meat Grinding Efficiency of the meat grinder.

6.1. Meat Grinding Rate (MGR)

This is the total quantity of meat grinder per unit time, which passes through the hole plate. It is measured in kilogram per second.

$$\text{Meat Grinding Rate(MGR)} = \frac{\text{Mass of Mear after Grinding}}{\text{Meat Grinding Time}} \qquad 23$$

6.2. Meat Grinding Efficiency (MGE)

This is used to show the proportion of the output (mass of meat after grinding) in respect to the input mass of meat before grinding.

$$\text{Meat Grinding Efficiency (MGE)} = \frac{\text{Mass of Meat after Grinding}}{\text{Mass of Meat before Grinding}} \times 100 \qquad 24$$

6.3 Testing Procedure

A 2.2kg of meat (1.1kg each) free from bones, muscles and fat was purchased from the market. The meat was washed and cut into strips for easy grinding. The machine was set up and the meats were grinded electrically and manually with 1.1kg of meat respectively. The time required and the mass of the meat after grinding were also noted and recorded.

6.4 Results and Discussion

Time required to grind 1.1kg of meat by manual operation T_m = 75sec
Time required to grind 1.1kg of meat by electrical (motorized) operation. T_e = 15sec
Mass of Meat before Grinding M = 1.1kg, Mass of meat after manual operation M_m = 0 .76kg
Mass of meat after electrical (motorized) operation M_e = 0.8 kg.

MGR (for manual operation) = $\frac{M_m}{T_m}$ = $\frac{0.76}{75}$ = 0. 010 kg/sec

MGR (for electrical operation) = $\frac{M_e}{T_e}$ = $\frac{0.8}{15}$ = 0.0 53 kg/ sec

MGE (for manual operation) $=\frac{M_m}{M} \times 100 = \frac{0.76 \times 100}{1.1} = 69\%$

MGE (for electrical operation) $\frac{M_e}{M} \times 100 = \frac{0.8 \times 100}{1.1} = 73\%$

The manual operation of the meat grinder had a meat mincing rate of 0.010kg/esc, while the electrical/motorized operation had 0.0.053kg/sec. This indicates the quantity of meat that can be grinded per second by the manual and motorized method. The motorized method had a high grinding rate due to the high speed of the electric motor. The manual and motorized method had high [69% and 73%] efficiency.. This shows that the manual and motorized meat grinder has a very low [27%and 31%] possibility of being inefficiency.

From Alaba international market, Lagos, the cost of a motorized meat grinding machine is ninety Thousand naira (#90,000.00). One of the objectives of this paper is to design and construct a single meat grinding machine with both manual and motorized mode of operation using simple available tools and materials in order to provide a local alternative. The cost of construction of the manual and motorized neat grinding machine was sixty-two thousand naira (#62.000.00, which is less than the imported meat grinding machines.

7.0 CONCLUSION

From the Shear Force (SF), Bending Moment (BM) diagram and the value of the Factor of Safety (F_S), It can be concluded that the design was safe. The manual operation of the machine had a meat grinding rate of 0.010kg/sec, while the motorized operation has a meat grinding rate of 0.053kg/sec. These indicate the quantity of meat that can be grinded per second by the manual and motorized method respectively. The manual and motorized operation of the machine had a high efficiency (69% and73%) indicating that the machine had a good working condition.

REFERENCES

Khurmi R.S. Machines design. Eurasia Publishing House. Ram Nagar, New Delhi. Pp 4-5, 52-57, 568-571, 716-719, 728-729,1012-1015. 2005.

Khurmi R.S. Theory of machines. Eurasia Publishing House, Ram Nagar, New Delhi. Delhi, Pp 341-345. 2005.

L. Robert Mott. Machine Element in Mechanical Design. Fourtt Edition. Upper Saddle River, New Jessey. Pp 548-551. 2004.

O. Robert and Parmley P.E. Illustrate Source of Mechanical Components.McGraw Hill Company Inc. Pp 4-5. 2000.

P.C. Sharma and Aggarwal D.K. Machine Design. Eleventh edition. S.K. Kataria and Son. Pp 390, 492, 641-644. 2006.

Principles of Meat Processing Technology. Available at; www.foa.org/dcrep/010/ai407e/ai407e04.htm. cited December 2014.