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Paper Shredding Machine

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Abstract

This paper deals with a detailed study design the procedure of a paper shredding machine. A detailed study of various parts of shredder machine like mainframe, transmission system, and cutting system is made and designed separately. The first part deals with the study of the cutting system of a shredder machine i.e. types of blades, different profiles, its dimensions, its alignment, advantages, and disadvantages of different types of blades. The second part includes problem definition, objectives, the procedure of design with the detailed design of each component of the cutting and transmission system i.e. designing a blade and making certain modifications in it and the frame. The third and last part deals with the design of the 3D model of various parts of Assault Systems “CATIA”

Keywords- CATIA, Shredder Machine

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Chapter 1

Introduction

1.1 A Paper Shredding Machine

A paper shredder is a mechanical device used to cut paper into a strip or a cross-particles or micro-particles.

Government organizations, businesses, and private individuals use shredders to destroy private, secret, or otherwise sensitive documents.

Paper shredders help companies keep secret records, it offers the easiest way to destroy a document and any concerns about privacy.

A paper shredder machine includes a shaft on which blades are adjustable mounted and a shaft assembly on which blades are securely connected. The two shafts move opposite each other provide a scissors-like cutting action.

To make this issue one may shred papers sequence or collectively, however, in the project, the machine will a paper shredding collectively up to a maximum twenty-papers and type of paper cut is a cross-particles [1] , an example of this type of machine can be shown in Figure 1.1.

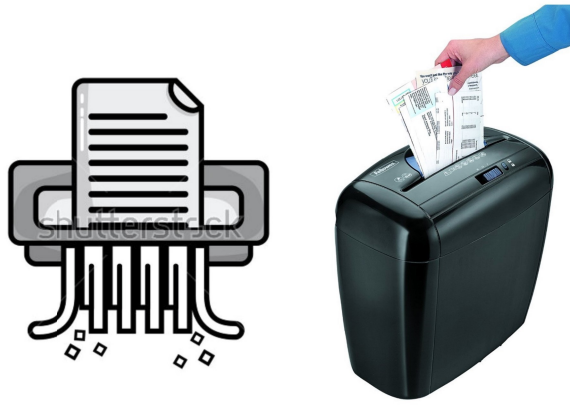


Figure 1.1: Example of Papers Shredding Machine

1.2 Types of Paper Cut

In this section, we will browse the several types of papers cutting that is the need in the machine industry, some of them are :

1- (Strip-Cut) Shredding :

The Strip Cutter is generally seen as the most basic type of shredding system but can be more than adequate for the less sophisticated user. A perfect example would be a home user who requires a reasonably low level of security but is determined to protect information from possible identity theft as shown in Figure 1.2.



Figure 1.2: (Strip-Sut) Shredding

2- (Cross-Cut) Shredding :

The cutting cylinders not only cut the paper width ways but also length ways too. The results are small particles.

Cross cut shredders have now become most used because the shredded waste is more secure as it is much harder to read the information that was held on the pieces of papers .

This type we will apply in this project as shown in Figure 1.3.



Figure 1.3: (Cross-Cut) Shredding

3- (Micro-Cut) Shredding :

The use of micro cut shredders is recommended for businesses or individuals where security is of paramount importance because the shredded waste is more secure as it is much harder to read the information that was held on the pieces of paper.

It is virtually impossible to reassemble a document in any way because of the small parts as shown in Figure 1.4.



Figure 1.4: (Micro -Cut) Shredding

1.3 Requirements

The following requirements should be achieved in this project :

- 1- The whole volume of the machine does not occupy large space.
- 2- The type of paper cut will be applied is (cross-cut) particles .
- 3- A paper size for shredding is the size (A4) or less .
- 4- Single phase power source.
- 5- Easy to assembly and maintenance.
- 6- System protection.

The project requirements have determined where the machine should be cheap as possible, useful and do not occupy large space.

1.4 Goals of the Project

The project aims to design and build a paper shredding machine to shred the papers collectively up to maximum twenty-papers (A4 size) at once. The type of paper cut is cross-particles to

keep secret information .

1.5 Related Works

Joseph Y. Ko in 2000 presented a machine with automatic feeding mechanism capable of shredding 20 sheets with approx. 9 inches width. It had a three way switch i.e. On, Off and Auto. The blades were knife rollers which cut paper strips, but can be occasionally configured to have confetti-cuts of paper. Feeding mechanism contained a pair of roller to direct the paper. The rollers and the knife blades were driven by a single AC Motor and a belt drive [1] .

Frank Chang in 2000 presented the blade assembly for paper shredder is in a juxtaposed manner. Conventional assembly consists of long and short partition rings. The disadvantage was that even if one part malfunctioned, the whole assembly gets loosened. Instead of having partition rings it had long and short plates casted with the blade ring. The blades were arranged on the rotary shaft to form a bladed shaft such that long and short projecting abut the long and short projecting plates of adjacent blades. This arrangement eliminated use of partition rings, reducing cost and enhancing assembly efficiency [3] .

Gu-Ming Zeng in 2006 presented the blades of the paper shredder that had serrated cutting edges which were formed by bending. This could be done by two methods.

The first method had a blade body and serrated edge integrally formed and punched from the same base material. Cost of production there was high and even high level material was required. The second method had serrated cutting edges specially thickened to reduce material consumption. They were also complex to manufacture.

Three types of blades could be designed according to him :

- a. four serrated edges evenly spaced with one annular protrusion.
- b. two serrated edges with corrugations on outer periphery.
- c. two serrated edges with three annular protrusions evenly spaced [4] .

Hunag, Simon in 2003 presented the paper shredder which had two rotary cutters each with multiple blades. Each blade had a first cutting blade with multiple first cutting edges and a second cutting blade with multiple cutting edges. Both the first and the second cutting blades were distributed in a non-quadrangular manner and each of the first cutting edges was offset to

each one of the second cutting edges, so that there was only one cutting edge that engaged with the paper to be shredded. When the amount of shredded paper increased, the paper shredder did not function normally because multiple cutting edges simultaneously engaged with the paper to be shredded paper stuck in the shredder. This problem was sorted out by using rotary cutter with multiple blades with numbers cutting edges. With the arrangement described here, the noise of the shredding was also greatly reduced [5] .

Emily Lo in 2008 presented the blade for a paper shredder cutting tool that includes an improved structure for one of two blades of each cutter of two rotary cutters of a paper shredder cutting tool. A protruding ring protrudes from a rim of a center hole of the blade, and the protruding ring and the blade are formed as an integrated body. The protruding rings not only enable disposition of paper chaff guides, but also will not deform because of thermal expansion and contraction when shredding paper, thereby preventing a gap from forming between the two blades, and thus the occurrence of paper jamming or wedging together of the blades of the upper and lower cutters [6] .

1.6 Project Schedule

The following project schedule shows the project introduction work time that is needed to achieve our goals,. This schedule is divided into sixteen weeks of the first semester as following. as shown Table 1.1 and Table 1.2 .

Table 1.1: First semester time plan

Weeks \ Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
T1	■	■	■	■												
T2				■	■											
T3					■	■	■	■								
T4							■	■	■	■	■					
T5										■	■	■	■			
T6														■	■	■

Where :

T 1: Selection the idea of the project .

T 2: Research about the idea of the project.

T 3: Introduction Chapter (1).

T 4: Mechanical Design Chapter (2).

T 5: Electrical Design Chapter (3).

T 6: Control Design Chapter (4).

Table 1.2: Second semester time plan

Weeks \ Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
T7	■	■														
T8		■	■	■	■											
T9					■	■										
T10							■	■	■	■						
T11										■	■	■	■	■		
T12													■	■	■	■

Where :

T 7 : Order the components.

T 8 : Selection the motors .

T 9 : Assemble the machine part.

T 10 : Testing and calibration.

T 11 : Implementation and validation.

T 12 : Write final report.

1.7 Cost

The estimated cost of the project is around 590 JOD, This cost comes due the high cost of each blade, however, the Table 1,3 shows the project component with there prices .

Table 1.3: Cost

Elements	Cost
Old machines	40 JOD
The Milling	190 JOD
Motor	120 JOD
Commander SE Driver	140 JOD
Arduino	20 JOD
Other Parts	50 JOD
The Paint	30 JOD
Total Cost	590 JOD

Chapter 2

Mechanical Prototype

2.1 Introduction to Mechanical Prototype of the Project

This section gives a three- dimensional prototype of papers shredding machine using CATIA software as shown in Figure 2.1.

Through our prototype, one can achieve smooth movement to pull the papers and shredding it. By using an AC motor that is connected with first and second shafts using appropriate gears to move together for a paper shredding.

Depending on the A4 paper size, with maximum twenty papers, we select the dimensions of the machine, shaft and blade.

Papers shredding machine consist of five main parts: main frame, cutting blade, main shaft, separate plate and transmission system , a dimensions of the shredding machine are $(50 \times 30 \times 70)cm$.

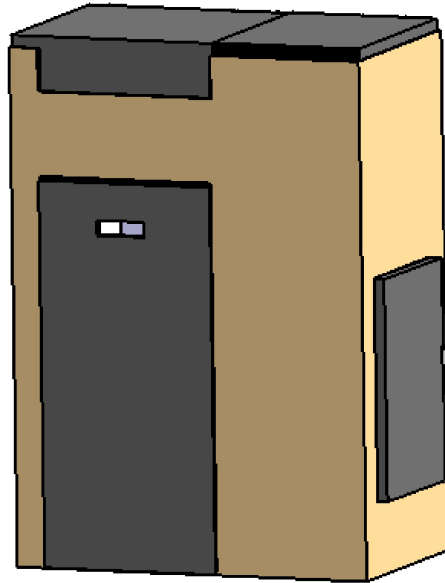


Figure 2.1: Prototype of Paper Shredding Machine

2.2 Contents of Papers Shredding Machine

As we mentioned , the paper shredding machine is consists of three main components, we will now go in detail of this components.

2.2.1 Main Frame

The job of main frame carries all parts of the machine: motor, shaft assembly,gears and bearing as shown in Figure 2.2 .The main frame consist of waste box , it contains remains of papers damaged .

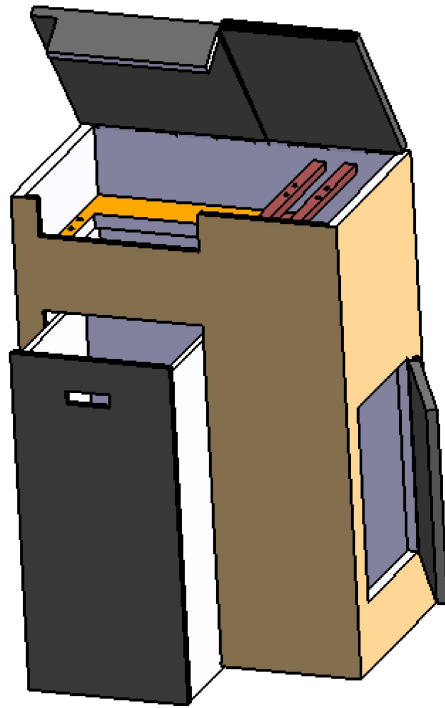


Figure 2.2: Main Frame

2.2.2 Cutting Blade

The cutting blades are the main cause of size reduction in the shearing shredder, they are hollowed hexagonally in order to meet the shape of the shaft and to be fixed on it, and there exist eleven cutting blades on each shaft as shown in Figure 2.3 .

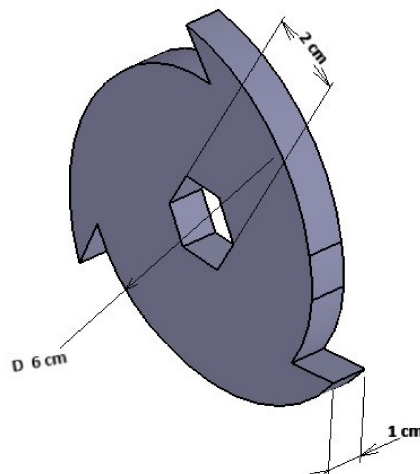


Figure 2.3: The cutting blade

2.2.3 Main Shaft

The main shaft serves as the cutting blade holder. The main shaft has a hexagon shape in the position of cutting blade holder and has a circle shape at both ends in the position of the

holder main bearings and gears as shown in Figure 2.4.

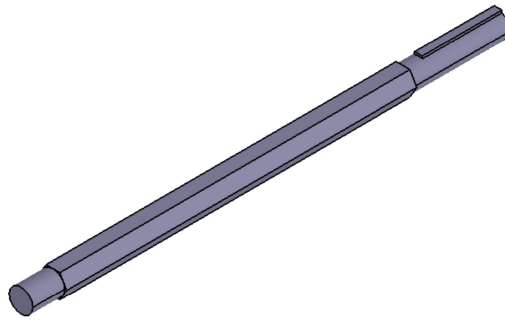


Figure 2.4: The Shaft

2.2.4 Separate Plate

The job of separating plates are prevent of return to out. The separating plates that exist between the blades, the separate neighbor blades from each other, they are fixed in the side casing as shown in Figure 2.5.

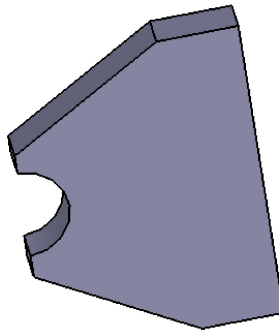


Figure 2.5: Separate Plate

2.2.5 Transmission System

1 - Assemble Shaft

The shaft assembly consists of blades and the gears. The distance between two parallel shafts is fifty-five millimeter. This distance is enough to interfere the blade rim for paper shredding as shown Figure 2.6

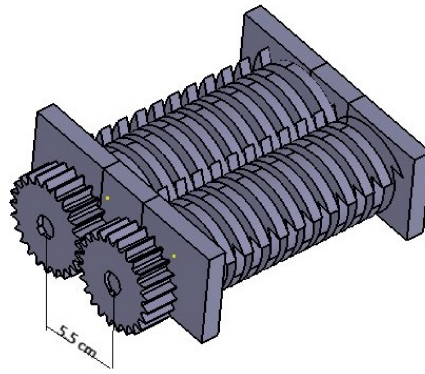


Figure 2.6: Assemble Shaft

2 - Bearing

The bearing fixed between the two shaft and the frame of the machine permit the rotational motion of the two shafts without affecting the frame as shown Figure 2.7.

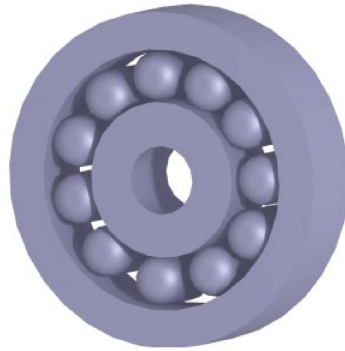


Figure 2.7: Bearing

3 - Gear

The gear are connected with the two shaft and with each other ,one of them is connected with the electrical motor ,it spins the other one in opposite direction since they are meshed together as shown Figure 2.8.

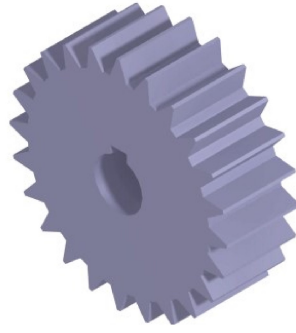


Figure 2.8: Gear

2.3 Static Analysis

In this section we show how the machine system is safe without structural failure. The main particles that are expected to fail or have deformation are the shafts that carry the weight of the blade. We need to determine loads, geometry, support conditions, and materials properties.

2.3.1 The Loads on the Shaft

The load on the shaft depends on weight of gears, weight of blade, and the reaction of the cutting force on each blade.

By using CATIA software to get mass for each part ,we get mass of parts: mass of blade=0.15 Kg, mass of shaft =0.44 Kg, and mass of gear = 0.82 Kg.

The weight of parts: weight of gears(W_G) = 8.2 N,weight of blade(W_B) = 1.5 N,and weight of shaft(W_S) = 4.4N.

cutting force The force require to shredding the paper depend on area of the papers, and the Shear ultimate strength as shown Figure 2.9.

$$F = S_{su} \times t \times w \quad (2.1)$$

$$F = 208N$$

Where:

F : cutting force for each blades in Newton.

S_{su} :shear ultimate strength of paper = $1.3 \times 10^7 Ps$

t : thickness of 20 papers = 2 mm

w : width of paper = 8 mm

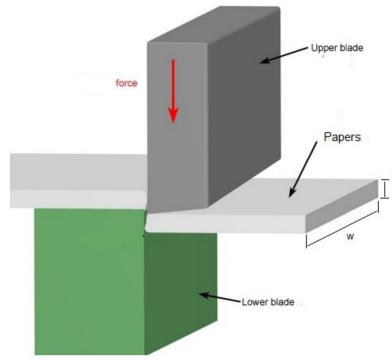


Figure 2.9: Shearing Force

2.3.2 Reaction Analysis

First calculate the reactions exerted on the shaft. Initially the shaft and the free body diagram of the shaft as shown in Figure 2.10 and Figure 2.11 . The carriage is supported at point A

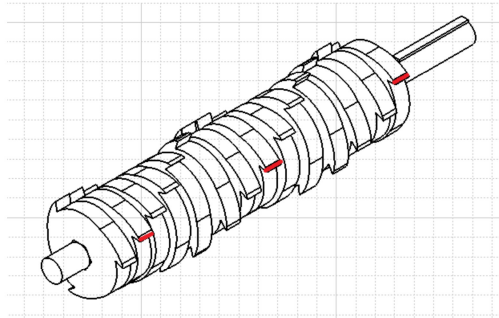


Figure 2.10: Show the effect of blades

and B. The reaction in (Newton) are denoted by $A_z, A_y, B_z,$ and B_y . Using the principle of reaction the forces.

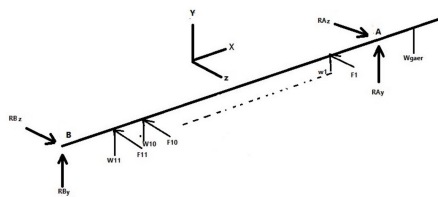


Figure 2.11: Free Body Diagram of the Shaft

Summing the forces in Z-direction on each shafts

$$\sum F_Z = 0 \tag{2.2}$$

$$(3 \times F) - R_{Az} - R_{Bz} = 0$$

$$R_{Az} + R_{Bz} = 624N$$

Where:

F: cutting force in Newton.

R: reaction in Newton

Summing the forces in Y-direction

$$\sum F_Y = 0 \quad (2.3)$$

$$-R_{Ay} - R_{By} + W_B = 0$$

$$R_{Ay} + R_{By} = 21N$$

Summing the bending moment in Y-direction at point A or B

$$\sum M_{Ay} = 0 \quad (2.4)$$

$$W \times d - R_{By} \times 28 = 0$$

$$W \times 183 - R_{By} \times 28 = 0$$

$$R_{By} = 9.8N$$

Summing the bending moment in Z-direction at point A or B

$$\sum M_{Az} = 0 \quad (2.5)$$

$$-R_{Bz} \times 28 + F \times 45 = 0$$

$$R_{Bz} = 334.2N$$

From this equation the reaction force in Z-direction $R_{Az} = 290N$ and in Y direction $R_{Ay} = 11.2$.Using Appendix A the reaction forces and reaction moments have been obtained.

Bearing load

$$R_A = \sqrt{(R_{AZ})^2 + (R_{AY})^2} = 290.2N$$

$$R_B = \sqrt{(R_{BZ})^2 + (R_{BY})^2} = 334.3N$$

The bending moments in the Z - direction

$$M = F \times D \quad (2.6)$$

$$M_{Z1} = R_{Bz}(1 \times 10^{-2}) = 3.3\text{N-m}$$

$$M_{Z2} = R_{Az}(14 \times 10^{-2}) - F(1 \times 10^{-2}) = 38.5\text{N-m}$$

$$M_{Z3} = R_{Az}(2 \times 10^{-2}) = 5.8\text{N-m}$$

The bending moments in the Y - direction

$$M_{Y1} = R_{BY}(1 \times 10^{-2}) = 0.1\text{N-m}$$

$$M_{Y2} = R_{AY}(14 \times 10^{-2}) - 1.5(1 \times 10^{-2}) = 1.5\text{N-m}$$

$$M_{Y3} = R_{Ay}(2 \times 10^{-2}) = 0.2\text{N-m}$$

The Maximum Bending Moment

$$M_1 = \sqrt{(M_{Z1})^2 + (M_{Y1})^2} = 3.3\text{N.m}$$

$$M_2 = \sqrt{(M_{Z2})^2 + (M_{Y2})^2} = 38.5\text{N.m}$$

$$M_3 = \sqrt{(M_{Z3})^2 + (M_{Y3})^2} = 5\text{N.m}$$

Max bending moment at $M_2 = 38.5\text{N.m}$

Where:

M : moment in Newton . Meter

F : force in Newton

D : distance in Meter

The Torsional Moment

$$M_T = F \times r \quad (2.7)$$

$$M_T = 624 \times 2.5 \times 10^{-2} = 15.5\text{N-m}$$

2.3.3 Static load:

Minimum diameter of a solid steel shaft [12]

$$D^3 = \frac{16}{\pi \iota_{max}} \sqrt{(k_b M_{max})^2 + (k_t M_t)^2}$$

$$D = 1.5cm$$

Bending Stress

$$\sigma = \frac{32M_{max}}{\pi D^3} = 116Mpa$$

Torsional Stress

$$\iota = \frac{16M_t}{\pi D^3} = 23.4Mpa$$

Where:

D: diameter of the shaft

ι_{max} : max shear stress = 87 Mpa

M_{max} : maximum bending moment in Newton.meter

M_t : torsion moment in Newton.meter

K_b : fatigue factor applied to bending moment = 1.5 (sudden loading)

K_t : fatigue factor applied to torsional moment = 1.5 (sudden loading)

Since the location, magnitude, and the direction of the reaction forces in shaft been determined. These reactions affect the shaft . The weight of the shaft will be treated as a distributed load. The distributed load means the load per length in (Newtons/meter).

2.3.4 The Maximum Angle of Twist

The angel of twist for a shaft subjected to twisting torque can be expressed by the following equation :

$$\phi = \frac{TL}{JG} \quad (2.8)$$

$$\phi = 0.0037 \text{ rad}$$

$$\phi = 0.21^\circ$$

where:

ϕ : the angle of twist in radians

T : applied torque (N.m)

L : length of the shaft in meter

J : shafts polar moment of inertia for solid shaft $=\pi\frac{r^4}{2}$ r : radius of the shaft

G : shear modulus of the material (N/m²)

2.4 Dynamic Analysis

The main goal of this section is to determine the size of the motor and gears on shaft .

2.4.1 Dynamic load :

For rotating round solid shaft neglecting axial load

$$\sigma'_{max} = \sqrt{(\sigma_m + \sigma_a)^2 + 3(\tau_m + \tau_a)^2} \quad (2.9)$$

$$\sigma'_{max} = \sqrt{\left(\frac{32K_f(M_m + M_a)}{\pi D^3}\right)^2 + 3\left(\frac{32K_{fs}(T_m + T_a)}{\pi D^3}\right)^2}$$

$$\sigma'_{max} = 1704MPa$$

When:

K_f :fatigue stress concentration factor for bending

K_{fs} :fatigue stress concentration factor for torsion

a :alternating moment or torque $M_a = \frac{M_{max} - M_{min}}{2}$

m :midrange moment or torque $M_m = \frac{M_{max} + M_{min}}{2}$

Factor of safety:

Compares maximum yielding stress with yielding strength

$$n_y = \frac{S_y}{\sigma'_{max}} \quad (2.10)$$

$$n_y = 0.2$$

Where:

S_y : yield strength 290 MPa

Using Appendix A the fatigue stress concentration factor (K_f and K_{fs}) and yield strength (S_y) have been obtained.

Minimum diameter for cyclic loading of a shaft

$$S_e = k_f k_s k_r k_t k_m S'_e \quad (2.11)$$

$$S_e = 1257 \text{ MPa}$$

$$D^3 = \frac{32 f_s}{\pi S_y} \sqrt{\left(M_m + \frac{S_y}{S_e} K_f M_a\right)^2 + \left(T_m + \frac{S_y}{S_e} K_f S T_a\right)^2} \quad (2.12)$$

$$D = 1.1 \text{ cm}$$

Where:

$$K_f = 1 + (K_c - 1) q_n$$

K_c :Stress concentration factor (function of geometry)

q_n :Notch sensitivity factor

S_e :Modified endurance limits

S'_e :Stress endurance limit for steels under idealised conditions (high-cycles fatigue)

k_f :Surface finish factor

k_s :Size factor

k_r : Reliability factor

k_t :Temperature factor

k_m :Miscellaneous factor

2.4.2 Dynamic basic load rating C

Dynamic basic load rating C – bearing load under which 90 % of bearing population reach Limiting speed 22000 r/min[16].

Equivalent load bearing A and B

$$P = X F_r [N] \quad (2.13)$$

$$P_A = 290 N$$

$$P_B = 334 N$$

where:

F_r : radial load

X : radial load factor

Using Appendix A the factor (f_d and f_t) have been obtained

Effective equivalent load for bearing A and B

$$P_e = P \cdot f_d \quad (2.14)$$

$$P_{eA} = 435N$$

$$P_{eB} = 501N$$

Effective dynamic basic load rating

$$C_{eA} = C_{eB} = C_e = C \cdot f_t \quad (2.15)$$

$$C_e = 8060N$$

Effective life for bearing A and B

$$L_h = \frac{10^6}{60n} \cdot \left(\frac{C}{p}\right) [hrs] \quad (2.16)$$

$$L_{hA} = 11812 [hrs]$$

$$L_{hB} = 7623 [hrs]$$

where:

C: dynamic basic load rating = 8060 [N] From bearings catalog [16]

P : equivalent bearing load [N]

p : exponent factor (p = 3 for ball bearings)

$f_d = 1.2$

$f_t = 1$

2.4.3 Power of the Motor

The torque required for rotation a shaft and to overcome the cutting force. The torque is given by

$$T = F \times r \quad (2.17)$$

$$T = 15.5N.m$$

Torque loading in two shafts (T_{total}) = $2 \times 15.5 = 31.2N.m$

Where:

T : torque transmitted by the shaft in Newton . Meter

F : cutting force in Newton
 r : radius of blade= 2.5 cm

The electrical motor must overcome the load on shafts and the cutting force . The require power to overcome this load calculated as follow:

$$hp = \frac{T_{total} \times rpm}{5252} = \frac{31.2 \times 30}{5252} = 0.17hp \quad (2.18)$$

$$power(KW) = 0.13KW$$

The gear box must reducing the speed of motor and increasing the torque of the motor. Gear ratio 1:45 to reducing the speed of the motor from 1320 rpm to 30 rpm and increasing the torque

2.4.4 Cutting Angles

That the size of the tool angles is decisive for the productivity of machine, and for the effectiveness. Incorrectly selected cutting angles can accelerate blunting of the tool, reduce the lifetime of the machine, increase the cutting resistance, and affect the productivity and effectiveness of the machinery[18].Figure 2.12 shows the geometry of a disintegration tool.

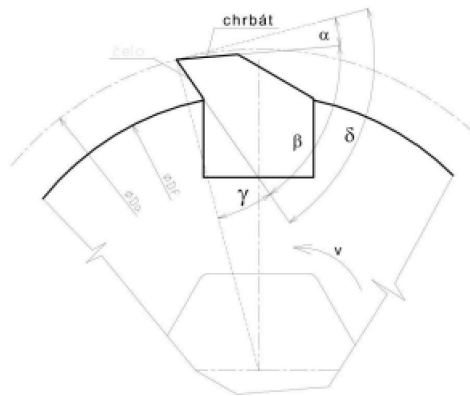


Figure 2.12: The Geometry of a Disintegration Tool

Where:

α : back angle.

β :disintegration wedge angle.

γ : face angle.

The most obvious and the biggest impact on the necessary input power is due to face angle γ . The bigger this angle is, the smaller the force that is necessary to overcome the resistance of the material that this wedge leaks into. This is because when there is disintegration with face angle $\gamma = 10$, the whole surface of the tool face presses on the material, so that there is a bigger surface to leak into the disintegrating material. When the face angle is $\gamma = 40$, the wedge leaks into the material progressively. It therefore does not need to disintegrate a big section all at once, but can disintegrate it progressively[18].

This fact was evident visually. When the face angle of the wedge is 40, the device runs considerably more easily and more smoothly. Due to the high financial cost of conducting experiments on the cutting angle, and Based on the experiences of previous studies, was chosen $\gamma = 40$ degree.

2.4.5 Specifications of Gear

In this application we use the gear to transform circle motion from motor to shaft that contain blades ,and to ratio the speed between motor and shaft as shown in Figure 2.1 3

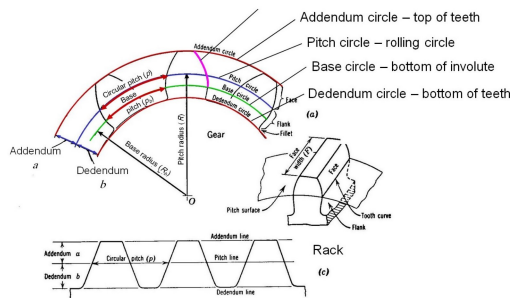


Figure 2.13: Gear Geometry [7]

The diameter of gear is known, from distance between two shafts is constant, and it equal 5.5 cm then the pitch diameter of gear equal 5.5 cm as shown in Figure 2.14

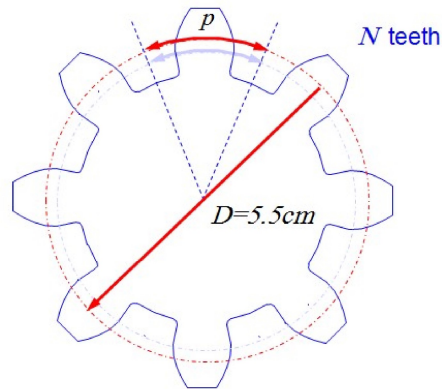


Figure 2.14: The Dimensions of the Gear

To calculate number of teeth, we find circumference of a pitch circle and pitch of gear

$$\frac{D}{2} = N \times P \times \pi \times 2 \quad (2.19)$$

$$N = 12 \text{ teeth}$$

Where :

D: pitch diameter = 5.5cm

P :pitch = 1.43 cm

Chapter 3

Electrical Design

This chapter explains how to select the electrical components that will be used in the project, Generally, Figure 3.1 shows the hardware components that will be used in the project and interaction between them.

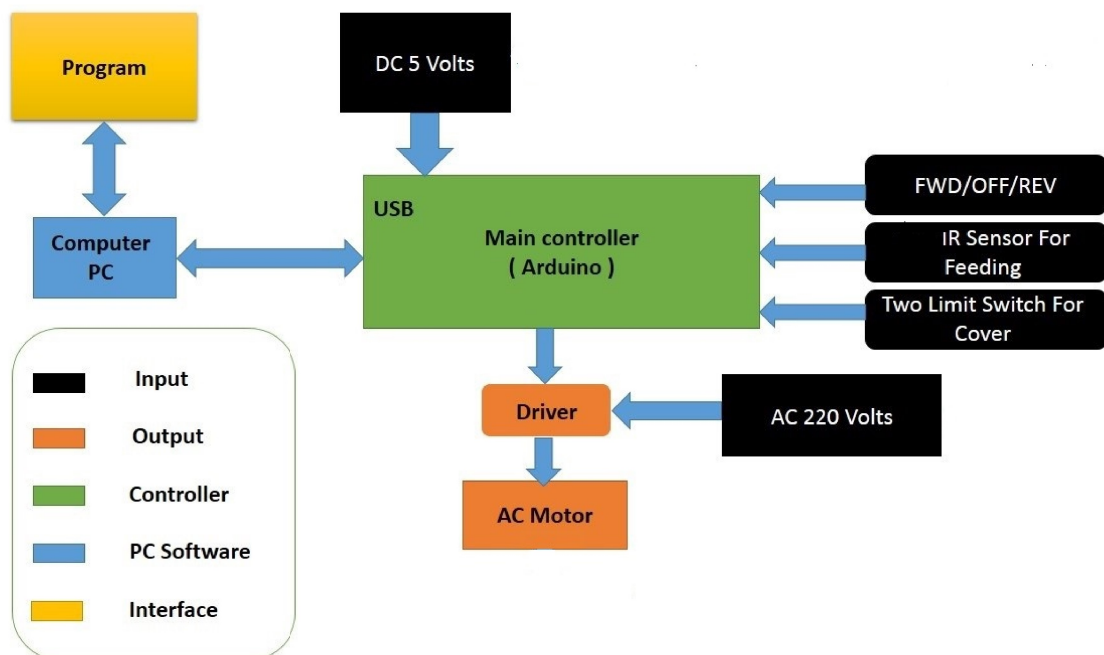


Figure 3.1: Block Diagram of Electrical Project Components.

In the following, we explain the functions of each part and what role does it play in the overall project.

3.1 An Electrical Motor

The speed of the electrical motor always depends on the properties of the electrical signals (voltage and frequency) that comes from drivers which are connected to the controller. It is used to transfer the motion to the gear that is connected to shaft holds cutting blades to rotate forward or reverse. thus the gear transfers the motion from the shaft as show the figure 3.2.



Figure 3.2: The motor gearbox

In this project, we will use three-phase AC motor ; the AC motor is an electric motor that converts electrical energy from AC to kinetic energy [8] , Table 3.1 shows the nameplate information of motor.

Table 3.1: Nameplate Information of Motor

Voltage	220 V
Power	0.18 Kw
Speed	1320 rpm
Frequency	50 HZ

3.2 Variable Speed Drives

A variable speed drive (VSD) as shown figure 3.3 , also known as a frequency converter, adjustable speed drive or inverter, is an electronic device that controls the characteristics of an electrical supply of a motor . Therefore, it is able to control the speed and torque of a motor, achieving a better match with the process requirements of the machine it is driving. So in applications where variable control is desirable, slowing down a motor

A VSD works by converting the incoming electrical supply of fixed frequency into a variable frequency output. This variation in frequency allows the drive to control the way in which the motor operates a low frequency for a slow speed, and a higher frequency for a faster speed. The output can also be changed to enable the motor to generate more or less torque as required. So,

the motor and drive combination might be used for turning a large load at fairly slow speeds, or turning a lighter load at high speeds, maximising efficiency [17]. When considering fitting



Figure 3.3: Commander SE driver

a VSD to a motor, there are a number of issues to consider:

- 1-Type of torque
- 2-Size required
- 3-Type of control needed

The Figure 3.4 show the typical connection of the driver.

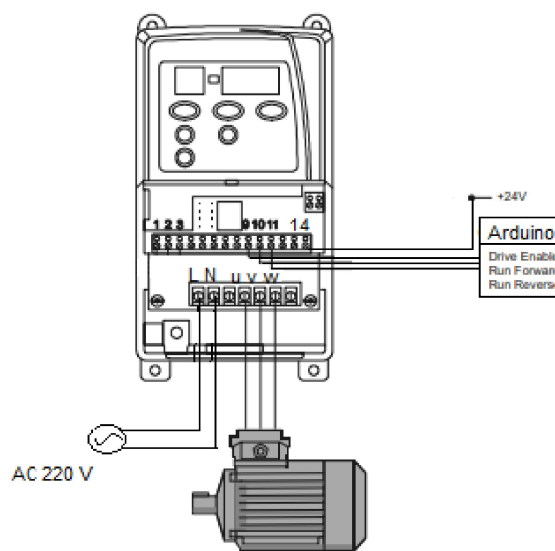


Figure 3.4: Driver Connection

4. The output circuit operates a high-current appliance such as a lamp or an electric motor.

3.4 Infrared Sensor

An infrared sensor (IR) sensor is a device that detects IR radiation falling on it. An IR sensor consists of two parts, the emitter circuit and the receiver circuit. This is collectively known as a photo-coupler or an optocoupler.

The emitter is an IR LED and the detector is an IR photodiode. The IR photodiode is sensitive to the IR light emitted by an IR LED. The photo-diode's resistance and output voltage change in proportion to the IR light received. This is the underlying working principle of the IR sensor. IR sensors are used in many applications and environments because of their effectiveness, ease of installation, and reliability of operation as shown the figure 3.7



Figure 3.7: IR sensor

There are in the feed opening for the project IR Sensor is connected with the control unit, when the paper is placed in the feed opening, the sensor is activated, which sends a signal to the Arduino to be processed and sent back to the electric motor to start work. Also use this sensor to protect the user during use and maintenance.

Figure 3.8 shows the top view of the machine and shows the location of the IR sensor.

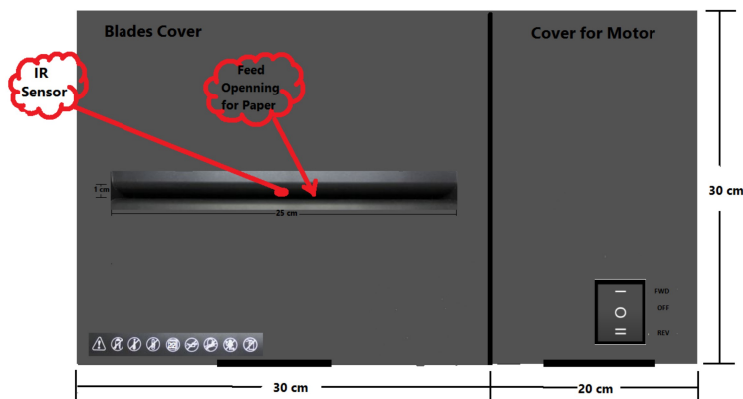


Figure 3.8: The Top View of the Machine

3.5 Limit Switch

In electrical engineering a limit switch is operated by the motion of a machine part or presence of an object. It is used for controlling machinery as part of a control system, as safety interlocks, or to count objects passing a point.

It consists of an actuator that is mechanically linked to a set of contacts. When an object comes into contact with the actuator, the device operates the contacts to make or break an electrical connection, as shown Figure 3.9 .

Limit switches are used in many applications and environments because of their effectiveness, ease of installation, and reliability of operation [11]

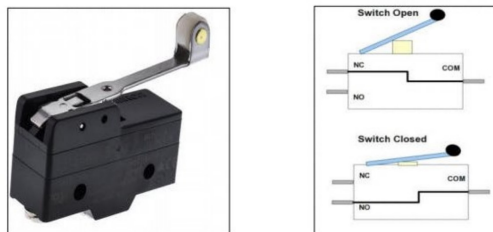


Figure 3.9: Limit Switch

In this project, The Limit switch is used to protect the user during the maintenance process so that the machine stops working when opening the cover, there is another limit switch underneath the paper container so that the machine does not operate without the container. Figure 3.10 shows the location of the limit switch .

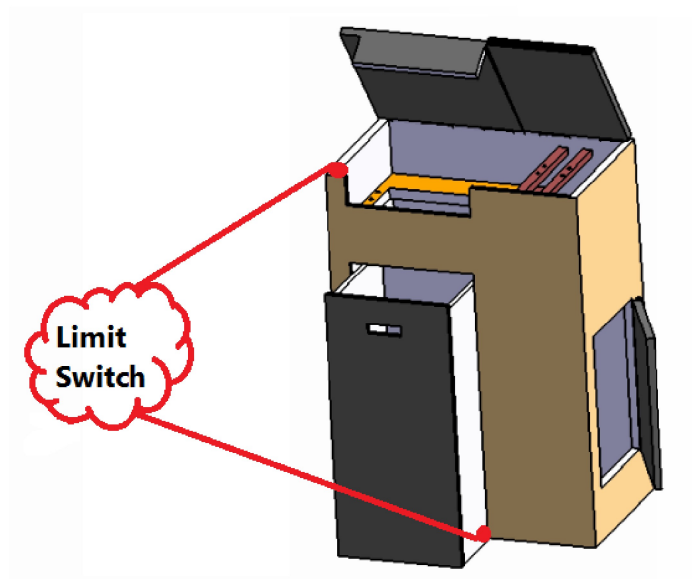


Figure 3.10: The Location of the Limit Switch

3.5.1 Selector Switch

Selector switch works on a general principle; they contain a simple selector switch on the front of the panel, and a broad range of potential contact combinations (via the contact blocks), on the inside of the enclosure. The major difference between the selector switch and the pushbutton is that, while a pushbutton has a plate that pushes down both contact plungers at the same time, a selector switch has a rotating cam with ridges and flats, allowing to actuate the plungers independently [13].

Selector switches are available in two, three, or four -position versions, and are often used when more than one control option is needed.

In this project there are three positions as shown Figure 3.11.

- 1.Run reverse (REV)
2. Run forward (FWD)
3. Stop motion (OFF)

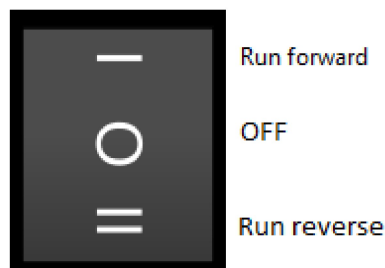


Figure 3.11: Select Switch

3.6 Temperature Sensor - LM35

It is sensor to temperature measurement, the output voltage is linearly proportional to the temperature, the temperature range ranges between -55 °C to 150 °C with accuracy of 0.05

LM35 is a three-legged integrated circuit as shown in the figure 3.12, the feeder voltage ranges from 4 to 30 V. This sensor was used to measure the temperature inside the machine to keep the cutting blades from excessive heat.

various expansion boards (shields) and other circuits. The boards feature serial communications interfaces, including Universal Serial Bus (USB) on some models, which are also used for loading programs from personal computers

Since Arduino is simple and accessible, It has been used in many projects and applications, Arduino software is easy-to-use because it uses C programming language (Programming high level language).

In this project Arduino is the main controller which receives commands from different switches and sensor and sends the desired signals to the driver, More details in chapter control

The Figure 3.12 show the typical connection of the arduino

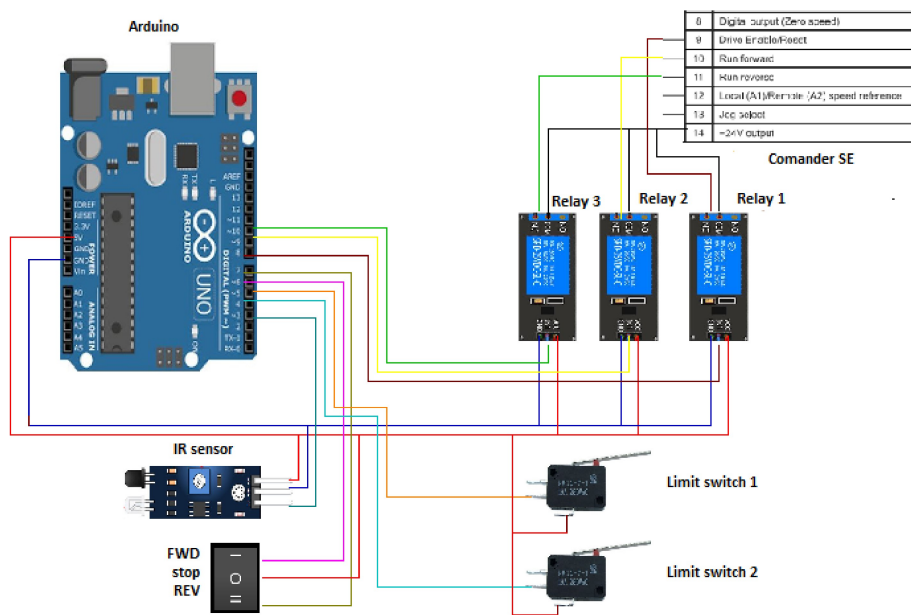


Figure 3.14: connection of the arduino

3.9 Conceptual Design

There are three switches in the electrical circuit that must be activated to begin shredding. First, the shredder must be closed to toggle the safety switch, and then the off/forward/reverse switch that allows power to go to the shredder must be moved to "forward". Finally, the paper being put into the shredder activation sensor ir which trips the third switch and sends signal to the arduino .The AC motor drives a gear train that reduces the speed of the shaft rotation and increases the torque. The first two gears are helical gears in order to reduce noise. At the end of the gear train, two spur gears are meshed and attached to individual shafts with cross-hatching blades. The blades are in a wave shape that cuts paper into the desired diamond shaped shreds. The blades spin in opposite directions and the paper is fed in between the spinning blades. The shredded paper falls into basket as shown Figure 3.15

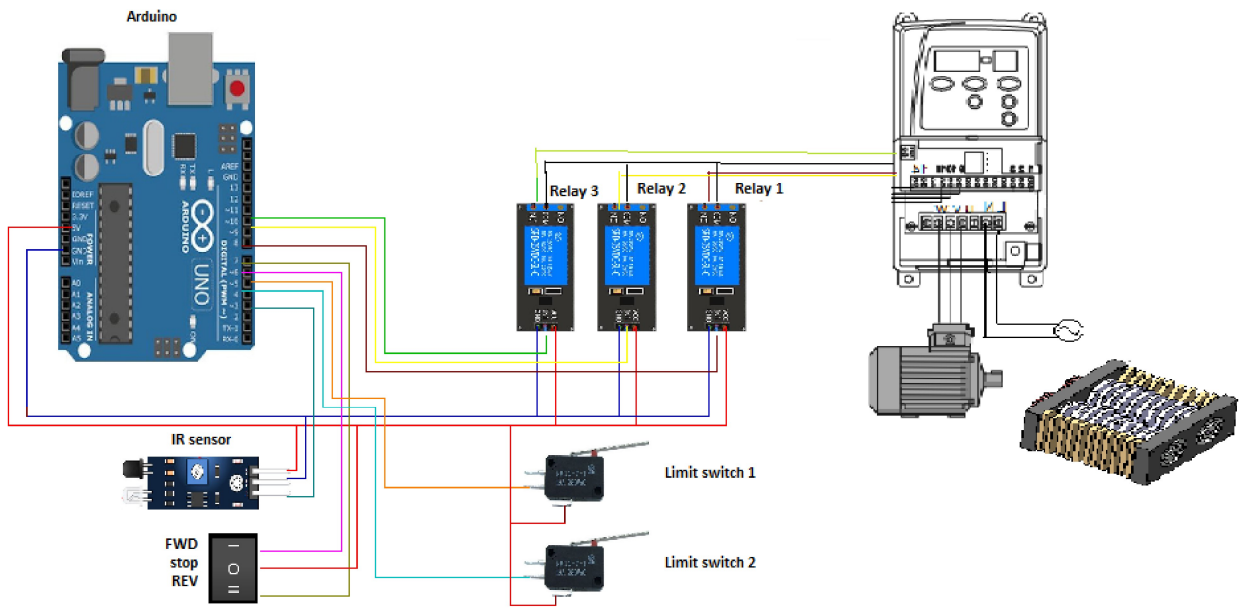


Figure 3.15: Conceptual Design

The Figure 3.16 show operation procedure

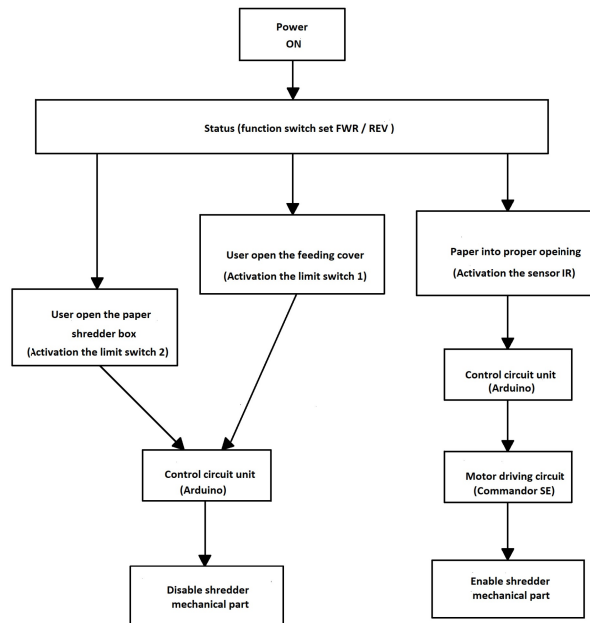


Figure 3.16: Flow Chart Operation Procedure:

Chapter 4

Project Control

The controller acts as the brain of the machine system. All parts (electrical and mechanical) of the controller are integrated together to serve the machine tasks. The primary task of the controller is to receive digital signals; a signal that represents a sequence of discrete values, from a computer and translate these signals into mechanical motion through motor drivers.

This chapter explains the controller design and the software program which will be used to control the movement the shafts

Open-loop control system will be used to control the machine since we use AC motor as mentioned in Chapter 3

4.1 Open - Loop Control System

Open-loop system Figure 4.1 is a type of continuous control system in which the output has no influence or effect on the control action of the input signal. In other words, in an open-loop control system, the output is neither measured nor feedback for comparison with the input. Therefore, the output signal naturally follow the input without feed back signal [15].

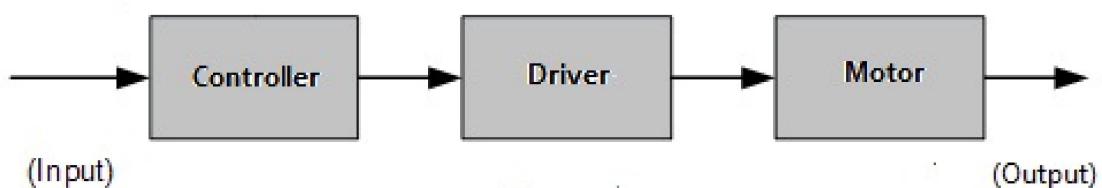


Figure 4.1: Open-Loop Control System.

In the open-loop control system, the controller receives the desired from the user before the controller create the necessary steps and direction signals to perform the desired task and send it to the motor driver. The driver leads the AC motor to rotate

Controlling system for driving a shredding machine by a motor to shred paper sheets increase shredding capacity represented by the number of paper that can be collectively shredded while limiting input current in an allowable range and reduces the time necessary for shredding number of papers.

The driving and controlling system include a motor for driving a shredding machine for shredding paper sheets and a controller between the motor and a power system to control power to be supplied to the motor.

The power supply module may include an AC power interface switch, safety switch, control switch, power supply of control circuit unit, and motor driving circuit unit.

4.2 Safety in the Project

Safety system for a machine, particularly for a tool having a moving blade

Safety protection system includes an electronically controlled safety switch in the feed opening, an electronic switch which cuts power to the motor when the waste box is opened or when the shred waste box is full, automatic reverse and power cut-off in case of a paper pending




4.3 Control Switches

A paper shredding machine include:

- 1-OFF switch
- 2- Revers direction control switch
- 3- Forward direction control switch

Table 4.1 shows how the selector switch works.

Table 4.1: Selector Switch Working States

Switch Position	Cam Results	Control Result	Control Effect
 <p>Run reverse</p>	<p>REV X ○ ○</p> <p>FWD ○ ○ X</p>	<p>REV Circuit = Closed</p> <p>FWD Circuit = Open</p>	<p>When the switch is on ' REV ', The motor works naturally with the clock.</p> <p>It is normal for the movement of the motor when the paper shredder.</p>
 <p>OFF</p>	<p>REV X ○ ○</p> <p>FWD ○ ○ X</p>	<p>REV Circuit = Open</p> <p>FWD Circuit = Open</p>	<p>When the switch is on "off", The motor has no power and cannot run.</p> <p>Note that both circuits are open or disconnected.</p>
 <p>Run forward</p>	<p>REV X ○ ○</p> <p>FWD ○ ○ X</p>	<p>REV Circuit = Open</p> <p>FWD Circuit = Closed</p>	<p>When the switch is on "FWD", The motor acts counterclockwise to reverse the rotation of the blades.</p> <p>This key is used when there is an overload on the motor, We need to reverse the motor rotation.</p>

4.4 Arduino Controller software

To interface with the output and input the address of each part must be known and named in the software [14]

Figure 4.2 show the upload the code by connecting micro-controller with computer, it can receive the desired commands from the computer. The micro-controller converts these commands to electrical signals, these signals are sent by micro-controller to the motor drivers which move the motors.

```

sketch_apr28a $
digitalWrite(En,HIGH );
digitalWrite(Rev,LOW );
}
else
{
digitalWrite(En,LOW );
digitalWrite(For,LOW );
digitalWrite(Rev,LOW );
}
}
{
if((digitalRead(IR) == LOW) & (digitalRead(SRev) == HIGH) & (digitalRead(SFor) == HIGH))
{
digitalWrite(En,HIGH );
digitalWrite(Rev,HIGH );
digitalWrite(For,LOW );
}
else
{
digitalWrite(En,LOW );
digitalWrite(For,LOW );
digitalWrite(Rev,LOW );
}
}
}
}

```

1

```

sketch_apr28a $
pinMode(En,OUTPUT);
pinMode(For,OUTPUT);
pinMode(Rev,OUTPUT);
}

void loop() {
{
if((digitalRead(IR) == LOW) & (digitalRead(SFor) == HIGH) & (digitalRead(SRev) == HIGH))
{
digitalWrite(En,HIGH );
digitalWrite(For,HIGH );
digitalWrite(Rev,LOW );
}
else
{
digitalWrite(En,LOW );
digitalWrite(For,LOW );
digitalWrite(Rev,LOW );
}
}
}
if((digitalRead(IR) == LOW) & (digitalRead(SRev) == HIGH) & (digitalRead(SFor) == HIGH))

```

2

```

sketch_apr28a $
void setup() {
// Input
int IR =3; // for IR sensor
int L1 =4; // for Limit Switch 1
int L2 =5; // for Limit Switch 2
int SFor = 6; // for Switch Forward
int SRev = 7; // for Switch Reverse

// Output
int En =8; //for Enable Driver of motor
int For =9; // for Forward Direction
int Rev =10; // for Reverse Direction
}

void loop() {
// put your main code here, to run repeatedly:
pinMode(IR, INPUT);
pinMode(L1, INPUT);
pinMode(L2, INPUT);
pinMode(SFor, INPUT);
pinMode(SRev, INPUT);
pinMode(En, OUTPUT);
pinMode(For, OUTPUT);
pinMode(Rev, OUTPUT);
}
}

```

3

Figure 4.2: Code arduino

Chapter 5

Manufacturing and Assembling

This chapter explains the processes of the machine setup that are used in this project. Five steps are used to build this machine; cutting, welding, drilling, finishing, and coating. In the following, we explain each process for each part in the machine.

5.1 Main Frame

Three steps are used to build the main frame . First, cutting the sheet steel with the desired dimension. Then weld the cutting sheet as the desired shape. Finally clean and coat it. Figure 5.1 shows the main frame in the coating process



Figure 5.1: Main Frame

5.2 Bearing Cover

Three steps are used to build bearing cover . These steps are cutting two aluminum plates with the desired dimension using Plasma CNC machine, finishing and drilling them to fix them with the shaft and the bearing as shown the Figure 5.2.

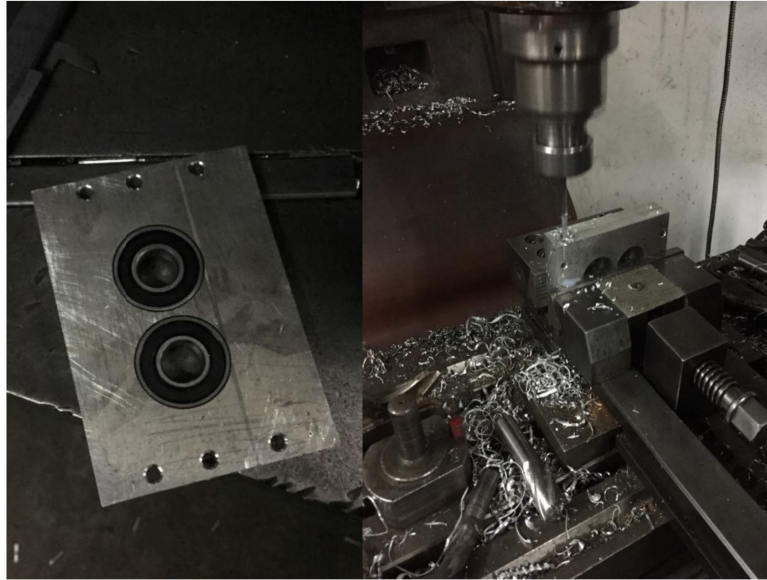


Figure 5.2: Bearing Cover

5.3 Motor Support

Three steps are used to build motor support. These steps are cutting the square steel tubes with the desired dimension , drilling and welding the cutting pieces inside frame as shown the Figure 5.3.



Figure 5.3: Motor Support

5.4 The Cutting Blade

Due to the high cost for lathing of blades, Old machine blades are used but operate less efficiently than the designed blades, The blade has a lower diameter and thickness, This problem was overcome by combining all four blades with one blade, To give a close efficiency of the efficiency of designed blades as shown the Figure 5.4.



Figure 5.4: The Cutting Blade

5.5 The Main shaft

Two step are used to build the hexagonal shaft. These steps are used to hold the ball bearing and gears inside it. The gears and ball bearing must be fit on shaft. Then threading the two shafts in order to fix the nut on shaft which prevent the gears to move from its place. This step can be done by a lathe machine as shown the Figure 5.5.





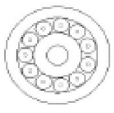




Figure 5.5: Main shaft

5.6 Assembly

After producing the shredding components of the machine , the following components are needed and must be ready for assembly as shown in Table 5.1.

Table 5.1: The shredding components of the machine

Item number	Part name	Figure	Number of part
1	Bearing cover		2
2	Blade		28
3	Shaft		2
4	Gears		2
5	Bearing		4
6	Separate plate		28
7	Distance ring		28

We need six steps to assemble the machine:

1- Start with pushing the two ball bearing in bearing housing as shown the figure 5.6. We press slightly to push the ball bearing in the bearing house, the ball bearing should slide easily in place we don't use a hummer or any other metal object to push the ball bearing in housing.

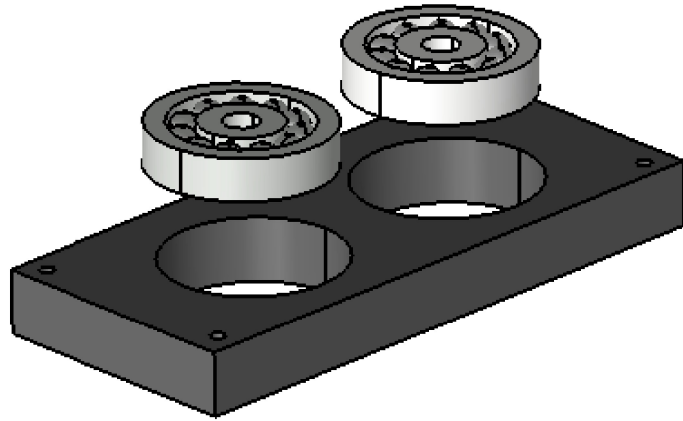


Figure 5.6: Assembly of bearing

2- Repeat this process one more time to assemble the second bearing housing. The two bearing housing should look like as the figure 5.7.

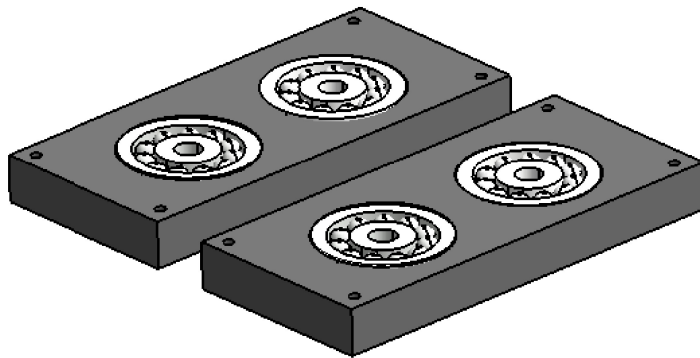


Figure 5.7: Bearing housing

3- Take one distance ring and slide it on the shaft and one blade on another shaft , and we check the distance between separative ring and blade as shown the Figure 5.8.

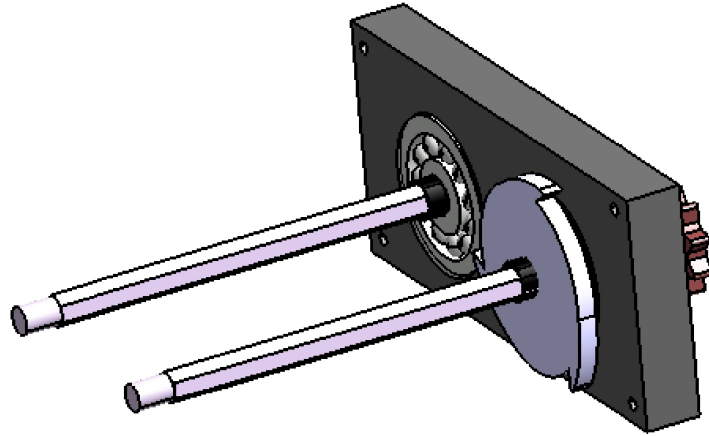


Figure 5.8: Assembly the blades and seperative rings on shaft

4- We Repeat this steps to get the parts as shown the Figure 5.9.

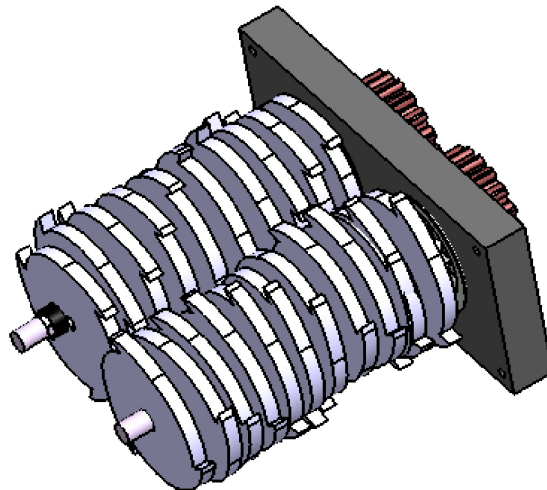


Figure 5.9: Assembly the blades and seperative rings on shaft

Then we install the second assembly bearing cover as shown the Figure 5.10.

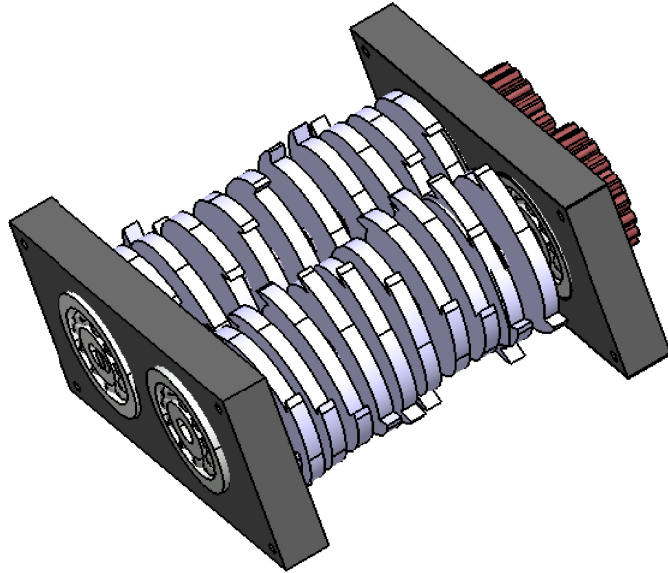


Figure 5.10: Assembly second bearing cover

5- Assembly separative plate, this separative plate prevent the shredded paper from sliding behind the blade. The separative plate must be fit between the blades in order to operate the machine smoothly. as shown the Figure 5.11.

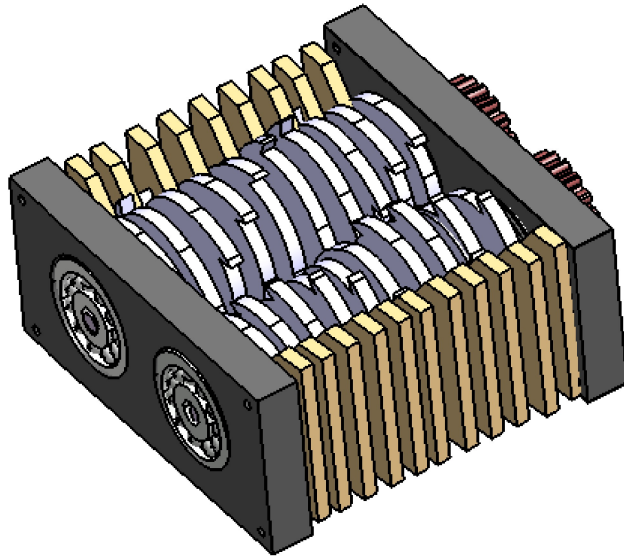


Figure 5.11: Assembly separative plate

6- Finally we fix the shredder and electric motor on a stand and connect them by double drive chain.

Chapter 6

Conclusion, Safety and Outlook

6.1 Conclusion

The project is a mechanical device used to shred paper collectively, when placing paper in the place to shred there is a sensor that transmits the signal to Arduino and then transmits a signal to the motor to operate and the shredding process begins.

This project has been selected to achieve many benefits, Such as preserving the secrets of paper in governmental and non-governmental departments and easy to get rid of dead papers with the lowest possible area and easy transfer of paper to places of recycling.

The construction of this project should be easy to use and deal with and be accessible to everyone, the most important the safety factor and ease of maintenance and installation should be also taken into account.

Design for usability and ergonomics is concerned with designing a product that is easy and comfortable to use. Considerations do not only have to be functional, they can also be aesthetic.

Shredder mounts easily on top of basket. On/off/reverse switch is on top of shredder for easy access and is well shaped for easy control. Shredder has convenient slot for paper and credit cards. Basket height is such that it can hold a lot of paper but still fit under the user's desk. Lightweight and portable for average users

Regarding average users, the ergonomics are terrific and the product is easy to set up for use. However, the product is not well designed for users with special needs. The basket is too heavy and the switch is hard to manipulate.

Design for Safety

Design for safety is used to address any safety concerns that can occur due to unforeseen, unconventional use or failure. This is a very important consideration because the welfare of the user is held most paramount at all times.

- There is a protective cover over the blades so that fingers cannot fit inside the paper slot but paper and credit cards can.
- Electrical components are housed inside of the shredder.
- Shredder has a safety switch that does not allow shredding to occur unless the shredder is on basket.
- Prevents access to blades while running.
- To keep the engine from getting hot
- The machine only works when the paper is placed in the paper slot and the engine stops working when the paper is finished.
- All components are housed, so any failure will not result in personal injury, just performance issues.
- Warning labels printed into top case, so always visible when using.
- Two limit switches were used to protect the user during the maintenance process so that the machine stops working when opening the cover.
- The machine cannot be run if the basket does not exist.

The design for this product addresses the safety issue very well. One possible improvement, though, would be a warning noise when the system malfunctions.

6.2 Outlook

The idea of manufacturing paper shredders is one of the ideas that has not been put up in the local market for manufacturing and producing they are not manufactured locally but imported by the market despite its importance, Due to the abundance of raw materials used in this project, it can be manufactured locally this encourages local industry and meets the needs of the local market of this product in all shapes and sizes.

This section contains our suggestions for improvements that could be made to the current design to overcome its shortcomings. Our recommendation for the most significant improvement would be to add a feeding mechanism to the shredder. We found some users had trouble feeding the paper manually, plus sitting around shredding large quantities is an inefficient use of time. Both these issues would be remedied by adding an automatic feeding mechanism. The user could easily load the paper, not having to struggle with it trying to get the teeth to grab it, plus they could load large stacks and move on to other tasks.

Areas of Possible Improvement

Although, the paper shredder has many design elements geared toward safety, efficiency, security, and ease of use, there are many areas that can be improved.

- Improved shredding capability for added security.
- Rotary blade in which confetti is funneled into.
- Way to empty basin without taking off top.
- Wall-mounting capabilities.
- Weight issues of shredder assembly which affect portability, storage, and emptying waste basket.
- Use a lighter material than machined steel.
- Decrease noise pollution of system.
- Improved feeding capabilities.
- Large queue where can position multiple sheets that will automatically feed.

Appendix A

Moment Shear and Deflection Diagrams

Table A-3

Optional SI Units for
Bending Stress
 $\sigma = Mc/I$, Torsion Stress
 $\tau = Tr/J$, Axial Stress
 $\sigma = F/A$, and Direct
Shear Stress $\tau = F/A$

Bending and Torsion				Axial and Direct Shear		
M, T	I, J	c, r	σ, τ	F	A	σ, τ
$N \cdot m^*$	m^4	m	Pa	N^*	m^2	Pa
$N \cdot m$	cm^4	cm	MPa (N/mm ²)	N^\dagger	mm^2	MPa (N/mm ²)
$N \cdot m^\dagger$	mm^4	mm	GPa	kN	m^2	kPa
$kN \cdot m$	cm^4	cm	GPa	kN^\dagger	mm^2	GPa
$N \cdot mm^\dagger$	mm^4	mm	MPa (N/mm ²)			

*Basic relation.

†Often preferred.

Table A-4

Optional SI Units for
Bending Deflection
 $y = f(Fl^3/EI)$ or
 $y = f(wl^4/EI)$ and
Torsional Deflection
 $\theta = Tl/GJ$

Bending Deflection					Torsional Deflection				
F, wl	l	I	E	y	T	l	J	G	θ
N^*	m	m^4	Pa	m	$N \cdot m^*$	m	m^4	Pa	rad
kN^\dagger	mm	mm^4	GPa	mm	$N \cdot m^\dagger$	mm	mm^4	GPa	rad
kN	m	m^4	GPa	μm	$N \cdot mm$	mm	mm^4	MPa (N/mm ²)	rad
N	mm	mm^4	kPa	m	$N \cdot m$	cm	cm^4	MPa (N/mm ²)	rad

*Basic relation.

†Often preferred.

Table A-5

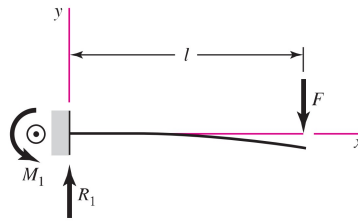
Physical Constants of Materials

Material	Modulus of Elasticity E		Modulus of Rigidity G		Poisson's Ratio ν	Unit Weight w		
	Mpsi	GPa	Mpsi	GPa		lbf/in ³	lbf/ft ³	kN/m ³
Aluminum (all alloys)	10.4	71.7	3.9	26.9	0.333	0.098	169	26.6
Beryllium copper	18.0	124.0	7.0	48.3	0.285	0.297	513	80.6
Brass	15.4	106.0	5.82	40.1	0.324	0.309	534	83.8
Carbon steel	30.0	207.0	11.5	79.3	0.292	0.282	487	76.5
Cast iron (gray)	14.5	100.0	6.0	41.4	0.211	0.260	450	70.6
Copper	17.2	119.0	6.49	44.7	0.326	0.322	556	87.3
Douglas fir	1.6	11.0	0.6	4.1	0.33	0.016	28	4.3
Glass	6.7	46.2	2.7	18.6	0.245	0.094	162	25.4
Inconel	31.0	214.0	11.0	75.8	0.290	0.307	530	83.3
Lead	5.3	36.5	1.9	13.1	0.425	0.411	710	111.5
Magnesium	6.5	44.8	2.4	16.5	0.350	0.065	112	17.6
Molybdenum	48.0	331.0	17.0	117.0	0.307	0.368	636	100.0
Monel metal	26.0	179.0	9.5	65.5	0.320	0.319	551	86.6
Nickel silver	18.5	127.0	7.0	48.3	0.322	0.316	546	85.8
Nickel steel	30.0	207.0	11.5	79.3	0.291	0.280	484	76.0
Phosphor bronze	16.1	111.0	6.0	41.4	0.349	0.295	510	80.1
Stainless steel (18-8)	27.6	190.0	10.6	73.1	0.305	0.280	484	76.0
Titanium alloys	16.5	114.0	6.2	42.4	0.340	0.160	276	43.4

Table A-9

Shear, Moment, and Deflection of Beams
 (Note: Force and moment reactions are positive in the directions shown; equations for shear force V and bending moment M follow the sign conventions given in Sec. 3-2.)

1 Cantilever—end load

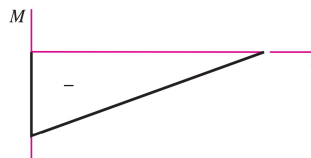


$$R_1 = V = F \quad M_1 = Fl$$

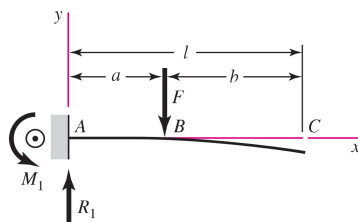
$$M = F(x - l)$$

$$y = \frac{Fx^2}{6EI}(x - 3l)$$

$$y_{\max} = -\frac{Fl^3}{3EI}$$



2 Cantilever—intermediate load



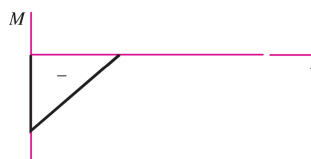
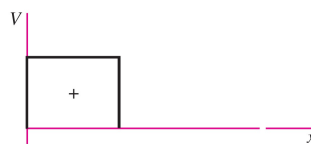
$$R_1 = V = F \quad M_1 = Fa$$

$$M_{AB} = F(x - a) \quad M_{BC} = 0$$

$$y_{AB} = \frac{Fx^2}{6EI}(x - 3a)$$

$$y_{BC} = \frac{Fa^2}{6EI}(a - 3x)$$

$$y_{\max} = \frac{Fa^2}{6EI}(a - 3l)$$

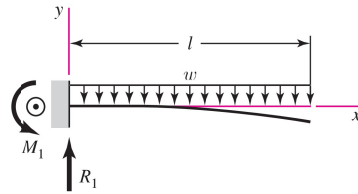


(continued)

Table A-9

Shear, Moment, and Deflection of Beams
 (Continued)
 (Note: Force and moment reactions are positive in the directions shown; equations for shear force V and bending moment M follow the sign conventions given in Sec. 3-2.)

3 Cantilever—uniform load

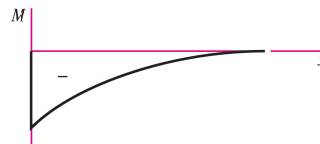
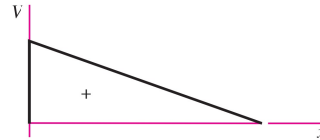


$$R_1 = wl \quad M_1 = \frac{wl^2}{2}$$

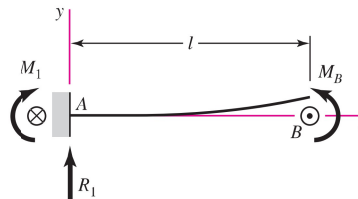
$$V = w(l - x) \quad M = -\frac{w}{2}(l - x)^2$$

$$y = \frac{wx^2}{24EI}(4lx - x^2 - 6l^2)$$

$$y_{\max} = -\frac{wl^4}{8EI}$$



4 Cantilever—moment load



$$R_1 = V = 0 \quad M_1 = M = M_B$$

$$y = \frac{M_B x^2}{2EI} \quad y_{\max} = \frac{M_B l^2}{2EI}$$

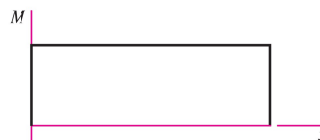
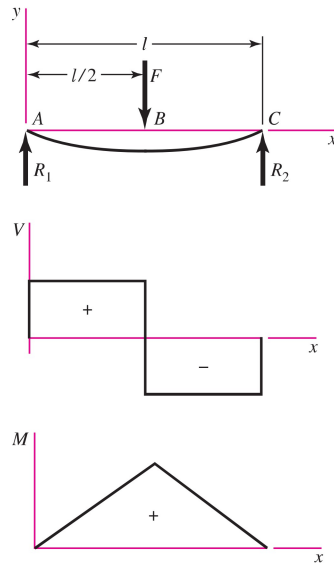


Table A-9

Shear, Moment, and Deflection of Beams
(Continued)

(Note: Force and moment reactions are positive in the directions shown; equations for shear force V and bending moment M follow the sign conventions given in Sec. 3-2.)

5 Simple supports—center load



$$R_1 = R_2 = \frac{F}{2}$$

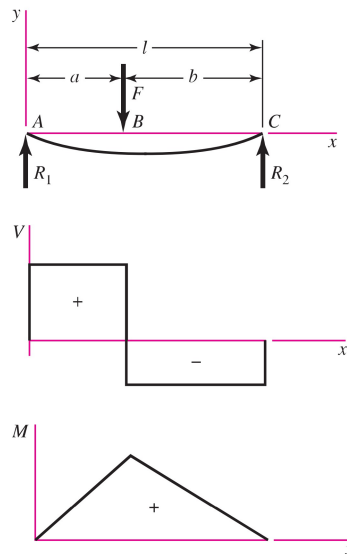
$$V_{AB} = R_1 \quad V_{BC} = -R_2$$

$$M_{AB} = \frac{Fx}{2} \quad M_{BC} = \frac{F}{2}(l-x)$$

$$y_{AB} = \frac{Fx}{48EI}(4x^2 - 3l^2)$$

$$y_{\max} = -\frac{Fl^3}{48EI}$$

6 Simple supports—intermediate load



$$R_1 = \frac{Fb}{l} \quad R_2 = \frac{Fa}{l}$$

$$V_{AB} = R_1 \quad V_{BC} = -R_2$$

$$M_{AB} = \frac{Fbx}{l} \quad M_{BC} = \frac{Fa}{l}(l-x)$$

$$y_{AB} = \frac{Fbx}{6EI}(x^2 + b^2 - l^2)$$

$$y_{BC} = \frac{Fa(l-x)}{6EI}(x^2 + a^2 - 2lx)$$

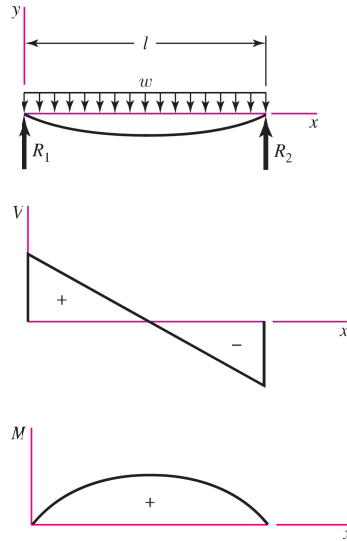
(continued)

Table A-9

Shear, Moment, and Deflection of Beams
(Continued)

(Note: Force and moment reactions are positive in the directions shown; equations for shear force V and bending moment M follow the sign conventions given in Sec. 3-2.)

7 Simple supports—uniform load



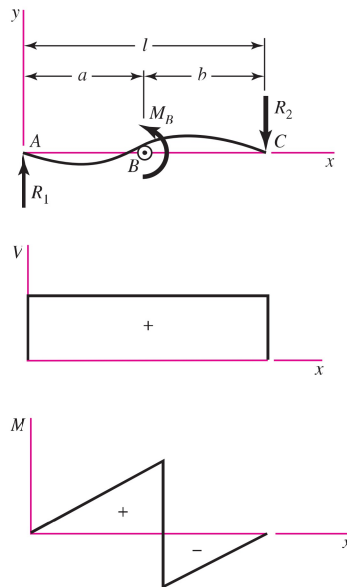
$$R_1 = R_2 = \frac{wl}{2} \quad V = \frac{wl}{2} - wx$$

$$M = \frac{wx}{2}(l - x)$$

$$y = \frac{wx}{24EI}(2lx^2 - x^3 - l^3)$$

$$y_{\max} = -\frac{5wl^4}{384EI}$$

8 Simple supports—moment load



$$R_1 = R_2 = \frac{M_B}{l} \quad V = \frac{M_B}{l}$$

$$M_{AB} = \frac{M_B x}{l} \quad M_{BC} = \frac{M_B}{l}(x - l)$$

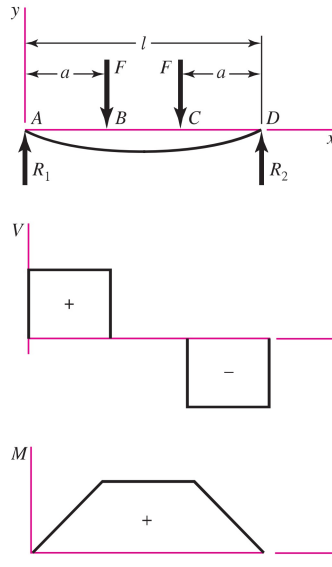
$$y_{AB} = \frac{M_B x}{6EI l}(x^2 + 3a^2 - 6al + 2l^2)$$

$$y_{BC} = \frac{M_B}{6EI l}[x^3 - 3lx^2 + x(2l^2 + 3a^2) - 3a^2 l]$$

Table A-9

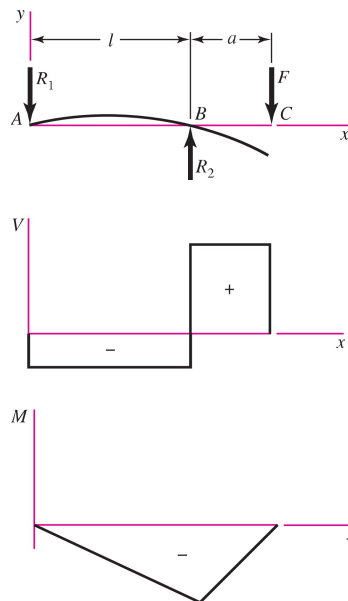
Shear, Moment, and Deflection of Beams
 (Continued)
 (Note: Force and moment reactions are positive in the directions shown; equations for shear force V and bending moment M follow the sign conventions given in Sec. 3-2.)

9 Simple supports—twin loads



$$\begin{aligned}
 R_1 &= R_2 = F & V_{AB} &= F & V_{BC} &= 0 \\
 V_{CD} &= -F \\
 M_{AB} &= Fx & M_{BC} &= Fa & M_{CD} &= F(l-x) \\
 y_{AB} &= \frac{Fx}{6EI}(x^2 + 3a^2 - 3la) \\
 y_{BC} &= \frac{Fa}{6EI}(3x^2 + a^2 - 3lx) \\
 y_{\max} &= \frac{Fa^2}{24EI}(4a^2 - 3l^2)
 \end{aligned}$$

10 Simple supports—overhanging load



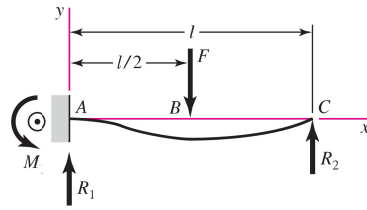
$$\begin{aligned}
 R_1 &= \frac{Fa}{l} & R_2 &= \frac{F}{l}(l+a) \\
 V_{AB} &= -\frac{Fa}{l} & V_{BC} &= F \\
 M_{AB} &= -\frac{Fax}{l} & M_{BC} &= F(x-l-a) \\
 y_{AB} &= \frac{Fax}{6EI}(l^2 - x^2) \\
 y_{BC} &= \frac{F(x-l)}{6EI}[(x-l)^2 - a(3x-l)] \\
 y_C &= -\frac{Fa^2}{3EI}(l+a)
 \end{aligned}$$

(continued)

Table A-9

Shear, Moment, and Deflection of Beams
(Continued)
(Note: Force and moment reactions are positive in the directions shown; equations for shear force V and bending moment M follow the sign conventions given in Sec. 3-2.)

11 One fixed and one simple support—center load



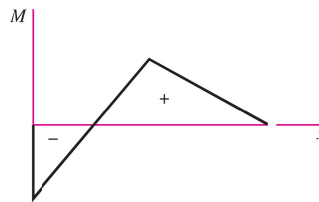
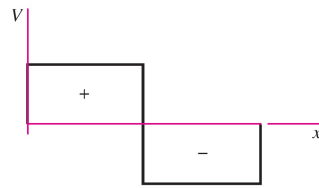
$$R_1 = \frac{11F}{16} \quad R_2 = \frac{5F}{16} \quad M_1 = \frac{3Fl}{16}$$

$$V_{AB} = R_1 \quad V_{BC} = -R_2$$

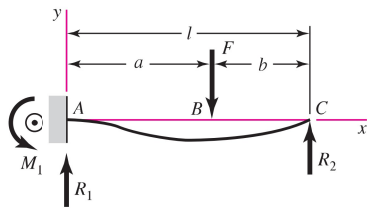
$$M_{AB} = \frac{F}{16}(11x - 3l) \quad M_{BC} = \frac{5F}{16}(l - x)$$

$$y_{AB} = \frac{Fx^2}{96EI}(11x - 9l)$$

$$y_{BC} = \frac{F(l-x)}{96EI}(5x^2 + 2l^2 - 10lx)$$



12 One fixed and one simple support—intermediate load



$$R_1 = \frac{Fb}{2l^3}(3l^2 - b^2) \quad R_2 = \frac{Fa^2}{2l^3}(3l - a)$$

$$M_1 = \frac{Fb}{2l^2}(l^2 - b^2)$$

$$V_{AB} = R_1 \quad V_{BC} = -R_2$$

$$M_{AB} = \frac{Fb}{2l^3}[b^2l - l^3 + x(3l^2 - b^2)]$$

$$M_{BC} = \frac{Fa^2}{2l^3}(3l^2 - 3lx - al + ax)$$

$$y_{AB} = \frac{Fbx^2}{12EI l^3}[3l(b^2 - l^2) + x(3l^2 - b^2)]$$

$$y_{BC} = y_{AB} - \frac{F(x-a)^3}{6EI}$$

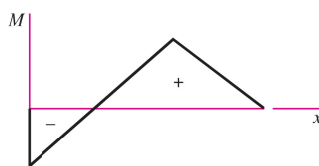
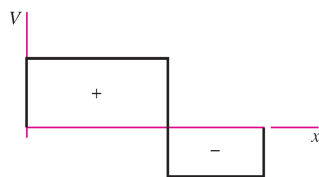
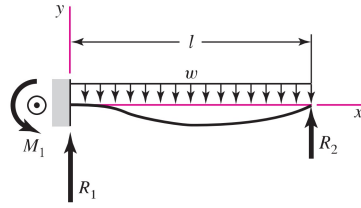


Table A-9

Shear, Moment, and Deflection of Beams
 (Continued)
 (Note: Force and moment reactions are positive in the directions shown; equations for shear force V and bending moment M follow the sign conventions given in Sec. 3-2.)

13 One fixed and one simple support—uniform load

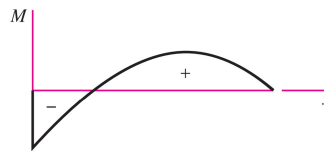
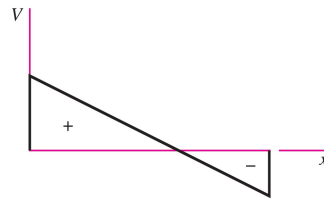


$$R_1 = \frac{5wl}{8} \quad R_2 = \frac{3wl}{8} \quad M_1 = \frac{wl^2}{8}$$

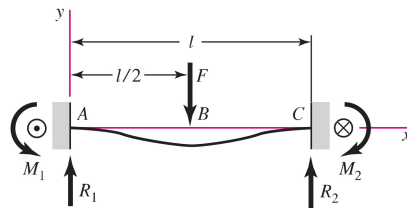
$$V = \frac{5wl}{8} - wx$$

$$M = -\frac{w}{8}(4x^2 - 5lx + l^2)$$

$$y = \frac{wx^2}{48EI}(l-x)(2x-3l)$$



14 Fixed supports—center load



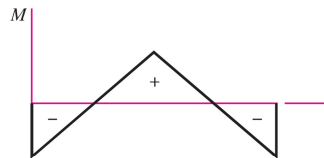
$$R_1 = R_2 = \frac{F}{2} \quad M_1 = M_2 = \frac{Fl}{8}$$

$$V_{AB} = -V_{BC} = \frac{F}{2}$$

$$M_{AB} = \frac{F}{8}(4x-l) \quad M_{BC} = \frac{F}{8}(3l-4x)$$

$$y_{AB} = \frac{Fx^2}{48EI}(4x-3l)$$

$$y_{\max} = -\frac{Fl^3}{192EI}$$

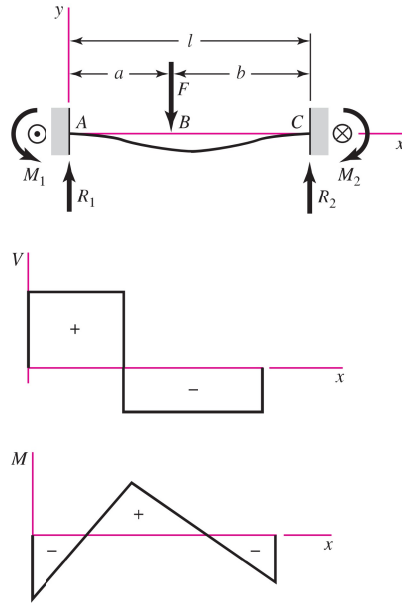


(continued)

Table A-9

Shear, Moment, and Deflection of Beams
(Continued)
(Note: Force and moment reactions are positive in the directions shown; equations for shear force V and bending moment M follow the sign conventions given in Sec. 3-2.)

15 Fixed supports—intermediate load



$$R_1 = \frac{Fb^2}{l^3}(3a + b) \quad R_2 = \frac{Fa^2}{l^3}(3b + a)$$

$$M_1 = \frac{Fab^2}{l^2} \quad M_2 = \frac{Fa^2b}{l^2}$$

$$V_{AB} = R_1 \quad V_{BC} = -R_2$$

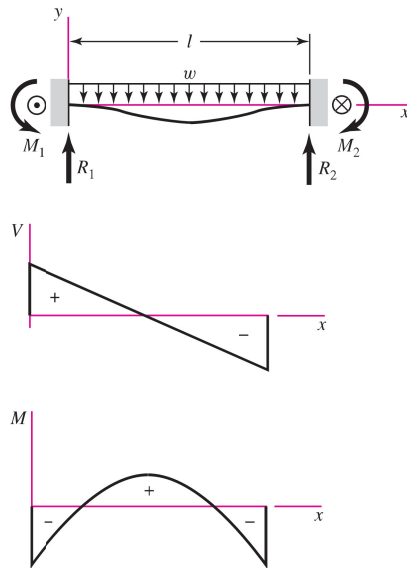
$$M_{AB} = \frac{Fb^2}{l^3}[x(3a + b) - al]$$

$$M_{BC} = M_{AB} - F(x - a)$$

$$y_{AB} = \frac{Fb^2x^2}{6EI l^3}[x(3a + b) - 3al]$$

$$y_{BC} = \frac{Fa^2(l - x)^2}{6EI l^3}[(l - x)(3b + a) - 3bl]$$

16 Fixed supports—uniform load



$$R_1 = R_2 = \frac{wl}{2} \quad M_1 = M_2 = \frac{wl^2}{12}$$

$$V = \frac{w}{2}(l - 2x)$$

$$M = \frac{w}{12}(6lx - 6x^2 - l^2)$$

$$y = -\frac{wx^2}{24EI}(l - x)^2$$

$$y_{\max} = -\frac{wl^4}{384EI}$$

Table A-15

Charts of Theoretical Stress-Concentration Factors K_t^*

Figure A-15-1

Bar in tension or simple compression with a transverse hole. $\sigma_0 = F/A$, where $A = (w - d)t$ and t is the thickness.

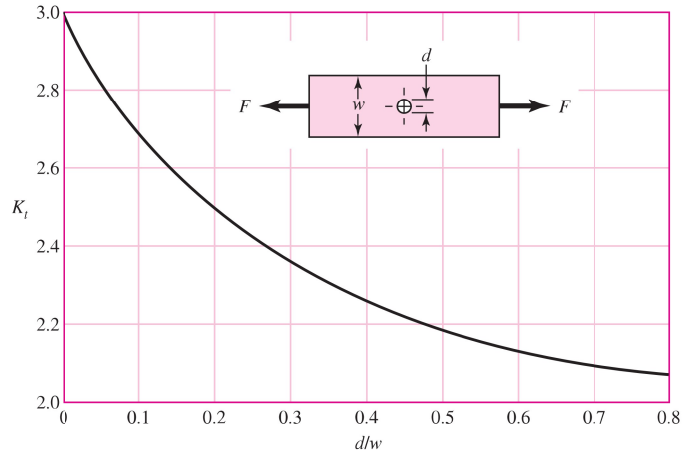


Figure A-15-2

Rectangular bar with a transverse hole in bending. $\sigma_0 = Mc/I$, where $I = (w - d)h^3/12$.

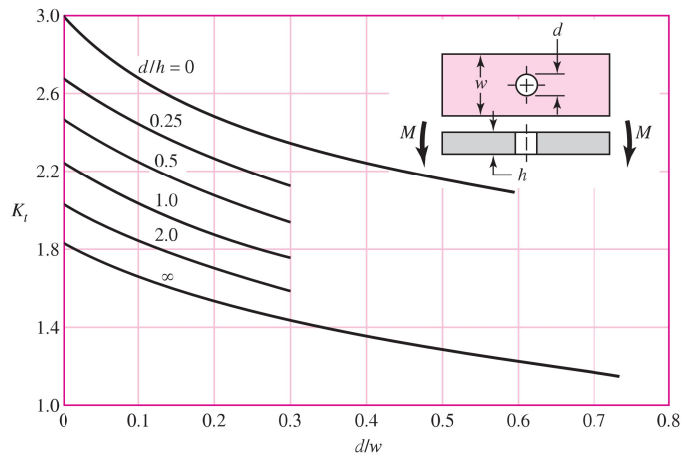


Figure A-15-3

Notched rectangular bar in tension or simple compression. $\sigma_0 = F/A$, where $A = dt$ and t is the thickness.

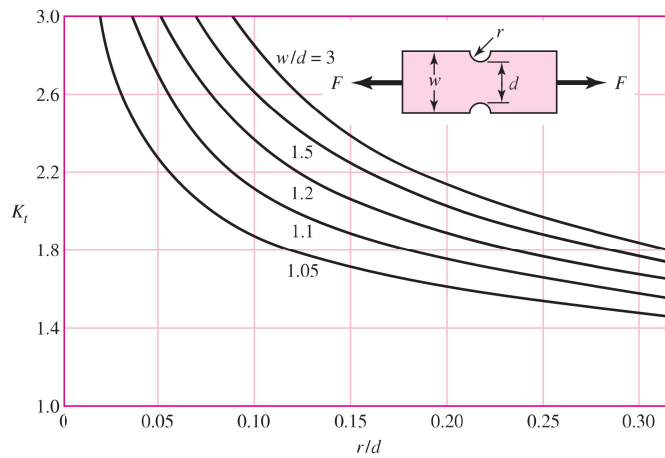
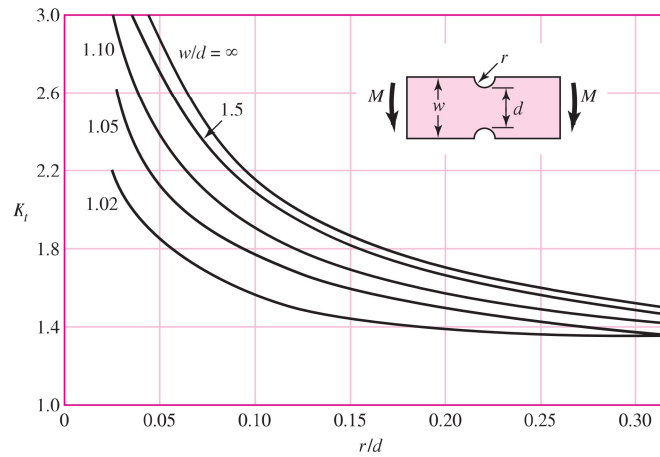
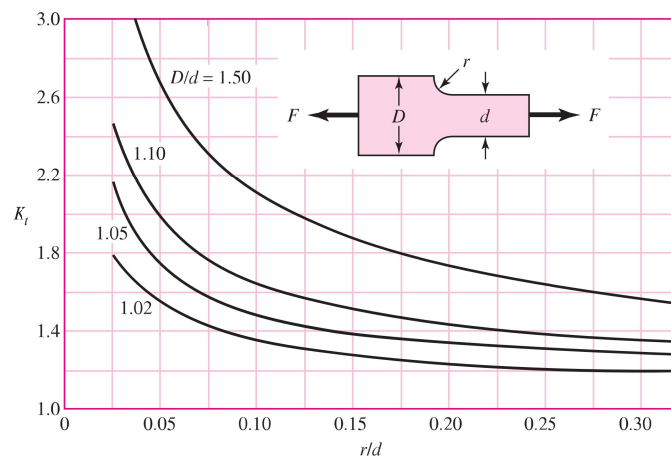


Table A-15Charts of Theoretical Stress-Concentration Factors K_t^* (Continued)**Figure A-15-4**

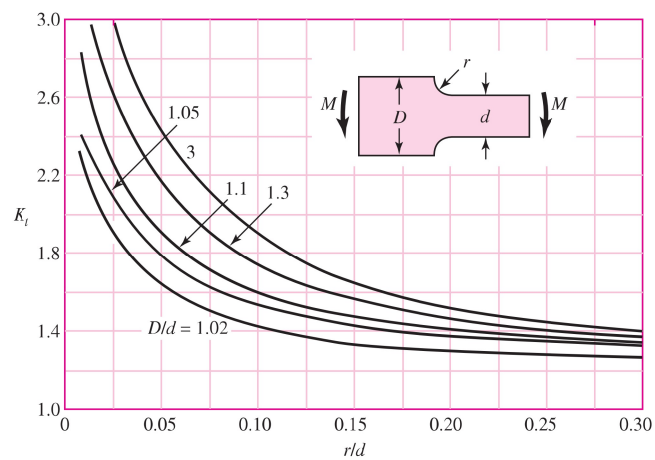
Notched rectangular bar in bending. $\sigma_0 = Mc/I$, where $c = d/2$, $I = td^3/12$, and t is the thickness.

**Figure A-15-5**

Rectangular filleted bar in tension or simple compression. $\sigma_0 = F/A$, where $A = dt$ and t is the thickness.

**Figure A-15-6**

Rectangular filleted bar in bending. $\sigma_0 = Mc/I$, where $c = d/2$, $I = td^3/12$, t is the thickness.



(continued)

*Factors from R. E. Peterson, "Design Factors for Stress Concentration," Machine Design, vol. 23, no. 2, February 1951, p. 169; no. 3, March 1951, p. 161, no. 5, May 1951, p. 159; no. 6, June 1951, p. 173; no. 7, July 1951, p. 155. Reprinted with permission from Machine Design, a Penton Media Inc. publication.

Table A-15

Charts of Theoretical Stress-Concentration Factors K_t^* (Continued)

Figure A-15-7

Round shaft with shoulder fillet in tension. $\sigma_0 = F/A$, where $A = \pi d^2/4$.

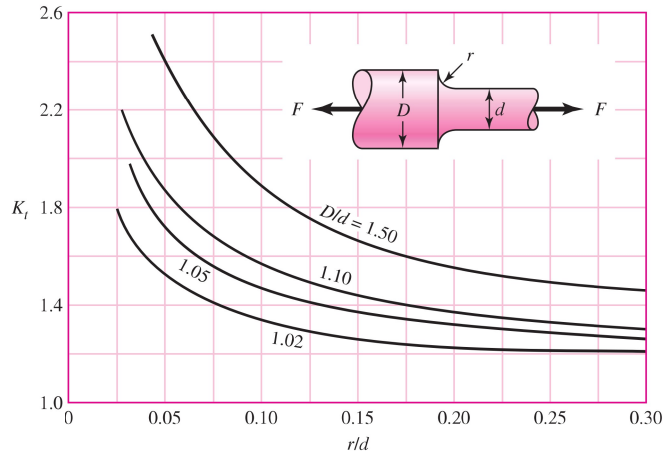


Figure A-15-8

Round shaft with shoulder fillet in torsion. $\tau_0 = Tc/J$, where $c = d/2$ and $J = \pi d^4/32$.

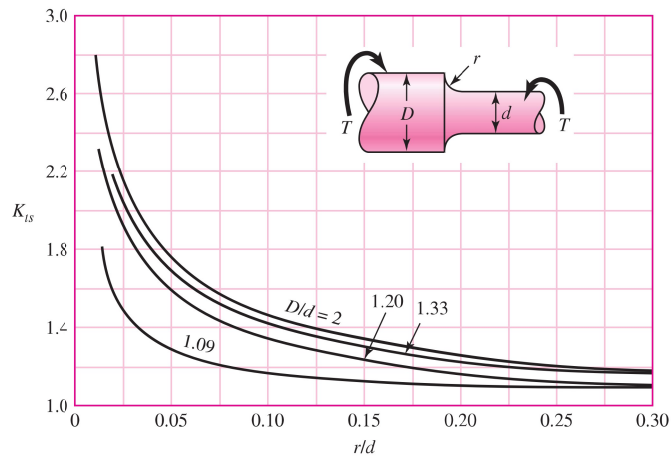


Figure A-15-9

Round shaft with shoulder fillet in bending. $\sigma_0 = Mc/I$, where $c = d/2$ and $I = \pi d^4/64$.

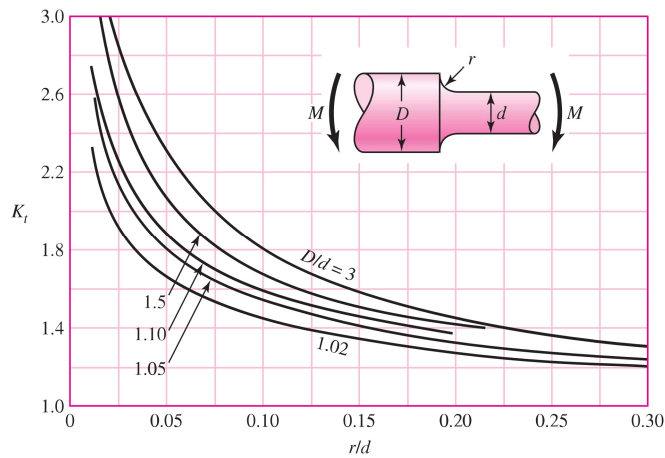
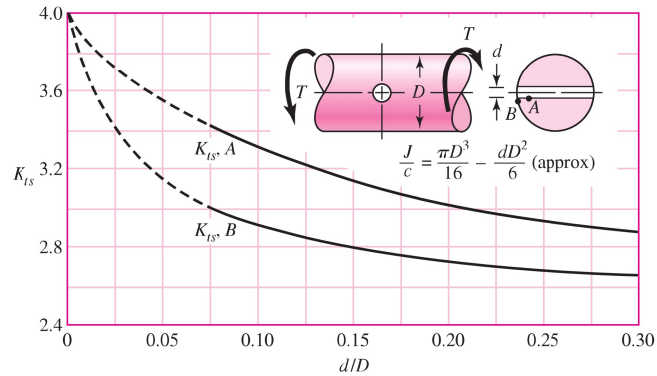
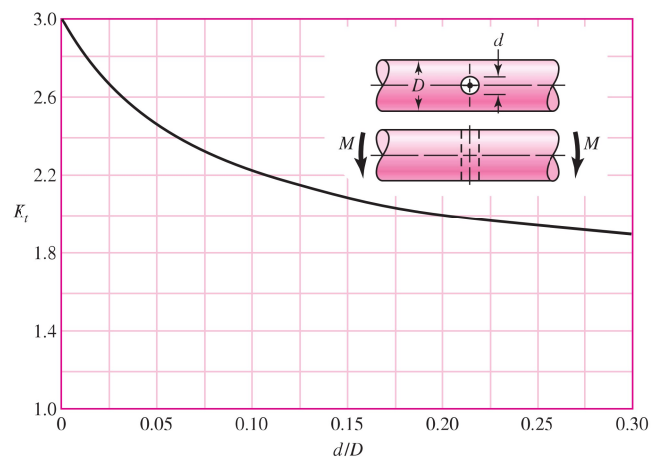
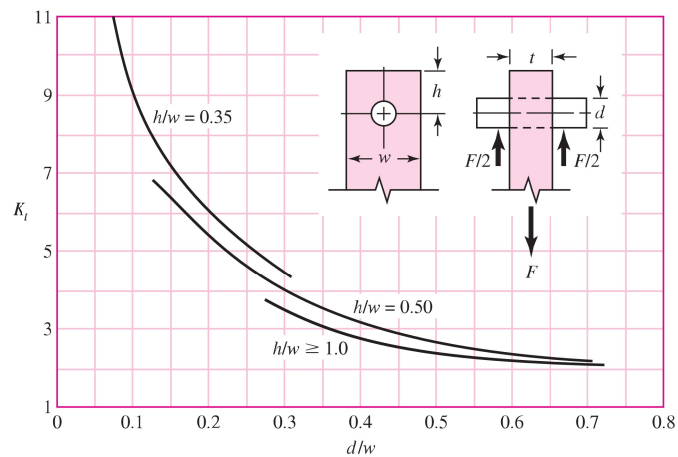


Table A-15Charts of Theoretical Stress-Concentration Factors K_t^* (Continued)**Figure A-15-10**

Round shaft in torsion with transverse hole.

**Figure A-15-11**Round shaft in bending with a transverse hole. $\sigma_0 = M/[(\pi D^3/32) - (dD^2/6)]$, approximately.**Figure A-15-12**Plate loaded in tension by a pin through a hole. $\sigma_0 = F/A$, where $A = (w - d)t$. When clearance exists, increase K_t 35 to 50 percent. (*M. M. Frocht and H. N. Hill, "Stress-Concentration Factors around a Central Circular Hole in a Plate Loaded through a Pin in Hole," J. Appl. Mechanics, vol. 7, no. 1, March 1940, p. A-5.*)

(continued)

*Factors from R. E. Peterson, "Design Factors for Stress Concentration," *Machine Design*, vol. 23, no. 2, February 1951, p. 169; no. 3, March 1951, p. 161, no. 5, May 1951, p. 159; no. 6, June 1951, p. 173; no. 7, July 1951, p. 155. Reprinted with permission from *Machine Design*, a Penton Media Inc. publication.

Table A-15

Charts of Theoretical Stress-Concentration Factors K_t^* (Continued)

Figure A-15-13

Grooved round bar in tension.
 $\sigma_0 = F/A$, where $A = \pi d^2/4$.

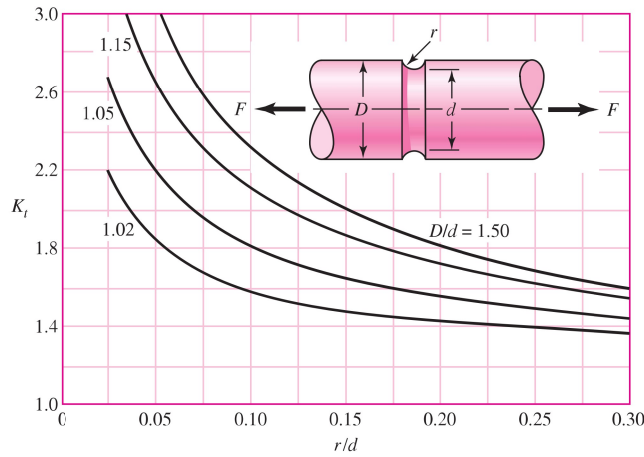


Figure A-15-14

Grooved round bar in bending.
 $\sigma_0 = Mc/I$, where $c = d/2$
 and $I = \pi d^4/64$.

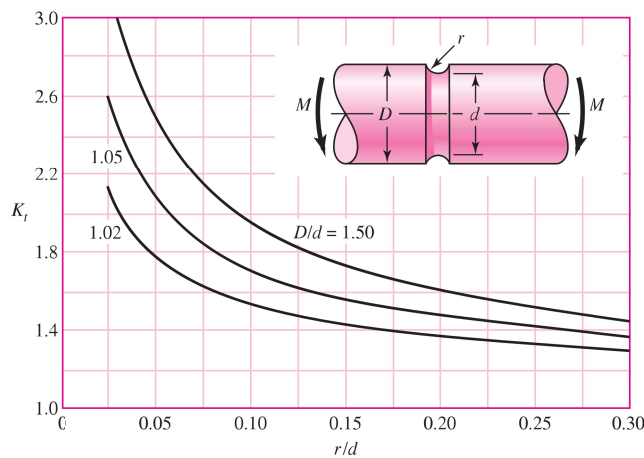
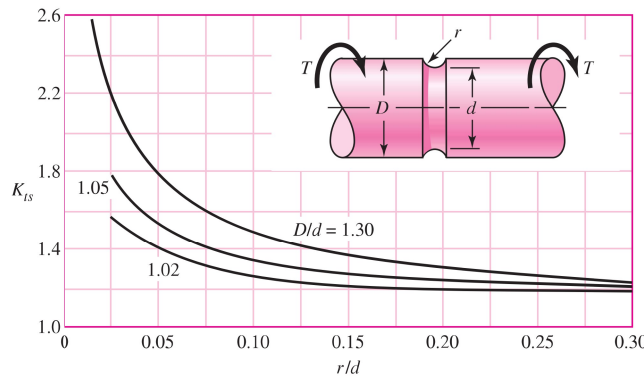


Figure A-15-15

Grooved round bar in torsion.
 $\tau_0 = Tc/J$, where $c = d/2$ and
 $J = \pi d^4/32$.



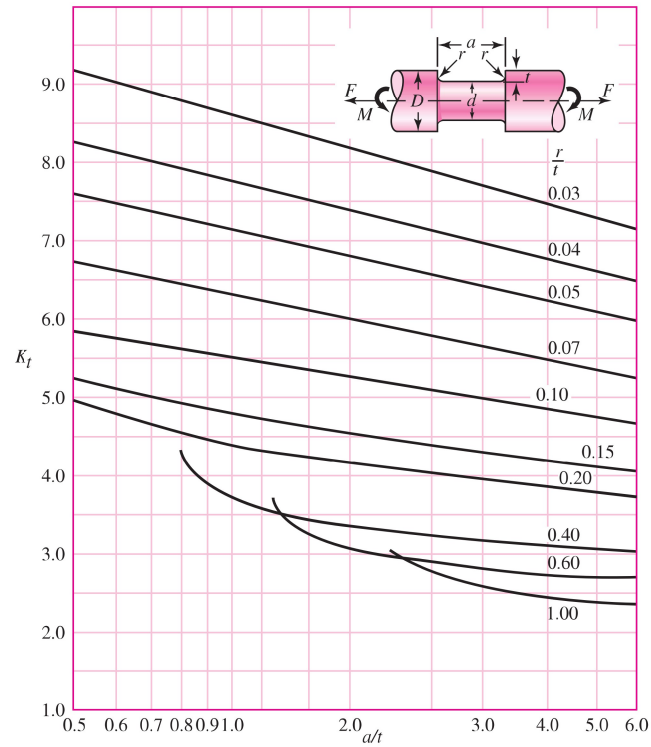
*Factors from R. E. Peterson, "Design Factors for Stress Concentration," Machine Design, vol. 23, no. 2, February 1951, p. 169; no. 3, March 1951, p. 161, no. 5, May 1951, p. 159; no. 6, June 1951, p. 173; no. 7, July 1951, p. 155. Reprinted with permission from Machine Design, a Penton Media Inc. publication.

Table A-15Charts of Theoretical Stress-Concentration Factors K_t^* (Continued)**Figure A-15-16**

Round shaft with flat-bottom groove in bending and/or tension.

$$\sigma_0 = \frac{4F}{\pi d^2} + \frac{32M}{\pi d^3}$$

Source: W. D. Pilkey, *Peterson's Stress-Concentration Factors*, 2nd ed. John Wiley & Sons, New York, 1997, p. 115.



(continued)

Table A-15

Charts of Theoretical Stress-Concentration Factors K_t^* (Continued)

Figure A-15-17

Round shaft with flat-bottom groove in torsion.

$$\tau_0 = \frac{16T}{\pi d^3}$$

Source: W. D. Pilkey, *Peterson's Stress-Concentration Factors*, 2nd ed. John Wiley & Sons, New York, 1997, p. 133

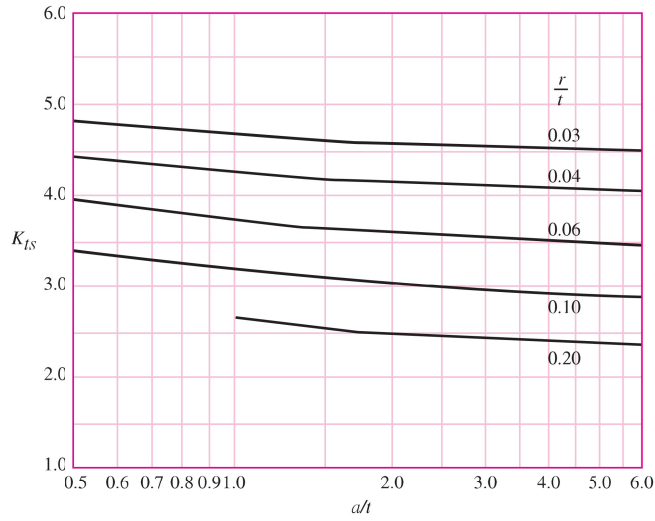
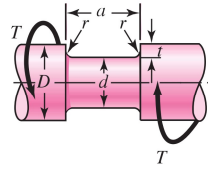


Table A-20

Deterministic ASTM Minimum Tensile and Yield Strengths for Some Hot-Rolled (HR) and Cold-Drawn (CD) Steels [The strengths listed are estimated ASTM minimum values in the size range 18 to 32 mm ($\frac{3}{4}$ to $1\frac{1}{4}$ in). These strengths are suitable for use with the design factor defined in Sec. 1–10, provided the materials conform to ASTM A6 or A568 requirements or are required in the purchase specifications. Remember that a numbering system is not a specification.] *Source:* 1986 SAE Handbook, p. 2.15.

1	2	3	4	5	6	7	8
UNS No.	SAE and/or AISI No.	Process- ing	Tensile Strength, MPa (kpsi)	Yield Strength, MPa (kpsi)	Elongation in 2 in, %	Reduction in Area, %	Brinell Hardness
G10060	1006	HR	300 (43)	170 (24)	30	55	86
		CD	330 (48)	280 (41)	20	45	95
G10100	1010	HR	320 (47)	180 (26)	28	50	95
		CD	370 (53)	300 (44)	20	40	105
G10150	1015	HR	340 (50)	190 (27.5)	28	50	101
		CD	390 (56)	320 (47)	18	40	111
G10180	1018	HR	400 (58)	220 (32)	25	50	116
		CD	440 (64)	370 (54)	15	40	126
G10200	1020	HR	380 (55)	210 (30)	25	50	111
		CD	470 (68)	390 (57)	15	40	131
G10300	1030	HR	470 (68)	260 (37.5)	20	42	137
		CD	520 (76)	440 (64)	12	35	149
G10350	1035	HR	500 (72)	270 (39.5)	18	40	143
		CD	550 (80)	460 (67)	12	35	163
G10400	1040	HR	520 (76)	290 (42)	18	40	149
		CD	590 (85)	490 (71)	12	35	170
G10450	1045	HR	570 (82)	310 (45)	16	40	163
		CD	630 (91)	530 (77)	12	35	179
G10500	1050	HR	620 (90)	340 (49.5)	15	35	179
		CD	690 (100)	580 (84)	10	30	197
G10600	1060	HR	680 (98)	370 (54)	12	30	201
G10800	1080	HR	770 (112)	420 (61.5)	10	25	229
G10950	1095	HR	830 (120)	460 (66)	10	25	248

Table A-21

Mean Mechanical Properties of Some Heat-Treated Steels

[These are typical properties for materials normalized and annealed. The properties for quenched and tempered (Q&T) steels are from a single heat. Because of the many variables, the properties listed are global averages. In all cases, data were obtained from specimens of diameter 0.505 in, machined from 1-in rounds, and of gauge length 2 in. unless noted, all specimens were oil-quenched.] *Source: ASM Metals Reference Book, 2d ed., American Society for Metals, Metals Park, Ohio, 1983.*

1	2	3	4	5	6	7	8
AISI No.	Treatment	Temperature °C (°F)	Tensile Strength MPa (kpsi)	Yield Strength, MPa (kpsi)	Elongation, %	Reduction in Area, %	Brinell Hardness
1030	Q&T*	205 (400)	848 (123)	648 (94)	17	47	495
	Q&T*	315 (600)	800 (116)	621 (90)	19	53	401
	Q&T*	425 (800)	731 (106)	579 (84)	23	60	302
	Q&T*	540 (1000)	669 (97)	517 (75)	28	65	255
	Q&T*	650 (1200)	586 (85)	441 (64)	32	70	207
	Normalized	925 (1700)	521 (75)	345 (50)	32	61	149
	Annealed	870 (1600)	430 (62)	317 (46)	35	64	137
1040	Q&T	205 (400)	779 (113)	593 (86)	19	48	262
	Q&T	425 (800)	758 (110)	552 (80)	21	54	241
	Q&T	650 (1200)	634 (92)	434 (63)	29	65	192
	Normalized	900 (1650)	590 (86)	374 (54)	28	55	170
	Annealed	790 (1450)	519 (75)	353 (51)	30	57	149
1050	Q&T*	205 (400)	1120 (163)	807 (117)	9	27	514
	Q&T*	425 (800)	1090 (158)	793 (115)	13	36	444
	Q&T*	650 (1200)	717 (104)	538 (78)	28	65	235
	Normalized	900 (1650)	748 (108)	427 (62)	20	39	217
	Annealed	790 (1450)	636 (92)	365 (53)	24	40	187
1060	Q&T	425 (800)	1080 (156)	765 (111)	14	41	311
	Q&T	540 (1000)	965 (140)	669 (97)	17	45	277
	Q&T	650 (1200)	800 (116)	524 (76)	23	54	229
	Normalized	900 (1650)	776 (112)	421 (61)	18	37	229
	Annealed	790 (1450)	626 (91)	372 (54)	22	38	179
1095	Q&T	315 (600)	1260 (183)	813 (118)	10	30	375
	Q&T	425 (800)	1210 (176)	772 (112)	12	32	363
	Q&T	540 (1000)	1090 (158)	676 (98)	15	37	321
	Q&T	650 (1200)	896 (130)	552 (80)	21	47	269
	Normalized	900 (1650)	1010 (147)	500 (72)	9	13	293
	Annealed	790 (1450)	658 (95)	380 (55)	13	21	192
1141	Q&T	315 (600)	1460 (212)	1280 (186)	9	32	415
	Q&T	540 (1000)	896 (130)	765 (111)	18	57	262

(continued)

Table A-21 (Continued)

Mean Mechanical Properties of Some Heat-Treated Steels

[These are typical properties for materials normalized and annealed. The properties for quenched and tempered (Q&T) steels are from a single heat. Because of the many variables, the properties listed are global averages. In all cases, data were obtained from specimens of diameter 0.505 in, machined from 1-in rounds, and of gauge length 2 in. Unless noted, all specimens were oil-quenched.] *Source: ASM Metals Reference Book, 2d ed., American Society for Metals, Metals Park, Ohio, 1983.*

1	2	3	4	5	6	7	8
AISI No.	Treatment	Temperature °C (°F)	Tensile Strength MPa (kpsi)	Yield Strength, MPa (kpsi)	Elongation, %	Reduction in Area, %	Brinell Hardness
4130	Q&T*	205 (400)	1630 (236)	1460 (212)	10	41	467
	Q&T*	315 (600)	1500 (217)	1380 (200)	11	43	435
	Q&T*	425 (800)	1280 (186)	1190 (173)	13	49	380
	Q&T*	540 (1000)	1030 (150)	910 (132)	17	57	315
	Q&T*	650 (1200)	814 (118)	703 (102)	22	64	245
	Normalized	870 (1600)	670 (97)	436 (63)	25	59	197
	Annealed	865 (1585)	560 (81)	361 (52)	28	56	156
4140	Q&T	205 (400)	1770 (257)	1640 (238)	8	38	510
	Q&T	315 (600)	1550 (225)	1430 (208)	9	43	445
	Q&T	425 (800)	1250 (181)	1140 (165)	13	49	370
	Q&T	540 (1000)	951 (138)	834 (121)	18	58	285
	Q&T	650 (1200)	758 (110)	655 (95)	22	63	230
	Normalized	870 (1600)	1020 (148)	655 (95)	18	47	302
	Annealed	815 (1500)	655 (95)	417 (61)	26	57	197
4340	Q&T	315 (600)	1720 (250)	1590 (230)	10	40	486
	Q&T	425 (800)	1470 (213)	1360 (198)	10	44	430
	Q&T	540 (1000)	1170 (170)	1080 (156)	13	51	360
	Q&T	650 (1200)	965 (140)	855 (124)	19	60	280

*Water-quenched

Table A-22

Results of Tensile Tests of Some Metals* Source: J. Datsko, "Solid Materials," chap. 32 in Joseph E. Shigley, Charles R. Mischke, and Thomas H. Brown, Jr. (eds.-in-chief), *Standard Handbook of Machine Design*, 3rd ed., McGraw-Hill, New York, 2004, pp. 32.49–32.52.

Number	Material	Condition	Yield			Ultimate			Strength (Tensile)			Fracture Strain ϵ_f
			S_{y1}	S_{y2}	MPa (kpsi)	S_{u1}	S_{u2}	MPa (kpsi)	σ_{fr}	MPa (kpsi)	Coefficient σ_0	
1018	Steel	Annealed	220 (32.0)		220 (32.0)	341 (49.5)		628 (91.1) [†]	620 (90.0)		0.25	1.05
1144	Steel	Annealed	358 (52.0)		358 (52.0)	646 (93.7)		898 (130) [†]	992 (144)		0.14	0.49
1212	Steel	HR	193 (28.0)		193 (28.0)	424 (61.5)		729 (106) [†]	758 (110)		0.24	0.85
1045	Steel	Q&T 600°F	1520 (220)		1520 (220)	1580 (230)		2380 (345)	1880 (273) [†]		0.041	0.81
4142	Steel	Q&T 600°F	1720 (250)		1720 (250)	1930 (210)		2340 (340)	1760 (255) [†]		0.048	0.43
303	Stainless steel	Annealed	241 (35.0)		241 (35.0)	601 (87.3)		1520 (221) [†]	1410 (205)		0.51	1.16
304	Stainless steel	Annealed	276 (40.0)		276 (40.0)	568 (82.4)		1600 (233) [†]	1270 (185)		0.45	1.67
2011	Aluminum alloy	T6	169 (24.5)		169 (24.5)	324 (47.0)		325 (47.2) [†]	620 (90)		0.28	0.10
2024	Aluminum alloy	T4	296 (43.0)		296 (43.0)	446 (64.8)		533 (77.3) [†]	689 (100)		0.15	0.18
7075	Aluminum alloy	T6	542 (78.6)		542 (78.6)	593 (86.0)		706 (102) [†]	882 (128)		0.13	0.18

*Values from one or two heats and believed to be attainable using proper purchase specifications. The fracture strain may vary as much as 100 percent.

[†]Derived value.

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