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Original Research Article

DESIGN AND DEVELOPMENT OF AN ELECTRIC PAPER SHREDDING MACHINE

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ABSTRACT

Many a time we draft letters, set examination questions or even write minutes of crucial meetings before getting them typed and these hand written ones are usually thrown into the waste paper basket. It is possible that wrong persons may have access to the waste papers, collect and use them in wrong or negative ways. There are incidents of examination paper leakages arising from such practice. The aim of the work is to design and produce an electric paper shredder that will help to provide an effective means of destroying secret or sensitive information on paper after use. The burden to proffer solution to the issue of disposal of important information that can compromise business and organization secret available on paper necessitated this research. In carrying out this work consultation was carried out on types, operation and construction of paper shredding machine. Performance test was carried out by cutting A4 sized papers several times using the paper shredding machine produced and the average time to shred paper was 3.6 seconds. The rotation of the cutting blades gave the paper a level P-5 security shredding. Cost analysis revealed a total cost of ₦128,000.

1. INTRODUCTION

As competition between businesses grows and offices and people in general become more concerned about protecting their personal information, it is of paramount importance for businesses and organizations to protect both sensitive internal information and sensitive information about their clients or workers. Although more and more information is stored digitally on computer servers, important information that can compromise businesses and organizations is still widely available on paper. It is expected that every organization, no matter how big or small, should regularly destroy documents, which are not meant for the public eye. This not only keeps the operations of the business safe, but also protects consumers and the members of the general public safe from identity theft, financial frauds and other security risks. Throwing whole pieces of paper containing such information into trash receptacles exposes businesses and organizations to great risk. One effective way preventing sensitive information falling into the wrong hands is to use a paper shredder.

A paper shredder is a mechanical device used to cut paper into chad, typically strips. It is a machine used to shred papers into pieces in a way it cannot be pieced together. According to Ayoola (2008) it is a security device, which reduces paper to small strips or confetti-like pieces, making it difficult for the individual piece to be put back together. Paper shredder is best to shred any unwanted document to avoid people using it to commit fraud or crime. Government organizations, businesses and private individuals use shredders to destroy private, confidential, or otherwise sensitive documents (Brassil, 2002). The main function of paper shredder is to crush sheet papers, especially confidential paper documents and other documents that are no longer required. Paper shredder can also be found in education sector such as schools tertiary, secondary or primary institutions. It could either used in offices or for paper disposal on campuses. According to Ujang (2008) privacy experts recommend that individuals shred bills, tax documents, credit card and bank statements, and other items which could be used by thieves to commit fraud or identity theft. A paper shredder is driven by an electric motor which delivers power to the cutting system and reduces the electric motors rotation to suit the needs of the blade rotation to destroy the paper. Paper shredder machine consists of three main parts which are the machine construction, transmission system and cutting system.

Proper and effective disposal arrangement should be made by every organization to make sure the all important paper documents are properly disposed. This has become inevitable, especially in this era of information and communication technology.

The aim of this work is to design and produce an electric paper shredder that will help to provide an effective means of destroying secret or sensitive information on paper after use.
Some works have been reported in the literature on the design of paper shredders. Ko (2000) designed a machine with automatic feeding mechanism capable of shredding 20 sheets with 9 inches width with three way switch i.e. On, Off and Auto. The blades were knife rollers which cut paper strips, 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. In another study, Chang (2000) also presented blade assembly for paper shredder consisting of long and short partition rings plates casted with the blade ring. Due to the problem associated with this machine, the researcher arrange the blades 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 the use of partition rings, reducing cost and enhancing assembly efficiency. Ho (2003) presented the paper shredder which had two rotary cutters each with multiple blades cutting edges. On the other hand, Zeng (2006) presented the blades of the paper shredder with serrated cutting edges formed by bending with two methods. The first method had a blade body and serrated edge integrally formed and punched from the same base material. High cost of production and material was required. The second method had serrated cutting edges specially thickened to reduce material consumption. They were also complex to manufacture. Siddiqui et al. (2017) presented a detailed study and design procedure of a paper shredder machine consisting essentially of the frame, transmission system and cutting system with the following specification:18 blades,10mm thickness and 51^{o} cutting angle, washers and

gear box mounted. Adigwerex (2012) designed and fabricated a paper shredder with the following specification: 186 watts electric motor, gear box mounted, a rake to remove pieces of papers, cutting disc. The work of Adigwerex (2012) differs from this work in the area of gear box. While Adigwerex used a gear box and chain, the present researcher used pulleys, belt and rollers attached for easy movement.

2. METHODOLOGY

2.1. Design Analysis

The paper shredding machine consists of the following components (Figures 1 and 2): Prime mover (electric motor) which is an electrical machine that converts electrical energy drive into mechanical energy to drive the pulley and belt system.

i. Bearing which allows relative motion between the contact surfaces of the components carrying the load.
ii. Belt drive (pulley and belt) which is endless belts which transmit power from the prime mover to the shaft that rotates the pulley.
iii. Spur gear which is a slow speed gear used to transmit rotation on a shaft.

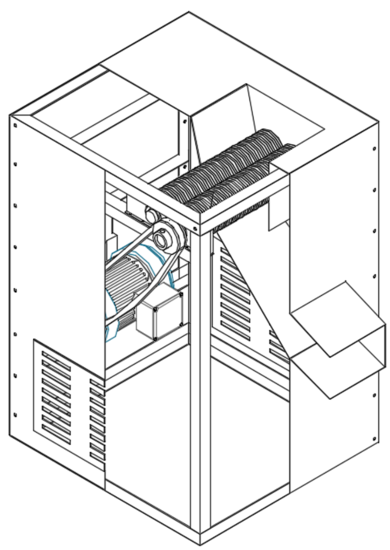

Figure 1: Cut away view showing the intricate of the shredding machine

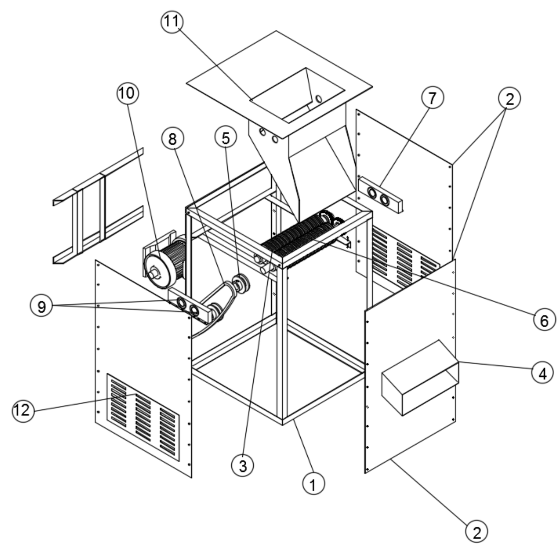

Figure 2: Exploded view of the shredding machine

Table 1: List of the shredding machine parts

No	Part name	No	Part name
1	Frame Assemble	7	Switch
2	Shredder Casing	8	Pulley belt
3	Ball Bearing	9	Spur Gears
4	Shredder paper outlet	10	Electric Motors
5	Pulley	11	Hopper
6	Steel shaft blade	12	Side Vent (Air inlet)

2.2.1. Design analysis

The mechanism of the machine was designed as follow:

2.2.1.1. *Pulley and belt analysis*

Pulleys are made of different materials such as mild steel, cast iron or aluminum. However, mild steel was selected because of its availability, machine ability, cost and durability. For the design of the pulley and belt, the speed of the driving and driven unit, center distance must be known (Khurmi and Gupta, 2006).

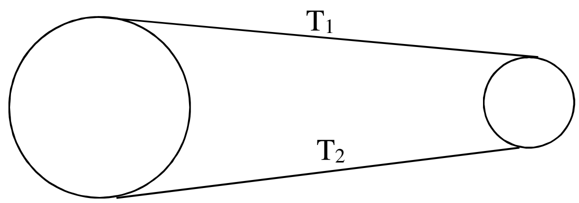

Figure 3: Design of pulley belt

T_1=Tension on the tight side of the belt, T_2=Tension on the slack side of the belt

Speed Ratio of the belt drive

The objective of the belt drive speed analysis was to determine the diameter of the main shaft pulley that will produce the speed required to shred the paper (Khurmi and Gupta, 2006).

$$\text{Speed Ratio } \frac{N_m}{N_s} = \frac{D_s}{D_m} \quad (1)$$

$$N_s = \frac{N_m \times D_m}{D_s}$$

Where N_m=speed of Electric Motor in rev/min

N_s =speed of main driving shaft in rev/min

D_m=Diameter of motor pulley

D_s=Diameter of pulley of the main shaft

The following values were selected as design standards for the belt drive:

$$N_m = 1440 rev/\min, N_s = ?,\ D_m = 54mm\ D_s = 98mm$$

$$N_s = \frac{1440 \times 54}{98} = 793.4694 rev/\min$$

Hence, the speed of the main shaft pulley N_s=793.4694 rev/min. This implies a speed reduction of 2:1.

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Peripheral belt speed

This was determined from Belt speed, (Khurmi and Gupta, 2006)

$$V = wr \tag{2}$$

$$V = \frac{2\pi N_s}{60} \times \frac{D_s}{2} \tag{3}$$

Since $w = \frac{2\pi N_s}{60}$ and $r = \frac{D_s}{2}$

Where:

w= angular speed in rad/sec

r= radius of the pulley in m

$$V = \frac{2 \times 3.142 \times 793.4694}{60} \times \frac{0.098}{2}$$
$$V = 4.072 m/s$$

Angle of lap (φ)

The angle of lap was determined from Equation 4 (Hannah and Stephens, 1998)

$$Cos\left(\frac{\varphi}{2}\right) = \frac{D_s - D_m}{2C} \tag{4}$$

Where D_m=Diameter of motor pulley in m
D_s =Diameter of pulley of the main shaft in m
C =Distance between the centre of the two pulleys
D_m = 54 *mm*, D_s= 98 *mm*=0.098 *m*, C= 304 *mm*

$$\therefore \varphi = 2 \times Cos^{-1}\left(\frac{0.098 - 0.054}{2 \times 0.304}\right) = 171.6999342^o = 2.9967 rad$$

Angle of lap, $\varphi = 171.6999342^o = 2.9967 rad$

Tension due to centrifugal force on belt

The centrifugal tension, T_c on the belt is determined from(Khurmi and Gupta, 2006)

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$$T_c = \frac{mv^2}{g} \tag{5}$$

Where v=peripheral belt speed in m/s

m=mass of belt per unit length

$m=1.06\ N/m$ for a belt type ($1.02N/m$)

$$T_c = \frac{1.06 \times (4.072)^2}{9.81} = 1.7916N$$

Tension due to centrifugal force on Belt, $T_c = 1.7916N$

Cross-sectional area of belt (a) $=$width of belt (b) × thickness of belt (t)

$$a = b \times t \tag{6}$$

$t = 8mm = 0.008m, b = 13mm = 0.013m, \mu = 0.12$, $\sigma = 7MPa$, $\rho = 1.2Mg/m^3 = 1200kg/m^3$, $l = 1m$ $a = 0.013 \times 0.008 = 1.04 \times 10^{-4} m^2$

Mass of belt per unit length (m) =Area of belt $(a)\times$ Length of belt $(l)\times$ density of belt material (ρ)

$$m = b \cdot t \cdot l \cdot \rho \tag{7}$$

$$m = 1.04 \times 10^{-4} \times 1 \times 1200 = 0.1248kg/m$$

Maximum tension was derived as follows:

$$T = \sigma \times a \tag{8}$$

Where $\sigma =$ maximum safe stress of the material = 7Mpa

$$T = 7 \times 10^6 \times 1.04 \times 10^{-4} = 728N$$

Tension T_1 and T_2 for the belt

The tension T_1 and T_2 of the belt was determined from(Khurmi and Gupta, 2006):

Power transmitted, $P = (T_1 - T_2) \times V$ (9)

$$P = T_1\left(1 - \frac{T_2}{T_1}\right) \times V$$

But

$$\frac{T_1}{T_2} = e^{\mu\varphi} \tag{10}$$

(Khurmi and Gupta, 2006)

T_1 = Tension of the tight side of the belt

T_2 = Tension on the slack side of belt

$$P = T_1\left(1 - \frac{1}{e^{\mu\varphi}}\right) \times V \tag{11}$$

Where $\mu =$ coefficient of friction between belt and pulley groove =0.12

$\varphi =$ angle of lap = 2.9967,

$P = 746W$

$$746 = T_1\left(1 - \frac{1}{e^{0.12\times 2.9967}}\right) \times 4.072$$
$$746 = T_1 \times 1.2299$$
$$T_1 = \frac{746}{1.2299} = 606.553N$$

$$\frac{T_1 - T_c}{T_2 - T_c} = e^{\mu\varphi Co\sec\beta}$$

Where $\beta =$ semi-angle of pulley groove =16°

$T_c = 1.7258N$

$$\therefore \frac{606.553 - 1.7258}{T_2 - 1.7258} = e^{0.12\times 2.996\times Co\sec 16^o}$$
$$T_2 - 1.7258 = \frac{604.8272}{3.6863} = 164.0743$$
$$T_2 = 165.8N$$

Torque on the machine pulley
Torque generated on machine pulley was determined from

$$T_t = (T_1 - T_2) \times R$$
$$= (606.553 - 165.8) \times \frac{0.098}{2}$$
$$T_t = 21.596897 = 21.597 Nm$$

For it to work, V-belt is selected because it cannot come out of pulley grooves, the gripping action results in a greater frictional force and lower belt tension, hence longer belt life and ability to absorb shock.

Power transmitted
Power transmitted by the belt from the main shaft to the other was determined from

$$P = (T_1 - T_2) \times V$$

$$P = (606.553 - 165.8) \times 4.072$$

$$P = 1794.746 W = 1.795 kW$$

Calculation of shredding force, F
Mass of paper $= 5g = 0.005kg$

Weight of paper $=$ mass of paper $\times$ Acceleration due to gravity

Weight of paper $= 0.005 \times 9.81 = 0.04905N$

Pressure $= \frac{Force}{Area}$ = weight of paper/ Area of paper

Area of paper $== (210mm \times 296mm) \times 10^{-3} = 0.0622m^2$

The pressure that the paper exert $= \frac{0.04905}{0.0622} = 0.78909 N/m^2$

For $n -$ number of papers, the force needed to shred papers becomes $F = n\rho(2\pi)$

Where:

ρ = Pressure force,

2π = revolution of the cutting disc, Radius of the cutting disc $= 20mm = 0.02m$,

Assuming n to be 2:

$$Force = 2 \times 0.78909 \times (2 \times 3.142) = 10N$$

Determination of pulley weight

The pulley is 98mm diameter and thickness of space removed is =8mm

Weight of pulley = Volume of pulley $\times$Density of pulley $\times$ Acceleration due to gravity

$$W = \rho V g \qquad (12)$$

Where W=weight of the pulley, ρ =Density of steel in Kg/m^3, V =Volume of pulley, m^3,

g=acceleration due to gravity=9.81m/s^2, Volume of pulley $= 2\pi rt$

Density of steel = 7850kg/m^3,R = radius of pulley $= 49mm = 0.049m$

r = radius of pulley when groove space is removed, $r = R - t$, t =thickness of space removed

$b =$ top width $= 13mm = 0.013m$, $r = 49 - 8 = 41mm = 0.041m$

Volume of pulley $= \pi \times 0.041^2 \times 0.013 = 6.866 \times 10^{-5} m^3$

Weight of pulley $= 7850 \times 6.866 \times 10^{-5} \times 9.81 = 5.287N$

2.2.1.2. Moment on the shaft

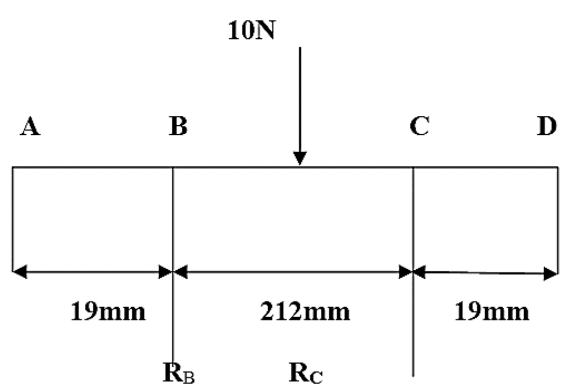

Figure 4: System of forces on the shaft

Taking moment about B and taking clockwise moment as positive

$$M_B + (10 \times 0.106) - (5.287 \times 0.019) - (2.36 \times 0.019) - (R_D \times 0.231) = 0$$

$$M_B - 0.231R_D = -0.9147 \quad (13)$$

Taking moment about D and taking clockwise moment as positive

$$M_B - (10\times 0.106) + (R_B \times 0.212) - (2.36\times 0.231) - (5.287\times 0.25) = 0$$

$$M_B - 0.212R_B = 2.926 \quad (14)$$

Considering the system when there is no motion, $M_B = 0$:

$$R_D = \frac{-0.9147}{-0.231} = 3.96N$$

$$R_B = \frac{2.926}{0.212} = 13.80N$$

Using $R_B = 13.80$,

$$M_B = 2.926 - (0.212\times 13.80) = 0.0004Nm$$

Using $R_D = 3.96N$

$$M_B = -0.9147 + 0.231 = -0.6837Nm$$

$M_B = 0.0004Nm$, since it is two shafts that rotates the total bending moment will be 0.0008Nm.

2.2.1.3. Gear analysis

Gears are machine components that are used to transmit motion by means of engagement of gear teeth. Gears help to increase or decrease speed depending on the required speed. Spur gears are used to transmit power between parallel cutting shafts at constant angular velocity.

T_G=numbers of teeth on the gear =20, *M=module=2*, D_G=diameter of gear=40 mm

b=face width=25 mm, W_G= gear weight

$$W_G = 0.00118T_G \times b \times M^2 \quad (15)$$

$$= 0.00118\times 20\times 25\times 2^2 = 2.36N$$

To obtain the power of motor:

W_R = resultant load on the gear

$$M_B = \frac{W_R}{X} \tag{16}$$

X = distance of overhang = 50mm = 0.05m

$$W_R = \frac{0.0004}{0.05} + (T_1 - T_2)$$

$$= 0.008 + (606.553 - 165.8) = 543.0N$$

$$W_R = \left(W_N^2 + W_G^2 + 2W_N \times W_G Cos\phi\right)^{\frac{1}{2}} \tag{17}$$

W_G=gear weight, W_N=normal load acting, ϕ = pressure angle which is taken as 14.5°

$$543.01 = W_N^2 + 2.36^2 + 2W_N(2.36Cos14.5)$$

$$W_N^2 + 4.5696W_N - 294854.29 = 0$$

Solving quadratically:

$W_N = 540.72N$ or $W_N = -545.29N$

Using $W_N = 540.72N$

Then:

$$W_N = \frac{W_T}{Cos\phi} \tag{18}$$

W_T=permissible tangential tooth load

$$W_T = 540.72 \times Cos14.5^o = 523.49N$$

$$W_T = \frac{P}{V} \times C_s \tag{19}$$

C_S= service shock

Considering the shock on this machine to be medium shock.

C_S = 1.54 (Khumi and Gupta, 2006)

P = power of motor

To obtain the power rating:

$$P = W_T \times \frac{V}{C_s} \tag{20}$$

At $V = 1.539 m/s^2$

$$P = \frac{1.539 \times 523.49}{1.54} = 523.15W$$

Therefore, $P = 523.15W$

2.2.1.4. Shaft analysis

A shaft is rotation member usually in cylindrical, whichis used to transmit torque, power and motion between various elements such as electric motors and gear sets, pulleys or turbines.Shaft may be classified as solid and hollow shaft. For this design work, a uniform solid shaft is used due to the following reasons:

1. To increase the life span of the shaft.
2. To allow efficient movement of the shaft through the support bearing.

Shaft design involves determination of correct shaft diameter to ensure satisfactory strength and rigidity when the shaft is transmitting power under various operating and loading condition. The shaft is under the combined effect of torsion and bending. The equivalent Torque, T_e

$$T_e = W_T \times \frac{D_G}{2} \tag{21}$$

$$T_e = 523.49 \times \frac{0.04}{2} = 10.47Nm$$

From Torsion Equation:

$$T = \frac{\pi d^3}{16} \times \tau \tag{22}$$

Where: T_e = Equivalent twisting moment

d = Diameter of shaft

τ = Torsional shear stress = 210MPa

d = shaft diameter, τ = shear stress (allowable), τ = 210MPa for steel

$$10.47 = \frac{\pi}{16} \times 210 \times 10^6 \times d^3$$

$$d = \left(\frac{16 \times 10.47}{\pi \times 210 \times 10^6} \right)^{\frac{1}{3}} = 6.33mm$$

From Bending Moment, Total weight on shaft = 5.287+2.36+10 =17.647N

Therefore, maximum bending moment is given as (Hall et al., 1980):

$$M = \frac{W_T L}{4} \tag{23}$$

where W_T = Total weight on shaft, L= Length of shaft =250mm

$$M = 17.647 \times \frac{0.250}{4} = 1.1029N$$

Torque required to shred the paper is T= F×r (24)

Where T= Shaft Torque, r = radius of cutting disc, F= Shredding Force

T = 10 ×0.02 = 0.2NM

The equivalent twisting moment (ME), is given as(Shigley and Misschke, 2001):

$$ME = \sqrt{M^2 + T^2} \tag{25}$$

$$ME = \sqrt{1.1029^2 + 0.2^2} = 1.1209NM$$

The equivalent bending moment (MEqu) is taken as: $MEqu = \frac{1}{2}(M + ME)$

$$MEqu = \frac{1}{2}(1.1029 + 1.1209) = 1.1119NM$$

The equivalent bending moment of the shaft is that moment which when acting alone produces the same tensile or compressive stress (σb) as the actual bending moment.

$$MEqu = \frac{\pi}{32} \times \sigma b \times d^3 \tag{26}$$

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Where σb =maximum allowable bending stress of shaft which is 30MPa (Marks and Banmerster, 2004).

From this expression, the diameter of the shaft(d) was evaluated

$$1.119 = \frac{\pi}{32} \times 30 \times 10^6 \times d^3$$

d= 7.277mm.

From the torsional analysis, the minimum diameter required to withstand the torque Loading is 6.33mm while the minimum diameter to withstand the bending stress is 7.277mm.Since the main shaft diameter is 7.277mm,then the main shaft will effectively withstand both torsional and bending stress.

2.2. Material Selection

In selecting materials for a component, the following factors were considered, availability of material and cost of production, function of each component part and its suitability, physical and mechanical properties of the individual parts, ability to be easily worked on. This was so because the shredding machine consists of the following components, electric motor, shredding shaft, belt drive (belt and pulley) and the housing.

2.2.1. Cutting shaft

Cutting shaft is designed mainly for the cutting of paper, therefore high friction will exist at the edge of the paper interface. To avoid backlingand also to minimize wear at the cutting edge tip, mild steel was selected. The diameter of the shaft is 40mm. An angle bar was used to support the cutting shaft s

2.2.2. Selection of gear

The material that was used was Teflon material. Teflon spur gear was selected because of its noise reduction, low cost, high efficiency, less weight and ability to operate without lubrication.

2.2.3. Bearing

The diameter of the shaft determined the bearing used. A ball bearing was selected because it is a rolling-element bearing. It was used to reduce rotational friction, it has lower load capacity, and good speed.

2.2.4. Belt drive (Pulley and Belt)

The diameter of pulley of the main shaft was 98mm, while that of the motor pulley was 54mm and the distance between centre of the two pulleys was 304mm. A belt was used to transmit power from one shaft to another by means of pulleys which rotate at the same or different speed. A Vee belt was used and it was made of rubber, with a length of 424mm, thickness of 8mm and width of 13mm.

2.2.5. Machine housing

The machine housing was made of steel sheet metal 1mm thickness by 360 x 355x 590mm and screwed to an angle bar 1 and ½ inches that was joined together by welding.

2.2.6. Electric Motor
The electric motor was selected based on the calculated power required to power the machine. The specifications on the electric motor are shown in Table 2.

Table 2: Power requirement of electric motor

Description	Value
Power	0.75Kw
Frequency	50Hz
Speed	1440 rev/min
Voltage	220V

3. MODE OF OPERATION

The paper shredding machine is a simple machine that can be operated. After assembling the components, the machine is operated electrically with the cutting shaft operated by one horse power electric motor. When the machine is switched on the speed of the electric motor is transmitted to the pulley via Vee belt and then to the shaft, which rotates the gears and the other shaft the meshing of the two shafts brings about the cutting of the papers when its fed into it.

4. MAINTENANCE

A good maintenance of the machine is important in order to have it in good working condition whenever it's to be operated. Due to the type of operation carried out on the machine, periodic maintenance of the components is necessary.

i. The processes of maintenance to be carried out are as follows:
ii. Cleaning and lubricating the cutting shaft, greasing the moving components and cleaning the inside of the machine.
iii. Checking the belt tension when carrying out maintenance.
iv. Cleaning the machine housing regularly when not in use.

Table 3: Bill of engineering measurements and evaluation

S/N	Parts name	Number of materials	Component dimension	Cost of unit (Naira)	Total cost (Naira)
1	Electric motor	1	1 horse power	20000	20000
2	Pulley material	-	-	5000	5000
3	Pulley machining	2	54mm and 98mm diameter	3000	6000
4	Belt drive	1	-	1000	1000
5	Mild steel shaft and machining	2	40mm diameter shaft A long and Shaft B 40mm diameter long	15000	30000
6	Gear machining	2	40mm diameter	7500	15000
7	Teflon	-	-	3000	3000
8	Bushing material	-	-	3000	3000
9	Housing material	-	360x355x 590mm	9000	9000
10	Bearing	4		500	2000
11	Frame for mechanism	-	-	4000	4000
12	Labour	-	-	30000	30000
	Total	-	-	-	128000

5. COST ANALYSIS

While designing the machine, cost in procuring the items and producing the machine played an important role. A well designed machine may fail economically if cost is not taken into consideration. The total cost of the machine was ₦128,000 and the details are shown in Table 3.

6. PERFORMANCE EVALUATION

After assembling all the working parts (shaft blade, bearings, spur gears, pulleys, electric motor, and belt) that make up the paper shredding machine, the machine was turned on It was allowed to run for 10 minutes before slotting in paper in between the two shafts blades and the machine shredded the paper well. The test carried out shows that the machine is functional and the results are shown in Table 4.

Table 4: Performance evaluation the paper shredder

S/N	Time (Seconds)	Average time
1	4.3	
2	3.2	
3	4.1	Average time = $\frac{21.8}{6}$ = 3.6 secs
4	3.1	
5	4.0	
6	3.1	

7. CONCLUSION

An attempt was made to produce a paper shredding machine and in the course of doing it, the machine was designed, fabricated and tested. The machine is made of blades arranged to mesh with one another and rotate in opposite direction, to shred papers for the purpose of destroying secret information and preparing waste papers for recycling. The machine is easy to operate and maintain.

8. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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