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Design and Production of a Paper Shredding Machine

W.A. Akpan[1], I.I. Nyaudo[2], E.S. Umana[3], W.I. Dawson[4], S.I. Bassey[5]

[1,2]Mechanical Engineering Department, Federal University of Technology Ikot Abasi, Nigeria

[3,4,5] Mechanical and Aerospace Engineering Department, University of Uyo, Nigeria

ABSTRACT: There are countless cases of cooperate and government espionage, identity theft, sensitive information leaks. This all led to the need for government agencies, private and public institutions and even private individuals to protect their sensitive information and prevent it from falling into the wrong hands. The act of discarding whole, readable documents containing sensitive information poses huge risks to an individual or organization, as these documents can be retrieved from a trash bin and the information they contain easily accessed. This has led to a number of identity theft cases, where a crime is committed using the information of an unsuspecting individual. Although advancements in information technology have resulted in electronic transmission and storage of information, a good number is still communicated via paper. This newly designed paper shredding machine utilized chain and sprocket in the powertransmission which offers a high transmission efficiency unlike some paper shredding machines that used belt and pulley which cause slip and transmission losses. The machine architecture is very compact with ergonomically suitable features, and the performance is high. The shredding efficiency was 94%.Improvement on further work to improve the shredding efficiency is required.

KEYWORDS: Shredding, machine, paper, documents, theft, leakage, information, protect

1.0 INTRODUCTION

Over the years, countless cases of cooperate and government espionage, identity theft, sensitive information leaks, all led to the need for government agencies, private and public institutions and even private individuals to protect their sensitive information and prevent it from falling into the wrong hands Discarding whole, readable documents containing sensitive information poses huge risks to an individual or organization, as these documents can be retrieved from a trash bin and the information they contain easily accessed. This has led to a number of identity theft cases, where a crime is committed using the information of an unsuspecting individual. Although advancements in information technology have resulted in electronic transmission and storage of information, a good number is still communicated via paper. It is highly recommended that organizations and private individuals destroy documents first before disposal, especially documents containing sensitive information, hence the need for a paper shredding machine.

A paper shredding machine is a mechanical device used to cut paper into either stripes or fine particles. According to [1], it is a security device which reduces paper to small stripes or confetti-like pieces, making it difficult for the individual pieces to be cut back together. Paper shredders are used to shred unwanted documents containing useful, sensitive information before disposal. Privacy expert recommends 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-blades mounted on a shaft and reduces the electric motor's rotation to suit the needs of the blade rotation to destroy the paper [2]

Paper is formed from wood. The wood pulp is compressed to form a flexible thin sheet. The thin layer of the intertwined fibre is paper [3] Paper is the substance that forms a document and hence often contains sensitive information. It is necessary to prevent this information from getting to the wrong hands.

The way forward was to destroy paper in a way that its content is of no use before discarding. This requires many studies to produce a device to serve this purpose. This is the origin of the paper shedding machine. Paper was invented in China, in AD 105, by the Chinese Eunuch Ts'aiLum. After the Chinese discovered paper, it took 500 years for paper to be used in Europe and through the years, the necessity for the paper to be destroyed rose to high degree. By the 2oth century, the paper was very popular and needed in almost every human activities. It is used to cut across personal needs to industrial/ company use.

Moreover, then in 1909, almost 6000 years after the invention of papyrus, the first paper shredding machine was invented by a man called Abbot Augustus Low [4]. Although his invention was never developed to a product, his design was implemented in offices and other places where paper need to

Be discarded and destroyed in a way that there will be no information leak. He did not develop beyond his initial prototype creation, so he is not recognized as the first inventor of the paper shredding machine. However, he is syill a notable inventor in American history, second only in patent holdings to ***Thomas Edison*** [4]). His invention was however never manufactured because the inventor died prematurely soon after filing the patent [5].

In 1935 the first known paper shredder was made by Adolf Ehinger. Supposedly it worked similarly to a hand –cranked pasta maker, where users would turn a crank while documents were pulled through and cut up. Ehinger made the device supposedly to destroy his anti-Nazi propaganda in order to avoid being questioned by authorities [6].Unlike the American inventor, he saw the need for the paper shredder to be manufactured . He has a lot of documents (anti-Nazi propaganda) whose information need to be kept confidential. It was in this moment that Adolf Ehinger knew that he needed to create a machine that would render confidential papers unreadable to shred the anti-propaganda to avoid the inquiries of the authorities[4].He later converted the hand –crank to an electric motor and marketed it as a paper shredder to government agencies and financial institutions. In 1959 his company also manufactured the first cross-cut shredder and continues to do so under the company name EBA Krug and PriesterGmbh and Co [7].

Right before the fall of the Berlin wall, a 'wet shredder' was invented in the former German Democratic Republic. To prevent paper shredders in the ministry for State Security (Stasi) form glutting, this device mashed paper snippets with water [5]**.**

On event that instigated a major change in document destruction design was the Iran hostage crisis of 1979. After having used standard cutting paper shredders to destroy sensitive documents, it was discovered by Iranian hostage that the stripes could simply be realigned to reveal the information

that intended to be destroyed. This prompted the invention of cross-cutting shredders , which remain in constant use today [7].

It was rare for individuals or smaller companies to use paper shredders until the mid -1980S. Shredders were generally still only used by government agencies and financial institutions until this time. After the California vs .Greenword supreme court ruling in 1988, that states the fourth amendment does not prohibit the warrantless search and seizure of garbage left for collection outside of the home, shredders started becoming more popular among concerned patrons and companies alike. Privacy concerns were high and identity theft cases continue to rise [7]**.**

The first paper shredders operated on a very similar basis to a pasta machine. As single sheet of paper would pass through the shredder and blades would cut it into stripes.. Initially, it was that this would be sufficient to ensure that the documents could not be reassembled and accessed after the shredding process had taken place. However, over the years criminal have become more sophisticated when it comes to accessing data and information and so methods of destruction have been forced to evolve too. Today, the more advanced version of shredding technology not only shreds documents into strips but also destroys each of the strips with an automated mechanism. This means that it's virtually impossible to get access to the contents of the documents once the shredding process has taken place.

The shredder cut style determines the security level of the secure paper shredder. High –security shredders help mitigate the risk of your sensitive information falling into the wrong hands. The security level of the shredder will depend on the kind of information contained in the paper that needs to be shred[8].There are basically three cut styles which are: stri-cut, cross-cut and micro-cut.

Strip cut shredding is the most common methods of destroying documents. It is also known as ribbon shredding. It is a process by which the paper is cut into long parallel strips as they pass through several blades on a horizontal shaft [9].A strip cuts paper into thin strips, ranging from 1.59 mm to 9.63 mm wide. The smaller the strip is better. The disadvantage of a strip cut shredder is that a motivated and patient criminal might be able to reconstruct shredded papers [10]**.** Strip-cut shredders often present an economical choice for everyday use in the home and office, largely due to their price and availability. But while this is a simple and accessible method of shredding, it is also known as the least secure[9] A strip-cut shredder is also known as a ribbon-cut, spaghetti—cut, or straight –cut shredder [11]

Cross –cut as opposed to simply shredding paper is long vertical strips, the cross-cut shredding method involves vertical and horizontal blades that cut the paper into tiny square(diamond) piece[9].A cross cut shredder provides more protection. It cuts paper diagonally into two directions, producing small diamond-shaped pieces. Cross cut shredders while still being economically priced[10]**.**

They use two contra-drums to cut rectangular, parralellogram, or lozenge (diamond-shaped) shreds [12]. A standard document is general getting shredded into approximately 400 particles. A cross-cut shredder is known as a confetti-cut shredder [11]**.**

Micro-cut is the highest security cut used for highly sensitive and confidential paperwork [8]. This kind of shredding grinds documents down into thousands of minuscule particle using fine-tooth blades [9]. Like the cross cut shredder, the micro-cut shredder cuts diagonally in two direction, but the pieces are square-shaped and significantly smaller[10]. Although a micro-cut shredder is a cross-cut shredding machine, it is more advanced shredder that offers high security for destroying highly confidential data [11]. While the above two methods produce shreds that can be reassembled given enough time, particle-cut shredding eliminates this possibility entirely. This makes it the most reliable form of shredding in terms of security [9].According to [11] a micro-cut shredder offers the most maintenance, so regular oiling of the machine is recommended. Also, be aware that micro-cut shredders shred documents at a slower pace in comparison with a cross-cut or strip cut shredder. This is due to the lower sheet capacity and slower shredding speed''

There is need to design and produce shredding machines that are cost effective, compact with the capability of waste collection. This is the focus of this research work.

2.0 MATERIALS AND METHODS

2.1 Theory of Operation of the Machine

The paper shredding machine worked by taking power in from an electric motor and sending it to the shaft upon which octa gonal plates were mounted via the transmission system. These shafts weredesigned to rotate in the opposite directions and at the same speed. On each shaft were mounted a row of octagonal plates arranged to regularly interlock intermittently as both shafts rotate. The interlocking of the plates on adjacent shafts meeting in opposite directions produced the shearing action on the load as one layer slides over the other creating a new surface area (the cut area).

For a large enough proportion of the complete transmission, the transmission system was designedusing chains and sprockets. Chains and sprocket was adopted as the transmission system in order toavoid transmission losses which is always very rampant with the belt and pulley system; Aside transmission losses, the chain and sprocket system went a long way in reducing the speed of the electric motor thereby increasing torque for the shredding of paper. The spacing of the blades on each shaft was just enough for the adjacent row of plates to pass through during rotation.

2.1.1 Operational Steps

The following are the sequences to operate the machine:

i.. The container box is put at correct place.

ii. Power is connected via the cord terminal.

iii. The knife switch is engaged in the "ON" position.

iv. When the knife switch is put on, the machine starts and is ready for loading. Do notinsert foreign objects into the machine.

v. Look in the crank hole to ensure that the sprocket is in motion. If the machine vibrates Without putting the sprocket in motion, use the crank bar, through the crank window tomove the sprocket about 20 degrees in reverse and let to drive.

vi. Insert the office A4 paper to be destroyed, not more than a single sheet per process.

vii. If there is jam, use the crank bar to reverse the sprocket via the crank window;

Viii. After operation shutdown the machine by moving the knife switch handle to the "OFF" Position.

2.1.2 Machine Maintenance

The machine requires maintenance which is dependent upon usage pattern. And the recommendedmaintenance processes are enumerated below:

i. Lubricate the bearings monthly.
ii. Use the crank bar to remove clogged strips of paper from the blades as soon as there is anoticeable reduction in the operation speed of the machine.
iii. In event of jam, manually reverse the machine through the crank window using the crankbar about 15 degrees per time until it sets back into work.
iv. Empty the paper tray when full.
v. Ensure that all bolts and nuts are firmly tightened one every month.

2.2 Design Criteria

The following criteria were considered in the design of the paper shredding machine.

1) Affordability: The materials and machine elements of the design were cost effective in otherto achieve desired results.
2) Ease of operation: With the implementation of an electric motor and suitable transmissionsystem, the design is ergonomically suitable to any operator.
3) Material availability/selection: All materials and machine elements for the design were sourced locally. This reduced the overall cost of production, as parts are readily available within the state. As such material selection for this project work is mild steel. Mild steel is considered because of it high tensile and yield strength, and ease of machining.
4) Strength and Durability: Materials and machine elements for the design are of considerablyhigh strength and durability. As such the machine a good service life.
5) Shred size: The design produced a paper shred size that meets at least Security Level 5 (P- This will ensure the security of sensitive information after shredding operation has been carried out.

2.3 Design Analysis

In the analysis of this machine, the main aim is to find the power required by the machine to overcome the maximum estimated load and the inertia of the machine. The design started by computing the mass moment of inertia (I) of each moving component of the machine, then findingthe torque required to overcome the inertia in each case and then putting together the separate inertial torques to get the total torque required to overcome the inertia of the machine or the startingtorque. Secondly, the inertial torque will be added to the load torque. The load torque is the torque requiredto overcome the maximum estimated load. The result will be the total or operating torque. The operating torque will be related with the angular velocity of the shaft to get the total required power.But there is a velocity ratio at the chain sprocket setup. This velocity ratio will be accounted for to get the minimum required operating power.

2.3.1 Starting Torque

This is the torque required to overcome the inertia of the two shafts with the blades they host. Theshaft is composed of the rod and the circular blades welded at equal intervals over it.

The mass moment of inertia for a rod is given by

$I_R = (m(r_r)^2)/2$ 1

Where m is mass of rod, d is diameter of rod

The mass moment of a circular cross-section for the blades is given by

$I_b = (m(r_b)^2)/2$ 2

Where m is mass and l is the thickness of the disc or circular cross-section.The torque required to overcome inertia is given by

$T = I.a$ 3

Where a is angular acceleration

The angular acceleration is given by $a = \frac{d\omega}{dt}$

Where ω is angular velocity, t is time take taken to attain that angular velocity 4

The angular velocity is given by $\omega = \frac{2\pi N}{60}$

5

where N is the rotational speed in Revolution per Minute (rpm)

The mass of all blades, m_b is found by the product of volume and density in Equation .6

$m_b = V \times \rho \times N_b$ 6

where N_b = number of blades on each shaft

The total mass of shaft (m_{sh}) is given in Equation 7

Total mass of shaft, $m_{sh} = m_b + m_r$ 7

where m_r is the mass of the rod

Inertia of shaft is given by equation 3.8

$I_{sh} = I_r + I_b$ 8

where I_r is the inertia of rod and I_b is the inertia of blades

2.3.2 Shaft Inertia Torque

This is the torque required to overcome the inertia of the shaft and is denoted as T_{Ish} (for both shaft)and $T_{sh(t)}$ (for a single shaft).

where $T_{sh(t)} = I_{sh} * a$ 9

Refer to Equation 4 for a and 3 for T.

For both shafts, the inertial torque will be Equation 3.10

$T_{Ish} = 2T_{sh(t)}$ 10

2.3.3 Sprockets Inertia Torque

This is the torque due to inertia of both sprockets and is denoted by T_{Isp}.

$T_{Isp} = I_{sp}a$ 11

Equation 11 is similar to Equation 9

But the inertia of the sprockets is given by I_P for the pinion sprocket (smaller sprocket) and I_G for the gear sprocket (larger sprocket). Therefore, correspondingly we have T_P for the pinion torque and T_G for gear torque.

2.3.4 Chain Inertia Torque

This is the torque due to the inertia of the chain as it translates around the sprockets and is denoted by T_{Ich}.

Where, $T_{Ich} = I_{ch} \times a$ 12

I_{ch} is the mass moment of inertia of the chain and is given in Equation 13.

$I_{ch} = M_{ch} \times L_{ch} \times R^2$ 13

Where M_{ch} is the mass per unit length of the chain in metric unit (metre).

L_{ch} is the Length of the chain that wraps around the sprockets. R is the Radius of the pinion sprocket

From Equation.13, the torque due to the inertia of the chain is expressed in Equation 14

$T_{Ich} = M_{ch} L_{ch} R^2 \times a$ 14

2.3.5 Total Inertia Torgue

Now the total torque required to overcome the inertia due to the different moving components is thesum of all the inertial torques considered so far. That is, torque due to both shafts, both sprockets and the chain are given in Equation 15

$\therefore T_I = T_{Ish} + T_{Isp} + T_{Ich}$ 15

This is the inertial torque of the system.

2.3.6 Load Torque

The load torque is the torque required to overcome the maximum load which is the total cutting force of the paper at the thirty-five (35) different cut positions of the strips.

In order to overcome the load, the blades have to pull in the paper through the increasing mesh profile.

The yield strength of a typical office copier paper for a range of thickness between (0.1-0.15) mm [13] is denoted as Y_S. This yield strength is measured using the TAPP T 494 standard test for office copier papers, and is given in terms of force required in Newton to cut a unitlength (mm) of a copier paper of thickness within the range of (0.1-0.15)mm. That Y_S is measured in N/mm of specified copier paper. This is force required per millimeter of cut along any axis (not the thickness).

Now, the torque required to make this cut is given by the product of the sheared (or yielded) area, A and the yield strength, Y_S in metric unit (metre). Therefore, the yield strength must be expressedfirst in N/m then multiplied by the area in m^2. This is because the blade impinges the thickness (m)

in kilogram force per time (kg/s^2) and tears along the distance (m) as it rotates. This is equivalentto the torque of the blade in N-m. That is $kg/s^2 \times m \times m = kgm/s^2 \times m$ dimensionally.

Therefore, the torque required to cut a unit length of the specified paper type is given by the productof yield strength and cut area as below, given in Equation 16.

$T_L = Y_S \times A$ 16

Where T_L is the Load torque per cut Y_S is the Yield strength of paper type.

A is the Instantaneous cut area in squared metres (m^2).

But 35 of such cuts will be made at every instant, so we use $35T_L$.

2.3.7 Instantaneous Cut Area

The blades are hexagonal in shape. It is assumed at any instance, the cutting force acts through an area, A. This area is equivalent to the product of the thickness of the sheet and the cut length. Mathematically given in Equation 17

$A = \Theta \times L$ 17

Where A is the Area through which the cutting pressure acts Θ is the Thickness of the material (paper)

L is the Cut length which is dependent on the geometry of the blade

2.3.8 Blade Element Analysis

From here one blade element will be taken. Since each blade is hexagonal, the length of each sidesof the hexagon will be taken as L, which impinges against the load (paper).

Since there are six (6) sides on the blade, each side is taken as one-sixth the circumference of its Inscribed circle. See Figure 1 .

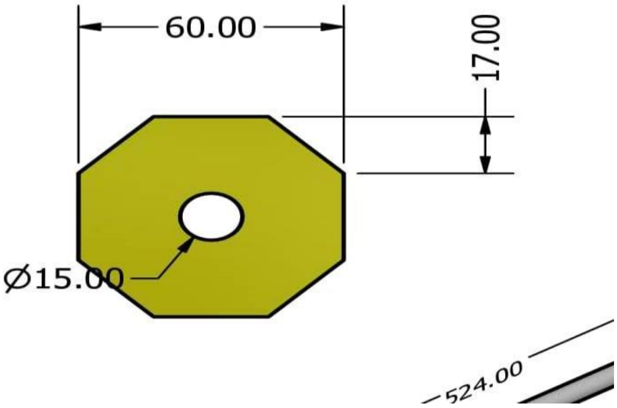


Figure 1: Blade element analysis

The circumference of the imaginary inscribed circle on the above figure is given by Equation 18 $C_b = 2\pi r_b$ 18

Where r_b is the radius of blade when considering imaginary inscribed circle. The circumference is also given by Equation 19

$C_b = 6L$ 19

The area (A) stated in Equation 17 is multiplied with the yield strength gives the torque (Equation16) required to make a cut of length, L on paper of the stated thickness, ϴ.

2.3.9 Operational Torque

This the sum of load and inertial torque or load and starting torque. It is the total torque required tooperate the machine considering its inertial and maximum load and it is denoted as T_{op}, given in Equation 20.

$T_{op} = T_I + T_L$ 20

2.3.10 Required Power

This is the minimum power required to operate the system at maximum load and it is given in Equation 21.

$P = T_{op} \times \omega$ 21

Refer to Equation 5 for ω.

<u>Note</u>: Factor of safety will be added in the computations in the next section at different stages.

2.3.11 Computations Based on Design Analysis

This section is dedicated to computations based on design analysis in the previous section andreferences are made intermittently to the Equations created previously.

2.3.12 Starting Torque, Ts

The starting torque is calculated thus;

Mass of 1 blade = 20.41g, as such mass of all 35 blades, $m_b = (35 \times 20.41)g = 714.35g$ Mass of rod, $m_r = 600g$

∴ Mass of full shaft, $m_{sh} = 1.3kg$ Refer to Equation 6 to 7

Inertia of shaft, $I_{sh} = 0.0477$ kgm^2, from Equation 8 Refer to Equations 8, 1 and 2

Where r_r is the radius of rod in metres

r_b is the radius of blades in metres The angular velocity, ω of the system;

$\omega = 43.98$ rad/sec^2

where the time taken to reach the velocity t = 7 secs Refer to Equation 3

2.3.13 Shaft Inertial Torque, TIsh

From Equation 9

$I_{sh} = 0.0477$ kgm^2, $a = 6.28$ rad/sec^2 $T_{sh(t)} = 0.3$ Nm

From Equation 10

∴ $T_{Ish} = 0.6$ Nm

2.3.14 Sprocket Inertial Torque, TIsp

From Equation 11

$T_P = 4.71 \times 10^{-6}$ Nm, $T_G = 4.80 \times 10^{-6}$

$I_G = 1.56 \times 10^{-6}$ kgm^2, $I_P = 7.50 \times 10^{-7}$ kgm^2

ω = 6.28 rad/sec

T_{Isp} = 1.45 × 10^{-5} Nm

2.3.15 Chain Inertial Torque, TIch

From Equation 14

I_{ch} = 1.4 × 10^{-3} kgm^2, a = 43.98 rad/sec^2 M_{ch} = 0.8 kg, L_{ch} = 0.7 kg, R = 0.005m

∴ T_{Ich} = 0.07 Nm

2.3.16 Total Inertial Torque, TI

Referring to Equation 15T_{Ish} = 6 × 10^{-1} Nm

T_{Isp} = 1.45 × 10^{-5} Nm

T_{Ich} = 7 × 10^{-2} Nm

∴T_I = 0.39 Nm

2.3.17 Load Torque, TL

Y_{sAvg} = 3.2 N/mm From Equation 18r_b = 0.003 m.

C_b = 188.5 × 10^{-3} m

From Equation 19

C_b = 188.5 × 10^{-3} m

L = 31.42 × 10^{-3} m

From Equation 17,ϴ = 0.0001 m

L = 31.42 × 10^{-3} m

A = 3.142 × 10^{-6} m^2 (area for a single instantaneous cut).From Equation 16

Y_s = 3200 N/m

A = 3.2991 × 10^{-8} m^2 (area for 35 instantaneous cuts)T_L = 1.056 Nm

A factor of safety of 1.4 is considered due to occurrence of friction and transmission losses in thesystem.

∴ Safe torque, T_{safe} = 1.4 × 1.056

= 1.48 Nm

This is the safe load torque.

2.3.18 Operational Torque, Top

From Equation 20T_I = 0.39 Nm

T_L = 1.48 Nm

∴ T_{op} = 1.87 Nm

2.3.19 Required Power, P

From Equation 21T_{op} = 1.87 Nm

ω = 43.98 rad/sec

∴ P = 82.24 Watt

A factor of safety of 1.6 is considered to obtain a safe power (P_{safe}). Thus;P_{safe} = 1.6 × 82.24

= 131.6 W ≃ 132 W

This is the minimum power required of the prime mover (electric motor) to operate the machine with the load of a sheet of paper. (The actual motor selected: Phase-Single phase, power supply 220V, power rating 0.3 KW, frequency 50-60Hz).

2.4 Design Analysis Based on Standard Approach

Consider the shredding machine operating in a steady state. The torque provided by the electric motor, T_m are:

1) Torque to drive the blade, T_b.
2) Torque to drive the shaft, T_{sh}.
3) Torque to drive the sprocket, T_{sp}.
4) Torque to drive the chain, T_{ch}.

This is given in Equation 22

$T_m = T_b + T_{sh} + T_{sp} + T_{ch}$ 22

The torque to drive the blade comprise of the blade torque, T_b and the blade inertia torque, T_{Ib} andis given in Equation 3.23

$T_b = T_{pr} + T_{Ib}$ 23

The torque to drive the shaft is given by the shaft inertia torque, T_{Ish} and is given Equation 24$T_{sh} = T_{Ish}$ 24

The torque to drive the sprocket is given by the sprocket inertial torque, T_{Isp} and is given in Equation3.25

$T_{sp} = T_{Isp}$ 25

The torque to drive the chain consist of chain static torque, T_{cL} and chain inertial torque, T_{Ich} and isgiven in Equation 26

$T_{ch} = T_{cL} + T_{Ich}$ 26

Equations 22 to 26 are arranged in terms of load torque, T_L and inertia torque, T_I and is givenin Equation 27

$T_m = T_L + T_I$ 27

where $T_L = T_p$ 28

$T_I = T_{Ib} + T_{Ish} + T_{Isp} + T_{Ich}$ 29

2.4.9 Blade Element Analysis

Figure 2 shows the force acting on a blade.

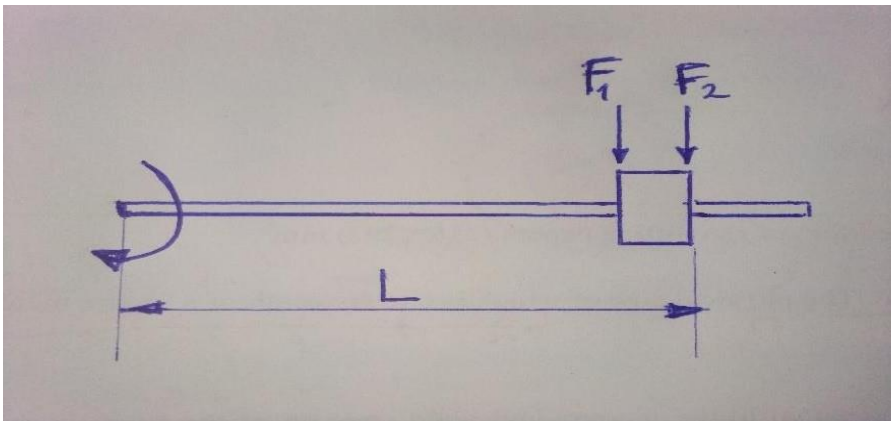


Figure 2: Force acting on blade

F is the shear force acting vertical on the sides of the blade. Taking an element of blade (one blade),F is given in Equation 30

$F = F_1 + F_2$ 30

The paper torque, T_{pr} is given in Equation 31

The total paper torque, T_{pr} $f_{pr}.\delta L A$

$T_{pr} = \int_0^L$

$= f_{pr}.L$ 32

where f_{pr} is the total force due to paper across the entire length of the shaft (L).f_{pr} is given by Equation 33

If we take F_s as the resisting force to shear a single paper of thickness ϴ, then the total force due to paper f_{pr} is given in Equation 33$f_{pr} = F_s \frac{L}{\theta}$

Thus the total paper torque is given in Equation 34 33

$T_{pr} = f_{pr}.L$

$= F_s.(L^2/\Theta)$ 34

3.5.2 Blade Inertia Torque

Figure 3 shows the inertia force on blade.

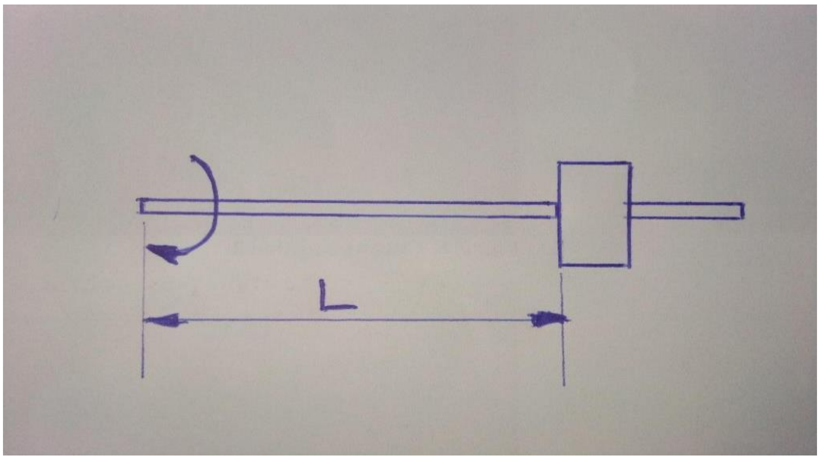


Figure 3: Inertia force on blade

$\boldsymbol{\delta} f_I = \boldsymbol{\delta} M_A.a$ 35

where M_A is the mass of the particle A and a is the linear acceleration of A tangent to the circular path of rotation.

$\boldsymbol{\delta} T_{IA} = \boldsymbol{\delta} f_I \times l$ 36

Total resisting force due to blade inertia

$T_{Ib} = \int \delta T_{IA}$ 37

but a = a L 38

Thus, T_{Ib} = a $\int \delta M_A.L^2$ 39

$T_{Ib} = I_b.a$ 40

I_b is the moment of inertia of the Blade

Note: a = $\frac{change\ in\ angular\ velocity}{time}$

a = $(\omega-\omega_0)/t$ 42

If $\omega_0 = 0$

$$a = \frac{w}{t}$$ 43

Figure 4 below shows the side view of the blade with hole for rod.

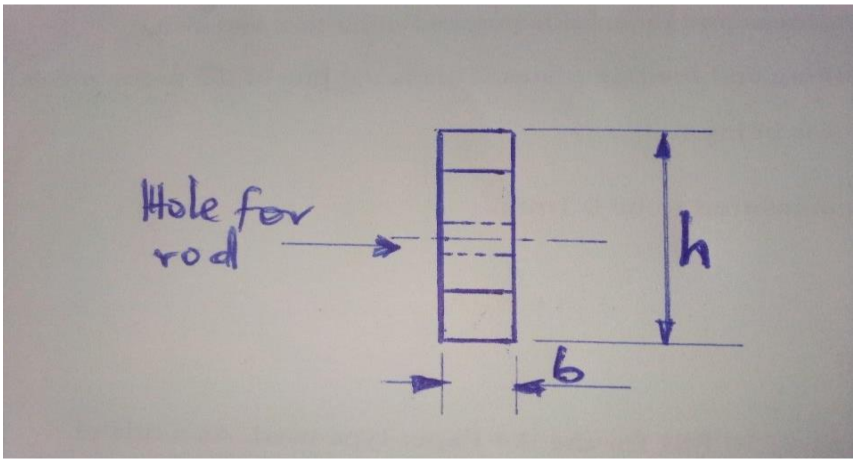


Figure 4: Side view of blade with hole

3.5.3 Shaft Inertia Torque

Figure 5 below presents the shaft twist analysis.

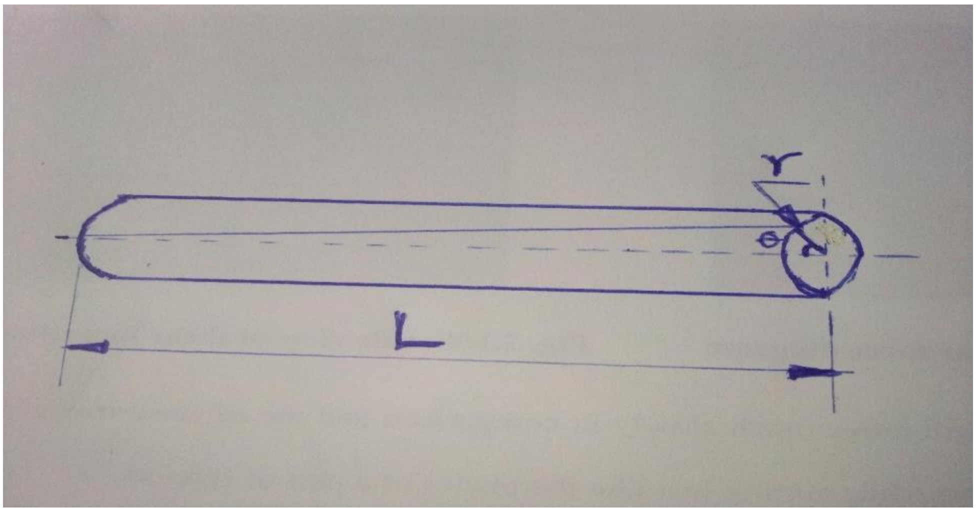


Figure 5: Shaft twist analysis

If Θ is the angle of twist of length L

$$q = \frac{G\theta}{L} r \quad (44)$$

$$\text{torque carried by shaft} = 2\pi r^2 q\,dr \quad (45)$$

$$= 2\pi r^2 \times \frac{G\theta}{L} .r \times dr \quad (46)$$

$$= 2\pi \frac{G\theta}{L} .r^2 dr \quad (47)$$

The torque carried by solid shaft

$$T_{Ish} = \int_0^{d/2} 2\pi \frac{G\theta}{L} .r^2 dr \quad (48)$$

$$T_{Ish} = (G\theta I_p)/L \quad (49)$$

$$I_p = \int_0^{d/2} 2\pi r^2 dr \quad (50)$$

$$= (\pi d^4)/32 \quad (51)$$

(d = diameter of shaft)

3.5.4 Sprocket Inertial Torque

The sprocket can be assumed to be a hollow shaft. Figure 6 below shows the sketch as well asdimensions of the sprockets.

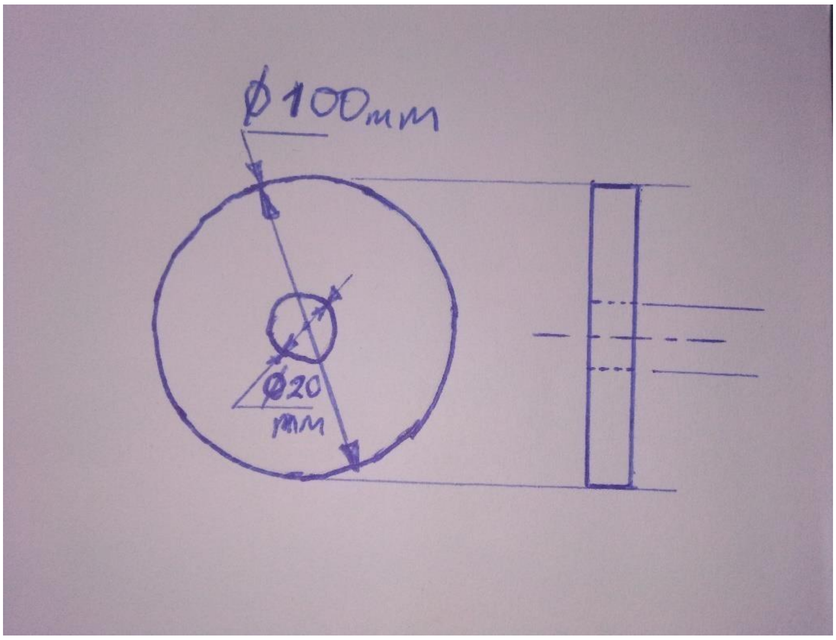


Figure 6: Sprocket schematics

$I_p = (d2^4 - d1^4)$ 52

$T_{Isp} = (G\theta I_p)/l$ l = thickness 53

3.5.5 Chain Inertial Torque

Figure 7 below shows the chain mounted on both sprockets.

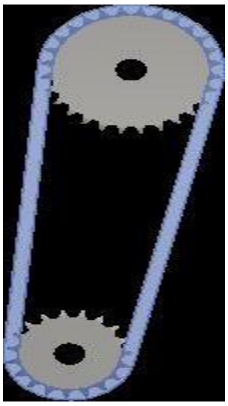


Figure 7: Chain mounted on sprockets

The chain inertial torque is expressed in Equation 54

$T_{Ich} = M_{ch}.L_{ch}.R^2 \times a$ 54

As can be seen Equation 54 is an exact replica of Equation 13, as such see Equation 13 for thedefinition of paramaters.

2.5 Materials Selection Based on Design Analysis and Computation

In this section the material selection is expressly discussed here part by part for every singlecomponent of the system in accordance to design analysis and computation.

2.5.1 Shaft Selection

A shaft is a rotating machine element used to transmit power from one place to another.Materials used for shafts should possess the following properties;

1) High strength
2) Good machinability

3) Low notch sensitivity factor
4) Good heat treatment properties
5) High wear resistance

From the computational analysis carried out, it was determined that the maximumexpected torque (T) on the shafts equal 2N-m.

Remember, $T = \frac{\pi}{16} \times \tau \times d^3$ 55

where, T = Torque delivered to shaft, N-m

τ = Allowable shear stress developed in each shaft, N/m^2d = Shaft diameter, m

From Equation 55, we can obtain the allowable shear stress τ for a shaft with diameter d and adriving torque T,

$$\tau = \frac{Tx16}{\pi d^3}$$

$$\tau = \frac{2x16}{\pi x 0.016^3}$$

$\tau = 2.5 MN/m^2$

The Ultimate shear stress, $\tau_u = \tau$ x Factor of Safety 56

where, Factor of safety is 2

$\tau_u = 2.5 MN/m^2 \times 2.0$

$\tau_u = 5.0 MN/m^2$ (For each shaft)

The ultimate shear strength (S_u) of medium carbon steel ranges from (455-1151) Mpa.

From the above calculations it can be deduced that the ultimate shear stress expected on each shaftequal $5.0 MN/m^2$, which is considerably low compared to available data for the ultimate shear strength of some selected steel grades of medium carbon content. Also, taking into consideration operating conditions for which the shaft elements are designed for, availability and cost of mediumcarbon steel, machinability, cost of production and service life, medium carbon steel is the preferredchoice for the shaft element.

2.5.2 Roller Chain Selection

Roller chain is an assembly of alternating roller links and pin links in which the pin links pivot inside the bushings and the rollers, or bushings, engage the sprocket teeth to positively transmit power.

From the computational analysis carried out in previous section of this work, it was established thatthe maximum torque expected on all dynamic components equal 2N-m. Therefore, a material of high strength is required to resist maximum torque load, having selected the roller chain as the preferred drive mechanism for power transmission.

2.5.3 Cutting Blade Selection

In selecting the appropriate material for cutting blade, certain parameters were considered.

2.5.3.1 Operating conditions.
2.5.3.2 Blade geometry.
2.5.3.3 Active stress on cutting blade.
2.5.3.4 Machining process.
2.5.3.5 Economics.
2.5.3.6 Wear resistance.
2.5.3.7 Availability of raw materials.
2.5.3.8 Strength and hardness.

Having duly considered the aforementioned parameters, medium carbon steel has an ultimate tensilestrength of 683 Mpa, and a yield strength of 414 Mpa and thus is the selectedmaterial.

2.6 Cost Analysis

This section accounts for the cost of the entire project work, taking into consideration; materialscost, production cost and miscellaneous cost.

2.6.1 Materials Cost

Table 1 shows the Bill of Engineering Measurement and Evaluation (BEME) for the costof materials used in the production.

Table 1: Bill of Engineering Measurement and Evaluation

S/N	Item	Quantity	Unit Price (₦)	Amount (₦)
1	Mild steel sheet, 1mm thick, 4ft × 4ft	1	15,500	15,500
2	Mild steel sheet, 3mm thick, 4ft × 4ft	1	28,000	28,000
3	Mild steel rod, Ø16mm, 5ft long	1	3,000	3,000
4	Mild steel angle iron, 18ft long	1	2,200	2,200
5	Knife switch	1	800	800
6	Bolts and nuts, Ø10mm	100	50	5,000
7	Washers, IntØ10mm	100	20	2,000
8	Washers, IntØ17mm	10	30	300
9	Bolts and nuts, Ø17mm	10	150	1,500
10	Gear sprocket	1	2000	2000
11	Pinion sprocket	1	1500	1500
12	Bush roller chain (B-2)	1	1500	1500
13	Gears, Ø55mm	2	2,500	5,000
14	Pillow block bearings, IntØ20mm	4	2,500	10,000
15	Electric motor	1	15,000	15,000
16	Electric cable, Ø2.5mm, 3 yards long	1	900	900
17	Masking tape	1	600	600
18	Electric plug	1	300	300
19	Sub-total			91,500

The sub-total of material cost is ninety one thousand, five hundred naira.

2.6.2 Production Cost

This section accounts for the cost of fabrication and assembly of the machine as it is expressly enumerated in Table 2 which is still the Bill of Engineering Measurement and Evaluation (BEME)accounting for the cost of fabrication/production.

Table 2: Bill of Engineering Measurement and Evaluation

S/N	Item	Quantity	Unit price (₦)	Amount (₦)
1	19 spanner	2	500	1,000
2	8 spanner	1	300	300
3	10 spanner	2	300	600
4	Drill bit, Ø16mm (tempered steel)	1	2,800	2,800
5	Drill bit, Ø16mm (HSS)	1	3,600	3,600
6	Cutting wheel	8	250	2000
7	Grinding wheel	3	250	750
8	Drill bit, Ø8mm	1	1,500	1,500
9	White chalk	5	1200	200
10	Measuring tape	1	1,500	1,500
11	Gloves	2 pairs	1,000	1,000
12	Filler	1	800	800
13	Paint	2 tins	800	1,600
14	Paint brush	2	300	600

15	Roller brush	1	800	800
16	Thinner (paint)	0.2 litres	1,800	400
17	Grinding machine rent	1	1,000 per day	15,000
18	Sub-total			39,950

The sub-total of production cost is thirty nine thousand, nine hundred and fifty naira.

2.5.2 Miscellaneous Cost

Table 3 below accounts for the Bill of Engineering Measurement and Estimation formiscellaneous cost.

Table 3: Bill of Engineering Measurement and Estimation (Miscellaneous cost)

Item	Description	Quantity	Rate (₦)	Amount(₦)
1	Market survey transportation	20 tours	100	2 000
2	Materials conveyance			4 500
3	Daily transportation cost	3 students	3 weeks	6 000
4	Printing and binding	20 copies	1 300	26 000
5	Refreshments	3 times	2 000	6 000
6	Internet	4 months, 3 students	1,000/month	12 000
	Sub-total			56 500

The total cost of project is the sum of materials cost, production cost and miscellaneous cost. Thatis:₦187 650.

2.6 Production Method

The machine is made up of four main parts namely; The base, machine main (on frame), top coverand base tray. The production method covers the process through which each part of the machine was produced. The parts are:

1) Blades.
2) Shaft-blade assembly - part nō 10.
3) The frame (beams and column) - Part Nōs 1-8.
4) Top Cover - Part Nō 16.
5) Base - Part Nō 14.
6) Tray - Part No 5.
7) Webs - Part Nō 20.
8) Apart from these parts, all other parts were purchased as is based on specification andrequirement and were incorporated into the design.

2.7.1 Blades

This part interacts directly with the load and does the cutting along its edges as it rotates while firmly fixed to either powered or idler shaft. Figure 3.8 and plate 3.1 below each shows the diagramof blades.

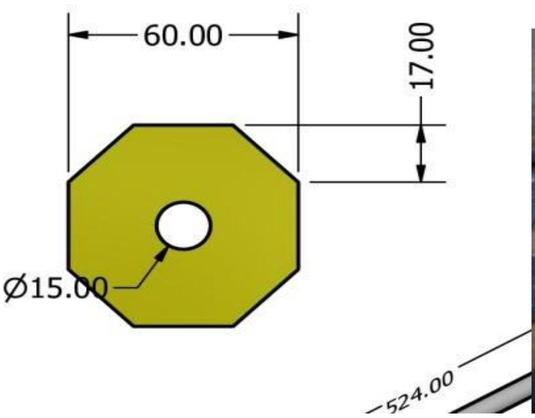
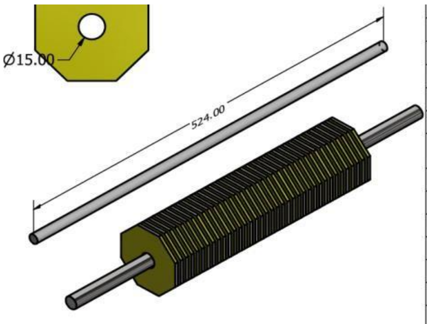


Figure 8 Cutting Blade. **Figure 9: Fully produced blades.**

The blades were produced by cutting 60mm×60mm squares out of a 3mm thick mild steel sheet. Seventy pieces of them were produced and their centres were located by geometric construction, marked, punched and drilled through to produce Ø16mm holes.

2.7.2 Shaft-blade assembly (Part Nō 10)

This assembly consists of blades welded onto a Ø16mm shaft which is 524mm long.



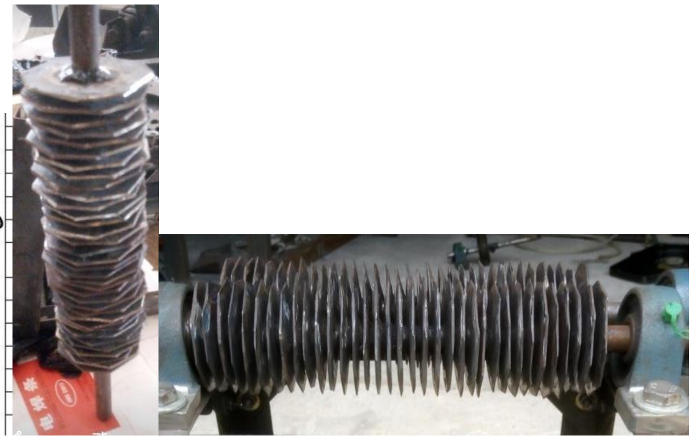


Figure 10: Shaft-blade assembly. Figure 11: Welded blades

There are two units of this component (the idler shaft and the powered shaft). Each was produced by Welding onto a Ø16mm shaft, 524mm the blades explained in the previous section. Each blade was introduce onto the shaft through its centred shaft hole, positioned and welded before the nextwas set onto the shaft.

2.7.3 Machine Frame (Part Nōs 1 - 5)

The machine Frame is a structural framework of the machine which on which other components such as pillow block bearings are mounted. It holds in place every other component of the machine.The frame consists of 90º angled mild steel bars measuring 40mm on each flange and 2mm thickness. There are several pieces of them each consisting of parts with serial numbers 1,2,3,4, and5 on the parts list.

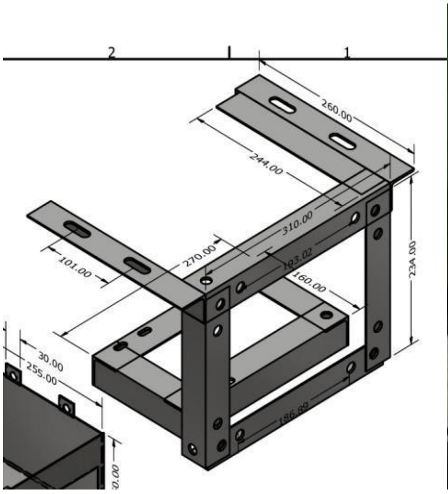


Figure 12: Machine Frame. Figure 13: Assembled frame.

The length of each component based on its length was marked out of an 18ft long - 90º angled barof said thickness. They were cut off, marked, punched and drilled based on specifications on the working drawings**.** There are fourteen pieces of them in total.

2.7.4 Electric Motor Base (Part Nōs 7 & 8)

This part is similar to the Machine Frame of the previous section and were made out of the same material following exactly the same process as above but with their own specifications of lengths and hole arrangements.

It is the part lying inside the frame consisting of four angled steels arranged into a rectangle on which the electric motor is mounted.

2.7.5 Top Cover (Part Nō 16)

The Top Cover is an n-shaped rectangular box with edge curves at the top corners and a paper slot.The main one is a pair of 50mm radius fillet at the back and front top edges while the inward curveis made at the slot. The bottom is open to let in the machine.

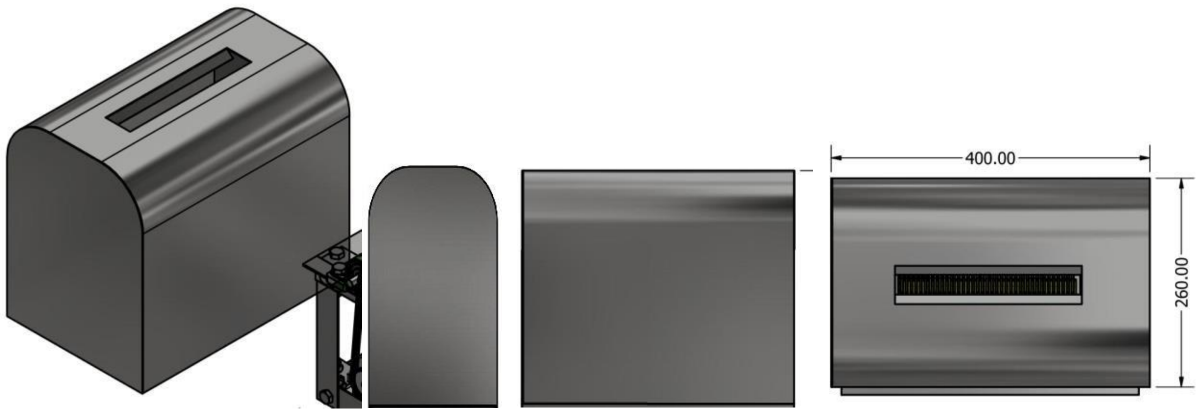


Figure: 14 Top Cover (Part Nō 16). Elevation, front and plan views.

The Top Cover was produced from three pieces. Two identical pieces of side plates (as in elevationview). Each is a 260mm × 350mm rectangular sheet of 3mm thickness with a fillet radius of 50mmat two edges. A third piece of 1mm thick sheet measuring 995mm × 260mm with a rectangular slotof length 220mm for papers. The third piece was measured, marked and cut off a large 1mm sheet,then marked for slot and bending. An H-shaped 220mm long cut was made for the slot and bent toa curve radius of about 20mm then the side curves were produced to a 90⁰ turn also, using a template.

The curves were produced by hammering on a wooden work bench and comparing with a template.

2.7.6 Collector Base (Part Nō 14)

The collector base is the part on which the frame and top cover sit and into which the tray is inserted.It makes contact with the ground and bears the weight of the entire machine. It is made of 3mm thick mild steel sheet and shape like a box with open top, four stands and a front tray slot.

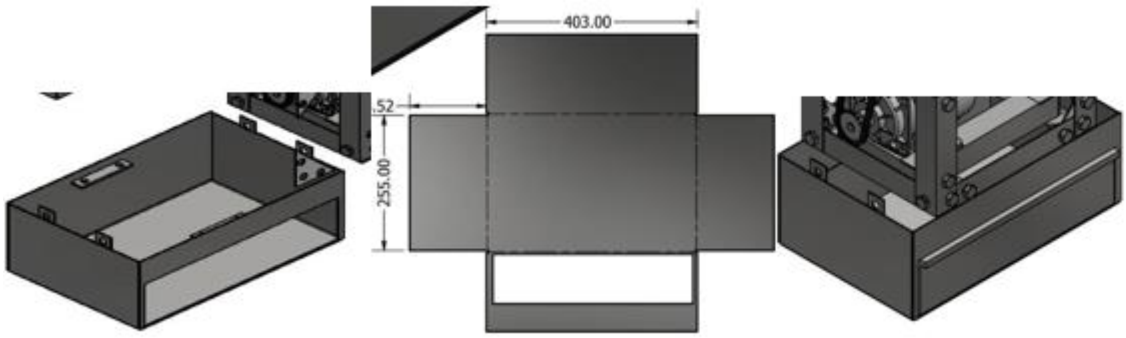


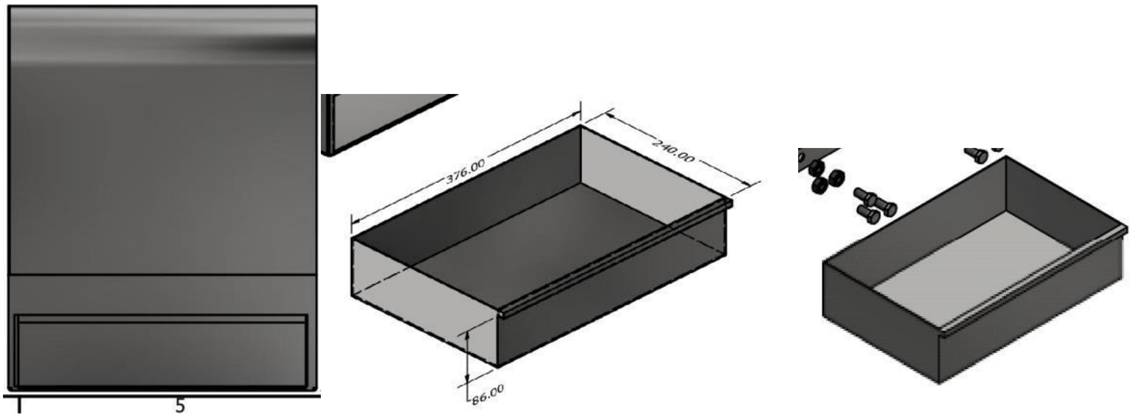
Figure 15: Collector base. (a) Free base. (b) Process cut. (c) Filled base.

The collector base was produced from a 3mm thick mild steel sheet. The dimensions were markedout and cut as shown in Figure 15b. Grooved lines were made along the path to be bent and thenthe piece was hammered into shape. After achieving the proper shape it was welded along the corners of the box to hold in place then the stand, top cover guide and frame sitting were producedand welded onto the collector base.

2.7.7 The Tray (Part Nō 5)

The tray is the part of the machine where cut strips of paper reside. It is a rectangular box shaped tofit into the collector base to form a drawer bin. It is the lightest of the main parts of the assembled machine.

Figure 16: (a) Fully assembled machine with tray. (b) Dimensioned tray. (c) Free tray.



The tray was produced from a mild steel sheet of 1mm thickness. It is a continuous piece in the dimensions were marked, edges cut off, bending grooves were made along the lines to be bent andthen it was hammered into shape on a square piece of wood which allowed the corners to be bent to 90^0 on hammering. Finally, the corners of the tray were welded to hold the sides in place.

2.7.8 Webs (Part Nō 20)

There are twelve identical pieces of triangular webs. Each one is essentially a flat piece of frame re-enforcement member that resist shear forces in the frame. They are attached to every corner of the machine frame where failure due to shear is possible.

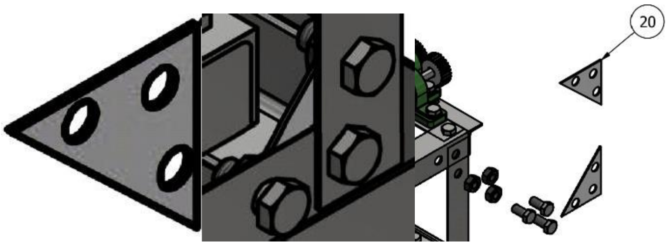


Figure 17: (a) Web. (b) Assembled web. (c) Exploded webbed joint.

The webs were produced by cutting off 100mm × 100mm squares from a mild steel sheet of 3mm thickness. Each 100mm square was cut along one of its diagonal and the holes were marked according to a template previously made for the webs and were drilled out to Ø8mm.

Generally, each part was milled after being cut out or drilled through to smoothen out rough edgesand enhance handling. Then machine was assembled and tested then dismantled and each part waspainted. Figure 18 shows the working/production drawing of the machine.

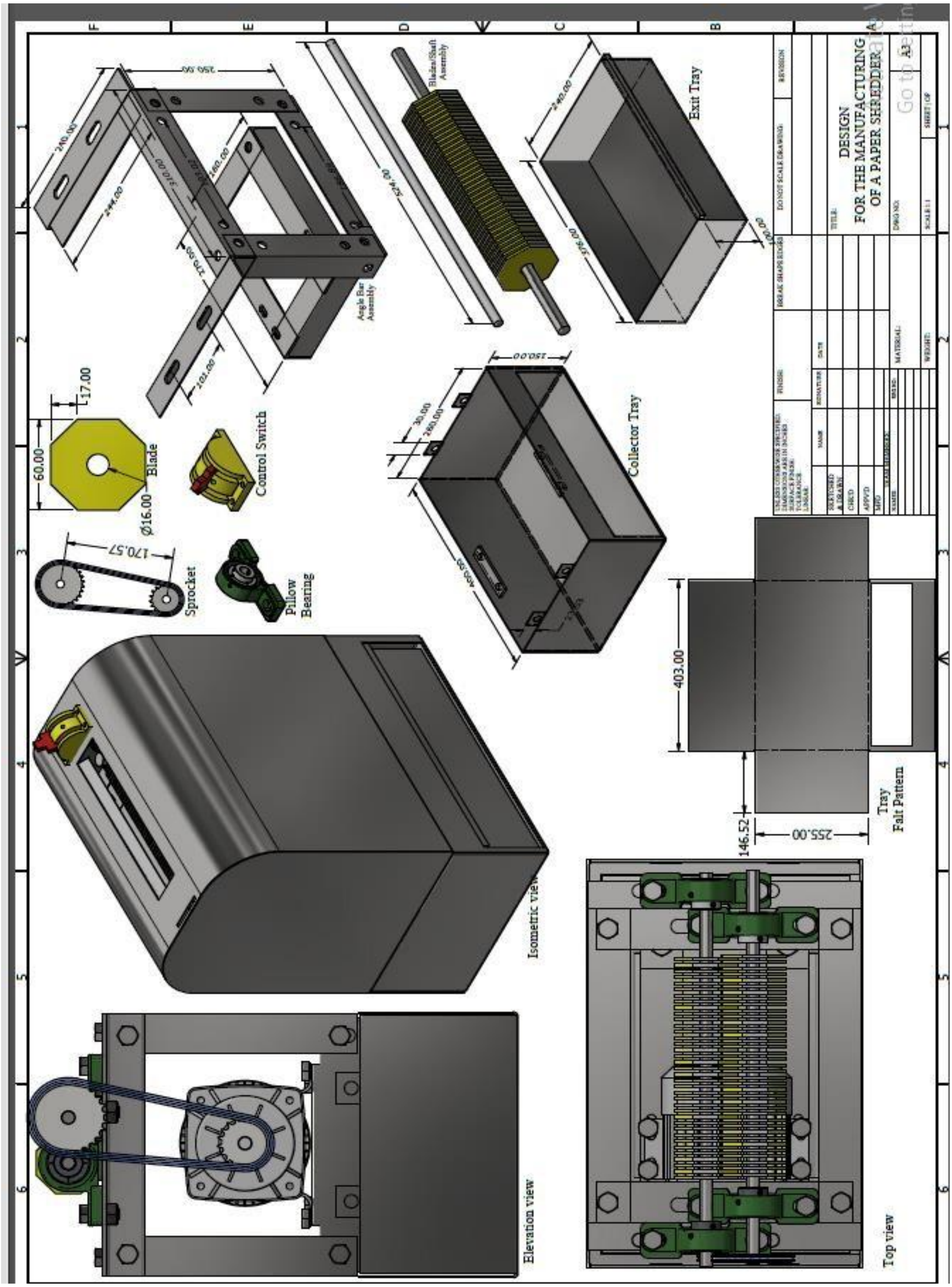


Figure 18: Working and Production drawing of the machine

2.8 Assembly Method

The machine was assembled mostly by the use of bolt joints. This choice was preferred for ease ofdisassembly. Ø10mm bolts were used to hold together members of the frame and electric motor base, while 19mm bolts were chosen to attach the bearings to the machine frame where it has to bear tension due to the load (paper) on the machine. Secondly, this bolt size was necessary to securethe shaft against violent vibration as the bearings already come with a standard hole on its pillow block. Then a few welding joints were used as necessary. Figure 19 below is the working/assembly drawing of the machine that shows the parts that were made out of separate pieces put together and the type of joint selected.

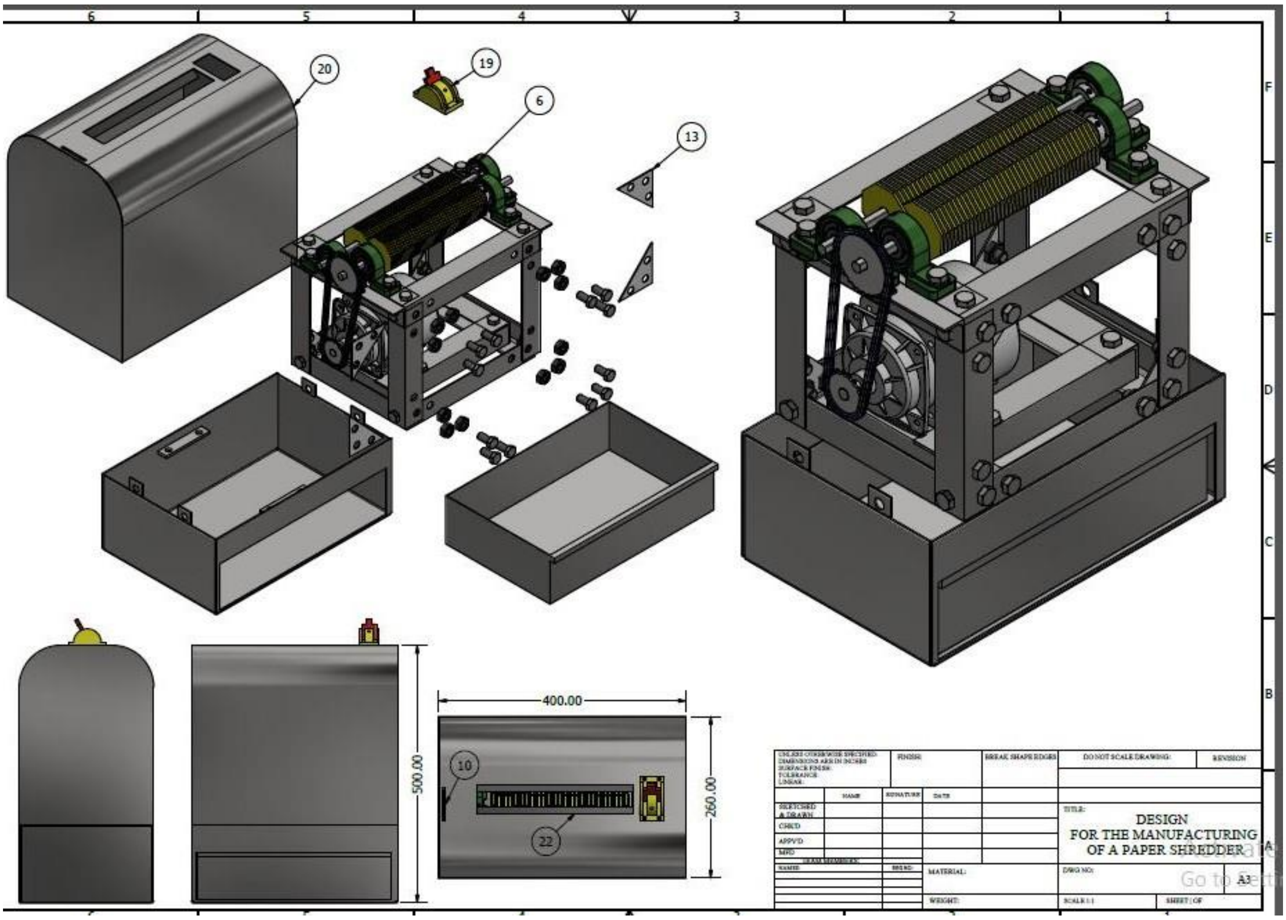


Figure 19 : Working and Assembly drawing of the machine

2.8.1 The Shaft-blade Assembly (Part Nō 10)

This part is composed of the cutting blades welded onto the drive shafts. Welding joint was preferreddue to ease of production against a cotter joint which was the next considerable alternative. The most notable reason for rejection of cotter joint was that spacers would be required for a key joint and there was not enough space to accommodate spacers that would be strong enough to resist failure. Secondly, there would have been the additional cost for production of pin or key and as many spacers as there are blades, therefore welding was the most favourable option.

2.8.2 Machine Frame (Part Nōs 1-5)

The machine frame composed of 90º angled steels joined together at the vertices of the cubic frameand webs added for re-enforcement against shear forces. Bolt joints were used throughout the framefor some considerations made in the selection were;

i. Ease of dismantling the machine when need arises.
ii. Ease of part replacement in event of failure.
iii. Ease of package and transportation, especially where mass production is required.
iv. For adjustability of the joints in event of compatible with other parts of the machine.

10mm bolt was found suitable for each point as each vertex had about seven of them giving an effective diameter of 70mm per vertex considered enough with factor of safety. These were hardened steel bolts. See Figure 3.10 for the diagram.

2.8.3 Electric Motor Base (Part Nōs 7 & 8)

For image, refer to Figure 3.10, the part dimensioned 270 ×160 (mm).

This part followed the same considerations as in as the previous section, hence bolt joints were used.

2.8.4 Top Cover (part nō 16)

Though made of different pieces, this part is considered a single piece based on it functions. Therewill never be a need for disassembly of its different pieces. This called for a permanent joint, hencethey were welded together. The top cover is added to the machine by being made to sit freely on thebased but secured in place by four guide clips. This was preferred against bolt joints as they may beoccasional need to access the internals of the machine either for lubrication maintenance or blade cleaning. The choice was motivated by convenience or ease of access. Also, there was no need fortougher joints as the top cover fits snugly into it clips and sits without wobbles, partly due to it carefully chosen weight and also perfect dimensions.

2.8.5 Collector Base.

The collector base is essentially the base of the entire machine, this part makes contact with the floor on which the machine is mount. After the frame, electric motor, chain, shafts and bearings have been assembled to obtain the main machine, it is placed in its sitting on this base and securedwith bolts to transmit any vibration and prevent relative motion of the base against the machine which may be disastrous. This is done before wiring and adding the top cover and then insertion ofthe strip paper tray as the last assembly Procedure.

2.8.6 Strip Paper Tray (part nō5)

This is the last part in the assembly procedure just before the machine is being tested. Please refer to figure 3.13. The tray collects the cut strips of paper. It is inserted into the collector base just likea drawer and does not require any special joints but restricted to one degree of motion (to-and-fro)in its slot. There was no need to secure the tray as the information contained in the paper have already been concealed.

2.8.7 Assembly Procedure

1) Use the working drawings to fix up the frame.
2) Set up the shaft and bearings as shown in the drawings and place them accordingly on the frame.
3) Fasten the setup to the frame using the 19mm bolts with washers.
4) Attach the electric motor to its base and insert the base in the lower part of the frame taking noteof its orientation as depicted in the drawings.
5) Put the chain over the two sprocket and adjust appropriately, then secure the electric motor basein its place using the 10mm bolts with washer.
6) Ensure that no hole is left unbolted on any of the joints, then turn the machine manually to ensurethat it is free to rotate.
7) If it does not rotate freely, adjust the setup until this is achieved, then tighten all the bolts firmly.
8) Wire up the machine and test.
9) Place it on its base and secure with 10mm bolts, nuts and washers.
10) Put on the top cover gently minding the switch.
11) Push in the tray and your machine is ready for use.

Figure 20 is the assembly view of the machine without top cover.

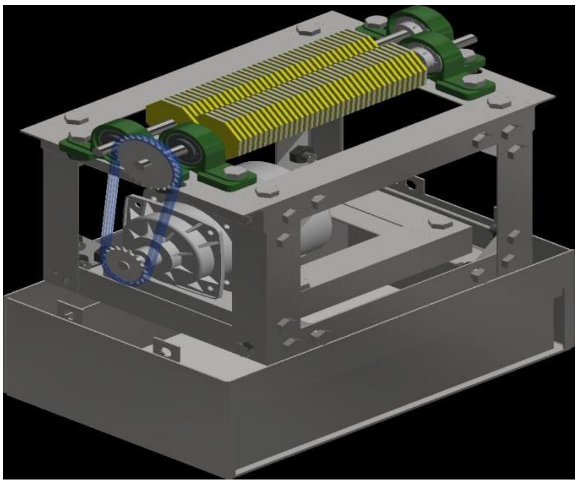


Figure 20: Assembly view of the machine without top cover

Figure 21 is the assembly and working drawing of the machine with the part list attached.

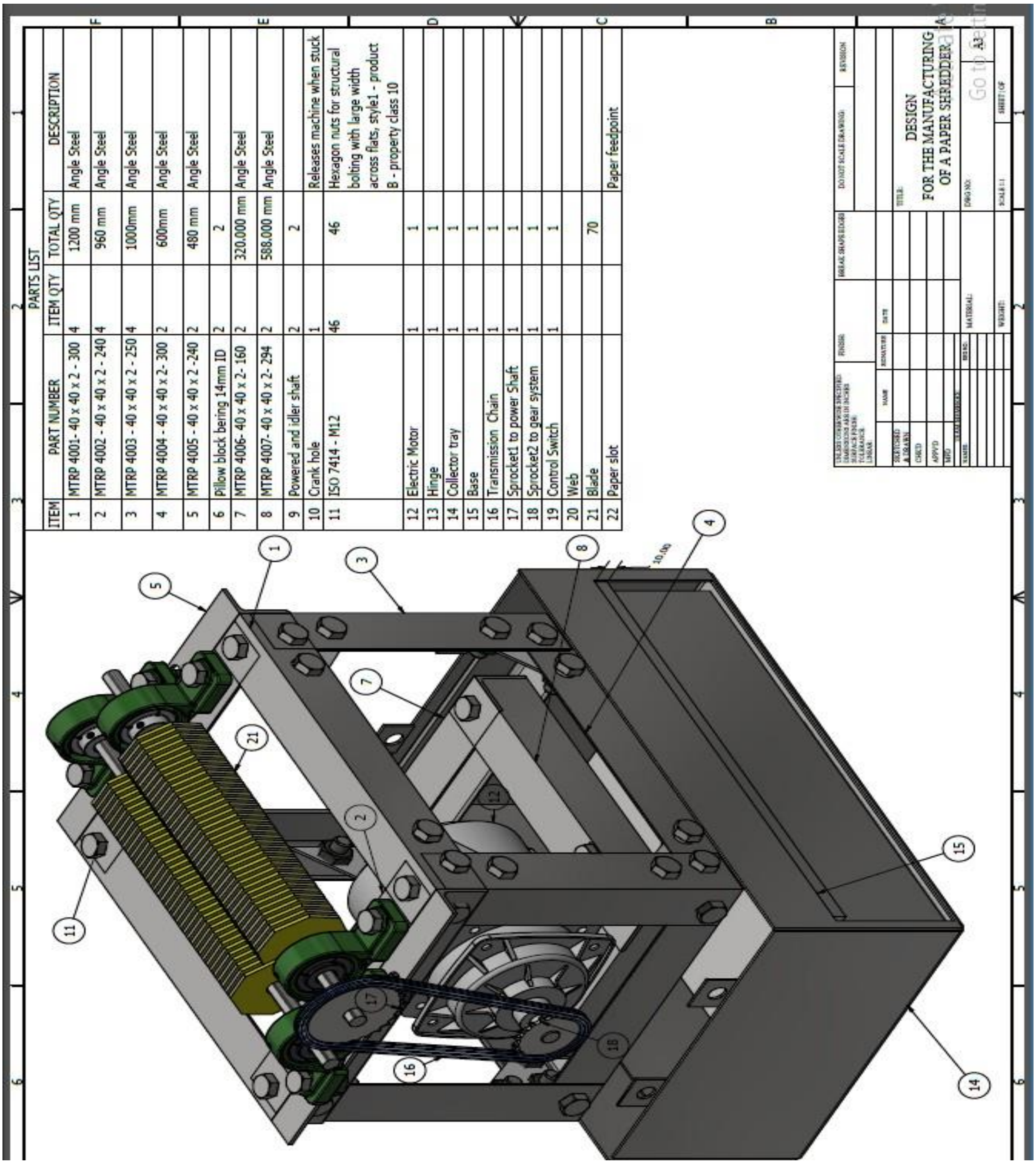


Figure 21: Assembly and working drawing with attached part list.

3. 0 RESULTS AND DISCUSSION

3.1 Testing and Evaluation of the Paper Shredding Machine

After fabrication and finishing operations, the machine was put into operation and left to run freelyfor about a minute before tested. Then A4 papers were inserted into the machine. It was observed that it takes approximately 15 to 20 seconds to shred 10 A4 papers put together. The shredding ratevaried according to the paper grade. The machine was also tested on the shredding efficiency.

3.1.1 Rates of Shredding

The number of papers and the shredding rate of the machine is presented in Table 4

Table 4.: Table showing how long it takes to shred a certain amount of A4 paper(s)

S/N	Quantity of paper(s)	Time for complete shredding (seconds)
1	1	0.3
2	2	0.8
3	3	1.6
4	4	2.4
5	5	3.2
6	6	4.0
7	7	4.8
8	8	5.6
9	9	6.4
10	10	7.2

3.1.2 Shredding Efficiency

It is noted that a standard A4 paper measures 210 mm by 297 mm (210 × 297) mm. And there are 35 blades mounted on each shaft, which means that shredding a single sheet gives 35 strips/sheet. And the number of strips produced will be the quotient of 210mm and 35 (6mm per strip).

That means the expected cut length will be 297mm × 35 = 10,395mm10,395mm is the total expected cut length (E).

Ten (10) samples of A4 papers were tested on the machine and the results (total actual cut length,A) can be seen in Table 5.

Table 5: Table showing the cutting length values

S/N	Expected cut length, E (mm)	Actual cut length, A (mm)	A/E
1	10 395	9 350	0.90
2	10 395	9 200	0.86
3	10 395	10 100	0.97
4	10 395	10 326	0.99
5	10 395	9 222	0.89
6	10 395	9 990	0.96
7	10 395	10 100	0.97
8	10 395	10 111	0.97
9	10 395	9 993	0.96
10	10 395	9 300	0.89
N=10			$\sum(\frac{A}{E}) = 9.36$

The shredding efficiency (Sheff) is then computed thus

$$Sheff = \sum(\frac{A}{E})/ 94\%$$

Therefore, the shredding efficiency (Sheff) of the machine is 94%.

3.2 Discussion of Results

From Table 4, when a single paper was put in the machine, the shredding time was 0.3 seconds. Then the number of papers was increased to 2, it took 0.8 seconds. As observed from table, the timeinterval difference keeps increasing slightly on the addition of an extra single sheet. From the tableit takes 7.2 seconds to shred 10 A4 papers at a time.

It should be noted that the shredding time (in seconds) is not fixed as it can be varied depending onsome certain factors.

4.0 CONCLUSION

From the configuration of the blades (octagonal blades) it is observed that this machine is a typicalcross-cut paper shredding machine with the security level of between P-3 to P-4 according to the international standard for shredder security levels (DIN 66399). As such, the machine would be suitable for office use just discussed in the chapter 1 of this research work.

The conclusion made from this research are:

i. The machine takes approximately 0.3seconds to cut each piece of paper.
ii. This cutting rate is fast enough to get an entire book of say 50 pages completely shreddedin less than a minute (about 50 seconds) based on the table values.
iii. The machine delivers a very high shredding efficiency of 94%.
iv. Shredding rate varies with different paper grades.
v. The shaft upon which the octagonal blades are mounted was observed to rotate atapproximately the same speed with the prime mover (electric motor)

The following recommendations are made for further work:

i. The design should be automated with a belt conveyor to take the shredded papers to packingspot.
ii. The prime mover should be replaced with one that has the ability to drive in reverse, in orderto ease the starting process and undoing jams in place of the manual crank window methodof reverse.
iii. A gear box system should be incorporated in further designs to ensure efficient power transmission.
iv. There should be adequate spacing of the blades to prevent jamming which causes friction which in turn reduces the efficiency of the machine.
v. Hardware programming technology should be incorporated into further designs for better ease of operation.
vi. The use of brush spacers to automatically clean up the blades to remove clogged strips in the blades spacing so as to increase the efficiency of the system and reduce the frequency ofhaving to open up the machine for clean ups.
vii. The shortening of inter-shaft spacing should be done to increase shredding efficiency.

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