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Design and Construction of an Automated Paper Shredder with a Cross-Cut Pattern

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ABSTRACT

A paper shredder can be used to shred or cut documents made of paper or plastic into tiny strips. Private businesses use it to shred sensitive papers, such as contracts, into tiny pieces or rubble. As a result, these gadgets secure information while reducing environmental waste. This research work focuses on the design and construction of an automated paper shredder with a cross-cut pattern. In order to actualize the design such as the construction of the metal frame, assembling of the cutter, integration of the electronic components, and programming of the automation technique; the design has been divided into two; Mechanical and Electronic Control Units. The Paper Shredder machine achieved a shredding dimension of 4x23 mm using a combination of Cross-Cutting and Strip-Cutting techniques. In addition, the fabrication process involves procedures like metal shaping, welding, machining, and the usage of mechanical fasteners. The cutting blades and shafts will consist of medium Carbon steel (gear). The machine uses an Arduino Nano microcontroller, a programmable integrated circuit to control the machine's operation. Other significant sections for this design include the power supply, blades, dc motor, microcontroller, indicator, and many more. Different sizes of paper dimensions such as 210 x 297, 148 x 210, 105 x 148, and 74 x 105 (mm) were inserted in the machine for the shredding test, the output showed a properly shredded form that validates its performance

1. Introduction

Documents are made of paper, which frequently contains sensitive information. Paper shredders are frequently categorized as consumer shredders because consumers utilize them the most. The previously designed shredder consisted of a microcontroller (Arduino Nano), two cutting shafts fitted with multiple cutting blades, LEDs, etc. By limiting the number of landfills, documents, and paper can be more easily transported to the recycling centre after destruction, which helps protect the environment [1, 2].

Shredders for documents are increasingly in demand in recent times. However, the high cost of effective paper shredders is a limiting factor to a large populace [3]. Many design techniques have been explored for shredder machine designs for various purposes [4-9].

The aim of this project is to design and construct a paper shredding machine using a cross-cut technique. This involves: researching previous shredder machine components, such as the blades, frame, and transmission system; implementing an engineering sketch for dimensioning, selecting and assembling the appropriate electronic components for the automation, and evaluating the performance of the developed system using a standardized paper shredder.

This calls for the use of Programmable logic circuit as an interface for controlling mechanical movements through electronic systems. Several paper shredding machines use strips, particles, cross-cutting, and many more.

A thorough analysis of the construction and operation of paper shredder machines was conducted [10]. The study focused on the individual parts' types, features, size, alignment, benefits, and drawbacks. Additionally, covered in the study are the motion study and stand analysis in ANSYS-15 as well as the construction of the 3D model of various elements of Dassault Systems' solid works.

Using a shredder that cuts this trash and turns it into nourishing fertilizer, [11] proposed a machine to improve the conventional technique of disposing of agro waste. The suggested device is an add-on for a KAMCO Tera-track 4W tractor, which supplies input power and support for the shredder. For chipping and powdering operations, numerous types of cutting blades (rotary, triangular, and screw blades) are available.

Also, an affordable, practical, and time-saving atomized paper shredder was developed [12]. The device eliminates constraints like time reduction and increased paper shredding per time. Eliminating paper backflow along cutting blades lowers noise and vibration. An enhancement was sought for the procedure of decreasing the buildup of post-consumer plastic waste. [13] created a system with carefully chosen characteristics to enhance current equipment.

[14] presented the blades of the paper shredder that had serrated cutting edges that were formed by bending. This could be done by two methods. The blade body and serrated edge of the first approach were produced and punched together from the same base material. There were considerable production costs involved, and even premium materials were needed. The second method used serrated cutting edges that were thickened especially to conserve material.

To prevent the cut material from accumulating around the blade shaft, stripper bars or fingers were provided between the blades of each shaft in the cutter zone [15]. The stripper's finger was received in this instance on the stripper block in the spaces between the blades. Due to the fingers' engagement with the support ribs of the opposing housing, the necessary stability was reached. The Stripper block was an injection mold component, making it easy to make, simple to build, and inexpensive.

2. Methodology

The purpose of this activity is to analyze, design, and assemble the electronic circuit of the gadget using readily available components and linking each part together. There are two primary categories for the hardware and software components that make up the paper shredder. The hardware interface comprises the blades, bearings, electric motor, shaft assembly, and microcontroller unit. The Arduino IDE and Proteus software, which function as a circuit simulator, is also a part of the software package. A power button was integrated into the machine to set it in ready-to-operate mode, while a push button was used to initiate the paper shredding mechanism. Also, the machine operation could be halted using the push button to alter the mechanism of operation.

The paper shredding machine uses a combination of cross-cut and particle-cut techniques. The reason for this is to ensure that the efficiency of the cutting technique outperforms previously designed systems that focused solely on an approach. The aforementioned paper techniques for this research work, it is expected to produce an efficient, safe, and reliable method of destroying sensitive documents.

Figure 1 shows the block components, while Table 1 shows the specifications of the mechanical components of the automated shredder machine. The components highlighted in Figure 1 are a combination of the electronic hardware and the mechanical materials required for the development of the research work. To develop the automated paper shredding machine, an engineering drawing of the system was designed as a template.

The block diagram critical unit of the developed system is the controller which communicates with the peripherals such as the relay, gears, blade, etc. The initialization of the design starts by pressing the power switch to turn it on to implement the sequence of shredding. Here, the power terminal is subdivided into two namely; ac mains (220 V) required for the operation of the electric motor, while the dc signal (5 V) is required for the operation of the microcontroller. In order to set the shredding time for the machine, the knob must be turned clockwise, which in turn will initialize the electric motor and also control the gear in a regular pattern for shredding different sizes and thicknesses of paper. A relay is used to cut-off power to the electric motor once the timeout of 3 minutes allocated for shredding is completed. Also, the shredder would go off for 2 minutes; this is done to ensure that the electric motor does not burn out while in operation. The blade interfaced to the gears is arranged in a zig-zag to ensure effective implementation of both strip and cut-cross patterns in paper shredding. Once shredded, the papers go through the funnel-like passage for immediate disposal. While in operation, the limit switch in the shredder is used to count a cycle of operation i.e. if the papers have been completely shredded and the 3 minutes allocated for shredding has completed, the limit switch will halt the gears, thereby restricting the movement for further paper shredding.

2.1 The Shredder

The shredder consists of different parts which include;

- Electric Motor: The electric motor transfers the required power in a forward rotation to shred paper. The electric motor used for this project rotated at a speed of 1450 revolutions per minute and has a power rating of 80 watts (0.08 kW).

- The Blades: The blade, which is a circular cutting blade, actually shreds the paper into strips. This design used a blade that was 2.0mm thick and constructed of medium carbon steel. The inside diameter of the blade will be converted into a hexagonal shape on a lathe in order for the intended shaft to fit. A total of 112 washers and 56 washers will be put on each shaft.

- Bearings: To lessen friction, this machine utilizes dip groove ball bearings, which will be situated at either end of the main shaft.

- Shaft Assembly: A shaft assembly is made up of gears, washers, and blades. The washer, which is shaped like a conventional ring, serves just to the line and lock the blades so that they don't move when the machine is in use. There will be 20 of them in total, and two of them will have lock nuts. The primary shaft gear is composed of the size and two spur gears.

The main section of the paper shredding machine is the machine frame, which serves as a support structure for other machine parts, especially the moving parts. The frame for this design will be made of mild steel with a 4 mm thickness and measured 1100 mm by 700 mm by 500 mm. The major structural elements of the machine are the mainframe, left base, right base, shredder support, and gear support.

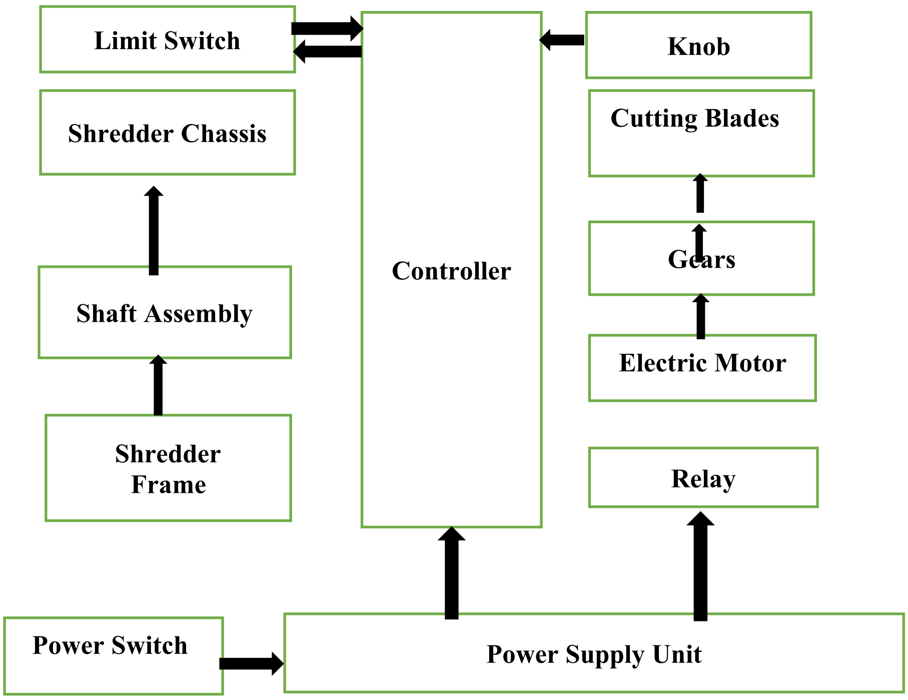


Figure 1: Block Diagram of an Automated Paper Shredding Machine

Several factors will be put into consideration during the fabrication of the machine

i. Torque of the machine
ii. Shaft diameter
iii. Power determination
iv. Bearing selection
v. Gear module
vi. Determination of the cutting force

2.1.1 Advantages of Cross-cut Pattern Shredder over Others

i. Ability to shred papers with staples and Clips without blade damage
ii. Ability to shred thicker materials like cardboard
iii. Ability to obscure the information more completely
iv. Cross-cut Shredder cuts into tiny pieces not larger than 4 x 23 mm

2.1.2 Cutting Force

Cutting force (Fc) = τ x t (1)

Tensile strength = 3.6 N/mm

Shear strength (τ) = 80% of tensile strength

τ = 80/100 x 3.6 = 2.88N/mm.

Considering a thickness of 4 mm

$F_c = 1.42x4 = 4.8N$ (2)

Fc = 1.42 x 4 = 4.8 N

Using a factor of safety of 3

Fc = $2.84x3 = 8.54N$ (3)

Considering the shaft as one with a uniformly distributed load,

The force at the cutting spot is 8.52 N and it is distributed at an interval of 12mm on the shaft with the cutting blades.

P $=\frac{aq}{n+1}$ (4)

n = the degree of parabola =0

q =8.52 N

12mm, a = 320mm

∴ p $=\frac{8.52\times320}{12}$ = 227.2 N = total cutting force

Cutting power (PC) = total cutting force (FTC) x cutting speed (SC) (5)

PC = 227.2 x 0.28 = 63.616 W

Using a factor of safety of 3 from standard values

PC = 63.616 x 3 = 190.85 W

- Transmitted power (PT) = cutting power (Pc) + power loss in belt (PLB) + power loss in gear (PLg) + power loss in bearing (PLb) (6)

PT = 190.85 + 0.05 PT + 0 + 0.62
(3)

PT - 0.05 PT = 191.47

0.95 PT = 191.47

PT = 191.47/0.95

PT = 201.55 W

Using a standard module of 3mm and rotational speed of 900 rpm

Using.

The ratio of the basic dynamic load rating to the equivalent dynamic bearing load is given as

C/P =10.3

C = 10.3 x P

P= 1 x FrA = 191.47 N

Therefore, C = 10.3 x 191.47= 1972.141 N

2.1.3 Cutting and Precision Tools

- Grinding machine: The mild steel pan and the shaft holding the blades were converted to a diameter of 50 mm and stepped down to a diameter of 25 mm from both ends to a length of 40 mm using the grinding machine and a cutting disc.
- Measuring Tape: A tape rule was used to measure the shaft and mild sheet metal.
- Vernier Caliper: It will be used to gauge the blade and gears' interior diameters.
- Bending Machine: The mild steel sheet metal was folded into a rectangular shape using the iron bender.
- Chalk: Chalk was used to mark out the mild steel sheet metal's measured length; the medium carbon steel shaft and other components relied on that measurement.
- Drilling machine: the drilling machine was used to drill holes in the metal sheet.
- Bench vice: The workpiece was primarily held in place throughout the cutting operation using the vice.
- Welding Machine: The machine frame and the metal sheet were both welded using an electric welding machine.

2.1.4 Design Interfacing

- Riveting: Using a riveting gun and pin, the supporting rollers that help the machine move was attached to the machine frame.

- Deslagging: Following the completion of the welding process, the impurities from the welded frame were removed using a wire brush and a chipping hammer.

- Electrical System: The driving shaft was connected to the 80-watt (0.08kw) electric motor and other electrical connections like the cable and plug were also made. The shredder support had an electric motor positioned inside of it.

- Mechanical Fasteners: bolts and nuts were used to firmly secure the electric motor and shaft to the shredder support as well as to the shafts.

- Painting: To enhance the finished machine's aesthetics, black oil paint was applied.

Figures 2, 3, and 4 below show the top, side, and rear views of the design.

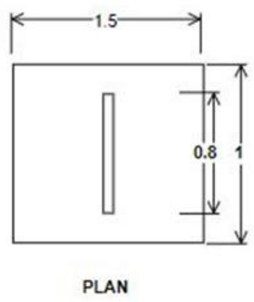
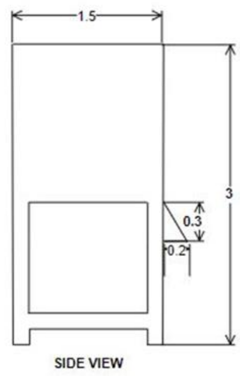


Figure 2: Top View



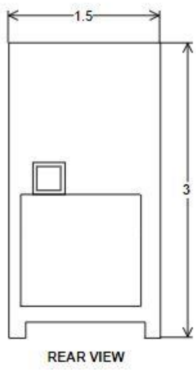


Figure 3: Side View

Figure 4: Rear View

Figure 5: Side View

2.2 Device Specification of the Developed Paper Shredding Machine

Table 1: Mechanical Components Specifications

Part	Features
Motor gear	N_{motor} = 6684 rpm
Third gear (connected to the shaft)	N_3 = 46.16 rpm
Single cutting blade force	$F_{cutting}$ = 0.27 N.
Total cutting force of the shredder	$F_{cutting, total}$ = 29.16 N
Maximum number of paper in each cut	5 papers, F_{paper} = 24.79 N
Torque on the shaft	T = 119.97 x 10^{-3} Nm

2.3 Electric Motor

The electric motor shreds paper by transferring the necessary power in a forward revolution. The electric motor utilized for this project has a 80-watt (0.08 kW) power rating and is rotated at a speed of 1450 revolutions per minute. The motor is made by the Ronning-Motor firm, and its features include:

- Shaft length: 14 mm
- Shaft teeth type: helical
- Diameter: 45 mm
- Length: 96 mm
- Armature core length: 26 mm
- Armature core width: 54 mm

2.4 The Blade

The blade is made up of multiple cutting edges made from two cylindrical rotary cutters that are separately mounted on hexagonal shafts, and the shafts are securely mounted with several cutting blades. The cutting blades are divided by a Spacer placed between each pair of adjacent cutting blades, allowing the cutting blades to be constructed and mounted on the two cylindrical rotary cutters in an interleaving manner. Moreover, each cutting blade is made up of two blades in total. The multiplicity of cutting edges on each of the two blades of the present invention are circumferentially oriented and minimally separated, providing a compact assembly of blade edges. Around five sheets of paper or cardboard can be fed into the paper shredder cutting tool at once, where they are quickly shredded into small bits. A typical description of the blade is represented in Figure 6.

Figure 6 : Multi – cut Shredder Blade

2.5 Cutting Force

The threshold of the cut on A4 paper can only be attained when the force applied to the blade is greater than the force required to tear the paper. (Slocum, 2008) states that the recommended cutting force for each blade is Fcutting = 0.27N. There are 108 cutting blades in total spread across two shafts in this design, with 54 blades in each shaft. According to this shredder, the total cutting force is equivalent to:

$$F_{cutting,\ total} = 0.27 \times C \quad (7)$$

Where 0.27 is the cutting force for each blade to cut A4 paper, and C is the total number of blades in the paper shredder.

Thus, the total cutting force of this paper shredder:

$$F_{cutting,\ total} = 0.27 \times 108 = 29.16 \text{ N}$$

2.6 The Shaft Assembly

A medium-grade steel rod with a circular cross-section was used to design the project's drive shaft. The steel rod was turned into a hexagonal shape using a lathe. The paper shredding machine was built with two shafts, one of which is the primary shaft and the other is the driving shaft. The torques on the shaft depend on the power of the motor and the speed of the paper shredder (N_3). It is calculated by the following formula.

$$T = (P \times 60) / (2\pi \times N_3) \quad (8)$$

Where P is the motor power P_{motor} = 579.9 watt (0.5799 kW) and N_3 is the paper shredder speed N_3 = 46.16 rpm.

Thus, the torque on the shaft:

T = (0.5799 x 60) / (2π x 46.16) = 119.97 x 10^{-3} kNm

2.6.1 Maximum Number of Sheets per Cut

(Oreko *et al.,* 2009) states that the following equation can be used to determine how much force is needed to cut a number of A4 sheets:

F_{paper} = n x p x 2π (9)

The pressure force applied to a single A4 sheet of paper is equal to p = 0.78909 N/m2, where n is the number of sheets in each cut [2]. In addition, for the blades to cut the paper, Fpaper must be smaller than Fcutting, in total.

Hence, the circumstance is $F_{paper <}$ 29.16 N. The maximum number of papers is therefore:

F_{paper} = 5 x 0.78909 x 2π = 24.79 N < 29.16 N

Each cut of the paper shredder may destroy up to five A4 sheets of paper.

2.7 The Gears

Plastic was utilized to create the gears for this project. On a lathe, four sets of gears were created, each with a distinct diameter and size. The second gear was designed to have 13 teeth with a 30mm diameter, whereas the first gear, which is connected to the electric motor directly, has four teeth with a 6mm diameter. Whereas the fourth gear was intended to have 42 teeth with a 42mm diameter, and the third gear was intended to have 37 teeth with a 56mm diameter.

2.7.1 The Gears Rotational Speed

Assuming a motor speed of N motor = 6684 RPM, the motor speed will rotate the first gear (N1), then N1 will rotate N2, and N2 will rotate N3, which is the speed of the paper shredder because it is directly connected to the driving shaft. The following relationship (Slocum, 2008) governs how speed is transferred between the gears (compound gears):

Output speed = (Input Speed) (Product of Transmission Teeth / Product of Receiving Teeth)
(4) Where the input speed is N_{motor} = 6684 and the number of gears teeth is according to the Solid Works design.

$$Output\ Speed = 6684 \left[\frac{37\ x\ 9}{7x28x6x41}\right] = 46.1\ rpm \quad (10)$$

The third gear speed (N_3) = the speed of the paper shredder = 46.16 RPM

2.8 Control Circuit

The seamless automation and control of the paper shredding were achieved using both mechanical and electronic components. The electronic circuit comprises discrete components such as an actuator, a potentiometer, an integrated circuit, resistors, capacitors, and a solid-state relay. For the programming implementation, Arduino Integrated Development Environment (IDE) was adopted, while the hardware interface comprises a limiting switch, a power supply filter, and a microcontroller.

Two classes of power supplies were required for the design; a direct current (dc) power source and an alternating current (ac) power source. The ac power source is 220 V/50 Hz obtainable from the mains, while the dc power supply is obtained via rectification and voltage reduction of the ac mains. The basic electronic components are powered via the dc supply of 5 V, while the motor required for the shredding of the paper is powered with a 220 V (ac) source.

2.8.1 Solid-State Relay

It is an electro-mechanical relay (EMR) that uses coils, magnetic fields, springs, and mechanical contacts to operate and switch a supply, the solid-state relay, or SSR, has no moving parts but instead uses the electrical and optical properties of solid-state semiconductors to perform its input to output isolation and switching functions.

Just like a normal electromechanical relay, SSRs provide complete electrical isolation between their input and output contacts with its output acting like a conventional electrical switch in that it has very high, almost infinite resistance when non-conducting (open), and very low resistance when conducting (closed).

SSR is utilized to run the activation of the motor to implement the mechanical process for shredding paper.

2.9 Design Implementation of the Developed Automated Paper Shredding Machine

2.9.1 The Welded Machine Frame

The machine frame is the fundamental component of the paper shredder and provides support for all other machine parts, particularly the moving parts. The dimensions of the frame for this design are 525 mm x 400 mm x 200 mm made of mild steel with of 2mm thickness. The mainframe, left base, right base, shredder support, and gear support make up the machine's construction. Mild steel with a 2mm thickness was used to make the shredder support. It was bent and laser-cut. The static blade holder's base is held in place by the shredder support, which was positioned on top of the machine frame.

2.10 Construction Procedures

The following procedures were followed to develop the paper shredding machine.

- Marking Out: The dimension of 525 mm x 400 mm x 200 mm was measured and marked using steel chalk and a tape rule on the acquired mild steel material and other metallic pieces.

- Cutting: Using a grinding machine and a cutting disc, the indicated pieces of the mild steel material were cut out of the bulk material in accordance with the specifications.

- Folding: To create a 90-degree angle, the chopped-off pieces that were to be folded were folded with the help of a folding machine.

- Tack welding: was used to reattach the cut-off pieces and the folded edges together. After that, welding was done using the E6013 electrode and the Manual Arc Welding (MMAW) procedure. The electrode has a 60000psi pressure specification.

- Deslagging: Following the completion of the welding process, the impurities from the welded frame were removed using a wire brush and a chipping hammer.

- Drilling: Following the completion of the welding process, a drilling operation was carried out in the machine frame part that needed it. The drilling machine used a 5" drilling bit to drill holes in the machine frame and hopper.

- Riveting: With a riveting gun and pin, the supporting rollers that help the machine move were attached to the machine frame. To the machine, the frame was four rollers that were fixed. Two hinges were further welded to the machine frame's door.

- Machining: The gears, blades, and shafts of the paper shredding machine were designed on a lathe using the design specifications specified in the template.

- When the blades, gears, and shaft have been machined, the cutting blades are fitted. Two shafts were equipped with cutting blades. Each shaft has 56 blades, for a total of 112 blades installed on them. In order to prevent displacement from the position during operation, a spacer was fixed between each of the four blades that were mounted in succession.

- Gear Fitting: The gears were mechanically attached to the shaft ends. The machine had four gears installed, one of which was attached to the electric motor and the other three to the shaft ends. The first gear was made to mesh with the second gear, and it has fewer teeth

- and a smaller diameter. They both move in opposing directions and have a 30mm diameter and 13 teeth.

- Installation of the Electrical System: Other electrical connections, such as the cable and plug, were connected together with the 80-watt (0.08 kW) electric motor, which was attached to the driving shaft. Inside the shredder, support was a mounted electric motor.

- Mechanical Fasteners: To ensure a secure grip of the electric motor and shaft, M4 bolts and nuts were used to fasten the motor to both the shredder support and the shafts.

- Roller Fitting: To enable the movement of the machine frame from one location to another, four rollers were mechanically fastened to the base of the frame.

- Painting: To enhance the machine's aesthetics, black oil paint was applied to the finished product.

3. Results and Discussion

This paper shredder machine is powered by an electrical source; the electric motor supplied the required electrical energy, and the gears converts the electrical energy into mechanical energy, reducing the speed of the electrical motor to the desired speed required by the paper shredder to successfully shred the papers into strips. The intermeshing washers, which were sandwiched between the strip-forming rollers grab and drag the paper sheet to create the shreds.
The procedure for the operation of the shredder is highlighted below:

- The knob on the electronic enclosure is turned clockwise to turn it on
- The paper shredder will initiate its blade for shredding for 2 minutes
- The shredder will turn off for 3 minutes to cool down the AC motor
- The processes in 2 and 3 above will be initiated until the machine is turned off
- To turn off the machine, the knob is turned anticlockwise

The developed machine is capable of shredding up to 10 papers at a time. It is important to note that the developed paper shredder has an allocated operation time of 2 minutes to shred paper and

an off time of 3 minutes. The reason for this precaution in the design is to allow the AC motor cool down after a continuous run-time of shredding. The time allocation for shredding and cooling of the motor is automated.

Figures 7 and below show the construction stage of the paper shredder and the completed stage respectively.
Figures 9 and 10 below show the paper before and after shredding respectively.

Figure 7: Construction Stage of the Paper Shredder

Figure 8: Completed Paper Shredder Construction

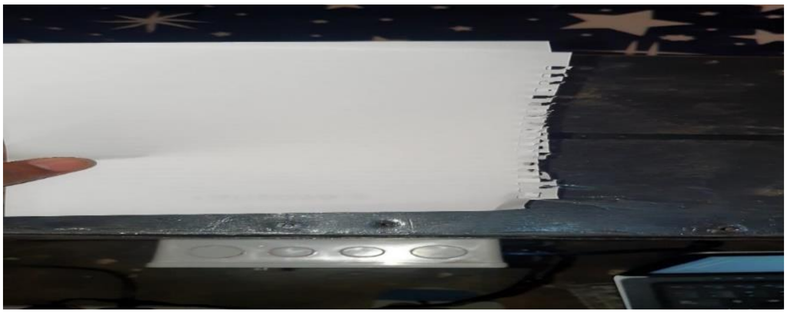


Figure 9: Before Shredding the paper

Figure 10: After Shredding the paper

3.1. Evaluation of The Performance of the Automated Paper Shredding Machine with a Cross-Cut Pattern

Evaluating the performance of an automatic paper shredding machine involves several factors, including efficiency, safety, reliability, and cost-effectiveness. Here are some key considerations when evaluating the performance of an automatic paper shredding machine:

- **Efficiency**: One of the most important factors in evaluating the performance of an automatic paper shredding machine is its efficiency. The machine should be able to shred paper quickly and effectively, without jamming or slowing down. The size and type of the machine, as well as the shredding mechanism, can impact its efficiency.

- **Safety:** Another important factor to consider when evaluating the performance of an automatic paper shredding machine is its safety. The machine should be designed to prevent accidents and injuries, with safety features such as automatic shut-off switches, safety guards, and overload protection. Additionally, the machine should be designed to handle different types of paper, including staples, paper clips, and other types of office supplies, without posing a risk to the user.

- **Reliability:** The reliability of the machine is also important when evaluating its performance. The machine should be able to consistently shred paper without breaking down or requiring frequent maintenance. The shredder blades should be durable and able to handle a high volume of paper shredding over time.

- **Cost-effectiveness:** Finally, the cost-effectiveness of the machine should also be considered when evaluating its performance. The machine should be priced competitively and should provide a good return on investment for the user. Factors such as energy efficiency, ease of use, and maintenance costs can impact the overall cost-effectiveness of the machine.

Overall, evaluating the performance of an Automated Paper Shredding machine involves considering a range of factors, including efficiency, safety, reliability, and cost-effectiveness. By carefully evaluating these factors, users can choose a shredding machine that meets their needs and provides reliable and effective paper shredding capabilities.

4. Conclusion

This research produced an efficient low-cost automated paper shredding machine using cross-cut and strip-cutting techniques machine capable of thoroughly shredding sensitive and discarded documents. In conclusion, the development of the paper shredding machine project is a significant step forward in ensuring the security and confidentiality of sensitive information. The project's objective was to create a reliable and efficient machine that can shred documents effectively and efficiently. Through the design and implementation of the project, the objectives have been successfully accomplished, resulting in a machine that can handle a wide range of paper sizes and thicknesses.
The paper shredding machine's development project required thorough research, planning, and execution. It employed expertise in mechanical engineering, electrical engineering, and software development to design and build a robust and user-friendly machine. The developed design used a jam-free system and an automatic shut-off function, which enhances its efficiency and reliability.

Furthermore, the project's impact extends beyond its immediate use in offices and institutions to contribute to the overall effort of protecting sensitive information from falling into the wrong hands. The development of the paper shredding machine project represents a significant achievement in the field of security technology.

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