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GRAIN MILLING MACHINE. PAPER I: DESIGN AND CONSTRUCTION

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Abstract

A work was carried out on the design and construction of a motorized grain milling machine. The machine was designed using auto-CAD, version 2012 and constructed in the Department of Agricultural and Environmental Resources Engineering, University of Maiduguri in 2013. The machine consists of main components that include the frame, Petrol engine (Prime mover), Milling compartment and the hopper. The various compnents were designed and constructed according to specifications given in the literature. The components were assemblied together to obtain the required machine. The total cost of producing the machine was about N40, 000 only, equivalent to USD 160 as at June 2013. The machine is recommended for small holders, local processors, rural farmers and for domestic use. The performance efficiencies will be presented in the next paper.

Keywords: Design, construction, motorized machine, grain milling

1. Introduction

Flour milling is as old as human history (Williams and Rosentrater, 2007). Grain milling refers to the process of grinding grain into flour or meal (Kaul and Egbo, 1985). The grinding of grain occurs by the application of mechanical forces that alter the structure of the grain by overcoming the interior binding forces, after which the state of the solid is changed to flour. Grain produce on the farm is processed in some form before it is actually consumed. One of the important processes involving a non-chemical change to the fullest extent is that of reducing the harvested grain to flour. Traditionally, and in some parts of the world to this day, milling is accomplished by grinding the grain between two stones. The grinding stone consists of a lower stationary one, called the Quern stone and an upper stone which is mobile and called the hand stone. The oldest known flour milling devices are saddle stones (Williams and Rosentrater, 2007). A saddle stone is a cradle-shaped piece of hard stone which holds the grain. The hand stone can either be a cylindrical piece of stone (held in both hands and drawn across the grain rather like a rolling pin) or a disc with a vertical handle on its back (rather like an upside-down mushroom) held in one hand. These hand stones were used to crush the grain and produce coarse flour (Thomas and Filippov 1999). In order to make grinding easier, the grain is normally malted. Malting refers to the process where by cereal grain is made to germinate by soaking in water and then have the germination halted by by drying in hot air. Obviously, such method is both laborious and time consuming. In addition, it produces only enough ground or cracked grain for a household or extended family.

According to Culpin (1992), grinding of grains has been practiced since very early times when a device resembling a pestle and a mortar was employed in the production of meal for human consumption. The first mills were modifications of this device, in which a grain was put through an opening in a disc-shaped stone which was caused to rotate upon another. The gradual development of this type of mills during thousands of years has led to the evolution of the burr stone mill. The earliest records of food production in Africa show that indigenous grains have long been milled to produce coarse flour for cooking. Traditional crops such as sorghum, millet and maize have been ground for centuries either with a crude mortar and pestle fashioned from a tree stump and branch or by using flat stones or rubbing stones (Figure 1). All these types of grinding systems are still in common use throughout Africa today. Nwaigwe *et al.*, (2012) reported that the indigenous way of producing cassava flour can no longer meet the demand for the product.

Brain and Rottger (2006) reported that in the mid-nineteenth century, electric motors were invented and higher speed machines, such as hammer and plate mills, began to replace traditional stone mills. A relatively low-speed, water-cooled diesel engine can, for example, power a hammer mill, producing maize flour of acceptable quality. These mills are in widespread use in rural parts of the world in areas where no electricity grid is available. Diesel-powered grain mills are limited to areas with access to fuel and spare parts. Many people still cannot afford paying for commercial grain-milling services and they grind by hand using traditional techniques. Therefore, pounding is a common sight and sound in many areas. It is often a social activity, carried out predominantly by women (Figure 2), and many hours are spent each day in this laborious and time-consuming task. The pestle may weigh up to 4 kg, and pounding requires a lot of effort (FAO**,** 1983).

Figure 1: Traditional rubbing and hand grinding stones

Figure 2: Traditional milling by women using pestle and mortar

Mechanically, milling operation is carried out by either of the following methods: grist mills, burr stone mills, hammer mills, roller crushers and many others. Each of these methods has its advantages and disadvantages.

The hammer mills are very common throughout Africa. As the name implies, hammers in the mill grind grains through impact. A hammer mill is essentially a steel drum containing a vertical/horizontal rotating shaft or drum on which hammers are free to swing on the ends of the cross, or fixed to the central rotor (Figure 3). The rotor is spun at high speed inside the drum while material is fed into a feed hopper. The material is impacted by the hammer bars and thereby shredded through screens in the drum of a selected size. The screen-less hammer mill uses air-flow to separate small particles from larger ones. It is designed to be more reliable, and is also claimed to be much cheaper and more energy efficient than regular hammer mills (Agricola, 1950). The grains are placed into a holding hopper on top of the hammer mill, and a small control gate allows the grains to trickle into the grinding chamber. The grains feed into the path of the hammers either through the centre of the front plate or through the top side of the case. The hammers strike the grains and shatter them before they can pass through the screen surrounding the hammers. The flour produced either falls by gravity into a chamber or sack below, or is propelled by air flow up through a cyclone into a holding container. The airflow is provided by either the fan effect of the hammers or by extra fan blades mounted on the hammer shaft. Hammer mills are simple in construction and parts can be easily replaced (Perry and Don, 1998). The power requirement of the hammer mills as reported by Henderson and Perry (1982) is just as low as 2.25kW (3hp).

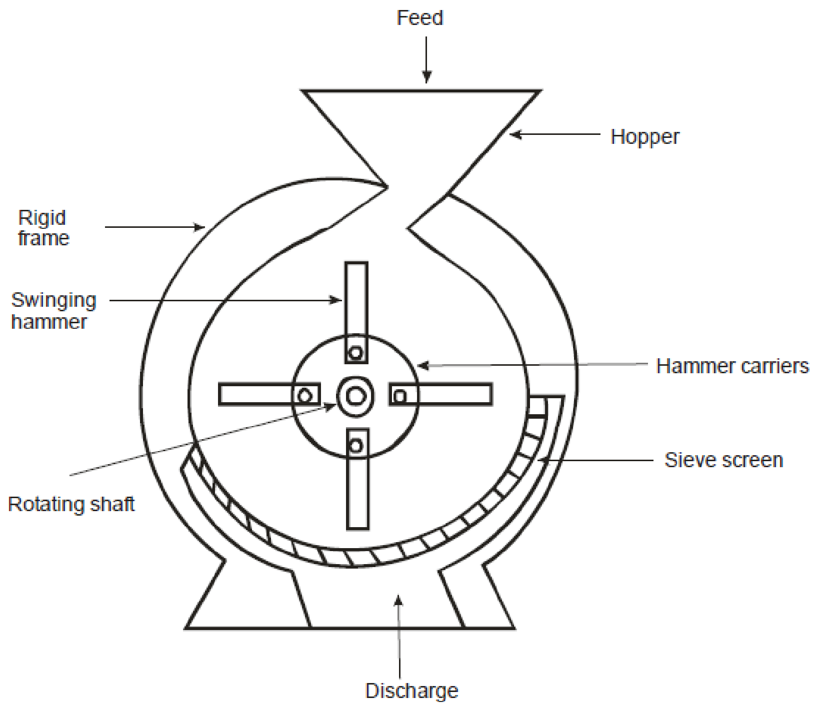


Figure 3: Diagrammatic representation of conventional hammer mill

For medium or coarse grinding of sorghum, maize or barley, the plate mill is satisfactory. It is less efficient for fine grinding. For fine grinding, the hammer mill is most efficient. On farms where a large herd of livestock is kept, it may be economic to use a plate mill, a hammer mill and a crushing mill to meet the variable requirements of the beef and dairy cattle, poultry and pigs. On smaller farms either a combination of plates and crushing mill or a small automatic mill is the most suitable equipment (Culpin, 1992).

Most of the rural farmers of Borno State have no access to financial assistance. The cost of modern milling machines was about N250,000:00 which is equivalent of USD 1,000 as of the time of this study. Therefore, there is the need for motorized grain milling machine to satisfy the milling needs of the rural population. These factors make it necessary to design and construct a simple hammer milling machine driven by a source of power, for domestic use. The objective of this work is therefore, to design and construct a motorized hammer milling machine using locally available materials that can be easily obtained by farmers.

2. Materials and methods

The construction of the machine was carried out at the Agricultural and Environmental Resources Engineering workshop, University of Maiduguri. All materials were sourced locally except the prime mover which was bought from the market. The machine was designed with the following considerations:

- Simplicity in design of the machine
- Ease of operation
- Easy replaceable parts
- Durability
- Ease of inspection
- Safety of operation

2.1 Machine Components

The machine is made up of the following major components:

frame, electric motor, milling compartment, and hopper. They are briefly described below:

2.1.1 Tool Frame

An angle iron made up of mild steel was used due to its strength and good working quality. When properly coated or painted, it has high corrosive resistance. It acts as a main support that carries all other units of the machine. It has a dimension of 370mm × 370mm in base, a height of 700mm and a rectangular top of 280mm × 300mm.

2.1.2 Prime mover (Petrol engine)

A prime mover (petrol engine) transmits power directly from its out put shaft to the rotary hammers. Before the selection of an appropriate engine for the machine was made, some certain factors were taken into consideration. These factors include; the output of the engine at the rated speed and voltage, torque requirement, starting and running torque. An engine of the following specification on the name plate was selected:
Power, P = 2.3 kW (3 hp)
Rational speed, N = 1440 rpm
Phase = Single
Frequency = 50 Hz

This is because of its availability, ease of maintainance and cheap to obtain.

2.1.3 Milling Compartment

The milling compartment consists of a cylindrical drum having a diameter of 430 mm, width of 2.5 mm and height of 100 mm, made from a mild steel material. It consists of 3 flat bars carefully constructed around the drum to serve as stationery stones for grinding, having a clearance of 28 mm from the rotating beaters. The beaters each have a length of 360 mm and a breadth of 40 mm. The beaters are four in number. The screen which sieves the grain particles after milling, located at the bottom section of the cylindrical drum has a length of 420 mm and a width 1.5 mm. The screen can be replaced based on the texture of the flour required.

The milling chamber is cylindrical in shape. It has a drum with diameter of 430 mm, radius of 21.5 mm and effective height of 100 mm. The volume may be deducted as:

$$V_T = \pi r^2 \times l \quad (1)$$

where:

V_T = the total volume of the cylinder (cm^3), r= effective radius of the cylinder (cm), l = lenght of the cylinder (cm)

Therefore, $V_T = 3.142 \times 21.5^2 \times 10 = 14523.9\ cm^3$

For the design consideration, however the total volume of the cylinder should not be filled up to the brim in order to keep little allowance for the grinding and beating.

2.1.4 The Hopper

The hopper is of trapezoidal shape made from 2.5 mm thick high steel material. It has a length of 360 mm, sides 120 mm and 260 mm. The hopper was tilted to some angle from the horizontal. This ia to give free flow of grains in to the milling chamber. The volume of the hopper was determined as follows:

Area of the trapezium = ½ sum of sides × length (2)

$A = ½ (120 + 260) \times 360 = 190 \times 360 = 68400\ mm^2 = 68.4\ m^2$

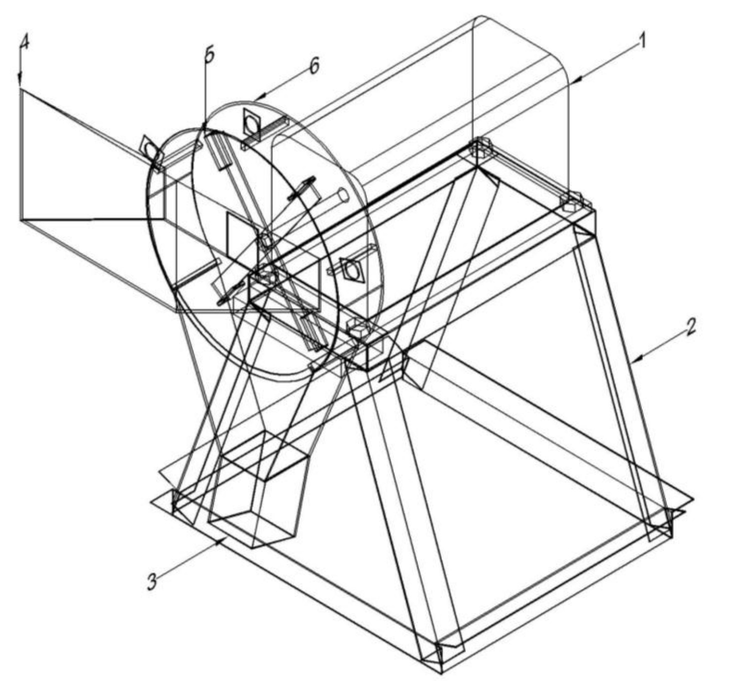
Volume of hopper = ⅓ × Area × height (3)

$V = ⅓ \times 68400 \times 360 = 8208000 mm^3 = 820.8\ m^3$

2.2 Machine Assembly

Various parts and components of the machine were fabricated and assembled together to function as a unit (Figure 4). The frame is the base where the milling chamber, hopper, the prime mover (engine) and other components are mounted. The coupling of this machine was achieved by involving different operations such as welding, tightening, screw fastening, bolting. The total height of the machine is 1080 mm which makes it comfortable for operation. The major components of the machine are shown in Figure 5. The complete assembly drawing of the machine is shown in Figure 6 while the isometric view of the machine is shown in Figure 7. The final process that was carried on the machine was painting. This was to ensure a good look to the machine.

Figure 4: Photograph of the complete milling machine



No.	COMPONENTS
1.	Prime Mover
2.	Frame
3.	Discharge Chute
4.	Hopper
5.	Hammer
6.	Milling Chamber

Figure 5: Diagram of milling machine showing the main components

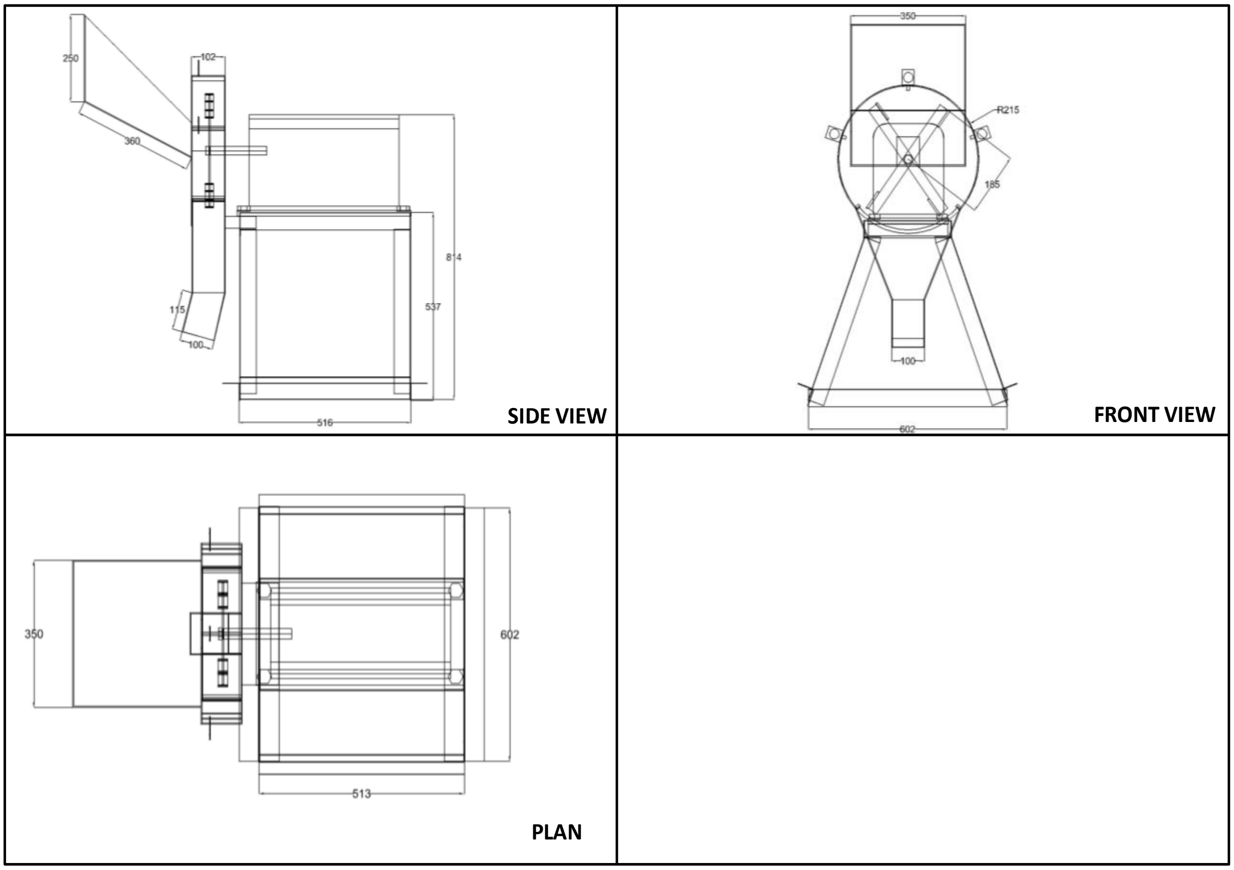


Figure 6: The othographic view of the milling machine

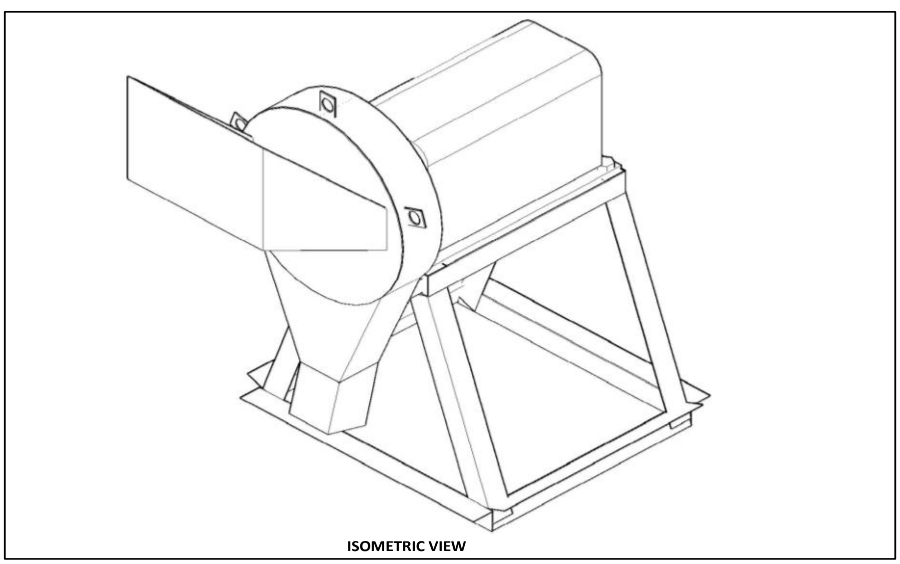


Figure 7: Isometric view of the machine

2.3 Operation principles of the machine

This machine works by hitting action of the rotating hammers. The rotating hammers are directly driven by the petrol engine outlet shaft. As grains are delivered into the milling chamber from the hopper, they are hitted by the rotating bars against the flat bars fixed around the drum. The longer the materials dwell inside the milling chamber, the more finer flour is obtained and it ensures that no grain escaped unmilled. This depends on the interest of the operator. The flour outlet of the machine is controlled by opening/clossing rag attached in the sprout.

3. Discussion

The grain hammer mill was designed and fabricated based on factors considered. The machine operates as follows: The appropriate quantity of grains is introduced into the hopper. The grain material is mettered into the milling chamber by gravity through the control feed gate. As the prime mover is started, the beaters which are attached directly to the out let shaft of the prime mover starts to rotate. The rotating beaters (operating on the vertical plane) hit the materials by centrifugal force to the rings, and the materials are subsequently grinded by impact force. The agitation caused by the operation of the engine ensures that the milled grains are sieved by the screen and is discharged through the outlet chute. Performance evaluations of the machine will be presented after this paper.

4. Conclusion

A grain miller was designed and constructed from locally sourced materials. The machine consists principally of the hopper, milling chamber, prime mover, shaft and discharge unit (chute). The assembled machine is presented in the appendix. The total cost of producing this machine is about ₦40, 000. This shows that the machine can be easily obtained by an individual when compared to the conventional grinding and sieving machine that costs between N200, 000 to N250, 000 installed.

5. Recommendations

For further improvement of this machine, the following are recommendations;

1. The gap between the milling chamber and its cover carrying the hopper should be fitted properly with a rubber material to reduce flour escape during grinding.
2. A lining should be provided in the milling chamber to preserve the eating quality of the milled product.
3. The machine should be tested to determine its performance efficiencies.

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