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Application of Reverse Engineering in the Design and Development of feed Pelleting Machine

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ABSTRACT

This research investigates the application of reverse engineering in the design and development of a feed pelleting machine. The animal husbandry industry is vital to meeting the global demand for animal protein. Producing high quality feed is critical to maximizing its growth and productivity. The challenge of producing animal feed in Nigeria has a significant effect in active animal farming, despite the growing efforts of these farmers to raise livestock continually and provide for the society a diet rich in animal protein. A widely applied method to enhance the nutritional content, digestibility, and handling characteristics of feed for livestock and poultry is feed pelleting. The feed pellets machine consists of a 4.8 Kilowatts petrol engine that drives a pulley system which in turn drives a screw conveyor to a fixed pelleting chamber (barrel). They were made of mild steel with exception of the bearings that were made from stainless steel. The mild steel materials were painted after fabrication to resist contamination due to corrosion. The developed machine measures 920 mm in length, 372 mm in width and 999 mm in height produced at a cheaper cost of one million, one hundred and sixty-five thousand, six hundred naira only with locally sourced materials. It has an average pelleting rate of 0.034kg/s and average pelleting efficiency of 98%.

1. INTRODUCTION

The growth of the agricultural industry requires the creation of innovative feed processing techniques to ensure that livestock and poultry eat feed that is both economically feasible and nutrient-dense (*Alves et al. 2003*).The capacity of feed pelleting to enhance feed quality, decrease feed waste, and encourage nutrient utilization has led to its rise in popularity in recent years (*You et al.2022*).This research aims to address the problems related to traditional pelleting processes, with an emphasis on the design, development and performance assessment of a feed pelleting machine for (poultry and livestock feed).A feed pelleting machine is a system that turns feed powder into easily picked pellets (*Olugboji et al. 2015*),The process of transformation, which is the subject of this specific scholarly study, comes into greater significance as technology advances.

The Nigerian government's interest in agriculture has attracted a lot of people to the farming industry, with many of them working as livestock and poultry farmers. This has led to a significant increase in the demand for feed, which has put significant strain on companies that produce animal feed and raised the price of buying it.

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However, in order to increase feed quality, decrease wastage and encourage nutrient utilization, local farmers need to convert these feed powders into pellets using feed pelleting technologies. It is however challenging for local farmers to purchase these feed pelleting machines from abroad because it is capital demanding. Therefore, in order to salvage the situation for the local farmers, researchers in Nigeria must urgently intervene to develop a more sophisticated, and affordable feed pelleting machine system.

A significant challenge facing the Nigerian agricultural industry is the high cost of imported feed pelleting machines. This has again prompted researchers in Nigeria to intervene, so as to develop a feed pelleting machine system that uses an alternative energy source, with a lower energy consumption rate to support industrial operations.

This research investigates the application of reverse engineering in the design and development of a feed pelleting machine that produces high quality feed pellets.

2. REVIEW OF LITERATURE

Animal feed account for over 60% of the cost of animal production, it is imperative that it receives more attention in order to improve output. Thus, an industry's performance will be impacted by quality control of its utilization. The amount of specific nutrients in feed that the animal may use to meet the needs of different bodily processes determines the feed's value (Craig et at. 2017).As a result of technological developments, grinding machines were created to turn cereals and grains containing a blend of nutrients into powder. Overtime, it was found that the animals favoured eating wholesome solid and soft meals (Shrinivasa and Mathur 2020).To make such feed, a pelletizing machine is one of the tools needed. One of the main functions of the pelleting machine is to mould animal feeds into capsules that are small enough for livestock and poultry birds to easily consume (Sarpong, 2020).The goal of processing livestock and poultry feeds is to maximize the nutrients utilization efficiency. Research has shown that there are significant advantages to feeding specific livestock and poultry birds with pellets (Kumar et al. 2024).Additionally, highly compressed pellets make storage and transportation easier since they make it cost-effective to move large amounts of feed from one place to another. Among the benefits of pelleting feeds, are the reduction of food waste, increased feed efficiency, decreased selective feeding, control of undesirable microorganisms, improved handling qualities, and an increase in bulk density (Somagond et al. 2024). Somagond et al. (2024) pointed out some advantages of pelleting feeds which include the saves made through decreased food wastage, improvement on feed efficiency, reduced selective feeding, control of undesired micro–organisms, increase in bulk density and better handling characteristics. The Researchers also added that quality addition to the feed include better durability and fewer fines of the Pellets, complete pasteurization, increased utilization of feeds, starch gelatinization increment and production of by-pass fat and by–pass protein. Their views were shared by (Orisaleye et al., 2024). Techniques for processing animal feeds have been developed for years (Ganesana and Rajauria 2020).The techniques are categorised as either hot or cold based on the heat level that is needed. It can equally be categorizes as either a dry or wet technique. These procedures use a variety of methods such as rolling, crushing, micro organization, roasting, chopping, cracking or crimping, popping, hot and cold pelleting, and reducing or grinding particle sizes (Mus et al. 2016).However the expensive cost of the pellet processing equipment limits the usage of the feed pelleting machine (Shrinivasa and Mathur

2020).Therefore processing and using advanced feed pelleting machine is quite challenging for local livestock and poultry producers in Nigeria. Hence this is the primary motivation of this research study.

3. METHODOLOGY

3.1 Materials

The tools and equipment's used for the construction of the feed pelleting machine are as follows: Electric arc welding machine, Oxy-Fuel welding machine, Grinding machine, Drilling machine, Sharpening stone, Hacksaw, Hammers and Screw drivers.

3.2 Materials used for the graphical design of the feed pelleting machine

1. Computer Aided Design (CAD) Software.

3.3 Materials used for the developing the feed pelleting machine

The materials used for developing the feed pelleting machine are:

1. Petrol Engine.
2. Mild Steel Sheet.
3. Bearing.
4. Bearing Casing
5. Driving Belt.
6. Feed Hopper.
7. Die Plates.
8. Bolts and Nuts
9. Electrodes (Gauge 12).
10. Screw Conveyor
11. Flat Bar.
12. Angle Bar.
13. Pulley.
14. Pelleting Chamber (Barrel).

The design of the feed pelleting machine integrates principles of mechanical engineering, materials science and animal nutrition. Important components of the feed pelleting machine are the feed hopper where the feed meal is fed into the machine and the pelleting chamber which houses the screw shaft which is seen to propel the feed. The shaft is operated by a pulley and belt system that is powered by a petrol engine system. The machine was designed to produce pellets of different sizes ranging from 2mm to 4mm to 6mm in diameter to aid the farmers to be independent in animal feed production. The output pellet is produced by compacting and forcing through a die opening via a mechanical process.

3.4 Development of the Feed Pellet Machine

In the development of the Feed pellet machine, the feed hopper which is made of 14 gauge steel metal sheet was first constructed into a frustum to a specification of bottom length and width of 88.9mm (3.5 inches) top length and width 368.8mm (14.5 inches) and slant heights of 355.6mm (14 inches). The frustum feed hopper was then welded on the pelleting chamber (barrel) which has a square hole cut in alliance with the bottom square area of the frustum feed hopper. The pelleting chamber (Barrel) which has a length of 203.2mm inner and outer diameter of 101.6mm and 177.8mm respectively and thickness of 38.1mm, housed the roller shaft cut to a length of 736.6mm and a diameter 23mm. The screw conveyor which was made of steel quarter rod welded on the shaft had a length of 203.2mm and a diameter of 76.2mm. On the other hand, the die plates constructed which were three (3) in number each 5mm thick were fixed one at a time at the terminal of the screw conveyor depending on the type of feed pellets to be produced. The holes drilled on the first die plates was 2mm in diameter to produce feed pellets of size 2mm.The second die plate had hole drilled to size of 4mm in diameter to produce feed pellets of size 6mm.Bearings two (2) in number where installed in the bearing cases at the front and at the back to support and reduce friction between the rotating shaft so that the shaft

of the pellet machine can run smoothly. The petrol engine (Gx200) which ran with a speed of 3,600rpm and a shaft diameter of 19.05mm was mounted on a steel table and connected to a driving pulley of 63.5mm diameter which rotates at the same speed as the (GX200) petrol engine. An A-38 V – Belt of length 807.3mm, width 13mm, nominal thickness 8mm and a cross-sectional area of 2419.35mm2, is used to connect the driving pulley of diameter 63.5mm to the driven pulley of diameter of 127mm which is attached to the pelleting shaft. When the (Gx200) petrol engine is running at a speed of 3,600rpm (3.58m/s), the A-38 V-belt attached to the driving pulley runs at a speed of 11.97m/s and the driven pulley attached to the pelleting shaft runs at a speed of 1800rpm (2.17m/s). The concept of the development of the feed pelleting machine was centered towards pelleting of strong and good textured pellets. The major components of the fabricated machine were captured fully in the design.

3.5. Design of the Die Plate

The die designed for production of the feed pelleting machine was made of mild (low carbon) steel and is used to form the feed pellets from the feed mash that was transported to it by the rotating screw conveyor built on the rotating shaft. The die used in the formation of feed pellets is flat and circular in shape having a specific number of drilled holes of a particular dimension, hence the feed pelleting machine is called flat die feed pelleting machine. The die which is attached at one end of the pelleting chamber (barrel) are three (3) in number. Each of these dies have a diameter of 200 mm, with an average of 206 holes of diameter 2mm each for the first die,132 holes of diameter 4mm each for the second die, and 110 holes of diameter 6mm each for the third die. To get the extension force and extension pressure we use the formula:

$$\text{Extrusion Pressure } (E_P) = \frac{\text{Extension Force (EF).}}{\text{Area of each hole (A) x number of holes}} \quad (1)$$

.

Extrusion Force (E_F) = Mass of the Feed Mash moving in the Pelleting Chamber (Barrel) x Accelerating Feed Mash moving by the Screw Conveyor. (2)

Accelerating Screw Conveyor =

$$\frac{\text{Speed of Screw Conveyor}}{\text{Time Taken for Feed Mash to Flow to the die from the inlet of the pelleting chamber (Barrel)}} \quad .(3)$$

.

$$\text{Speed of Screw Conveyor} = \frac{\text{Material Flow Rate}}{\text{Screw Conveyor Capacity per revolution}} \quad . \quad (4)$$

Screw Conveyor Capacity per revolution = $\frac{\text{Screw Conveyor Capacity}}{\text{Number of Revolution}}$. (5)

Material Flow Rate Q = 1.89 Kg/s or 113.64Kg/min.

Therefore,

Speed of screw conveyor capacity per revolution

= $\frac{52676.41}{1884.0\text{x}60}$ = $\frac{52676.41}{113040}$ = 0.47 kg/rev

Therefore, Speed of screw conveyor = $\frac{113.64}{0.47}$

Speed of screw conveyor = 241.790 rev/min.

Converting speed of screw conveyor in rpm to m/s

RPM = $\frac{V}{\pi D}$ x 60 (6)

241.790 = $\frac{\text{V x } 60}{3.142 \text{ x } 0.076}$

57.54= 60V

V = $\frac{57.54}{60}$

V = 0.96m/s

Therefore to get the mass of feed mash that can contain the pelleting chamber (barrel) we say:

Bulk density of Feed Mash =. $\frac{\text{Mass of Feed Mash in the Pelleting Chamber (Barrel)}}{\text{Volume of Pelleting Chamber (Barrel)}}$. (7)

1275.46=. $\frac{\text{Mass of Feed Mash in the Pelleting Chamber}}{0.000720850}$

1275.46 x 0.000720850= Mass of feed Mash in Pelleting Chamber (Barrel).

0.92kg = Mass of Feed Mash in Pelleting Chamber.

Therefore, to get the Time Taken for feed Mash to flow through the pelleting chamber we say:

Mass Flow Rate = $\frac{\text{Mass of Feed Mash in Pelleting Chamber}}{\text{Time Taken for Feed Mash to Flow through the Pelleting Chamber}}$ (8)

$$1.89 = \frac{0.92}{\text{Time Taken}}$$

Therefore, Time Taken for Feed Mesh to flow Through the Pelleting Chamber (Barrel) = 0.920

$$= \frac{0.49}{1.89}$$

Therefore, to get the Acceleration of the Feed Mash we say:

Acceleration of Feed Mash =

$$\frac{\text{Speed of the Screw Conveyor,Conveying the Feed Mash}}{\text{Time Taken for Feed Mash to Flow through the Pelleting Chamber (Barrel)}} \quad (9)$$

Acceleration of Feed Mash = $\frac{0.96}{0.49} = 1.96\text{m/s}^2$

Therefore, Extrusion Force (E_F) = 0.92 x 1.96 = 1.80N

Therefore, to get the Extrusion Pressure for a die which has holes of diameter 2mm (0.002m), we say:

$$\text{Therefore, Extrusion Pressure} = \frac{\text{Extrusion Force}}{\text{Area of Holes x Numbers of Holes}} \quad (10)$$

$$\text{Extrusion Pressure} = \frac{1.8}{3.142 \text{ x } (0.001)2 \text{ x } 205}$$

Extrusion Pressure = 2795.03 N/m^2 or 2.795 x 10^3 N/m^2

To get the Extrusion Pressure for a die of which has holes of diameter 4mm (0.004m),we say:

$$\text{Extrusion Pressure} = \frac{1.8}{3.142 \text{ x } (0.002)2 \text{ x } 116}$$

Extrusion Pressure = 1245.13N/m^2 or 1.245 x$10^3 N/m^2$.

So therefore to get the Extrusion Pressure for a die which have holes of diameter 6mm (0.006m).

$$\text{Therefore, the Extrusion Pressure} = \frac{\text{Extrusion Force}}{\text{Area of Holes x Numbers of Holes}}$$

$$\text{Extrusion Pressure} = \frac{1.8}{3.142 \, x \, (0.003)2 \, x \, 55}$$

Extrusion Pressure = 1200 N/m^2 or 1.20 x $10^3 N/m^2$.

Table 1: Bill of Engineering Measurement and Evaluation

S/N	Material Description	Quantity	Unit Price, ₦	Amount, ₦
1	Petrol Engine GX 200	1	450,000	450,000
2	Shaft	3	10,000	30,000
3	Bearing	6	2,500	15,000
4	Driving Belt	4	1,000	4,000
5	Bearing casing	2	2,550	5,100
6	Flat Bar	6	15,000	90,000
7	Housing cup	3	12,000	36,000
8	Mild steel plate	2	30,000	60,000
9	Mild steel electrode (gauge 12)	1 Packet	28,500	28,500
10	Cutting disc	2	10,000	20,000
11	Angle Bar	2	24,000	48,000
12	Saw Blade	1	5,000	5,000
13	Mesh	2	25,000	50,000
14	Pulley	4	10,000	40,000
15	Bolts, Nuts, Washers	3	28,000	84,000
16	Miscellaneous	1	100,000	100,000
17	Labour			100,000
Total				1,165,600

One million, one hundred and sixty-five thousand, six hundred.

4. RESULTS AND DISCUSSION

Results of the research have been shown in the tables above. These parameters will form the basis of our discussion.

Following are the scientific data gotten from the Pelleting Machine that was fabricated using reverse engineering principles.

Table 2: Analysis of the design capacity of (GX200) petrol engine used to power the feed pellet machine.

S/N	Features	(GX200) Petrol Engine
1.	Output Power	4.8 kw
2.	Velocity of Shaft	3600rpm (3.58m/s)
3.	Number of Revolution	3598.09rev
4.	Diameter of Shaft	19.05mm (0.019m)
5.	Rotational force of the shaft	1340.8N (1.34KN)
6.	Mass of the rotational shaft	0.99Kg
7.	Acceleration of rotational shaft	1349.0m/s^2
8.	Angular velocity	376.84rad/s
9.	Energy expended by the machine	286886.0J (286.88KJ)
10.	Time taken for the machine to work	59.8min (approximately 1hr)
11.	Output Capacity (Kg/hr) of feed pelleting machine.	13.70Kg/hr for 2mm diameter hole.(224 Holes).

		54.92Kg/hr for 4mm diameter hole.(116 Holes). 122.40Kg/hr for 6mm diameter hole.(55 Holes).

Table 3: Output Of Feed Pelleting Machine

Times taken in hrs	Output capacity (kg/hr) of feed pellet machine		
	2mm	4mm	6mm
1	13.70	54.92	122.40
2	27.40	109.84	244.80
3	41.10	164.76	367.20
4	54.80	219.68	489.60
5	68.50	274.6	612.0
6	82.20	329.52	734.40
7	95.90	384.44	856.80
8	109.60	439.28	979.20
9	123.30	494.28	1,101.60
10	137.00	549.20	1,224.0



Figure 1: Picture of feed pelleting machine



Figure 2: Picture of feed pelletized feed produced

From the table 2, we could obviously see that the output power of the (GX200) Petrol engine 4.8Kw. The main reason for such Power was that the diameter of the rotating shaft of the (GX200) petrol engine is small. Another reason for this, is that the mass of the rotating shaft is small thereby leading to a small rotating force for the shaft, thus leading to a small torque. Also from the table we see that the velocity and acceleration of the rotating shaft of the (Gx200) petrol engine is high. The first reason being the mass of the rotating shaft of the (Gx200) petrol engine is less, and so the rotating shaft of the (Gx200) petrol engine rotates with a greater force leading to a higher velocity and acceleration. For clarity, the research will focus on three stages or processes of the machine: input, throughput (processing) and output. The input process displayed input parameters with the Gx200 petrol engine power of 4.8kw, and high velocity and acceleration of the rotating shaft. The time taken to expand its energy is 59.8mins. the size of the feed hopper is another factor and they are all affected y height of feed hopper, volume of feed mash and bulk density of feed mash, and mass of feed in feed hopper. The Throughput (processing) has some factors considered: the mass flow rate was 113.50kg./min, volume flow rate was 0.089m2/min, and time taken was 0.213 min. Also considered here were the length of screw conveyor which was 0.203m, length of flight of the screw conveyor was 0.248m. Speed of shaft and screw conveyor was 1800rev/min (2.17m/s for rotating shaft and 7.16m/s for screw conveyor. The number of revolution was 19884.00rev. These throughput parameters helped in speedy processing of the feeds into pellets at the output point. The output parameters or factors that helped in giving us our designed outcome of the research were the outer diameter of the pelleting chamber, which served as the interface between the throughput and the output points. The diameter of the die, extrusion force, speed at which the screw conveyor pushes the feed mash to the die, acceleration at which the screw conveyor is moving to push the feed mash to the die, are all factor that contribute to the extrusion pressure of the output. It was observed that 2mm holes gave an output of 13.70kg/hr and since the machine can run for ten(10) hours per day, then we know that it can produce 137.0kg of feed pellets per day. This type/size of pellets is good for fishes and chicks in poultry production. The 4mm has the capacity of producing 54.92kg of feed pellets per hour and can go on to produce 549.20kg of feed pellets at the end of ten (10) hours per day. Also, the 6mm diameter holes can produce 122.40kg of feed pellets per hour and can produce a total of 1224.0kg of feed pellets at the end of ten (10 hours per day. The design criteria of this feed pellets machine using reverse engineering method is to produce feed of between 300kg to500kg per day. From the 4mm diameter hole feed pellets production, it was evident that at the sixth hour, we had produced above the minimum criteria of 300kg and at tenth (10^{th}) hour, we had

produced above the maximum criteria of the machine. From the 6mm diameter holes, at three hours, we have exceeded the minimum criteria of the design and at the fifth hour, we had exceeded the maximum production level expected. And, at the tenth hour, production has doubled the expected quantity. This implies that the designed machine is very good and has served the purpose of its design.

5. CONCLUSION

The design and fabrication of the feed pelleting machine was successfully carried out. Numerous modifications were performed during the machine's design process to meet the machine performance requirements. The feed hopper of the feed pelleting machine was shaped to resemble a hallowed frustum with a volume of 0.019 m^3. Its square areas at the inlet and exit were 0.135 m^2 and 0.0079 m^2 respectively, and its slant height was 0.327 m. In comparison to the factory-made feed pelleting machine, which had a volume of 0.015 m^3, the locally-made machine had a larger volume. The purpose of the augmentation was to boost the local feed pelleting machine's output capacity. The shaft in the pelleting chamber (barrel) had dimensions 0.736 m for length and 0.023 m for diameter, with a yield stress of 4.66 x 107 N/m^2. The screw conveyors were constructed on a revolving shaft, with dimensions of 0.203 m for length, and 0.0762 m for diameter, 0.067 m for pitch, 52675.41 Kg/hr for capacity (Q), and 5.507 Kw for power rating (P). As the shaft length extended, the screw conveyor's screw pitch dropped by 25.4%. This was done to make sure the feed mash was compressed in the Pelleting chamber (barrel) in order to boost the binding force and simultaneously lower the feed mash's moisture content. The actual pelleting chamber (barrel) was intended to be cylindrical, measuring 0.203 m in length, 0.10 m in internal diameter, and 0.0072 m^3 in capacity. The flat circular die was designed so that it could be readily removed from the rear of the pelleting chamber (barrel). Every die that was designed has holes of different diameters, although they all had 0.2 m diameter. The first die had 250 holes, each with an average diameter of 2 mm. The average diameter of the 116 holes on the second die was 4 mm. In contrast, the third die had 55 holes, each with an average diameter of 6 mm. The driven pulley, which was attached to the shaft in the barrel's Pelleting chamber, and the driving pulley, which was attached to the shaft of the (GX390) petrol engine, were 0.254 m apart and have diameters of 0.127 and 0.0635 m, respectively. The belt travelled at a speed of m/s and was intended to be 0.807 m long, with a cross-sectional area of 0.002419 m^2. The developed machine measures 920 mm in length, 372 mm in width and 999 mm in height produced at a cheaper cost of one million, one hundred and sixty-five thousand, six hundred naira only with locally sourced materials. It has an average pelleting rate of 0.034kg/s and average pelleting efficiency of 98%.

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