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Design and Production of a Screw Conveyor with an Automated Bagging Unit

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Abstract: *The design and production of a screw conveyor with automated bagging unit, capable of conveying grains was successfully carried out using local available materials. This model screw conveyor has Section 1- the transmission unit; Section 2- the conveying mechanism; Section 3 - the frame of the machine andSection 4 - the bagging unit, which consists of bagging base, the balancing weight and limit switch. Provision is made on the top of the housing for an inspection hole covered by a sliding gate. The machine is driven by 1.14kW single phase electric motor. The workability of the screw conveyor was test-run using beans grain and the result showed an efficient conveying and bagging of 5 kg and 7 kg samples. It is hoped that the model screw conveyor will be useful in agricultural grains handling and also in demonstration classes.*
Keywords – *Bagging, Conveyor, Grains, Screw, Transmission*

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I. Introduction

There are several methods used to convey agricultural materials. Since agricultural materials may be granular, powder, fibrous, or any combination of these, a conveying method is selected based on material-type. Generally, conveying is accomplished by a combination of mechanical, inertial, pneumatic, and gravity forces. Conveyors utilizing primarily mechanical forces are screw, belt, and chain conveyors. Screw conveyors are popular devices for conveying farm and agricultural products. They are very effective conveying devices for free flowing or relatively free flowing bulk solids, giving good throughput control and providing environmentally clean solutions to process handling problems because of their simple structure, high efficiency, low cost and maintenance requirements. Screw conveyors vary in size from 75 mm to 400 mm in diameter and from less than 1m to more than 30 m in length [1].

Screw conveyor consists essentially of a shaft- mounted screw rotating in a trough and a drive unit for running the shaft. The material is moved forward along the axis of the trough by the thrust of screw thread or flight. The trough is usually of the U-shape. The basic principles of operation may be explained with a helical blade attached to a drive shaft which is coupled to a drive unit. The shaft is supported by end and intermediate bearings. The U-shaped trough has a cover plate with loading and discharge gates. More than one feed hopper and discharge hopper may be fitted according to necessity. The basic principle of material along the trough is similar to the sliding motion of a nut along a rotating screw when the nut is not allowed to rotate. The weight of material and its friction against the trough wall prevent the load from rotating with the screw [2].

Screw conveyors may be grouped, broadly, into two categories, the U-shaped trough type conveyor and the fully enclosed conveyor incorporating a tubular casing. Screw conveyors with U-shaped trough type casings are widely used in the industry, their operation being restricted to low angles of elevation, low speeds and low fill ratios. The low fill ratios are to protect the hanger support bearings when long conveying distances are employed. Screw conveyors with fully enclosed tubular type casings are more versatile. They operate over a wide range of speeds and angles of elevation up to the vertical. They perform well at higher fill ratios, with the conveying action due to the helical screw being enhanced by the resistance to rotary or vortex motion of the bulk solid being provided by the total casing surface. Their disadvantage is the limitation in conveying distance since they need to operate without intermediate support bearings [2].

The working principle of the screw conveyor is based on same principle as the Archimedes screw that was used in ancient times in Greece and Egypt to draw water for irrigation purposes or to drain water from low lying mining areas. Archimedes' screw consists of a screw (a helical surface surrounding a central cylindrical shaft) inside a hollow pipe. The screw is turned usually by a windmill or by manual labour. As the shaft turns, the bottom end scoops up a volume of water. This water will slide up in the spiral tube, until it finally pours out from the top of the tube and feeds the irrigation systems [3].

The basic transport mechanism is that the material resting between two adjacent screw flights on the same axis is promoted to slip down the face of the rising side of the flight as the screw rotates. This action moves the product forward at the rate of one pitch per rotation of the screw, provided the material does not spill over the centre shaft to fall back into the proceeding pitch space as when the cross-sectional loading exceeds the height of the centre tube or the machine axis is excessively inclined.

Screw conveyors are but one class of screw type solids handling devices, albeit a major form in industrial applications. Other types of helical screw-based solids handling machines are commonly described as screw feeders, screw elevators, hopper discharge screws, and metering screws. Many forms of processing operations also utilize helical screws in their composition and many of the features described will equally apply to their operating circumstances [4].

Today the screw conveyor plays an important role in a wide variety of industries. Because it is compact, versatile and economical, it has become one of the most useful mechanisms for the transport and distribution of bulk materials. Aside from its utility as a means of moving materials, the screw conveyor, with certain modifications and/or variations in mechanical arrangement, may also be used to perform, a number of other important functions. A conveyor screw is either right hand or left hand depending on the form of the helix. The hand of the screw is easily determined by looking at the end of the screw. The screw to the left has the flight helix wrapped around the pipe in a counter-clockwise direction, or to your left, same as left hand threads on a bolt [3].

II. Materials and Methods

2.1 Materials:The screw conveyor with bagging unit is made up of the following locally sourced materials and parts - mild steel plate, pulleys, thick plate, mild steel, single phase motor (1.14kW), ball bearings, limit switch, weights for balancing (from 10 kg – 30 kg), switch panel, open and close gate. The above materials were used in the production of the model screw conveyor, which is shown in the working drawing, Fig. 1.

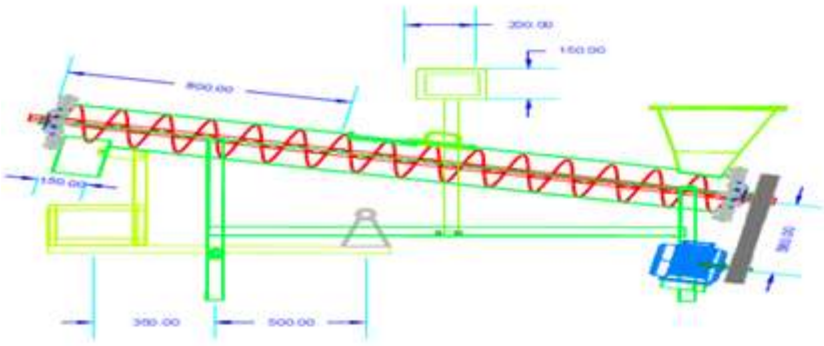

Figure 1. Screw Conveyor Working Diagram

2.2 Design Components

The design that is chosen for the screw conveyor comprises: transmission, conveying mechanism, frame, base, bagging unit, and electrical controls. The transmission system in this design consists of the 1.14kW electric motor, the fan belt and two pulleys of 100 mm and 200 mm diameter, respectively. The 100 mm pulley is attached to the electric motor while the 200 mm pulley is attached to one end of the driving shaft. The two pulleys are connected together by a fan belt. The belt is used to transmit power from one shaft to the other by means of pulleys which rotate at different speeds. Velocity ratio, which is the ratio of the driver pulley on the electric motor to the follower or driven pulley, may be expressed mathematically as;

$$N_1/N_2 = d_1/d_2 \qquad (3.1)$$

Where,

N_1 - Speed of driver (rpm)

N_2 - Speed of the driven (rpm)

d_1 - Diameter of driver

d_2 - Diameter of driven

Therefore, length of the belt that passes over the driven in one minute is

$$L_1 = \pi d_1 N_1 \qquad (3.2)$$

Similarly, the length of the belt that passes over the driver

$$L_2 = \pi d_2 N_2 \qquad (3.3)$$

Since the length of belt that passes over the driver is equal to length of belt that passes over the driven in one minute, therefore;

$$\pi d_1 N_1 = \pi d_2 N_2$$

Giving the velocity ratio;

$$N_2/N_1 = d_1/d_2 \quad (3.4)$$

When the thickness of the belt (t) is considered, the velocity ratio,

$N_2/N_1 = d_1 + t + d_2 + t$ (3.5)

The peripheral velocity of the belt on the driving pulley:

$$V_1 = \frac{d_1 N_1}{60} m/s \quad (3.6)$$

And peripheral velocity of the belt on the driven pulley

$V_2 = \frac{d_2 N_2}{60} m/s$ (3.7)

When there is no slip

$V_1 = V_2$ (3.8)

Therefore:

$$\frac{\pi d_1 N_1}{60} = \frac{\pi d_2 N_2}{60} \text{ or } \frac{N_2}{N_1} = d_1/d_2 \quad (3.9)$$

Mathematically, if the diameter of driver and driven pulleys are 100 mm and 200 mm, respectively and the speed of rotation of the motor is 150 rpm, then:

Length of belt over the driver in one minute

$L_1 = \pi d_1 N_1$

$Given\ d_1 = 150\ mm = 0.15m$

Note: Since the pulley in use is up to 200 mm, then the max rpm for driven = 150 rpm

$N_1 = 150\ rpm$

Angular velocity $(w) = 2\pi N/60$

= 2 x 3.142 x 150/60π

= 942.6/60

= 15.71 rad/sec.

Therefore,

Length of belt = $\pi d_1 N_1$ = 3.142 x 0.1 x 15.71 = 4.93 m.

Length of belt that passes over the driven in one minute $\pi d_2 N_2$

Recall, $N_1/N_2 = d_1/d_2$, then $N_2 = N_1 d_1/d_2$

$d_2 = 200\ mm = 0.2\ m$

$N_2 = 150\ x \frac{0.1}{0.2} = 75\ rpm$

Angular velocity (ω) = 2πN/60

= 2 x 3.142 x 75/60

= 471.3/60

= 7.86 rad/sec.

Length of belt driven by pulley $L_2 = \pi d_2 N_2$

= 3.142 x 0.2 x 7.86 = 4.93 m

Velocity Ratio

V = $N_2/N_1 = d_1/d_2$

V = N_2/15.71 = 0.1/0.2

N_2 = 15.71 x 0.1/0.2 = 7.86

Velocity of the belt on the driver

$V_1 = \pi \frac{d_1 N_1}{60} m/s$

V_1 = 3.142 x 0.1 x 15.71/60

= 4.936/60

= 0.082 m/s

Velocity of the belt on driven pulley

$V_2 = \pi d_2 N_2/60$

V_2 = 3.142 x 0.2 x 7.86/60

= 4.93/60

= 0.082 m/s

The pulleys are standard parts in different sizes, grooves, pitch etc. Its main function in this project is to transfer the d_1 motor rotation (150 rpm) to d_2 (200 rpm) rotation of the screw conveyor. The sizes of the pulley selected are 100 mm and 200 mm, respectively. The 100 mm pulley is attached to the d_1 motor shaft while 200 mm pulley is attached to screw conveyor shaft. The two pulleys are connected by a fan belt.

The conveying mechanism in this project is the screw conveyor shaft. A shaft is used to transmit power from one place to another. The power is delivered to the shaft by some tangential force and resultant torque (or twisting moment) set up within the shaft. The screw conveyor is secured at both ends with two ball bearings. The screw shaft is 2060 mm in length and screw pitch of 180 mm (distance behind adjacent screw flight). To satisfy our requirements, we select SKF bearing NU2208 from TABLE 1.

Table 1: SKF Bearing Standard

Bearing (SKF)	No.	d mm	D mm	B mm	r mm	r1 mm	F mm	Basic capacity, N*		Max. permissible speed rev/min
								Static (C0)	Dynamic (C)	
NU2205		25	52	18	1.5	1.0	32	11030	15790	13000
2206		30	62	20	1.5	1.0	38.5	16970	23140	13000
2207		35	72	23	2.0	1.0	43.8	27655	35600	10000
NU2208		40	80	23	2.0	2.0	50	32750	40700	10000
2209		45	85	23	2.0	2.0	55	35600	43640	8000
2210		50	90	23	2.0	2.0	60.4	38540	45500	8000
NU2211		55	100	25	2.5	2.0	66.5	45500	52560	8000
2212		60	110	28	2.5	2.5	73.6	59820	69630	6000
2213		65	120	31	2.5	2.5	79.6	74040	81640	6000
NU2214		70	125	31	2.5	2.5	84.5	78450	85910	5000
2215		75	130	31	2.5	2.5	88.5	84730	96350	5000
2216		80	135	33	3.0	3.0	95.3	98070	109340	5000
NU2217		85	150	36	3.0	3.0	101.8	117680	12700	4000
2218		90	160	40	3.0	3.0	107	135820	140235	4000
2219		95	170	43	3.5	3.5	113.5	160340	173580	4000

Source: [3]

The machine frames are made from mild steel to provide support and accommodate the bagging system. The frames were carefully welded using electric arc welding machine. They are made in “A” form to provide balance and withstand vibration that may be produced by the rotation of the screw conveyor. The two frames of height 900 mm and 600 mm are joined together through an angular iron carefully welded to them. The bagging system is attached to the 900 mm angular stand.

The base is made of a thick plate of 100 mm square with thickness of 3 mm. It serves as the foundation to the equipment and is strong enough to withstand weight of the machine and the alternative weight and vibration. These were carefully welded to the angular frame of the machine.

The bagging system is an automated unit that accommodates the bag, measures the weight of the grains from the screw conveyor and compares with the balancing weight. It has a short frame of 1000 mm, on one side is the balancing weight and the other side is the bagging housing. The balancing weight is of different weights such as 10 kg, 20 kg, 30 kg, etc. An empty bag is hung on the bagging unit end, and a balancing weight at the other end. Grains are fed into the system through the hopper, and once the weight of grains discharged corresponds with the balancing weight, the bag drops. While dropping it triggers the limit switch which automatically stops the motor rotation, thus the screw conveyor. When the bag is removed, it releases the limit switch then the motor starts working again.

The tonnage capacity of screw conveyor ‘Q’ in kg/hr is given by

$$Q = V\gamma = \frac{\pi D^2}{4} SN\Phi\gamma C \text{ x } 60 \text{ kg/hr} \qquad (3.10)$$

Where,

V	-	Volumetric capacity, m^3 per hour
γ	-	Bulk density of material, kg/m^3
S	-	Screw pitch, m
N	-	Rotational speed, rpm
ϕ	-	Loading efficiency of the vertical cross sectional area
C	-	Varies with flow ability of material as shown below:

TABLE 2 shows the loading efficiency for different materials.

Table 2: Loading Efficiency

Materials Characteristics	Value of ϕ
Slow flowing, abrasive (ash)	0.125
Slow flowing mild abrasive	0.25
Free flowing mild abrasive (sand)	0.32
Free flowing non- abrasive (grain)	0.4

Source: [3]

A free flowing, non-abrasive grain, which is our material to be conveyed has value of $\phi = 0.4$. Value of 'C' varying with inclination angle β is related as shown in TABLE 3.

Table 3:Factor Depending on Inclination

B	0°	5	10	15	20	30
C	1.1	0.9	0.8	0.7	0.65	0.60

Source: [3]

It is safe to assume 150 rpm of rotation speed for our model, we have
N = 150 rpm
$\phi = 0.4$
C = 0.65 (for inclination at 20°)
TABLE 4 shows the permissible speed for screw conveyors.

Table 4: Permissible Speed for Screw Conveyor

Screw diameter (mm)	160	200	250	300	400	500	630
Maximum (rpm)	150	150	120	120	95	90	75
Minimum (rpm)	25	25	20	20	20	15	10

Source: [3]

Since the steepest segment of our model is at 20°, thus the maximum capacity of the conveyor is
D = 200 mm = 0.2 m
S = 180 mm = 0.18 m

$$\therefore Q = V\gamma = \frac{\pi D^2}{4} SN\Phi\gamma C \text{ x } 60 \text{ kg/hr}$$

$$= \frac{3.142 \text{x} 0.2^2}{4} \text{x}0.18\text{x}150\text{x}0.4\text{x}0.65\text{x}60$$

$$= 13.23 \text{kg/hr}$$

The screw diameter and speeds vary widely depending on the designed capacity of the conveyor and the material handled. However, the speed is generally reduced as the diameter goes up.

1S1296:1990 'Determination of Power Requirement of a Screw Feeder – General Requirement [5] has recommended the method for calculation of power requirement of a screw conveyor. Power of a loaded screw conveyor may be estimated by formula

$$P = P_H + P_N + P_{st} \qquad (3.11)$$

Where,
P_H - Power necessary for conveying material
P_N - Driving Power of Conveyor at no load
P_{st} - Power requirement for inclination of this conveyor.

Power necessary for conveying material,

$$P_H = \frac{QL\lambda}{367} \text{ kW} \qquad (3.12)$$

Where,
Q - Mass flow ratio in tones/hour
L - Length of Material movement in conveyor, m
λ - Progress resistance coefficient (friction coefficient) which is equals to 4

$$P_H = \frac{13.24\text{x}2.06\text{x}4}{367} = 0.297 \text{ kW}$$

Drive Power at no load,

$$P_N = \frac{DL}{20} \text{ kW} \qquad (3.13)$$

Where,
D - Nominal Screw Diameter, m
L - Length of Screw, m

$$P_N = \frac{0.2\text{x}2.06}{20} = 0.02 \text{ kW}$$

Power requirement for inclination of this conveyor is given by

$$P_{st} = \frac{QH}{367} \text{ kW} \qquad (3.14)$$

Where,
Q - Mass flow ratio in tones/hour

H - Height of the inclination in m

$H = L \times Co\}s\ 20^{0}$

= 2.06 x Cos 20°

= 0.9396

$$P_{st} = \frac{13.24x0.9396x4}{367}$$

$= 0.1356 = 1.356 \times 10^{-3}$ kW

Total Power Requirements

$P = P_H + P_N + P_{st}$

= 0.297 + 0.02 + 0.1351

= 0.4521 kw = 0.5 kw = 500 watt

This gives us the minimum power needed to rotate the screw conveyor at minimum load condition. At maximum load condition, a 1140 Watt electric motor was selected to drive the screw conveyor and contend all other power requirements of the system.

III. Results and Discussion

A model screw conveyor attached with automatic bagging unit which successfully demonstrates easy conveying, measuring and precise bagging of grains has been designed and produced. The following parts have been successfully designed in accordance to their selection criteria. The designed screw conveyor has the following specification.

Capacity – 13.23 kg/hr
Power - 1140 Watt
Conveyor speed - 498.64 rpm
Material handled - Grains
Length of material travel - 2060 mm
Height of material travel - 100 mm = 0.1 m
Screw diameter (D) - 200 mm = 0.2 m
Shaft diameter - 40 mm = 0.04 m
Screw pitch - 180 mm = 0.18 m

In the course of designing and producing the conveyor belt, various experiments, tests and analyses were carried out. For smooth running, the tensioning of the belt played a vital role as it was experimented, firmly securing the base reduced vibration especially when feeding or loading the machine. The result from the experiment shows that, the grains should be fed into the machine while in motion, this is because loading the machine before operation poses a challenge to the electric motor which causes wear to the belt and obstruction along the casing. It was also observed that loading the machine should be done gradually.

IV. Summary, Conclusion and Recommendations

4.1 Summary

Screw conveyor with a bagging unit plays a vital role in the society. It replaces the rigorous process of conveying material and bagging it differently. It also replaces the man labour of bagging the grains to the expected weight.

The screw conveyor with a bagging unit is economical to design and produce. It can be fabricated and assembled without difficulties. It has a long service span when properly and frequently maintained. Regular maintenance will reduce frequent breakdown and repairs.

4.2 Conclusion

The aim of the work was to design and produce a screw conveyor with automated bagging unit for easy conveying, measuring and precise bagging of grains hereby reducing double handling process and downtime. This has been efficiently achieved and it will play a very effective role in agricultural grains handling environment and in other manufacturing sectors.

Finally, the introduction of bagging unit attached to a screw conveyor, opens up a different dimension for improvement of this design. The functionality of this work encourages more research in the field of materials science and design.

4.3 Recommendations

The following recommendations are made;

i. The routine maintenance of the machine should be carried out to enhance its service life span and maintain its efficiency.

ii. In redesigning of this model, the conveyor screw housing and screw conveyor should be made of non-corrosive material like stainless steel (series 350).

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