Design and Development of Rice Straw Rope Maker

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Abstract:- Rice straws are the most prevalent and plentiful of the five rice-related products. Heavy rainfall during the wet season significantly reduces the quantitative and qualitative availability of straw. Hand tools or a machine designed for the purpose can be used to twist straw into rope. A straw rope maker was designed and developed to improve the quality and efficiency of rope production. The designed hypothesis was a rope with a helix angle of 25^0 to 30^0 and a diameter of 4 to 20 mm. Test the developed rope maker in the laboratory and on the farm. A-frame, a wool basket, a rope divider, two twisting funnels, two small stone pounds, a reel, and a gear mechanism make up the rope maker. The rope maker was constructed with an MS angle bar, cast iron, nylon plastic and plain sheet. The twisting mechanism consists of two twisting funnels made of plain sheet, a wool basket rope divider, a rope mouth, and a small cast iron stone pound. The rope maker allows for simple rope gathering and unloading. The rope-making capacity of the machine was observed at 55 mm s^{-1}. The rope's tensile force and strength were determined to be 458.64±5 N and 7.20±0.5 MPa, respectively, with a rope diameter of 8.60±0.8 mm. The machine was easy to run, requiring only power of 0.56 kW. The straw rope maker was good for producing rope continuously that was of high quality and had the desired diameter. The farmer can use this machine to reap the benefits of making easy, quick, and high-quality rope.

Keywords: Twisting mechanism, helix angle, capacity, rope diameter, straw divider

1. INTRODUCTION

Straw assets are becoming more immoderate and beneficial due to revolutionary improvements in agricultural science. It has been efficiently utilized in a range of really useful functions because of its cheapness, being locally available, and ecofriendly [1 - 2]. Rice straws are the most common and abundant agricultural byproduct taken over of the dead stalks regarding cereal vegetation afterward the grain or chaff hold been removed. Crop residue accounts for approximately 70 percent of the roughage available, while rice straw accounts for approximately 87 percent of the chaff accessible to cattle [3]. It is predictable that amount about 63.2 million tons (Fig. 1) of rice straw dry matter are produced in Bangladesh. About 21 percent of rice straw is lost every year due to poor storage and heavy rainfall in Bangladesh [4]. The quantitative and qualitative post-harvest losses of straw occur due to heavy rainfall during the wet season. Improper handling, delayed or incomplete drying causes also post-harvest losses of rice straw. Farmers will not burn rice straw if they can use it for something better and more beneficial to them. The world will stop using fossil fuels when something better comes along to replace them, which, unfortunately, will not be soon. There are also several 'craft' uses for cereal straw that has historically supported, and may continue to support, small rural industries. Today, this rope is primarily used to pack materials such as concrete pipes and rope can be widely applied to tree and brick protection, vegetable bundles, etc.

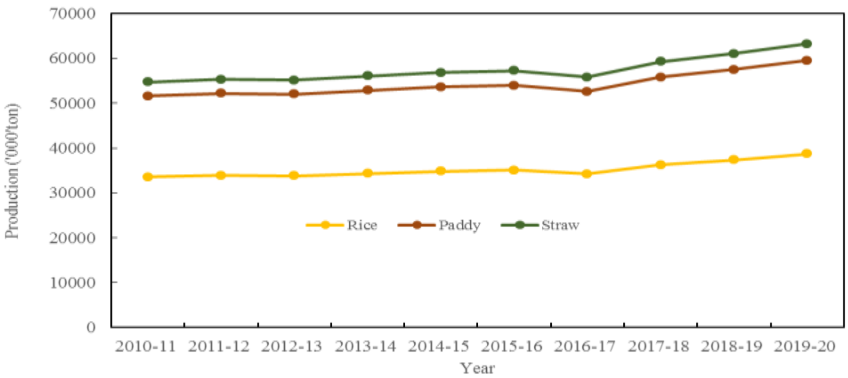

Fig. 1 Paddy, rice, and straw production scenario in Bangladesh
(Source: Prepared by the authors using the data BRRI, 2022)

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The product made of straw rope needs to meet fashionable capabilities consisting of fineness, right useful size, and shape with no distortion or bending. The quality of straw ropes needs to be uniform in size and durable. Local ropes are redesigned to add extra value to housing decoration. Straw rope woven which allows for good ventilation is ideal furniture for topographic and climatic conditions such as in Thailand and other tropical countries for its strength and durability.

Straw can be twisted into the rope using either hand tools or a machine designed for the purpose. The mechanically twisted straw rope has been successfully used in room decoration, furniture production, and agricultural field. Several studies have been reported on the design, fabrication, and performance of rope maker [5 - 8]. Problems of high operational rpm, feeding rate, low clearance between the shrimp and wool basket, and absence of adjustment for different diameter rice (*Oryza sativa* L.) straw rope were found during the operation of the machine [9]. Therefore, in this study, a mechanical twisted machine called BRRI Straw Rope Maker is redesigned and fabricated using locally available raw material and adapted spare parts with the calculation of material strength, torque, and power transmission system for multipurpose uses of straw. The diameter of the rope can be adjusted by changing the trumpet-shaped inlets in the machine. The result of the research would offer a significant contribution to preparing eco-friendly, low cost and versatile uses of rope.

2. MATERIALS AND METHODS

2.1 Design Consideration

The design of the straw rope maker was done with the help of CAD engineering tools (SolidWorks 2020). According to the design, the prototype of the machine was fabricated using locally available raw materials in the research workshop of Farm Machinery and Postharvest Technology Division, Bangladesh Rice Research Institute, Bangladesh. Lightweight, structural stability, and uniformity of rope diameter were considered during design. The diameter of the funnel opening was fixed at half the diameter of the rope as the twisting quantity determines the rope's strength.

2.2 Twisting theory

The theory regarding rope manufacturing is complicate. The twist may lie both left-handed and right-handed. These are referred to in conformity with namely S and Z twists in the textile industry, as illustrated in Fig. 2. The helix angle is used to measure the degree of twist in a helical structure. The angle is moderate relative by the path over the rope which explains in Fig. 3. The twist is introduced by the revolution over the pulley speed. A single turn of the large pulley inserts triple turns over twists of the yarn to a forward approximation. The traveler revolution lags behind the revolution of the reel to wind the fiber onto the small stone pound. The rope inserted is consequently slightly much less than that amount found using (reel revolution)/(small stone pound revolution) [10]. The helix angle is shown in Fig. 3. In another sense, the twist degree is the ratio of the number of turns and unit of length.

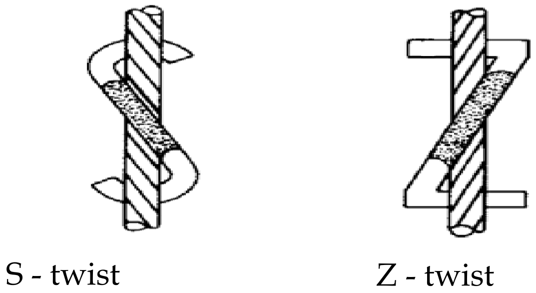

Fig. 2 S (Left-handed) and Z twist (Right-handed)

There is a straight relationship between the twist degree and rope hardness. Angle is measured regarding the track of the helical structure, that is $0^0 < \gamma < 90^0$.

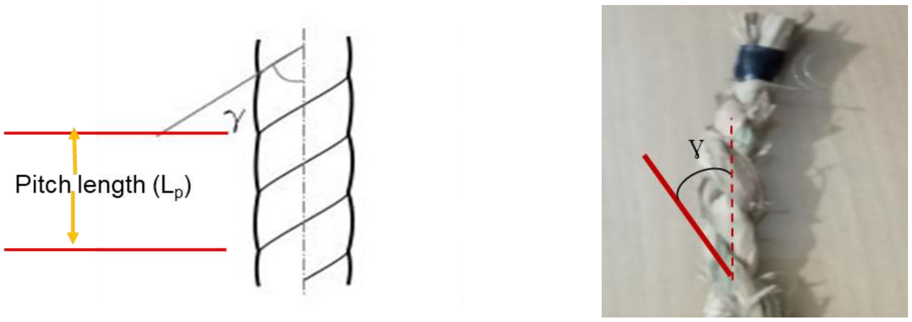

Fig. 3 Visualization of the helix angle in Z twisted helix structure

A research findings reported that the degree of twist is desirable between $25^0 < \gamma < 30^0$ for decorative purposes whereas $<15^0$ and $>55^0$ is not applicable, and $\gamma = 10^0$ is described as soft, $\gamma = 20^0$ is described as medium, and so on [11].

2.3 Design calculation

Engineering design and drawing is the method of applying the different practices and systematic principles to define a problem or a process with possible solutions to fulfill the stated objectives for the happiness of human beings [12].

2.3.1 Determination of length of the belt

The belt length is given by [12].

$$L = 2C + \pi[D_R+D_N]/2+\frac{(D_R-D_N)}{4C} \quad \ldots\ldots(1)$$

Where,

D_R = Diameter of the driver pulley, mm
D_N = Diameter of the driven pulley, mm
L = Length of the belt, mm
C = Centre to center distance between sheaves, mm

2.3.2 Determination of belt power transmission

The power transmission by the belt is measured by [12].

$$P = (T_1-T_2)V/1000 \quad \ldots\ldots(2)$$

Where,

P = Power, W
V = Belt velocity, m s^{-1}

2.3.3 Determination of the bevel gear shaft's rpm

The RPM of bevel gear is given by [12].

$$N_2=\frac{N_1T_1}{T_2} \quad \ldots\ldots(3)$$

Where,

N_2 = RPM of the straight bevel gear shaft
N_1 = RPM of straight bevel pinion
T_1 = Number of teeth of straight bevel pinion
T_2 = Number of teeth of the straight bevel gear

2.3.4 Determination of the small stone's rpm

The rpm of bevel gear is given by [12].

$$N_4=\frac{N_3T_3}{T_4} \quad \ldots\ldots(4)$$

Where,

N_4 = rpm of the small stone
N_3 = rpm of straight bevel pinion
T_3 = Number of teeth of spur gear of the bevel gear shaft
T_4 = Number of teeth of spur gear of the small stone shaft

2.3.5 Determination of theoretical capacity of a rope maker

The theoretical capacity of rope maker is calculated by the following equation

$$C_{th}=\pi \times D \times \text{rpm of the small stone} \quad \ldots\ldots(5)$$

Where,

C_{th} = Theoretical capacity of a rope maker, m min^{-1}
D = Diameter of the small stone, m

2.3.6 Determination of maximum straw twisting power

The twisting of straw or torque is calculated by the following equation according to [13]

$$T = m \times g \times d\sin\theta \quad \ldots\ldots (6)$$

Where,

T = torque, N-m
m = mass, kg
g = 9.8 m s^{-2}
d = Distance, m

θ = Angle between arm and direction of force

Power requires for twisting by [14]

$$P = \frac{T \times N}{9.5488} \quad \text{……….………………………………..(7)}$$

Where,

T = torque, N-m
N = rpm
P = Power, kW

2.3.7 Determination of torque for rope pulling by the small stone pound
The pulling torque of the straw rope is calculated by the following equation

$$T = m \times g \times d\sin\theta \quad \text{………………………….… (8)}$$

Where,

T = Torque, N-m
m = mass, kg
g = 9.8 m s $^{-2}$
d = Distance, m

2.3.8 Determination of reel drive wheel torque
The calculation of torque of reel drive wheel is measured using the following formula
.

$$\text{Torque, } Tr_{23} = \frac{teeth_{23}}{teeth_{25}} \times T_{tr25} \times \eta \text{………… (9)}$$

Where,

T_{r23} = 23 tooth gear torque, in N-m
T_{r25} = 25 tooth gear torque, in N-m
T_{25} = Number of teeth, 25
T_{23} = Number of teeth, 23
η = Machine efficiency, %

For spur gear, η is 98%.

Again,

$$\text{Torque, } T_{r19} = \frac{teeth_{19}}{teeth_{23}} \times T_{tr23} \times \eta \text{………… (10)}$$

Where,

T_{r23} = 23 tooth gear torque, in N-m
T_{r25} = 25 tooth gear torque, in N-m
T_{25} = Number of teeth, 25
T_{23} = Number of teeth, 23
η = Machine efficiency, %

Source: [15]

2.3.9 Determination of wrap and pull power of rope on reel
Total torque for wrapping and pulling straw rope by the small stone pound, and reel drive wheel is
Total torque, T = Drive wheel torque+ Rope pulling torque
Power is calculated from equation 7.

2.3.10 Determination of total power required to operate the machine

Power = (Wrap and pull power + Straw twisting power + belt power transmission) × FoS

Where,

FoS = Factor of safety

2.4 Material selection criterion
The selection of materials was done considering the different characteristics of materials such as weight, durability, flexibility, strength, corrosiveness, machinability, casting ability, welding or hardening ability, and electrical resistivity. The tests are

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required to verify the properties of the materials used to make a component. Table 1 shows the material selection criterion for the straw rope maker.

Table 1. Material selection criterion

Name of material	Reason for selection
ASTM 1020 (plain sheet)	1020 is the plain carbon steel consisting of approximately 0.20% carbon content and 0.50% manganese which ensures good strength and malleability of the product.
Gray Iron ASTM A48 Class 30 (cast iron)	Gray iron has great vibration and sound dampening properties. This material pulley allows you to implement the force in any action, not just the one in which the force is to be applied.
ASTM A36 (mild steel)	Good ductility and welding ability, High impact strength, and low cost
AISI 1010	Good combination of strength and ductility
Nylon 101	It is an unfilled extruded type material that shows high strength and rigidity

Source: [16 - 18]

3. RESULTS AND DISCUSSION

3.1 Engineering drawing of the machine

Engineering drawings incorporate all of the details about a component's layout aspects. It is very useful to understand the particular components of the engineers. The drawing shows the precise dimensions of the design on paper. In the isometric view, here is an illustration of the various parts of the straw rope maker machine in Fig. 4 and major parts in Fig. 5.

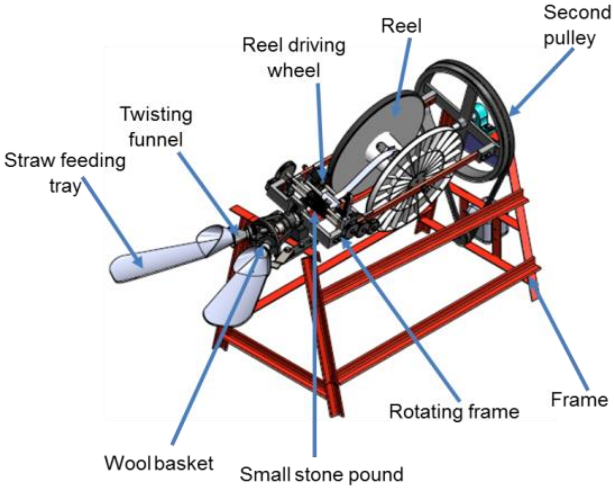

Fig. 4 Isometric view of BRRI straw rope maker

(a) Gear and pinion

(b) Small and big umbrella wheel

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(c) 11 tooth gear, small stone pound, Lifting

(d) No. 3 side holder (shaft bracket)

(e) No. 4 side holder (shaft bracket)

(f) No 1 side tile holder (Shaft bracket)

(g) 2 no. side tide holder (shaft bracket)

(h) Fixed sleeve

(i) Wool basket

(j) Rope mouth

(k) Rotating frame

(l) Into the grass wheel

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(m) Prawns and Shrimp

(n) Reel Core

Fig. 5 Major parts of the rope maker (a-n)

3.2 Description of important parts of rope maker

The descriptions of numerous significant parts are given in the following section and drawing dimensions are expressed in mm.

3.2.1 Machine frame

The frame is necessary for keeping various parts such as a reel, gears, second pulley, rope divider, wool basket, small stone pound, straw feeding tray, and twisting funnel (Fig. 6). ASTM A36 steel was used to construct the structure (mild steel). The frame's length, height, and width were 1000, 590, and 570 mm, respectively. A nut and bolt were used to tighten the framework.

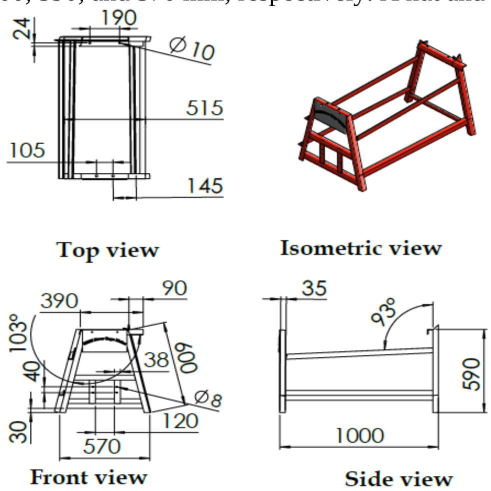

Fig. 6 Drawing of the machine frame

3.2.2 Second pulley

It is an A section V-belt with two grooves and a cast iron main pulley. The pulley had a diameter of 395 mm. There were two slot points at 275 mm diameter for attaching the two bars and rotating with the pulley (Figure 7).

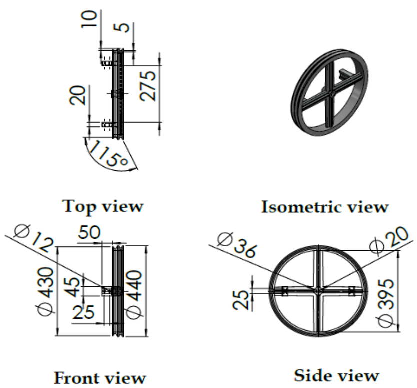

Fig. 7 Drawing of the second pulley

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3.2.3 Twisting funnel

Twisting funnels were used to twist the straw, which is made of ASTM 1020 (plain sheet). There were various sizes of funnel openings, such as 4, 6, and 8 mm in diameter, which could be used to determine the rope diameter (Fig. 8).

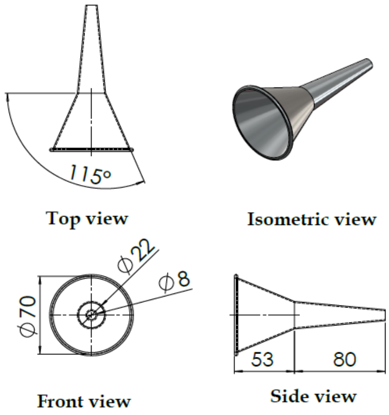

Fig. 8 Drawing of the twisting funnel

3.2.4 Small stone pound

The two stones are located above and below each other and resemble a tapered cylinder. They rotate in opposite directions to pull the rope to the reel. The larger and smaller diameters were 35 and 25mm, respectively, with a height of 70 mm made of cast iron for better grip (Fig. 9).

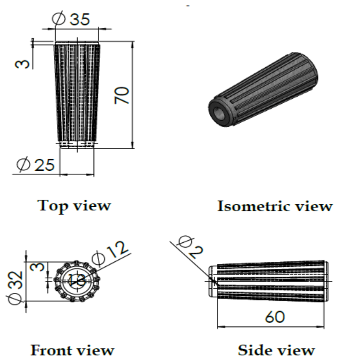

Fig. 9 Drawing of the small stone pound

3.2.5 Wool basket

The 125mm diameter wool basket was made of cast iron, which rotates the two into the grass wheel and rotates at the same rpm as the second pulley. The wool basket main parts of primary twisting and power gain form the rotary frame bar, which is connected to the second pulley (Fig. 10)

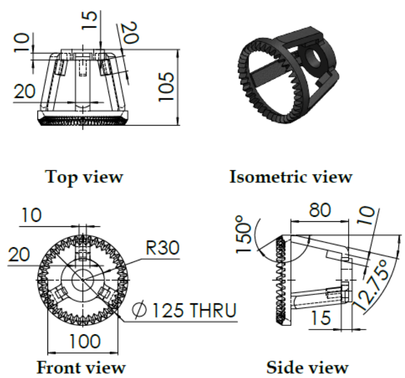

Fig. 10 Drawing of the wool basket

3.2.6 Reel

The reel was made of nylon 101 and had a two-reel side cover and a single reel core that looked like a tapered cylinder (Fig. 11). The reel was an outer diameter of 435mm and a width of 23mm. It aids in gathering the rope around the reel core. The reel is a rope collection unit that works by rotating the reel on its core. The reel rpm is significant because the minimum rpm legging the rope and the maximum rpm affect the rope quality. For better quality, the rpm should be about four times slower than the small-scale pound rpm.

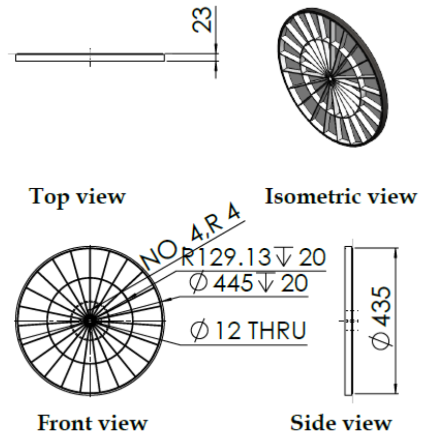

Fig. 11 Drawing of the reel side cover

3.3 Load analysis of machine frame

Stress, strain displacement, and factor of safety were determined using static load analysis (Fig. 12). The ASTM A36 grade material was used to design the straw rope maker machine frame. It was designed to hold working elements and a prime mover electric motor. Four loads are provided for frame load modeling in this practice, with normal forces of 80 N and 225 N and torques of 26 N-m and 0.98 N-m, respectively. According to the simulation, the frame is safe, with a minimum safety factor of 2.9.

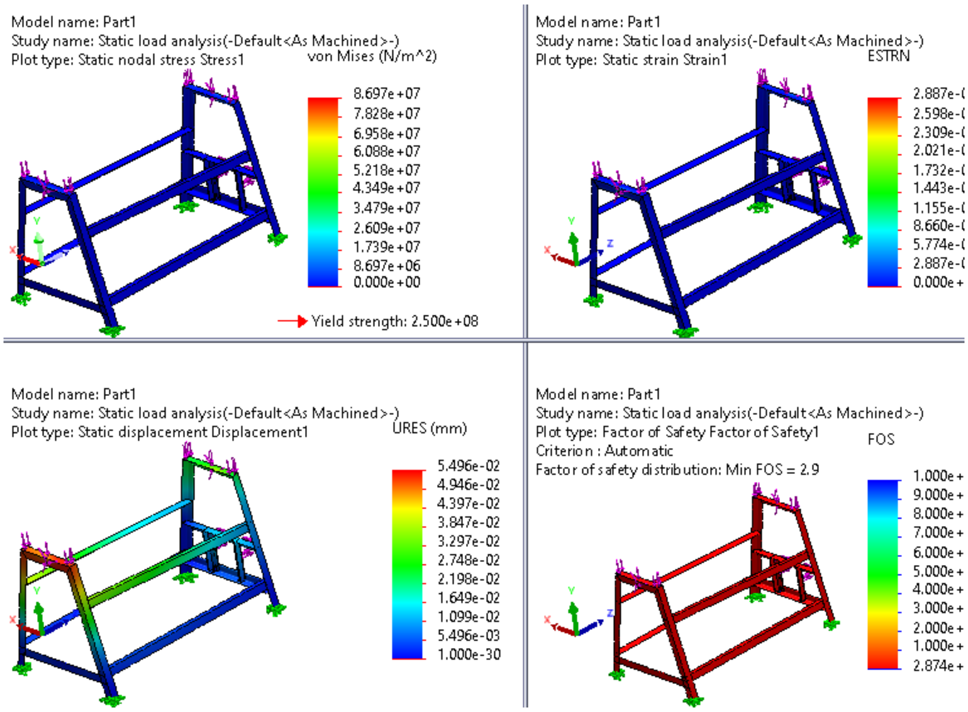

Fig. 12 Static loads of 345 N and torques of 26 N-m and 0.98 N-m were analyzed for the frame

3.4 Working principle

While the rope maker machine is constantly rotating, the user inserts the straw into two inlets simultaneously, and the two strands are twisted into one rope. A rotating frame powered by a motor and teethed gear drives, the twisting funnel, into the grass wheel and wool basket complete the twisting mechanism, and the winding is done by a rotary frame powered by the second pulley where the winding mechanism together twisted strand and make rope. The prototype machine's production practice discovered that the power transmission system is complicated during the rotating and twisting process due to the high-speed rotation of the rope reel and the transmission gear. Users can stop operation when the reel core diameter is nearly equal to the reel side cover diameter of the two inlets. Finally, the operator rotates the screw away from the two plates, allowing the rope to be taken from the center axis.

3.5 Power transmission systems of BRRI straw rope maker machine

The power transmission system is shown in block diagrams from the motor to the twisting funnel and wrapping reel through the V-belt and spur gear (Fig. 13). The V belt is solely used to convey power from the motor to the second pulley, and the twisting funnel and reel drive wheel receives power from the grain train, while the reel gets power from the 80 mm diameter cast iron wheel.

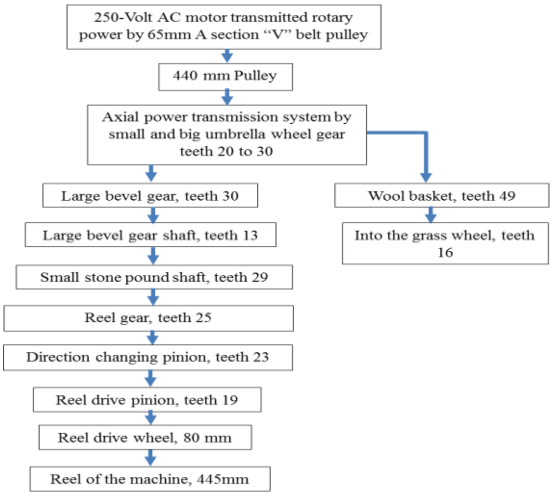

Fig. 13 Block diagram of the power transmission system

3.6 Performance of BRRI straw rope maker

The performance of the straw rope maker is shown in Table 2. Machine capacity depended on operational rpm, increasing power decreasing rope quality, and rope quality depended on helix angle (Fig. 14). Some critical data was compiled in Table 2 to test the machine's performance and rope quality. The belt length of the straw rope maker was calculated as 1780 mm. The revolution of bevel gear and small stone was observed at 85 and 38 rpm, respectively. The torque of rope pulling and reel drive wheel was observed at 14.90 and 10.87 N-m, respectively. The specification of the BRRI straw rope maker is given in Table 3.

(a) (b) (c)

Fig. 14 Performance test of BRRI straw rope maker (a) Pictorial view, (b) Data collection and (c) Straw rope

Table 2. Performance data of BRRI straw rope maker

Parameter	Value
Belt length, mm	1780
Bevel gear revolution, rpm	85
Small stone's rpm	38
Rope pulling torque, N-m	14.90
Reel drive wheel torque, N-m	10.87
Wrap and pull power of rope on reel, kW	0.104
Maximum straw twisting power, kW	0.13
Energy consumption, kW	0.40±0.004
Tensile force, N	458.64±5
Tensile strength, MPa	7.20±0.5
Helix angle, γ^{0}	33 ± 5
Theoretical capacity, mm s^{-1}	57 ± 4
Rope making capacity, mm s^{-1}	55 ± 4
Rope diameter, mm	8.6±0.8
Rope pitch, mm	30 ± 5
Total power required, kW	≃0.56

Table 3. Design specification of BRRI straw rope maker

Parameter	Unit
Name	BRRI straw rope maker machine
Model	BRRI SRM 2021
Dimensions (length×width×height), mm	1625×660 ×880
Weight, kg	58
Funnel opening, mm	10
Rope mouth opening, mm	12
Motor power (AC 220V), kW	0.56

4. CONCLUSION

The BRRI straw rope maker was fabricated in the research workshop to twist straw into rope and increase the versatile use of a straw. The BRRI straw rope maker's operating principle was user-friendly, and the rope maker's overall performance was adequate for making rope. The rope maker's capacity was 55±4 mm s^{-1} with uniform pitch and strand based on labor skill. It is a suitable technology for making straw rope of high quality and desired diameter. Farmers can get the benefit of making easy, fast and high quality rope using this machine.

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