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Design and Performance Evaluation of Small-Scale Corn Shelling Machine

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Abstract

This paper focuses on the design and performance evaluation of small-scale corn shelling machine. The motor power of the corn shelling machine is 0.75 hp and rotational speed is 1400 rpm. This motor used v-belt transmission system to drive the shelling cylinder shaft. The number of a belt is used in this transmission system. The standard diameter of the corn shaft is 25 mm. The ASME code equation is used to design the shaft for corn shelling machine. Single-row deep groove ball bearing is selected for left and right bearing of corn shaft. The average shelling efficiency, output capacity and damage efficiency of corn were compared with difference spike teeth and various speeds. The average shelling efficiency of 24, 27 and 30 spike teeth are 87 %, 94 % and 81 %. The average output capacity of 24, 27 and 30 spike teeth are 232 kg/h, 281 kg/h and 263 kg/h. The average damage efficiency of 24, 27 and 30 spike teeth are 13 %, 6 % and 19 % respectively. The maximum shelling efficiency and output capacity are found 27 spike teeth at cylinder speed of 690 rpm. The minimum damage efficiency is 6% at 27 spike teeth.

A. Introduction

Corn, also known as maize, is one of the most widely grown cereals in the world. It is staple food for millions of people, particularly in developing countries where it provides a significant source of nutrition and income. Corn is used in a wide range of products, including flour, animal feed, biofuels, and industrial products. The six main types of corn are sorghum, flint corn, pod corn, popcorn, flour corn, and sweet corn. A sugarcane varieties called sweet corn is grown for food as a seed, while field corn is grown for animal feed, various corn-based human food uses (including grinding into cornmeal, pressing into corn oil, and fermentation and distillation into alcohol (such as bourbon whiskey), and as chemical ingredients. Corn is also used in making ethanol and other biofuels. The main area of corn cultivation in Myanmar is center of the country, especially in the Shan State, which has about 52 percent of the total production since corn can be grown in the hilly areas and dry part of the country. Most of the farmers use high yield hybrid seeds provided or bought from foreign entities.

Figure 1. Small-scale Corn Shelling Machine

Nowadays, quality seeds have been changed in production. Up to 2008, Myanmar has exported over 300 thousand of corn annually to Malaysia and Bangladesh through oversea trade. Presently, 73 private companies have exported Myanmar maize mainly to China through border trade. Myanmar maize has been sold collectively at Muse (China Border) as per prescribed specification. A Maize specification has been set up as per international standard .

Small-scale corn shelling machine is operated by the single person with compact design. The main components of the small-scale corn shelling machine are inlet hopper, outlet for corn cob, bearing, pulley and belt assembly, frame, motor, shelling cylinder cover, outlet for corn kernel, shelling cylinder shaft and spike tooth. The aim of this paper is to carry out the design and performance evaluation of small-scale corn shelling machine and compare the performance of the existing spike tooth and modified spike tooth of the shelling cylinder shaft. Figure 1 shows the small-scale corn shelling machine.

B. Materials and Method

There are three steps in the design and performance evaluation of small-scale corn shelling machine. The first step is to design and calculate the shelling cylinder shaft of the small-scale corn shelling machine. The second step is to draw 3D model of shaft by using SolidWords software. And the third step is the performance evaluation of small-scale corn shelling machine.

Design Consideration of Small-scale Corn Shelling Machine

Power Transmission System

The main source of power transmission system is electric motor which connected to power supply was use to transmit torque to rotate the shaft for shelling process. The motor power of the small-scale corn shelling machine is 0.75 hp and the speed of motor (N_1) is 1400 rpm. There are many types of transmission system which transmit power from one shaft to another. In this machine selects the v-belt drive transmission system because easy to maintain and operates. The diameter of motor pulley is 57 mm and diameter of machine pulley is 116 mm. The speed of machine pulley is calculated according to this velocity ratio equation [5],

$$VR = \frac{N_2}{N_1} = \frac{D_1}{D_2}$$

(1)

So, the speed of the machine pulley is 690 rpm.

The length of the belt using the equation below,

$$L = \frac{\pi}{2}(D_1 + D_2) + 2 \times C + \frac{1}{4}(D_1 + D_2)^2 \quad (2)$$

$$L = \frac{\pi}{2}(57 + 116) + 2 \times 390 + \frac{1}{4}(57 + 116)^2 = 1.053\ \text{m}$$

The angle of contact for the driver and driven pulleys using the following equations,

$$\sin\beta = \left(\frac{D_2 - D_1}{2C}\right) \quad (3)$$

$$\beta = \sin^{-1}\left(\frac{D_2 - D_1}{2C}\right) = \sin^{-1}\left(\frac{116 - 57}{2 \times 390}\right) = 4.3$$

The angle of lap on the smaller pulley is,

$$\theta_{1,2} = 180 \pm 2\beta \quad (4)$$

$$\theta_{1,2} = 180 \pm 2(4.3) = 3.29\ \text{rad and } 2.99\ \text{rad}$$

The belt velocity is,

$$v_b = \frac{\pi D_1 N_1}{60} \quad (5)$$

$$v_b = \frac{\pi \times 0.057 \times 1400}{60} = 4.178\ \text{m/sec}$$

The area of the belt is,

$$A = \frac{1}{2}(b_1 + b_2) \times t \quad (6)$$

$$A = \frac{1}{2}(10 + 12) \times 8 = 88\,\text{mm}^2$$

The mass of belt per length is,

$$m = \rho A \tag{7}$$

$$m = 1140 \times 88 \times 10^{-6} = 0.1\,\text{kg}$$

The tension of the tight side is,

$$T_1 = S_1 \times A \tag{8}$$

The centrifugal tension of power transmission system is,

$$T_c = mv^2 \tag{9}$$

$$T_c = 0.1 \times 4.178^2 = 1.75\,\text{N}$$

The tension of the slack side is,

$$\frac{T_1 - T_c}{T_2 - T_c} = e^{\frac{f\alpha_1}{\sin\theta/2}} \tag{10}$$

$$\frac{149.6 - 1.75}{T_2 - 1.75} = e^{\frac{0.3 \times 2.99}{\sin 20/2}}$$

$$T_2 = 12.49\,\text{N}$$

The total tension on the tight side and slack side of the belt using the equations below,

$$T = T_1 + T_2 \tag{11}$$

$$T = 162\,\text{N}$$

The power transmitted per belt for this system using the following equation,

$$P = (T_1 - T_2) \times v_b \tag{12}$$

$$P = (149.6 - 12.49) \times 4.178 = 572.85\,\text{W} = 0.75\,\text{hp}$$

Design of shelling cylinder Shaft

The weight of shelling cylinder, weight of pulley, centrifugal force and belt tension are considered acting on the shelling cylinder shaft. The length of shaft is 500 mm and weight of pulley is 400 N. The shelling cylinder length and diameter are 260 mm and 107 mm. The centrifugal force acting on shelling cylinder shaft is also calculated.

Weight of Shelling Cylinder,

$$W_{cyl} = \rho \times V_{cyl} \times g \tag{13}$$

$$W_{cyl} = 7480 \times 2.34 \times 10^{-3} \times 9.81 = 171.71\,\text{N}$$

Centrifugal Force of Shelling Cylinder,

$$F = m_{cyl} \times r \times \omega^2 \quad (14)$$

$$F = 17.9 \times 0.058 \times 72.22^2 = 5.39\ \text{kN}$$

Maximum permissible shear stress (S_s) for AISI 1137 is [5],

S_s =0.18 S_{ut} = 194.94 MPa (15)

(or)

S_s = 0.3 S_y= 281.4 MPa

(Choose smaller value194.94 MPa)

Combined shock and fatigue factor applied to bending moment, K_b =1.5

Combined shock and fatigue factor applied to torsional moment, K_t =1

Maximum Bending Moment, M_b = 329.99 Nm

Maximum Torsional Moment,

$$M_t = \frac{P \times 60}{2\pi\pi} = 7.74\ \text{N} \quad (16)$$

ASME Code equation for solid shaft is,

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \quad (17)$$

d=23 mm

Therefore, the standard shaft diameter is 25 mm. In this paper selects the right and left bearing number of 6305 single row deep groove ball bearing. Figure 2 shows the 3D model of shelling cylinder shaft. The geometry was created by SolidWords software.

The result data of small-scale corn shelling machine is shown in the Table 1.

Table1. Design Result of Small-scale Corn Shelling Machine

Parameter	Symbol	Value	Unit
Speed of machine pulley	N_2	690	rpm
Length of belt	L	1.053	m
Velocity of belt	v_b	4.178	m/s
Mass of belt	m	0.1	kg
Tension of tight side	T_1	149.6	N
Tension of slack side	T_2	12.4	N
Power transmitted by belt	P	0.75	hp
Number of belt	n	1	-
Weight of shelling cylinder	W_{cyl}	171.71	N
Mass of shelling cylinder	m_{cyl}	17.9	kg
Centrifugal force of shelling cylinder	F	5.39	kN
Maximum torsional moment	M_t	7.74	N
Diameter of shaft	d	25	mm
Bearing number	N	6305	-

3D Diagram of Corn Shelling Machine

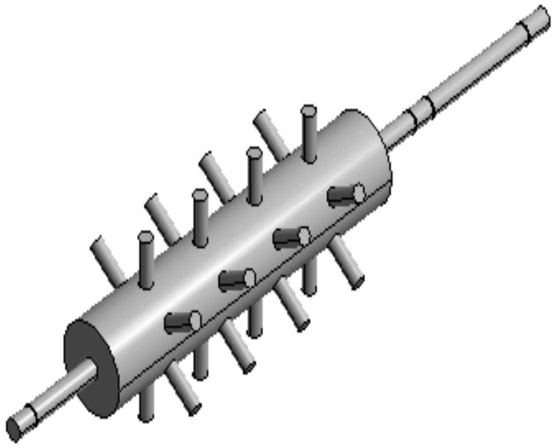

Figure 2. Shaft of Corn Shelling Machine

Performance Evaluation of Corn Shelling Machine

The performance test of the corn shelling machine is tested for five times and the maximum output capacity and shelling efficiency of the machine were recorded from these performance tests. The moisture content of the corn were determined by using moisture meter. Moisture percent of the corn is 12.15 %. The total running time is five times with various speed and spike tooth. The moisture contents are shown in Figure 3.

Figure 3. Moisture test of Corn

The weight of shelled corn and unshelled corn were recorded for each experiment. Measuring the weight of corn, shelled corn and unshelled corn are shown in Figure 4, 5 and 6.

Figure 4. Weight of Corn

Figure 5. Weight of Shelled Corn and Unshelled Corn

The performance result of small-scale corn shelling machine with 24 spike teeth is shown in the Table 2.

Table 2. Performance result of Small-scale Corn Shelling Machine with 24 Spike teeth

Shaft Speed (rpm)	Weight of Corn (kg)	Weight of Shelled Corn (kg)	Weight of Unshelled Corn (kg)	Time Taken (s)	Shelling Efficiency (%)	Output Capacity (kg/h)	Damage Efficiency (%)
350	1.815	1.565	0.251	32	84	176	16
395	1.815	1.597	0.218	28	86	205	14
420	1.815	1.615	0.200	25	88	233	12
525	1.815	1.618	0.197	23	88	253	12
690	1.815	1.625	0.190	20	88	293	11
Average	1.815	1.604	0.2112	26	87	232	13

The performance results of small-scale corn shelling machine with 27 Spike teeth shown in the Table 3.

Table 3. Performance result of Small-scale Corn Shelling Machine with 27 Spike teeth

Shaft Speed (rpm)	Weight of Corn (kg)	Weight of Shelled Corn (kg)	Weight of Unshelled Corn (kg)	Time Taken (s)	Shelling Efficiency (%)	Output Capacity (kg/h)	Damage Efficiency (%)
350	1.815	1.658	0.142	27	91	221	9
395	1.815	1.682	0.133	25	92	242	8
420	1.815	1.695	0.120	22	93	277	7
525	1.815	1.722	0.093	20	95	310	5
690	1.815	1.765	0.050	18	97	353	3
Average	1.815	1.704	0.111	22	94	281	6

The performance results of small-scale corn shelling machine with 30 Spike teeth shown in the Table 4.

Table 4. Performance result of Small-scale Corn Shelling Machine with 30 Spike teeth

Shaft Speed (rpm)	Weight of Corn (kg)	Weight of Shelled Corn (kg)	Weight of Unshelled Corn (kg)	Time Taken (s)	Shelling Efficiency (%)	Output Capacity (kg/h)	Damage Efficiency (%)
350	1.815	1.498	0.317	25	79	216	21
395	1.815	1.519	0.296	24	81	228	19
420	1.815	1.532	0.283	22	82	251	18
525	1.815	1.537	0.278	19	82	291	18
690	1.815	1.546	0.269	17	83	327	17
Average	1.815	1.526	0.2886	21	81	263	19

C. Result and Discussion

In this motorized corn shelling machine, different number of spike teeth of shelling cylinder shaft have been studied. The 1.815kg of each sample corn cobs is used in the experiment. Firstly, the corn cobs are fed into the hopper. Corn cobs are filled in the hopper to prevent overloading of the machine. Corn cobs are passed through the shelling chamber, which contains rotating components such as spike tooth cylinder. These components break the corn cobs and separate the kernels from the cobs. The experimental tests were carried out by running the machine five times for difference speed and modified the spike tooth. The shelling efficiency and capacity were evaluated for each experiment. The average shelling efficiency at the 27 spike teeth is more than the other two spike teeth but the damage efficiency is less than the other. The comparison of shelling efficiency at various shaft speeds with 24 spike teeth is shown in Figure 6.

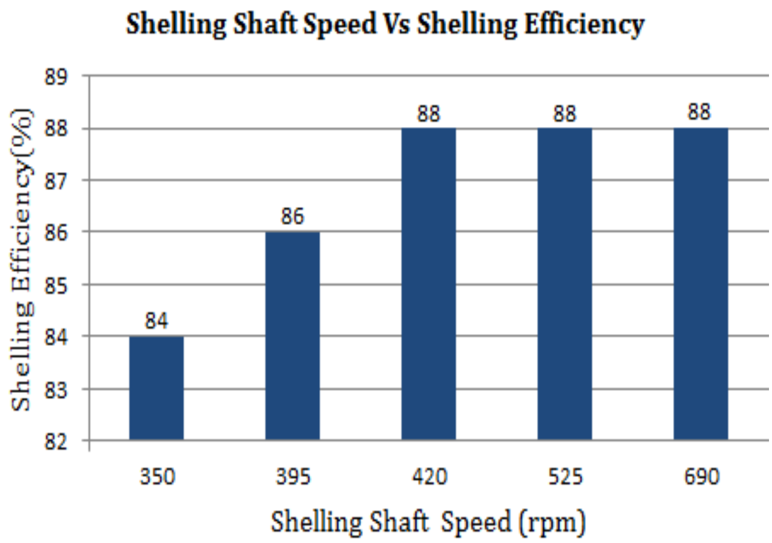

Figure 6. Comparison of Shelling Efficiency at Various Shaft Speeds with 24 Spike Teeth

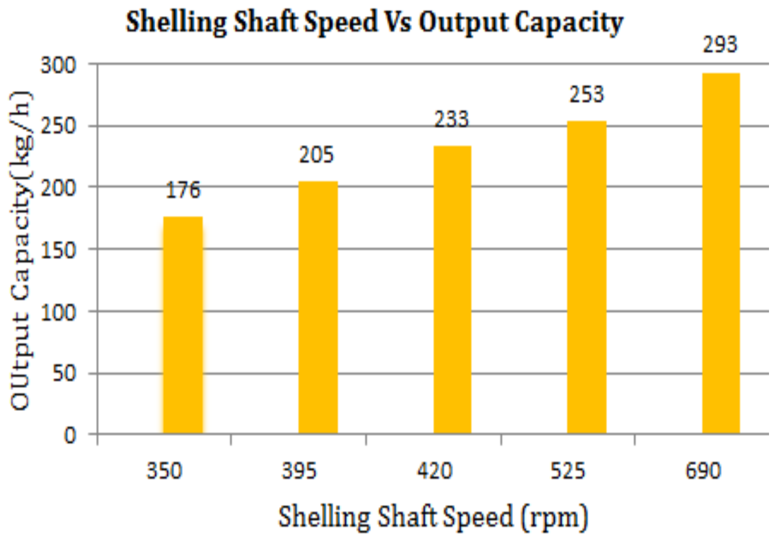

Figure 7. Comparison of Output Capacity at Various Shaft Speeds with 24 Spike Teeth

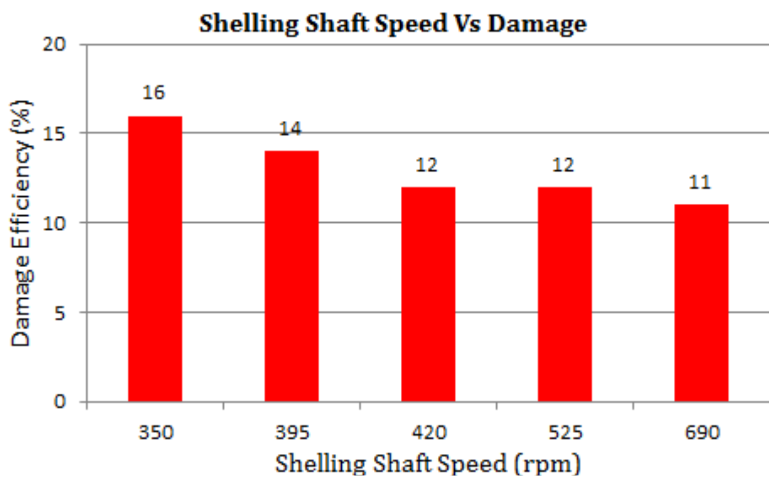

Figure 8. Comparison of Damage Efficiency at Various Shaft Speeds with 24 Spike Teeth

Figure 7 shows the comparison of output capacity at various speeds with 24 spike teeth. And then the comparison of damage efficiency at various speeds with 24 spike teeth is shown in Figure 8.

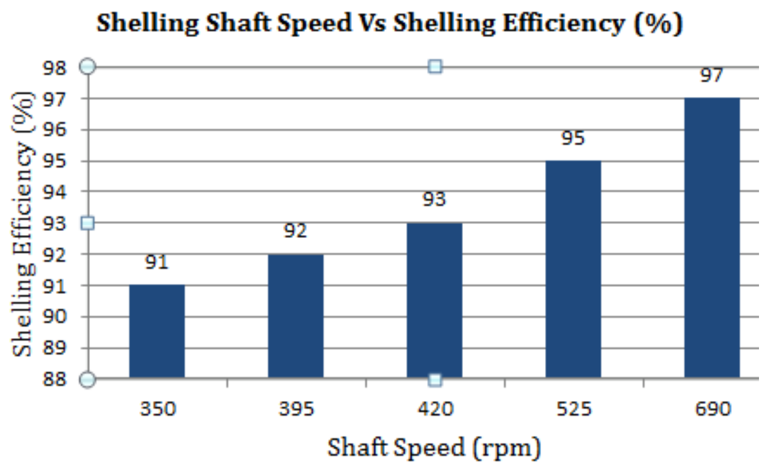

Figure 9. Comparison of Shelling Efficiency at Various Shaft Speeds with 27 Spike Teeth

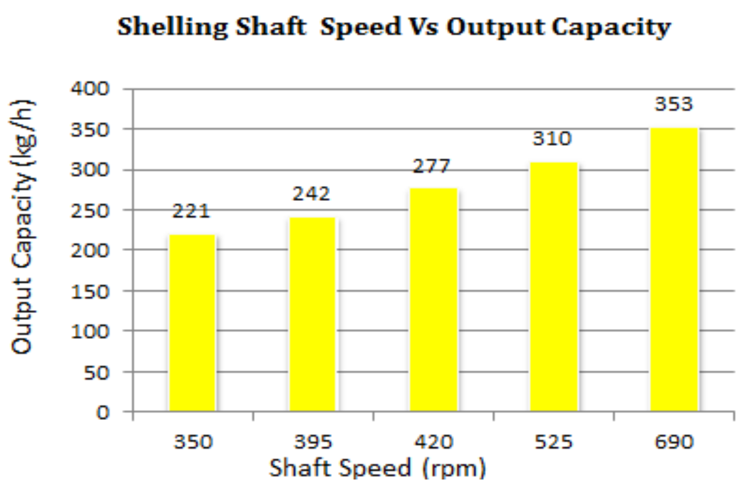

Figure 10. Comparison of Output Capacity at Various Shaft Speeds with 27 Spike Teeth

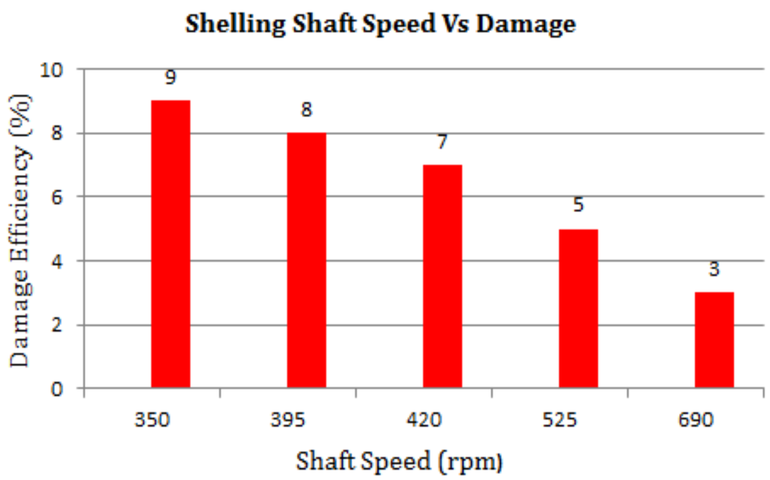

Figure 11. Comparison of Damage Efficiency at Various Shaft Speeds with 27 Spike Teeth

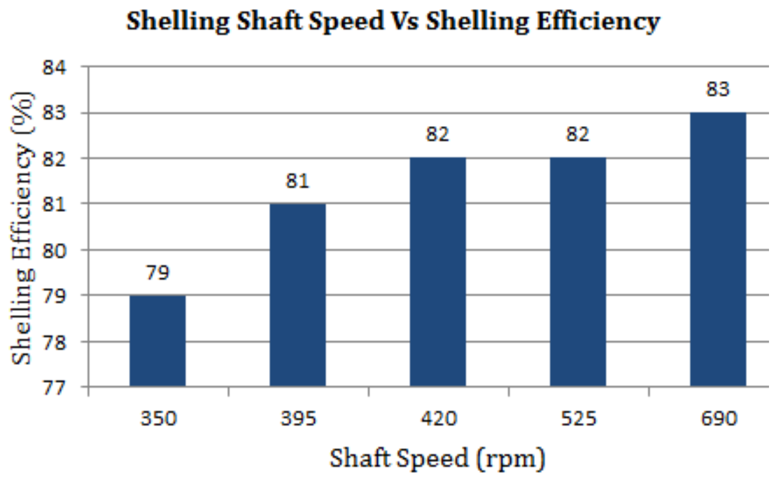

Figure 12. Comparison of Shelling Efficiency at Various Shaft Speeds with 30 Spike Teeth

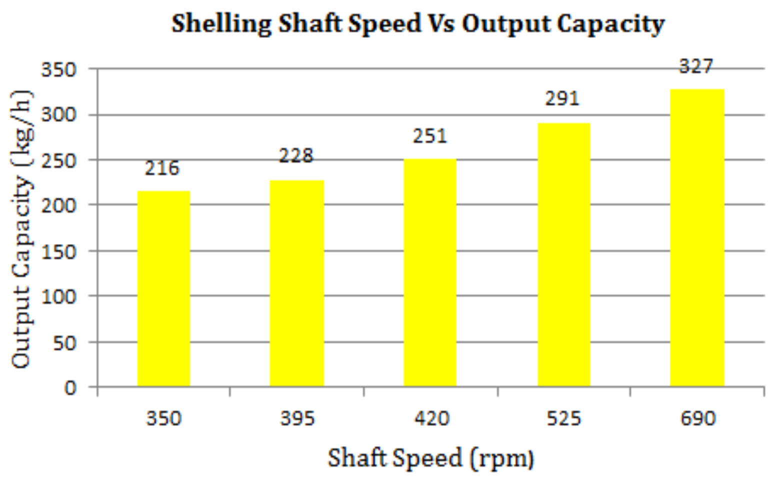

Figure 13. Comparison of Output Capacity at Various Shaft Speeds with 30 Spike Teeth

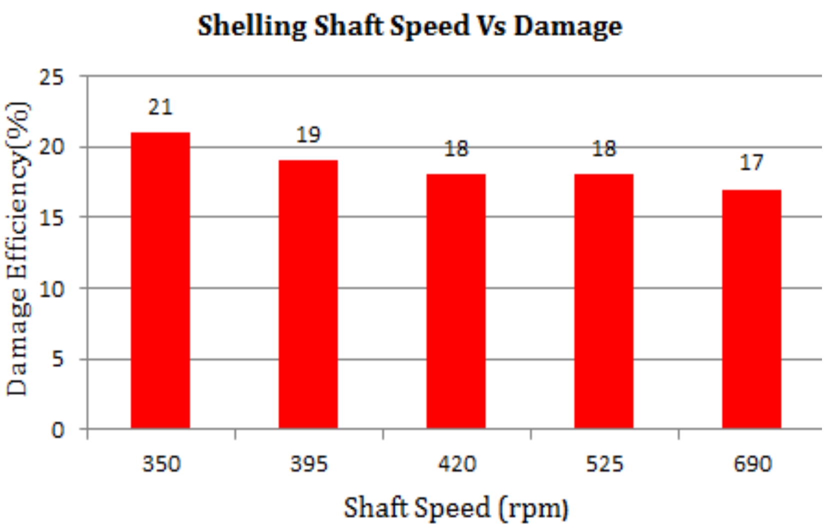

Figure 14. Comparison of Damage Efficiency at Various Shaft Speeds with 30 Spike Teeth

The comparison of shelling efficiency, output capacity and damage efficiency at various speeds and the numbers of 27 spike teeth are shown in Figure 9 to 11 and the numbers of 30 spike teeth are shown in Figure 12 to 14.

According to the experimental results, the average shelling efficiency of 24, 27 and 30 spike teeth are 87 %, 94 % and 81 % respectively. The shelling efficiency of the 27 spike teeth machine increases with the increase in shelling shaft's speed and the maximum shelling efficiency is 94 % at the maximum speed of 690 rpm.

The average output capacity is 232 kg/h at 24 spike teeth and 30 spike teeth of average output capacity is 263 kg/h. The output capacity of the machine increases with the increase in shelling shaft's speed and the maximum output capacity is 353 kg/h at the maximum speed of 690 rpm. As above results, the output capacity of corn increases at the high speed of machine.

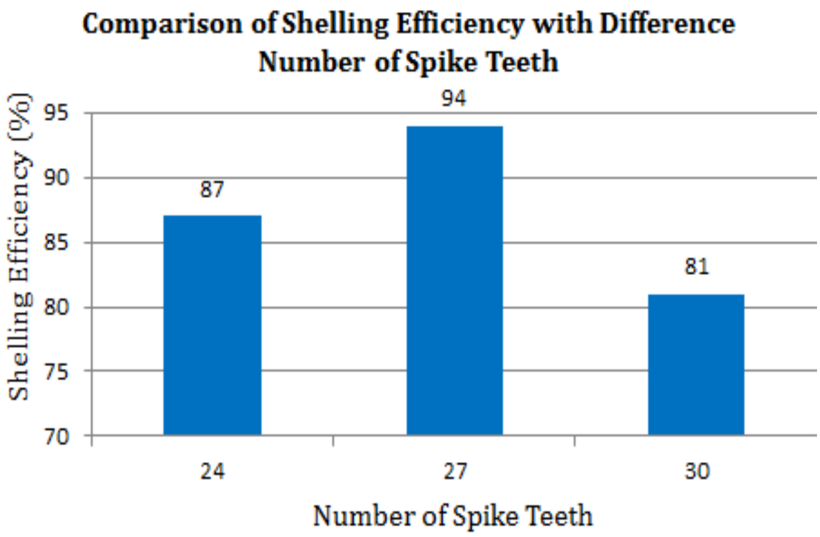

Figure 15. Comparison of Shelling Efficiency with Difference Number of Spike Teeth

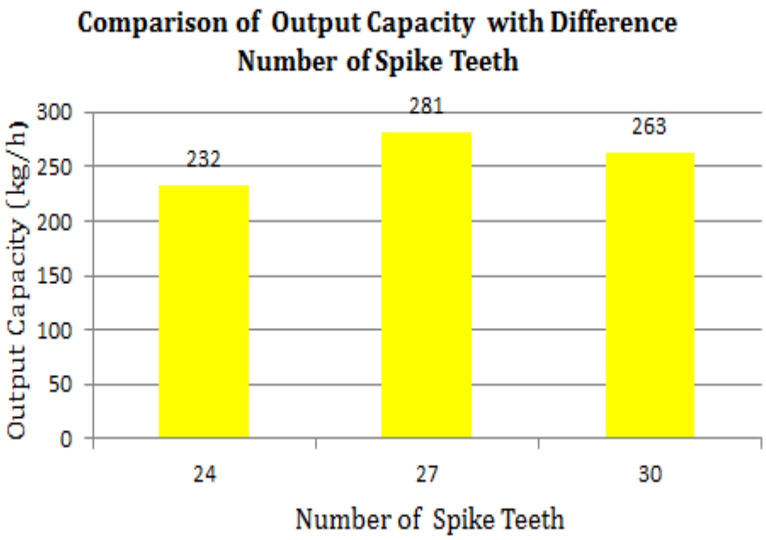

Figure 16. Comparison of Output Capacity with Difference Number of Spike Teeth

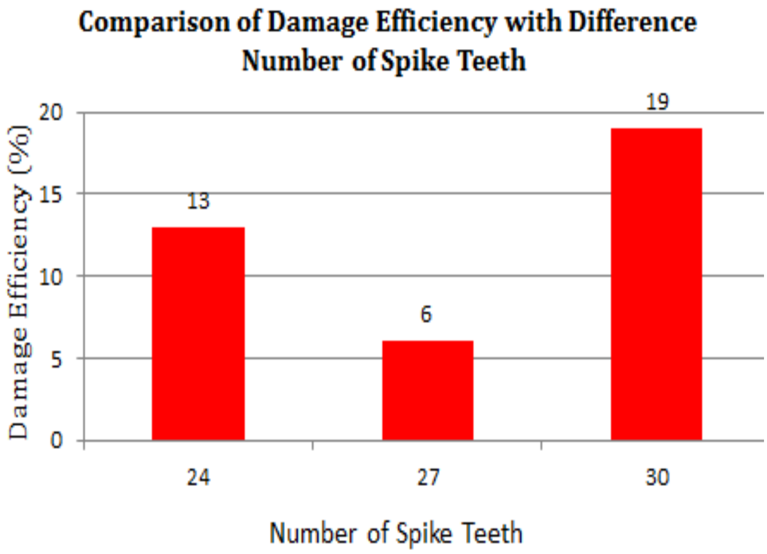

Figure 17. Comparison of Damage Efficiency with Difference Number of Spike Teeth

The comparison of shelling efficiency with difference number of spike teeth is shown in Figure 15. Figure 16 shows the comparison of output capacity with difference number of spike teeth. And then the comparison of damage efficiency with difference number of spike teeth is shown in Figure 17.

D. Conclusion

This research presents the design of shaft and the standard shaft diameter is 25 mm. The length of cylinder and diameter are 260 mm and 107 mm for a corn shelling machine. The length of belt is 1.053 m and the numbers of one belt is used. The required motor power of the machine is 0.573 kW. So choose 0.75 hp to save and overcome the required power of the machine. The performance of this machine has been tested for five times with various speeds and difference numbers of spike teeth. Having tested the performance of the motorized corn shelling machine, it could be concluded that the average of shelling efficiency, output capacity and damage efficiency are 87 %, 232 kg/h and 13 % respectively at 24 spike teeth. By changing the spike tooth at the numbers of 27, it was found that average shelling efficiency 94 %, output capacity 281 kg/h and damage efficiency 6%. At 30 spike teeth, shelling efficiency, output capacity and damage efficiency are 81 %, 263 kg/h and 19 % respectively. By consideration all factors such as damage efficiency, shelling efficiency and output capacity of 27 spike teeth are better than other spike teeth. Therefore, the 27 spike teeth of the corn shelling machine is more convenience and efficient than the other machine.

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