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Research Article

THE DESIGN AND ANALYSIS OF THE SCREW CONVEYOR BLADE FOR THE SMALL RICE MILLING MACHINE

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ABSTRACT:
The objective of this study was to design and analyze a screw conveyor blade for a small rice milling machine using Finite Element Analysis. The machine consists of a hopper with a cover, housing, the main structure support and a power transmission unit. The geometry of the machine was developed using Autodesk Inventor software. The model analysis for Finite Element Analysis was analyzed using Stress Analysis. Appropriate materials were selected for the components and design analysis was carried out. The maximum Von Mises stresses on the screw conveyor for the galvanized steel and stainless-steel materials were 1.649 and 1.645 MPa, respectively, and the maximum value of total deformation was 0.001998 and 0.001993 mm when a force of 9 N was applied to the screw conveyor and the main support of the structure. The result of FEA prediction leads to the comparison of the results of the analytical and experimental model.

Keywords: *Small rice milling machine, Finite element analysis, Dynamics simulation*

1. INTRODUCTION

This present in Thailand. The use of rice milling machine in agriculture industries has increased tremendously. Due to rice is very important to Thailand since it is the staple food of its people and Thailand is among the world's top rice exporters [1-3]. Milling is the process wherein the rice grain is transformed into a form suitable for human consumption [4-6]. Rice milling is removal or separation of husk and bran to obtain the edible portion for consumption [7]. At present there are various forms of rice milling machine those have been sold in general market in Thailand. The small rice milling machines for households are also one of them. Rice milling machines that are able to perform task efficiently are how a requirement in most factories and market.

The common rice milling problems is using the improper motor rotation. It will directly affect the result of breakage of the milled rice grains for separate the husks [8, 9]. Thus, this paper presents of the new design and analysis of screw conveyor blade of the small rice milling machines for the order to reduce the breakage of rice during Milling using 3D Computer Aided Design (CAD) and 3D Computer Aided Engineering (CAE) software called Autodesk Inventor Professional version 2014. shortened by enabling easy changes to the rice milling machine design. This software was chosen as it had previously been used other researchers and was able to help shorten small rice milling machines development time [10, 11]. Autodesk Inventor Professional enables development time to be shortened by enabling easy changes to the rice milling machine design.

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The use of Autodesk Inventor Professional is to the following goals. To calculate the optimum parameters for the design of a small rice milling machine based on Thai industrial standards (TIS). Design of a screw conveyor blade in a housing unit to understand the 3D geometric model. Analysis of the stress distribution and deformation on the screw conveyor blade by using simulation in stress analysis module of Autodesk Inventor Professional 2014. Analysis of the belt torque and diameter of the drive pulley using dynamic simulation module. The new design and development of a small rice milling machine in this work as shown in Fig. 1.

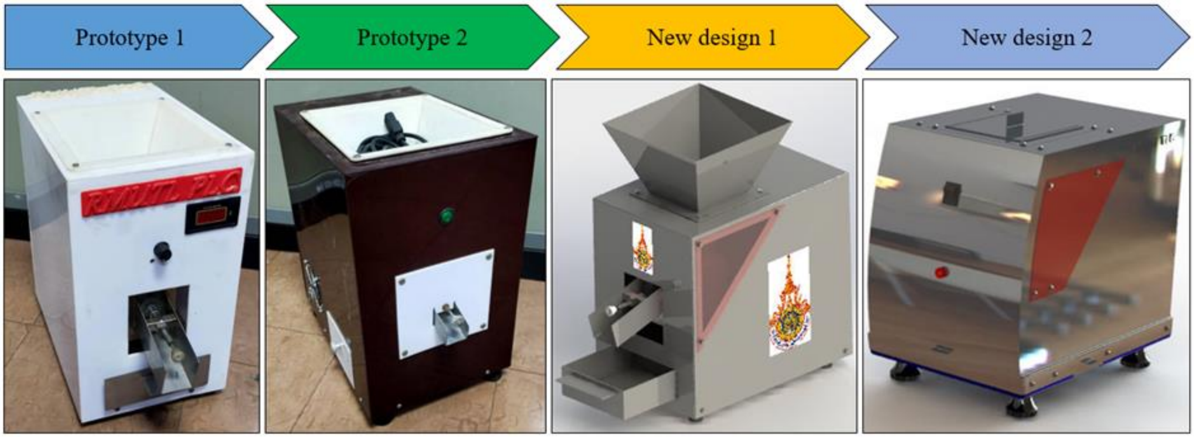

Fig. 1. The new design and development of the small rice milling machine [12].

From prototypes 1, 2 and new design 1, as shown in Fig. 1. Testing have found there are several problems, both in the distance where the screw conveyor blade and power transmission system was installed inappropriately. This causes vibrations in the operating system, as well as the positions of hopper rice unit that are to a small, etc. For this reason, the researchers decided to make a new design. By expand the shape of a small rice milling machine to a larger size, originally sized 350×350×350 mm and new size is 400×400×400 mm. And make a design to relocate the installation of the power transmission. The purpose of this paper is, therefore, to design the blade of the screw conveyor, hoppers unit and motor unit are suitable and improve the operating system to work properly. And choosing the right material for the actual prototyping. The new design 2 is the design and development of a small rice milling machine at obtained data of prototypes 1, 2, and the new design 1. The process of designing and developing a prototype for the new design 2 of a small rice milling machine can be illustrated as follows.

2. EXPERIMENTAL SETUP

The optimal design and procedure are to find the parameters associated with the small rice milling machine. Thus, we can calculate the parameters as follows:

2.1 Parameters calculation of a small rice milling machine

2.1.1 The hopper design

The hopper of a small rice milling machine was designed to provide space for easy assembly. The volume for the upper part (V_1), the volume of the lower part (V_2) and can be calculated V_{totoal} as follows [8, 9, 13, 14].

$$V_1 = \frac{H}{3} \times \left(a^2 + ab + b^2\right) \tag{1}$$

$$V_1 = 3.86 \times 10^{-4} m^3$$

$$V_2 = L \times B \times H \tag{2}$$

$$V_2 = 6.31 \times 10^{-5} m^3$$

$$V_{total} = 4.49 \times 10^{-4} m^3$$

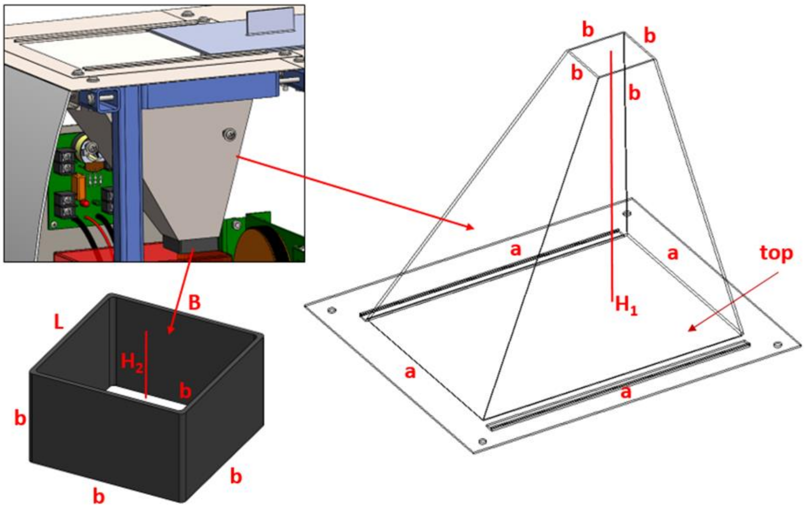

Fig. 2. Detail of the machine hopper and housing of the small rice milling machine.

Figure 2 shows the parameters values of hopper and housing, where a is Area of top section of hopper = 0.03848 m2; b is Area of bottom section of hopper = 0.000841 m2; L is Width of bottom section of hopper = 0.029 m; B is Width of bottom section of hopper = 0.029 m; H1 is Height of top section of hopper = 0.075 m; H2 is Height of Bottom section of hopper = 0.020 m.

2.1.2 Determination of the weight of rice in hopper

The weight of rice in the hopper can be determined as follows.

$$W_1 = \rho_B \times V_{totol} \times 9.81 m/s^2 \tag{3}$$

Where (ρ_B) = Bulk density of the unhusked rice=0.642 g/ml (642 kg/m^3)

$$W_1 = 641 kg/m^3 \times 4.49 \times 10^{-4} m^3 \times 9.81 m/s^2$$

$$W_1 = 2.82 N$$

In this work, the design of the screw conveyor blade, researcher determined of values of the compression force for weight of rice in the hopper are 3, 6 and 9 N.

2.1.3 Define of electric motor

An electric motor connected to pulley was use to transmit torque to the rotor shaft and screw conveyor blade for conveying of paddy. The motor is rated 1/2 HP 1,750 rpm. The electric motor for small rice milling machine system as shows Fig. 3.

Fig. 3. The electric motor for small rice milling machine system.

2.1.4 Pulley diameter design

In this work, the researcher requirement to select a motor size of 1/2 HP at 1,750 rpm, the diameter of the pulley is 26 mm for pulley motor and diameter of 90 mm for the driven pulley. Motor speed in this work is used for driven shaft connected to pulley of screw conveyor blade. The rpm of screw conveyor blade can be determining by [8, 9].

$$d_1 N_1 = d_2 N_2 \tag{4}$$

Where d_1 and d_2 is the diameter of the is the diameter of the driving pulley. A d_1 is 26 mm and a d_2 is 90 mm. The rotational speed of the motor (N_1) is: 1,750 RPM. Thus, the speed on shaft can be shown below:

$$N_2 = \frac{d_1 N_1}{d_2} = \frac{0.026 \times 1,750}{0.090} = 506 rpm$$

2.1.5 The design of belt size

The belt length can be calculated by using the equation as follow:

$$L = \frac{\pi}{2}(d_1 + d_2) + 2c + \frac{1}{4c}(d_1 + d_2)^2 \tag{5}$$

Where L is length of belt (mm).
C is center distance (mm).

$$L = \frac{3.14}{2} \times (26+90) + (2 \times 80) + \left(\frac{1}{4 \times 80}(26+90)^2 \right) = 384.17 mm$$

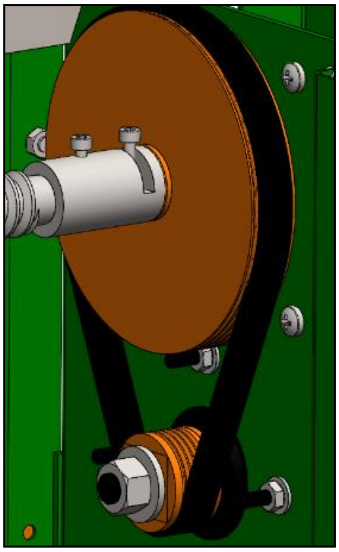

Fig. 4. New design of belt sizes by using Autodesk Inventor Professional program.

Figure 4 shows the new design of the belt sizes, shaft pulley, and the location of the pulley installation by using Autodesk Inventor Professional program. When the center distance (C) between the motor pulley and the shaft pulley was determined to be 80 mm.

2.1.6 Contact angle of belt

The contact angle of belt (θ) for both the driver can be determined by using the equation below:

$$\sin \alpha = \frac{d_2 - d_1}{2c} \tag{6}$$

$$\theta = 180^{O} - 2\alpha \tag{7}$$

$$\sin\alpha = \frac{d_2 - d_1}{2c} = \frac{90mm - 26mm}{2\times 80mm} = 0.4$$

$$\alpha = \sin^{-1}(0.4) = 23.58$$

$$\therefore \theta_1 = 180^{O} - 2\times(23.58) = 132.84^{O}$$

$$\therefore \theta_2 = 180^{O} + 2\times(23.58) = 277.16^{O}$$

2.1.7 Calculation of the belt speed

In this work, we can be calculated the belt speed by using the formula as follow:

$$Belt\ speed = \frac{\pi d_1 N_1}{60} \tag{8}$$

$$Belt\ speed = \frac{3.14\times 0.026m\times 1,750rpm}{60} = 2.83m/s$$

2.1.8 Calculation of torque on the shaft

The torque on the shaft of the screw conveyor blade can be calculated by using the equation below:

$$T = \frac{60P}{2\pi N} \tag{9}$$

$$T = \frac{60\times 370W}{2\times 3.14\times 1,750rpm} = 2.02N.m$$

2.1.9 The shaft sizes design for the screw conveyor blade

The design of the shaft sizes for the screw conveyor blade can be calculated by using the equation below:

$$\tau_{\max} = \frac{Tr}{J} \tag{10}$$

Where $\tau_{\max}$ is maximum shear stress (N/mm^2)
T is torque ($N.m$)
J is the polar moment of inertia (m^4)
r is radius (m)
T is torque ($N.m$)

$$\therefore 150N/mm^2 = \frac{16\times 2.02\times 10^3}{3.14\times D^3}$$

$$\therefore D = \sqrt[3]{\frac{16\times 2.02\times 10^3}{150\times 3.14}} = 4.09mm$$

The safety of factor FOS value for the shaft sizes design is 3. Thus, the size of the shaft used in this work is 12 mm.

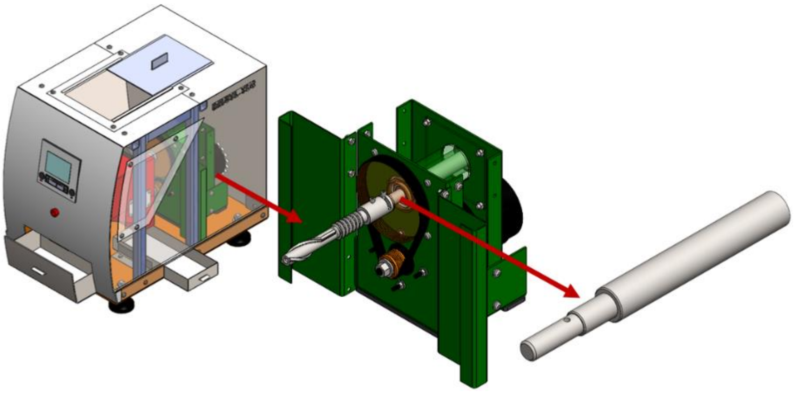

Fig. 5. Shaft of the screw conveyor blade.

Figure 5 shows the shaft sizes for the screw conveyor blade obtained by design. Thus, the design is safe since the FOS value is greater than 2.0.

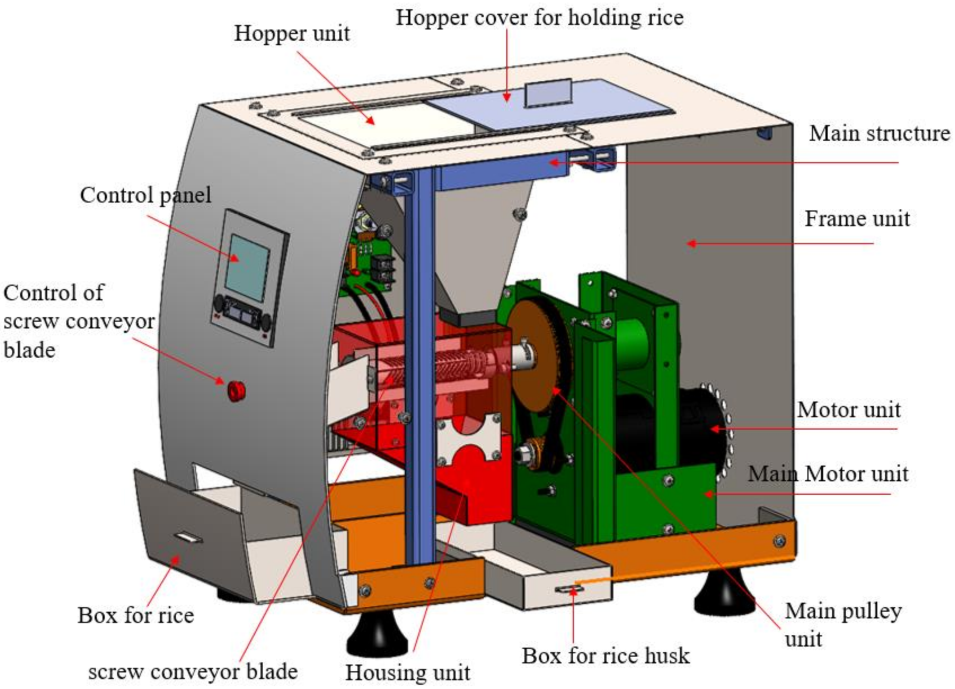

Fig. 6. New design for a component of the small rice milling machine.

Figure 6 shows the components that were used to assemble the small rice milling machine. Part modelling and assembly, the operation of the mechanism, and operation for the small rice milling machine system were newly designed. The main structure of the small rice milling machine is 305 mm long, 445 mm wide, and 418 mm high.

2.2 Theory of analysis

2.2.1 Principle of the finite element model

The model of finite element structure. Consisting of a node and element. The element, considering only one node, found that the degree of freedom has a maximum of 6 independent variables. The detail of the mesh element model was shown in Fig. 7.

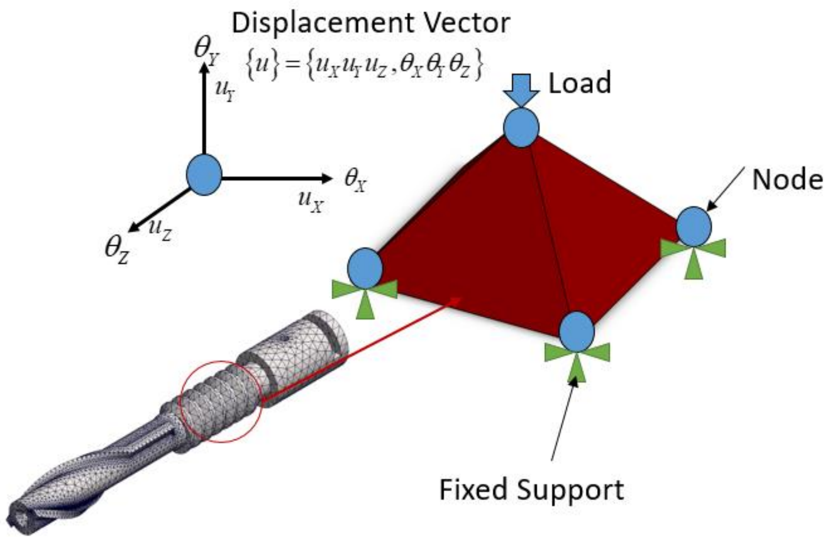

Fig. 7. Detail of mesh element model

Figure 7 shows the degree of freedom of mesh element employed in most cases is shown given below.

Tree Translations $(u_X u_Y u_Z)$ (11)

Tree rotations $(\theta_X \theta_Y \theta_Z)$ (12)

When $\{u\} = displacement\ vector$

$\{u_X u_Y u_Z, \theta_X \theta_Y \theta_Z\}$ (13)

2.2.2 Theory of finite element analysis

In this works, we can the concepts and determine formulated into matrix equations that are suitable for analysis by using the FEM technique. For the structural analysis of the designed screw conveyor blade can be seen that the displacement, stiffness, and loads are related. Thus, the governing equation of the linear static finite element analysis is given below.

$$[K]\ \{q\} = \{F\} \tag{14}$$

Where $[K]$ is structural stiffness.

$\{q\}$ is Nodal displacement.

$\{F\}$ is load matrix.

2.3 Numerical of simulation

2.3.1 Estimation of FEA meshing

In this works, the details of the settings for creating a mesh can be displayed as follows.

- Type of element is the triangular.
- Elements of the screw conveyor blade is 61,723.
- Nodes of the screw conveyor blade is 93,551.
- Crating the curve mesh element for the screw conveyor blade. The creation of the FEA meshing, as detailed above, is shown in Fig. 8.

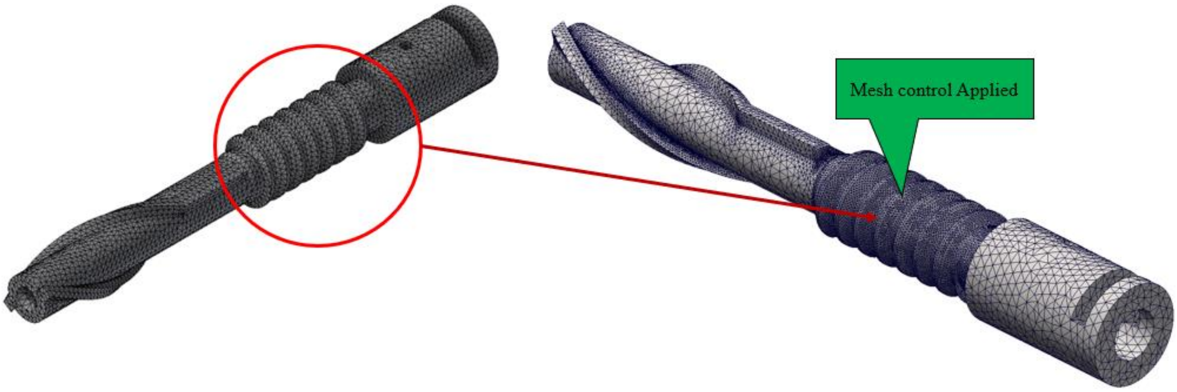

Fig. 8. Estimation of FEA meshing for the screw conveyor blade.

Figure 8 shows the area where mesh element resolution is controlled. This is because it is where the rice from hopper falls on the surface of the screw conveyor blade. Controlling mesh elements in areas where accurate results are required reduces the percentage of error in the result.

2.3.2 Material properties

The materials properties of stainless steel and steel galvanized are selected with young's modulus, Poisson's ratio, shear modulus and Mass density. Materials properties as shown in Tables 1 and Table 2.

Table 1: Stainless steel parameters.

Parameters of AISI304:	**Value**	**Unit**
Young's modulus	193,000	MPa
Poisson's ratio	0.30	N/A
Shear modulus	86,000	MPa
Mass density	8,000	Kg/m^3

Table 2: Steel galvanized parameters.

Parameters of alloy steel:	**Value**	**Unit**
Young's modulus	200,000	MPa
Poisson's ratio	0.30	N/A
Shear modulus	75,842	MPa
Mass density	7,850	Kg/m^3

2.3.3 Boundary condition

To reduce the simulation time, the Remote force boundary condition is used to apply a force to a face of a screw conveyor blade from a remote point [8, 9]. From calculating Equations 1, 2 and 3 for the hopper design and the weight of rice in the hopper and defined, the value of the force of 3 N, at the distance point, is 191 mm. The fixed supports and pined constraints are applied at the screw conveyor blade axis. The screw conveyor blade is analyzed under its self-weight by applying gravitational acceleration of 9.81 m/sec2 in the Stress Analysis module in Autodesk Inventor software. The Boundary condition for FEA was shown in Fig. 9.

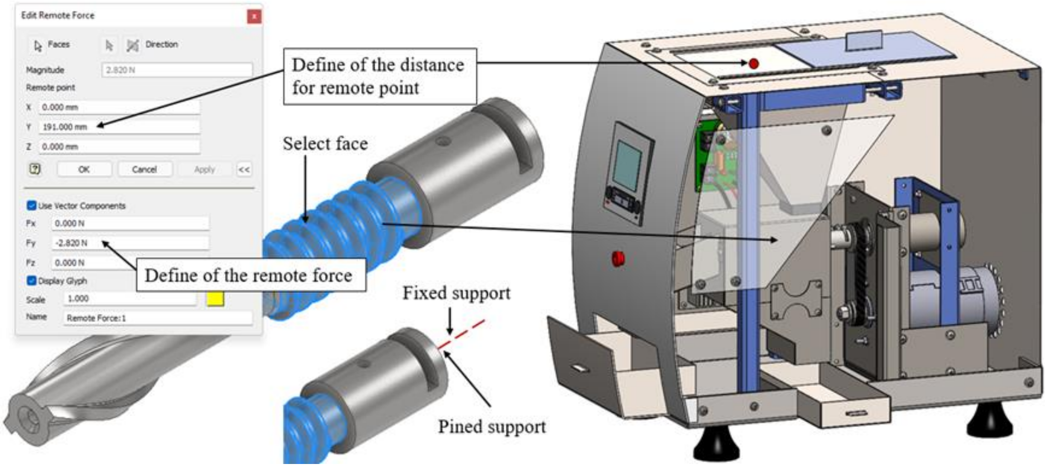

Fig. 9. Boundary condition of the screw conveyor blade.

3. Results and Discussion

The material properties of stainless steel and galvanized steel are selected from Tables 1 and 2. For the simulation in this paper, the researcher set the values of force to 3, 6 and 9 N, respectively. Fixed supports and pined constraints are applied at the screw conveyor blade axis. The screw conveyor blade is analyzed under its own-weight by applying gravitational acceleration of 9.81 m/sec^2. The stress analysis results are shown in Fig. 10-15.

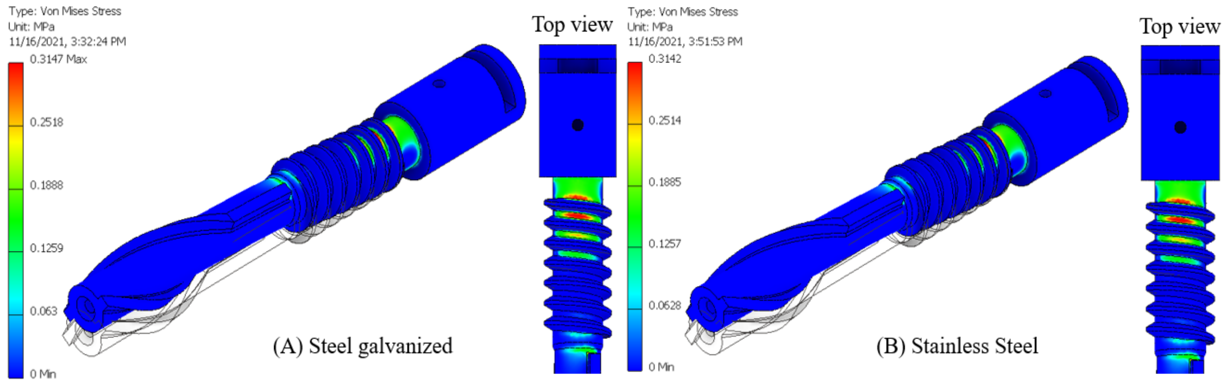

Fig. 10. 3D Von miss stress on the screw conveyor blade for a force at 3 N.

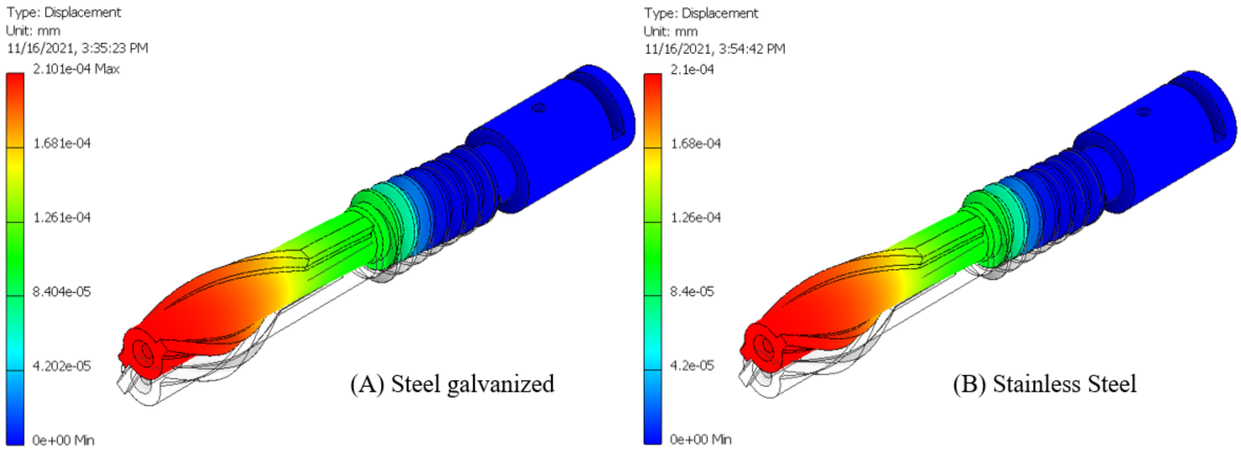

Fig. 11. Maximum displacement on the screw conveyor blade for a force at 3 N.

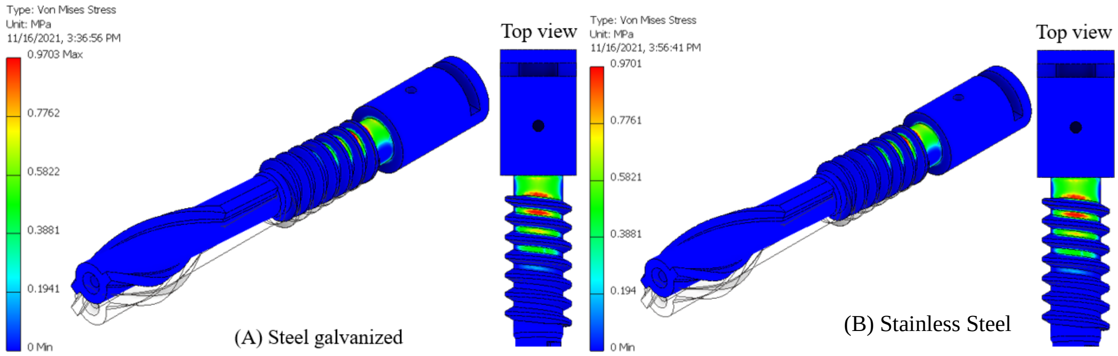

Fig. 12. 3D Von miss stress on the screw conveyor blade for a force at 6 N.

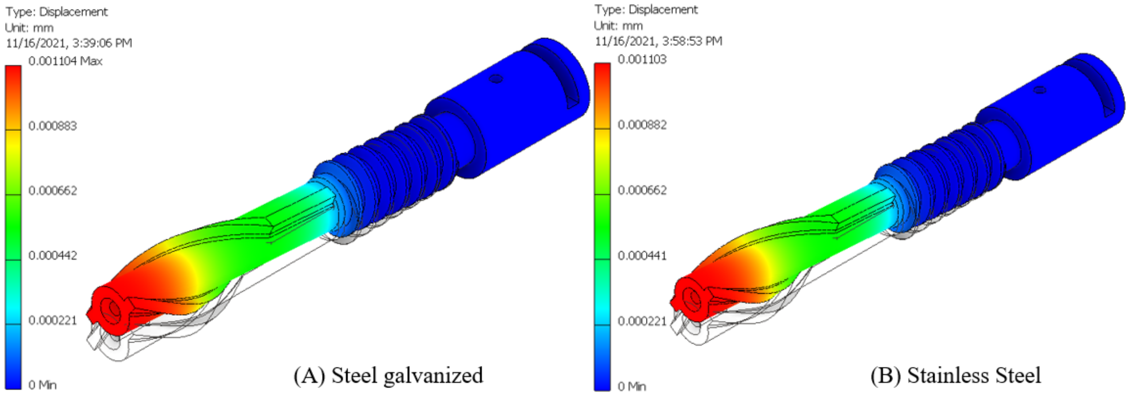

Fig. 13. Maximum displacement on the screw conveyor blade for a force at 6 N.

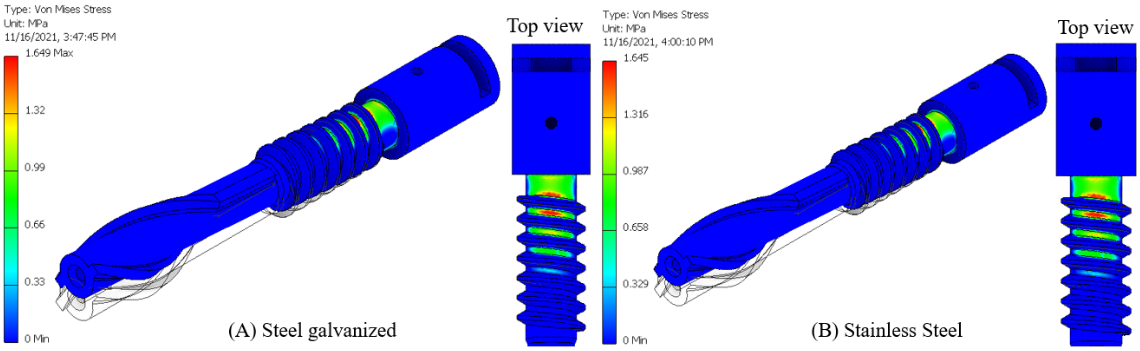

Fig. 14. 3D Von miss stress on the screw conveyor blade for a force at 9 N.

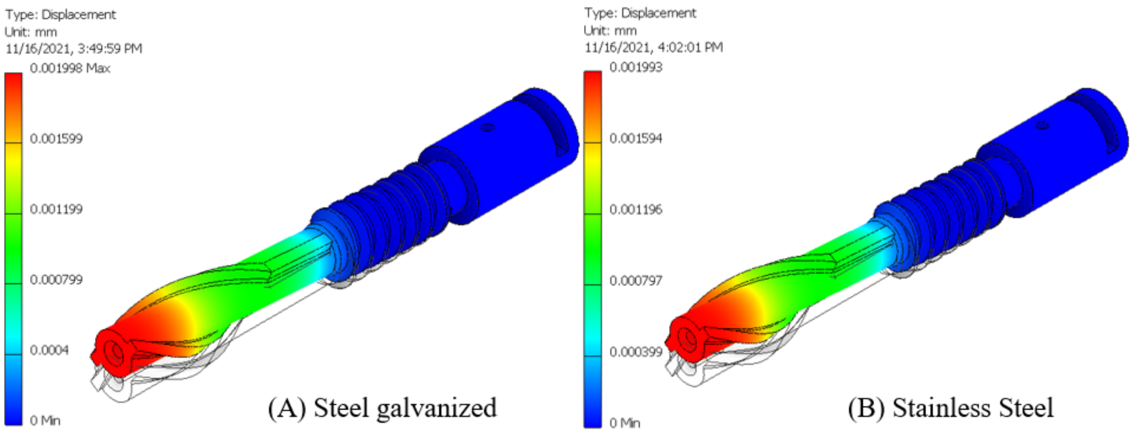

Fig. 15. Maximum displacement on the screw conveyor blade for a force at 9 N.

The finite element models for both material types in this study are shown in Fig. 7. The maximum Von Mises stresses at the screw conveyor blade of 9 N for the galvanized steel and stainless-steel materials were 1.649 and 1.645 MPa, respectively, as shown in Fig. 14. The total deformation when the weight of the rice in the hopper impinged on the screw conveyor blade of both types of material was maximum at a joint of the screw conveyor blade structure. The maximum value of total deformation at a compressive force of 9 N was 0.001998 and 0.001993 mm, as shown in Fig. 15. The screw conveyor blade with a maximum load of 9 N maximum, safety factors of 15 ul maximum and minimum 2.453 and 2.491 ul, respectively. Table 3 shows the results of FEA simulation with different types of forces. The use of different forces aimed to find the maximum strength of the screw conveyor blade of the small rice milling machine structure.

Table 3: Table showing a summary of the analysis of two different materials.

Resulting	Parameter	Materials					
		Steel galvanized			Stainless steel		
	Mass of rice	0.30 kg	0.61 kg	0.92 kg	0.30 kg	0.61 kg	0.92 kg
	Force	3N	6N	9N	3N	6N	9N
Von mises stress (MPa)	Min	0	0	0	0	0	0
	Max	0.3147	0.9703	1.649	0.3142	0.9701	1.645
3st principal stress (MPa)	Min	-0.0743	-0.232	-0.388	-0.091	-0.302	-0.507
	Max	0.9564	1.175	2.017	0.356	1.055	1.758
3rd principal stress (MPa)	Min	-0.376	-1.208	-2.071	-0.376	-1.144	-1.911
	Max	0.0623	0.187	0.312	0.884	0.283	0.478
Displacement (mm)	Min	0	0	0	0	0	0
	Max	$2.101e^{-04}$	$1.104e^{-03}$	$1.998e^{-03}$	$2.10e^{-04}$	$1.13e^{-03}$	$1.993e^{-03}$
Safety factor (ul)	Min	2.045	2.353	2.453	2.051	2.138	2.491
	Max	15.00	15.00	15.00	15.00	15.00	15.00

In this works, the researchers introduced the Dynamics Simulation module in Autodesk Inventor Professional 2014 to help with the design. The main purpose is to design and analyses are the calculated for the motor speed, and range of power suitable for small rice milling machines. The Dynamics Simulation is an important tool in today's design. Researcher can use it generate results for the angular velocity, angular acceleration, motor torque, and power consumption. The details of the settings for creating a dynamics simulation can be displayed as follows.

- Define the CAD domain of the problem for dynamics Simulation module.
- Define the degree of freedom (dof) is imposed motion.
- Define the motor speed ranges of the screw conveyor blade at 1500, 1600, 1700 and 1800 rpm.
- Define time for analysis is 7s.
- Computes the unknown values of the dynamic simulations.

Figure 16 shows the comparison results for the motor speed ranges of the screw conveyor at 1500, 1600, 1700 and 1800 rpm, respectively. From the plot of angular velocity versus time, it can be seen that the highest angular velocity is obtained in the motor speed range between 1700 and 1800 rpm at 7s. This speed range was also in accordance with the design specifications.

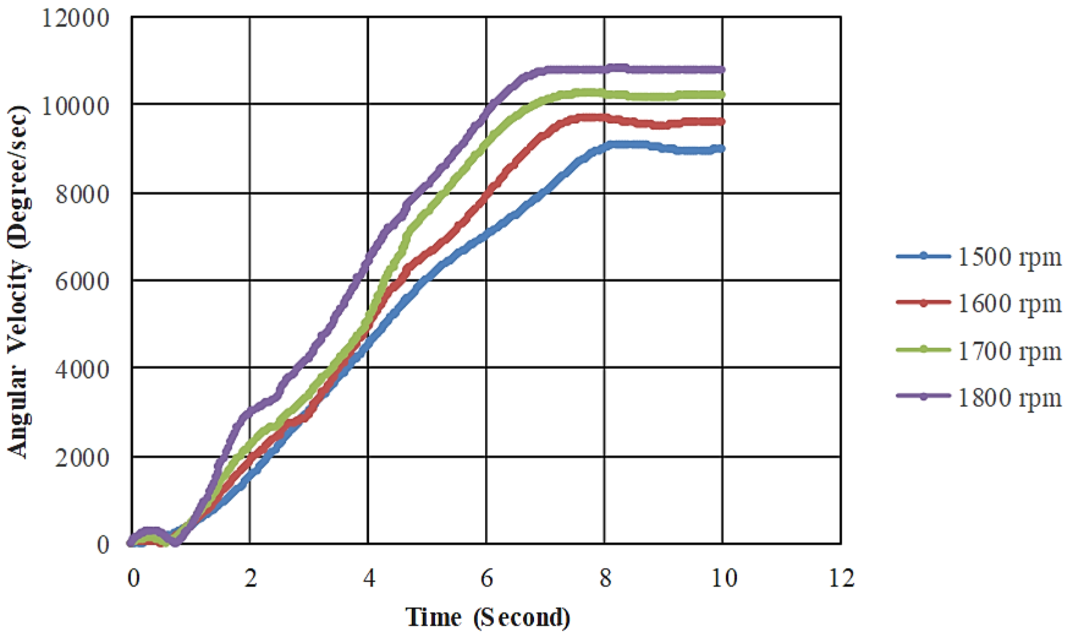

Fig. 16. Comparison the results for the rotation speed ranges.

In this paper, angular acceleration is defined as the rate of change of the angular velocity. From the graph of angular acceleration versus time, it can be seen that the highest acceleration occurs in the motor speed range between 1700-1800 rpm at 1.5s. This speed range also matched the planned specification, with the researcher had chosen a motor size of 1/2 HP at 1,750 rpm. The graph of angular acceleration is shown in Fig. 17.

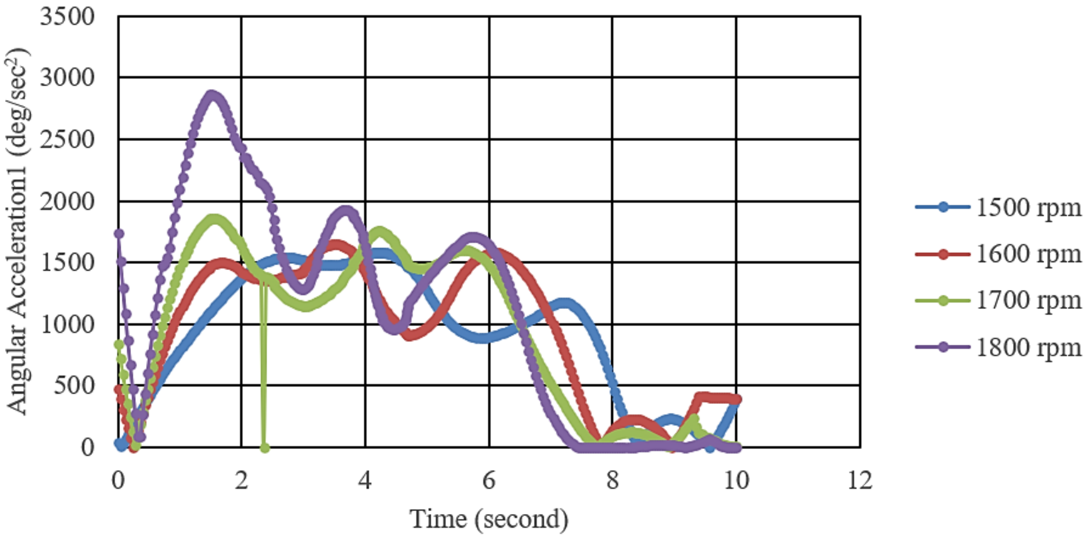

Fig. 17. Comparison the results of the angular acceleration.

Figure 18 shows the results of the motor torque. From the plot of motor torque versus time, it can be seen that the motor torque is in the speed range between 1500-1800 rpm and that the optimum design of the motor speed range is 1700-1800 rpm. Due to the rotational speed range of 1700-1800 rpm, which can work to transmit paddy rice to the paddy separator point more suitable than other rotation cycles when comparing each other. This is in accordance with the planned specification. In the range of the motor speed between 1500 and 1600 rpm. This is the range where the highest power is generated when driving the pulley. This results in wastage of power consumption in the actual working system. The result of power wastage of the motor speed at 1500 and 1600 rpm is shown in Fig. 19.

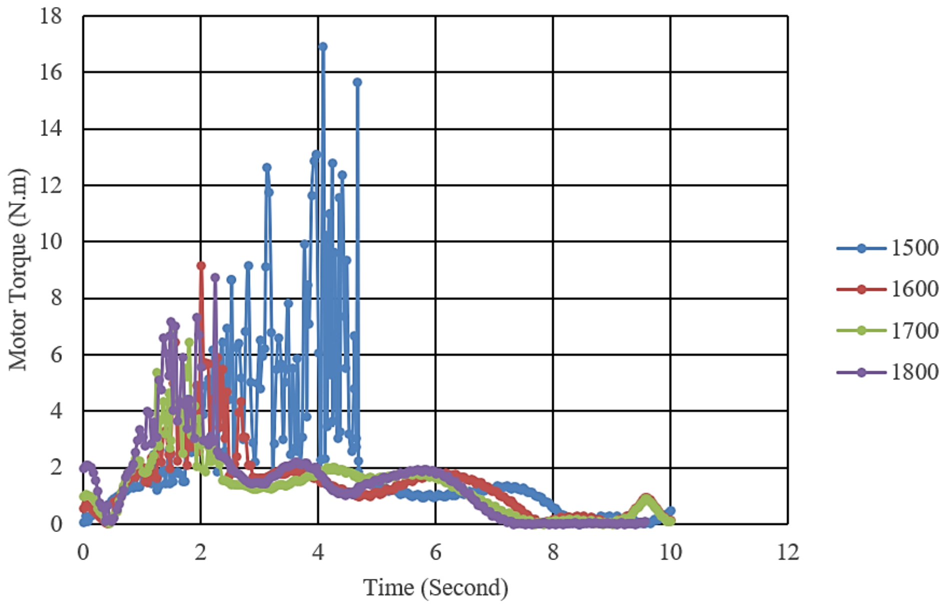

Fig. 18. Comparison the results of the motor torque.

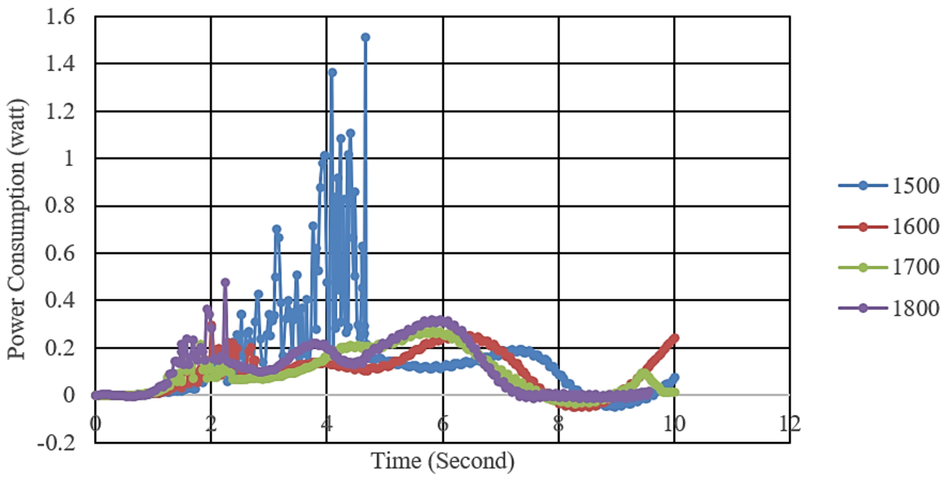

Fig. 19. Comparison the results of the power consumption.

In conducting the performance evaluation of the design and analysis of the small rice milling machine. The hopper was designed for a maximum weight of 0.30, 0.61 and 0.92 kg with a compressive force of 3, 6 and 9 N of the paddy rice. Stress analysis and deformation of the small rice milling machine were performed by using a stress analysis module of Autodesk Inventor Professional 2014 software. In this study, the compressive force and weight of rice varied in the hopper of area from 3, 6, and 9 N, respectively. Figure 9, 11, and 13 compare the maximum Von Mises stresses and maximum value of total deformation obtained for both types of materials and compressive force of 3, 6, and 9 N. The maximum Von Mises stress obtained from the galvanized steel and stainless steel at the screw conveyor blade of the small rice milling machine was 1.649 and 1.645 MPa, respectively. The maximum total value observed on the screw conveyor blade obtained from the galvanized steel was 0.001998 mm. Contrastively, the maximum value of total deformations of 0.001993 mm was observed on the screw conveyor blade obtained from the stainless steel. From the results, it can be seen that, the parts of the screw conveyor made of the galvanized steel and stainless steel have similar results. Therefore, investigators were able to select a galvanized steel material with cheaper prices to build actual prototypes. Based on the dynamic simulation results, it was found that the optimum motor speed ranges of screw conveyor blade are 1700 and 1800 rpm at 7s, as shown in Fig. 13. The result of the motion analysis of angular acceleration, motor torque and power consumption of the screw conveyor blade showed that the optimum motor speed ranges are 1700 and 1800 rpm which also met the designed specification, as shown in Fig. 17-19.

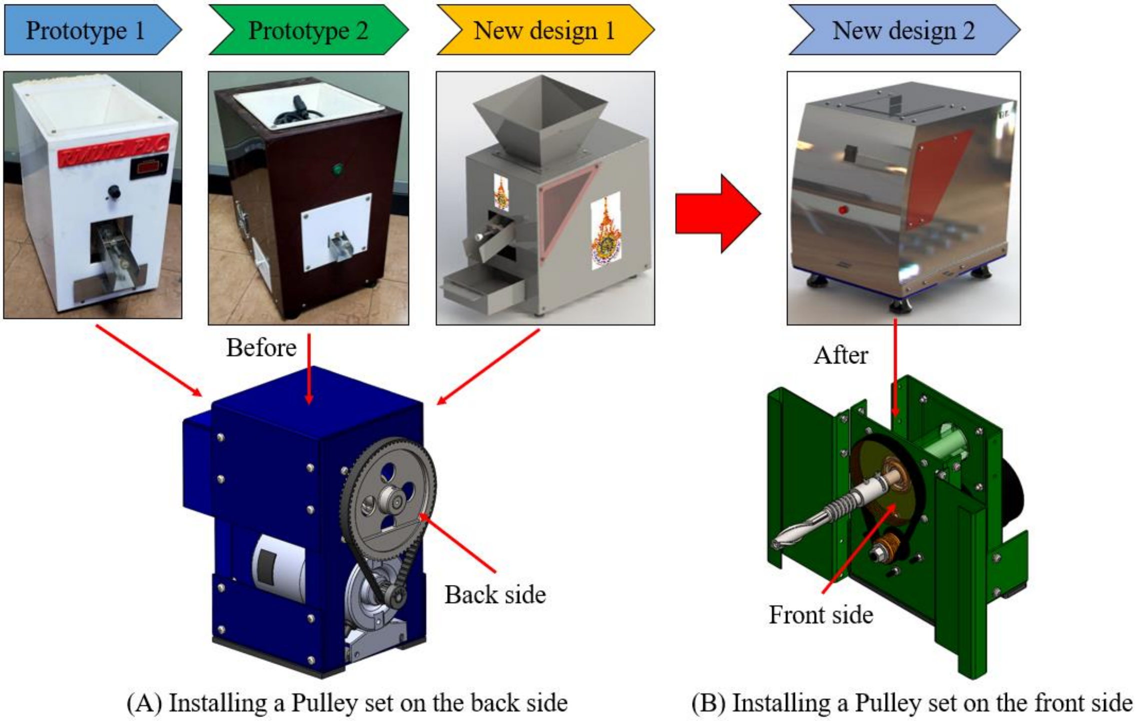

Fig. 20. Comparison the designs of the power transmission system for the screw conveyor blade.

Figure 20 the researchers showed a pattern comparing the results of the installation of older and redesigned motor power transmissions. According to studies and designs of the installation of the motor power transmission system of the small rice milling machine for prototype 1-3, which has installed a Pulley set on the back side of the rice milling machine. As a result, it affects more vibration than installing a Pulley kit in front side of a small rice milling machine redesigned in the research.

4. CONCLUSION

Based on the simulation results of the analysis of the construction strength of the screw conveyor blade for the small rice milling machine using the Autodesk inventor professional software 2014, it can be concluded that;

1. The construction of the screw conveyor blade can withstand a load of 9 kg.
2. The maximum stress occurs at 9 N loading, amounting to 1.645 MPa.
3. Maximum deformation occurs at 9 N loading, amounting to 0.001993 mm.
4. Installing a Pulley kit on the back of the rice milling machine will affect the vibrations more than installing the Pulley set in front of the rice milling machine.
5. Investigators were able to select a galvanized steel material with cheaper prices to build actual prototypes.

This result of the stress analysis and dynamics simulation of can be calculated from the mathematical parameters of a design program for the developing of a main structure of the small rice milling machine for the high efficiency community. The best combination of different design parameters will lead to efficient and successful implementation and help to meet the requirements of rice milling machine demands with low installation cost and negligible maintenance for agricultural industry in Thailand.

NOMENCLATURE

C	center distance, mm
D	diameter of shaft, mm
F	load matrix
J	the polar moment of inertia, m^4
K	structure stiffness matrix

L	length of belt, mm
q	nodal displacement
r	radius, m
T	torque, $N.m$
u	displacement vector, m/s
V_1	the volume of the upper part, m^3
V_2	the volume of the lower part, m^3
V_{total}	total volume of a rice grain, m^3
W_1	weight of a rice, N
ρ_B	bulk density of the unhusked rice, kg/m^3
$\tau_{\max}$	maximum shear stress, N/mm^2
θ	contact angle of belt

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