Research Article

Study on Track Frame Model of a Thai-Made Rice Combine Harvester

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Abstract: A rice combine harvester has an important role in Thai rice production and has been popular in Thai farmer. Almost Thai-made rice combine harvester is too heavy and large in size. Because the track frame of Thai-made rice combine harvester is a main component that affects the harvester's size and weight, the objectives of this research, therefore, were to investigate and improve the track frame strength using the finite element method (FEM). Similitude analysis was employed for determining the proper scale of experimental frame. The strength analysis using the loading test with experimental frame was used to verify the accuracy of the FEM. Two field-work conditions of the harvester's header were selected namely horizontal position and maximum lift position. The FEM results showed that the maximum stresses of those conditions were 91.13 MPa and 91.69 MPa, respectively, while the maximum deflection 2.31 mm and 2.36 mm, respectively. The experimental results from the loading tests confirmed that the strength analysis of track frame using FEM had a high accuracy and could be applied in practical use. The improvement of the track frame model could increase the strength about 40% and reduce mass about 18%.

Keywords: Rice Combine Harvester, Track Frame, Strength Analysis, Finite Element Method

1. Introduction

Agriculture is not alone in dealing with human food shortages, but still needs to supply enough renewable energy to meet the needs. While agricultural land and labor continued to reduce in order to increase agricultural productivity and efficiency. Therefore, agricultural machinery and various technologies have been introduced to help with farming. Agricultural machinery plays an important role in the different procedures of agricultural work.

A rice combine harvester is agricultural machinery that plays an important role in the rice production process of Thailand. The main mechanical systems of the Thai rice combine harvester can be classified into 4 systems: harvester and conveying system, threshing and cleaning system, undercarriage and drive system, and the powerful engine system [1]. The development approach of the Thai rice combine harvester often focuses on having high performance and being able to work in any area. As a result, the rice combine harvester has a working width and relatively large and heavyweight. The development of the combine harvester in this direction has a negative effect on rice cultivation because it causes structural damage to the soil [2]. It also makes the combine harvester more expensive [3]. When comparing the Thai rice combine harvester with the foreign rice combine harvester, it was found that the foreign rice combine harvester was relatively small and lightweight. These factors are the main reasons why the foreign rice combine harvester is increasingly popular with farmers. Although the foreign rice combine harvester will operate in a limited state of the land. Therefore, the Thai rice combine harvester needs to be developed to a suitable size to minimize the impact on the farm, reduce production costs, as well as increasing competitiveness in both domestic and export markets.

From a discussion meeting between Thai rice combine harvester manufacturers and researchers, a solution to the above problem has been established. It focuses on improving parts of the Thai rice combine harvester to be able to lose weight, increase strength, and reduce energy consumption in driving. Studying the factors involved in the production of Thai rice combine harvester, it was found that the construction of the undercarriage was simply the introduction of the tracked drive system of a large caterpillar tractor. This results in a very strong structure, quite large size, and heavyweight. In general, the Thai rice combine harvester weighs approximately 7,000-10,000 kg, the undercarriage of the combine harvester weighs more than 30% of the machine weight, requires about 35-40% of the power to drive the plant [4]. The undercarriage of the Thai rice combine harvester consists of a track frame, a drive chain set, a sprocket set, a roller set, and a track blade set. The track frame weighs approximately 25% of the undercarriage [5]. Therefore, this research project has an idea to improve the track frame of the Thai rice combine harvester to reduce weight. However, it is still able to support the weight of the other structures of the Thai rice combine harvester as well or better than the original track frame.

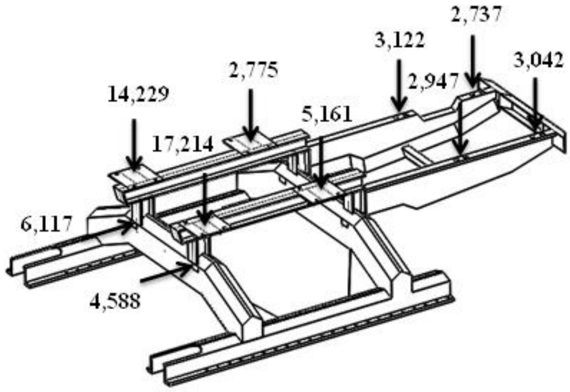
2. Research Objectives

This research has the objective to investigate and improve the track frame strength of the Thai rice combine harvester to reduce weight. However, it is still able to support the weight of other structural parts of the Thai rice combine harvester.

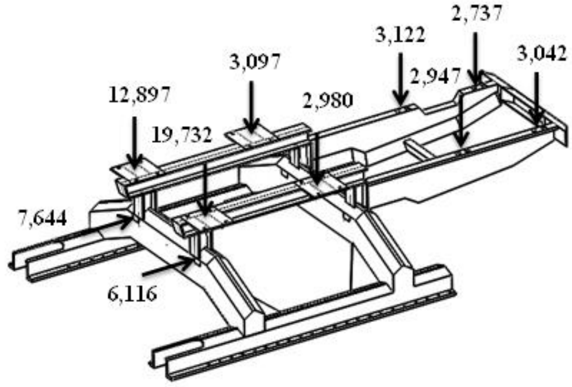
3. Research Methods

A. Load Exerted on the Track Frame of the Thai Rice Combine Harvester

The track frame of the Thai rice combine harvester does not have a clear design and standard. Therefore, this research uses data from Talaythong brand rice combine harvester from Talaythong Factory Co., Ltd. [5]. The weights from the rice combine harvester components act on 10 undercarriages, divided by 2 types of performance characteristics as follows: 1) The horizontal header position means the rice combine harvester is being harvested. And 2) The maximum lift header position means the rice combine harvester reversing head and changing working area as shown in Fig. 1 [6].



(a) Horizontal header position



(b) Maximum lift header position

Fig. 1 Direction and magnitude of external forces on the track frame model under two field work conditions (digits denote forces in Newton)

B. Strength Analysis by Finite Element Method

The strength analysis by finite element method is divided into 3 steps: 1) Real proportionate finite element modeling with SolidWorks program. 2) Setting the conditions, model material properties, and the force exerted on the track frame according to the working characteristics and 3) Stress and deflection analysis of the model.

The finite element model of the Thai rice combine harvester track frame was made to be a 10-node tetrahedral element and unequal in size due to its complex structure. Therefore, the model has a suitable mesh size of 150-19 mm, which makes it has 45,360 elements and 89,887 nodes as Fig. 2. By similitude analysis [7], the miniature track frame models were obtained with suitable mesh sizes in the range of 50-7.2 mm, resulting in 44,553 elements and 88,217 nodes.

Static structural analysis was applied to condition the finite element model of the track frame. The von Mises failure theory was determined as follows: Table I. The von Mises failure theory was analyzed for the strength of the model.

Fig. 2 Mesh of the track frame model

Table I Material property for FEM analysis

Property	Mild Steel
Young's modulus (GPa)	200
Shear modulus (GPa)	79.3
Yield stress (MPa)	250
Tensile strength (MPa)	400
Poisson ratio	0.26
Density (Mgm^{-3})	7.85

C. Experimental Model of Thai Rice Combine Harvester Track Frame and Loading Tests

The experimental model of the Thai rice combine harvester track frame was created to verify the accuracy of the strength analysis using the finite element method. The validity was validated by comparing the stress and deflection between the finite element method (FEM) and the loading test under the rated load. The experimental model was constructed of SS400 steel, features as shown in Table I, and is welded to the same structure by arc welding.

The stress on the experimental model was measured using a 45° 3-element Rosette TML strain gauge, stacked type model FRA-1-11-1L, and was amplified with a Yokogawa brand amplifier MW100. The Kennedy 300-7520K dial gauge with a resolution of 0.01 mm was used to measure the deflection of the model.

Due to the load determination limit on the experimental model, the loading test is divided into two types: The type 1 loading test was a simple force test by hanging weights with dimensions 103 N 227 N 330 N 503 N 727 N 1005 N and 1257 N performed vertically at the center of mass (CG) of the model as shown in Fig. 3. To compare the stress and deflection values that occurred in the FEM model with the experimental model, the strain and deflection were measured with position C. The type 2 loading test (Fig. 4) was performed to simulate the track frame load situation. A load of 500 N performed vertically in positions A, B, E, and F, and a load of 230 N act vertically at positions C, D, G, and H, to measure the stress occurring on position A, B, C and D, as well as to measure the deflection of the experimental model at the position I (Fig. 5) [6].

Fig. 3 Loading test 1

Fig. 4 Loading test 2

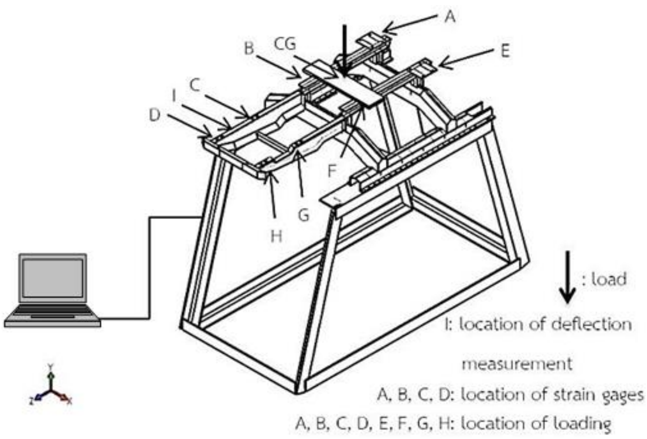


Fig. 5 Loading test set-up

D. Improvement of the Track Frame Model of the Thai Rice Combine Harvester

The track frame model of the rice combine harvester has been redesigned to be robust, in line with agricultural machinery design principles, and has reduced mass. However, it still corresponds to the parts of the old system, that the operator has already produced. There are 3 types as follows: Pattern 1, install a steel beam with a thickness of 9 mm to increase the strength at the center of the two rear pillars of the track frame as shown in Fig. 6. Pattern 2, developed to reduce the additional installed mass 50% from pattern 1, as shown in Fig. 7. And pattern 3, developed from model 1 by modifying the track frame design to simplify machining and assembly. Including reducing the thickness of steel A, B, C, D, E, and F from 9 mm to 6 mm to reduce the weight of the track frame and have the appropriate strength as Fig. 8.

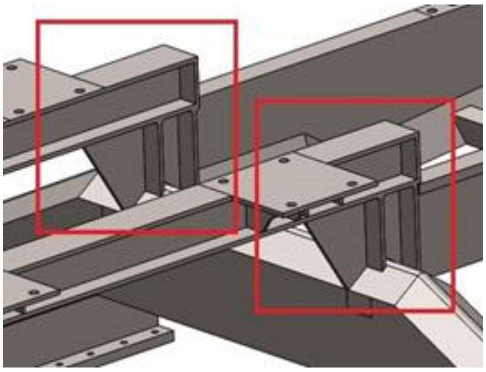


Fig. 6 The development in pattern 1

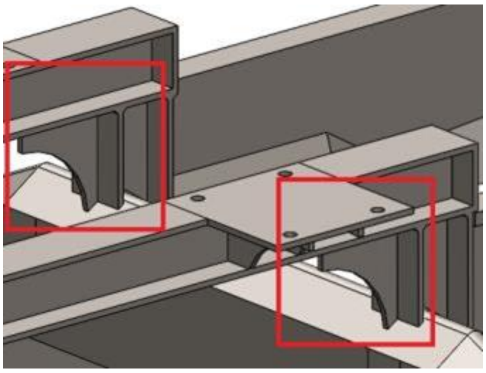


Fig. 7 The development in pattern 2

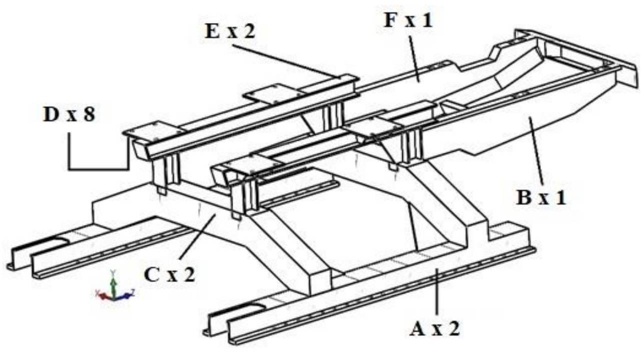
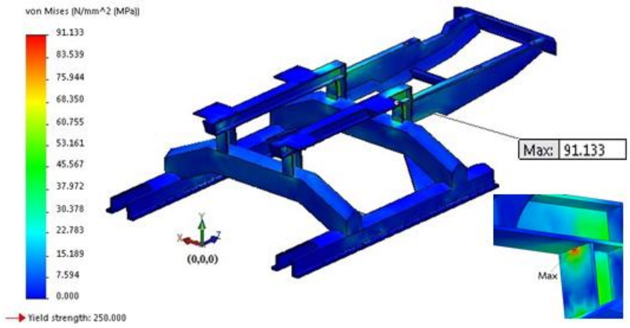


Fig. 8 The development in pattern 3

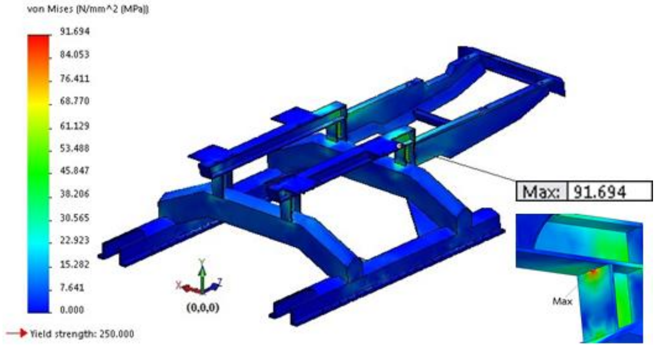
4. Research Results

A. The Results of the Analysis of the Track Frame Strength of Thai Rice Combine Harvester by Finite Element Method

From measuring the load on the track frame of the harvester, it was found that the maximum load position is 17,214 N and 19,732 N in the case of the header was in the horizontal position and the header was raised at the maximum lift position, respectively. At the same time, the least loaded position is equal to 2,737 N (Fig. 1). The results of the analysis of the track frame strength of the Thai rice combine harvester by finite element method showed that the maximum stress occurred in the case of the header was in the horizontal position and the header was raised at the maximum lift position, the values were 91.13 MPa and 91.69 MPa, respectively. This resulted in a safety factor of 2.7 in both cases as shown in Fig. 9. The maximum deflection that occurred in the case of the header was in the horizontal position and the header was raised at the maximum lift position were 2.31 mm and 2.36 mm, respectively, as Fig. 10.

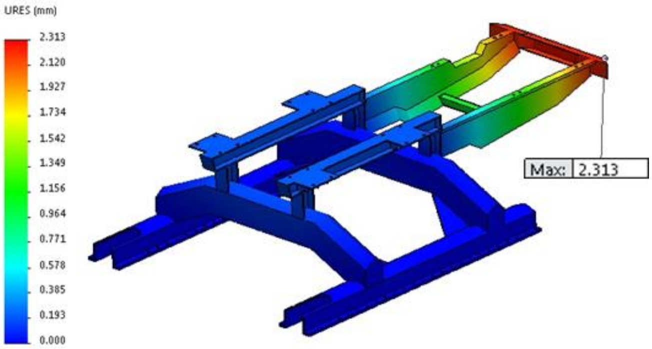


(a) Horizontal header position

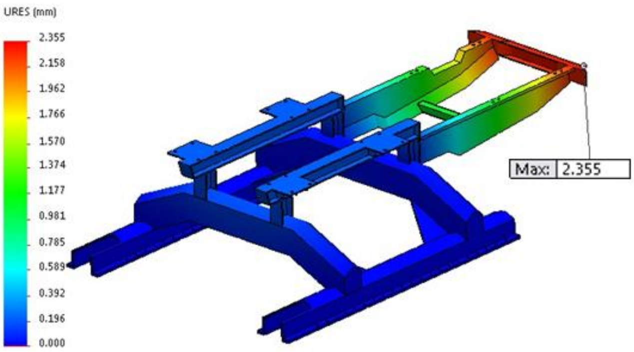


(b) Maximum lift header position

Fig. 9 Stress distributions on the track frame model under two field work conditions



(a) Horizontal header position

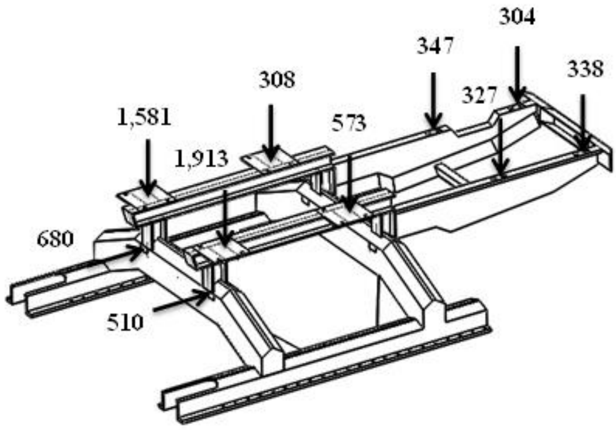


(b) Maximum lift header position

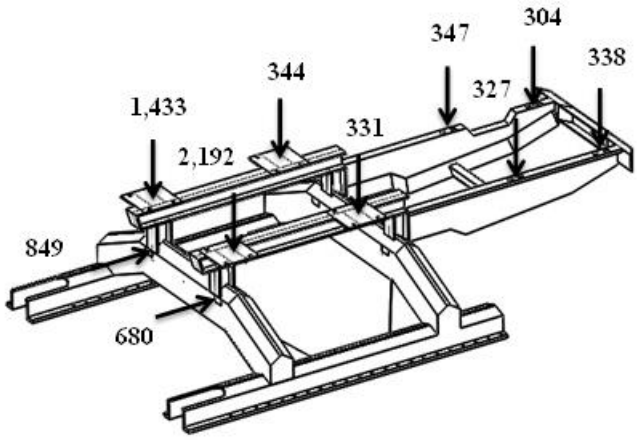
Fig. 10 Deflection distributions on the track frame model under two field work conditions

B. Analytical Results of the Similitude

Fig. 11 shows the force acting on the mini rice combine harvester track frame model at different positions, which is 9 times reduced from the prototype rice combine harvester track frame model based on the analysis of similitudes. The results of the strength analysis showed that the maximum stress, safety, and maximum deflection achieved in the case of the header was in the horizontal position, the values were 90.97 MPa, 2.7, and 0.77 mm, respectively. In the case of the header was at the maximum lift position, the values were 92.16 MPa, 2.7, and 0.79 mm respectively, which occurred at the position as Fig. 9 and Fig. 10.



(a) Horizontal header position



(b) Maximum lift header position

Fig. 11 Direction and magnitude of external forces on the similitude model of the track frame under two field work conditions (digits denote forces in Newton)

C. Loading Test Results

The loading test was performed by comparing the stress values at position C of the loading test type 1. It was found that the stress values from the finite element method and the actual readings of the experimental model were different by 1%. In the type 2 loading test, the difference between the finite element method and the stress from the experimental model was less than 5%.

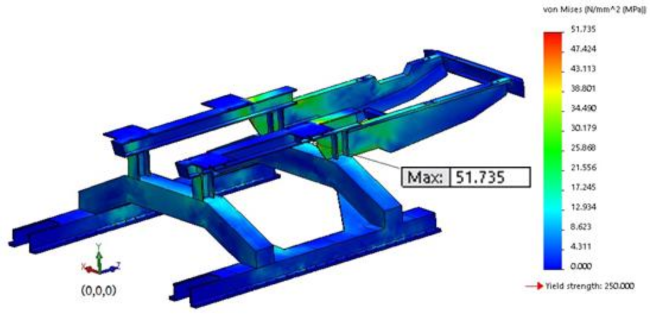
From measuring the deflection of the track frame model of the mini scale rice combine harvester found that loading test type 1 deflection from the finite element method was 0.008 mm while deflection from the experimental model could not be measured due to the limitations of the measuring instrument. Loading test type 2 deflection from the finite element method was 0.396 mm and the deflection from the experimental model was 0.40 mm, which was not different.

D. Improvement of the Track Frame Model of the Thai Rice Combine Harvester

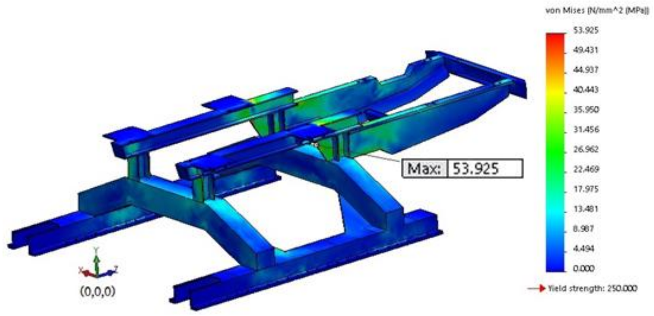
Table II shows the results of the improvement of the track frame models of various types of Thai rice combine harvesters. By the results of the analysis of the track frame model pattern 1, the maximum stress occurred in the case of the header was in the horizontal position and in the case of the head lifted at 56.12 MPa (decrease by 38.42%) and 56.09 MPa (decrease by 38.83%). Respectively, the maximum deflection that occurred in the case of the head parallel to the ground and in the case of the head raised, the values were 1.78 mm and 1.82 mm respectively.

In the track frame model pattern 2, the analysis results showed that the maximum stress that occurred in the case of the head parallel to the ground and in the case of the maximum lifted was 66.30 MPa (reduction of 27.26%) and 66.96 MPa (reduction of 26.97%), respectively. The maximum deflection occurred in the case of the header was in the horizontal position and in the case of the hob being raised, the maximum values are 1.93 mm and 1.97 mm respectively.

In the track frame model pattern 3, the analysis results showed that the maximum stress arising in the case of the head parallel to the ground and in the case of the maximum lifted was 51.74 MPa (43.2% decrease) and 53.93 MPa (41.2% decrease), respectively, as Fig. 12. The maximum deflection that occurred in the case of the head parallel to the ground and in the case of the peak raised was 1.66 mm and 1.70 mm respectively, as shown in Fig. 13.

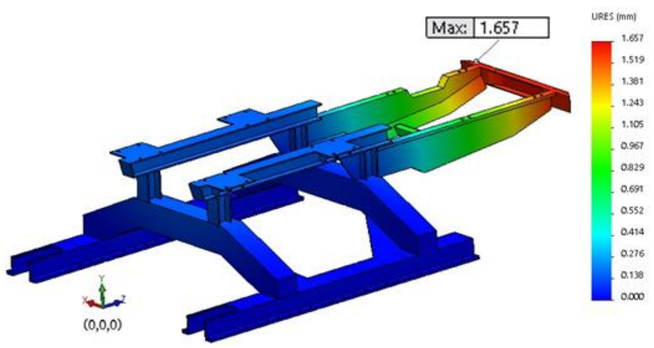


(a) Horizontal header position

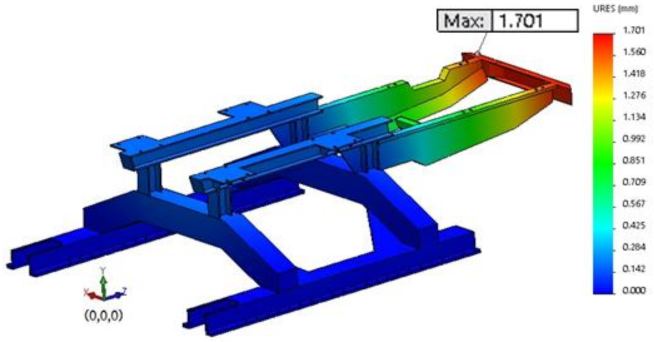


(b) Maximum lift header position

Fig. 12 Distribution of the track frame stress, pattern 3



(a) Horizontal header position



(b) Maximum lift header position

Fig. 13 Distribution of the track frame deflection, pattern 3

Table II Improvement of the track frame models of various types of Thai rice combine harvester

Approach	Mass (%)	Horizontal Header Position		Maximum Lift Header Position	
		Max. Stress (MPa)	Max. Deflection (mm)	Max. Stress (MPa)	Max. Deflection (mm)
1	+0.30	56.122	1.777	56.094	1.817
2	+0.16	66.295	1.931	66.962	1.967
3	-18.00	51.735	1.657	53.925	1.701

5. Discussions

From measuring the load on the track frame of the rice combine harvester, it was found that the position that has the highest load comes from the harvester and conveying system, threshing and cleaning systems. The position that is the least loaded comes from the powerful engine system. The results of analyzing the track frame strength of Thai rice combine harvester using finite element method showed that the maximum stress occurs at X = -325, Y = 616.78, Z = 1,717, located in the middle of the junction between the left beam and the left rear column under the threshing and cleaning system. The maximum deflection occurred at X = -430, Y = 619.78, Z = 3270, which is located on the left side of the rear beam supported by the engine power system. The stress and deflection values occurring on the prototype model and the fractional model were related to each other. Thus, the stress distribution on both models is similar. Therefore, it can be concluded that the similitude results of the track frame of the Thai rice combine harvester are correct.

From the loading test results, the slightest error occurred due to the FEM model has homogeneous material properties in every position of the material of the structure and without using the weld to be analyzed. This is not correct for the experimental model because experimental modeling goes through welding processes, cutting, and abrasion, etc. Therefore, changing mechanical and thermal properties. By this experiment showed that the analysis of the strength of track frame of the Thai rice combine harvester by finite element method is accurate to a reliable level.

The improvement of the track frame model of the Thai rice combine harvester, pattern 1, showed that the maximum stress occurred at X = -320.5, Y = 619.78, Z = 1849.625 located on the left inner edge of the beam near the column. Behind the left under the threshing and cleaning system. The maximum deflection occurred at X = -430, Y = 619.78, Z = 3270, which is located on the left side of the rear beam supported by the engine power system. By improving this design can strengthen the track frame as well but gives a 0.30% increase in mass.

The improvement of the track frame model of the Thai rice combine harvester, pattern 2, revealed that the maximum stress occurred at the position X = -329.5, Y = 535.129, Z = 1671.39, which was in the center of the extended left beam. Under the threshing and cleaning system, the maximum deflection occurred at X = -430, Y = 619.78, Z = 3270, which is located on the left side of the rear beam supported by the engine power system. This improvement has not been able to increase the rigidity of the suspension sufficiently. It also gives a 0.16% increase in mass.

The improvement of the track frame model of the Thai rice combine harvester, pattern 3, revealed that the maximum stress occurred at X = -320.5, Y = 619.78, Z = 1831.34, located on the left inner edge of the beam near the column behind the left under the threshing and cleaning system. The maximum deflection occurred at X = -430, Y = 619.78, Z = 3270, which is located on the left side of the rear beam supported by the power engine system (Fig. 13). This improvement can strengthen the track frame as well. It is also possible to reduce the mass by 18%.

6. Recommendations

A. Recommendations for Practices

The distribution of the load exerted on the track frame of the Thai rice combine harvester should be improved.

B. Recommendations for Further Research

1. The effects of weight reduction of the track frame of the Thai rice combine harvester should be studied.

2. The strength of the track frame of the Thai rice combine harvester should be analyzed when being performed by a load in a dynamic state.

7. Conclusion

1. The maximum stress arising in the case of the head parallel to the ground and in the case of the maximum lifting head were 91.13 MPa and 91.69 MPa, respectively. Resulting in a safety factor of 2.7 in both cases. The values were 2.31 mm and 2.36 mm in the case of the head parallel to the ground and in the case of the head raised, respectively.

2. The similitude method for statically elastic structure can be accurately applied to the track frame of the Thai rice combine harvester.

3. The finite element method can be applied to analyze the strength of the track frame of Thai rice combine harvester with a reliable level of accuracy.

4. The improving of the track frame, the third type of Thai rice combine harvester can increase the strength of the track frame well and can reduce the mass by 18%.

Acknowledgement

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