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Reducing Fan Blade Vibration in Rice Harvesters and Combine Harvesters by Applying Product Grouping

Kittichote Supakumnerd[1, a], Phaireepinas Phimpisan [2, b], Chatchapol Chungchoo[3, c] * and Pichai Asadamongkon [1, d]

[1]Department of Mechanical Engineering, Faculty of Engineering, Srinakharinwirot University, Nakhon Nayok, 26120, Thailand.
[2]National Metal and Material Technology Center, 114 National Science Park, Klong Nueng, Klong Luang, Patumthani, 12120, Thailand.
[3]Department of Mechanical Engineering, Faculty of Engineering, Kasetsart University, Bangkok, 10900, Thailand.

[3]ORCID: 0000-0002-0692-0831

Abstract

Currently, several thousand of rice harvesters and combine harvesters are assembled every year. These harvesters are sold within Thailand and exported to the CLMV and South Asian countries. However, one of the major claims of these products is broken bolts at the connection between fan blade and fan shaft. The investigation indicated that a cause of this failure is high vibration of a fan unit. In order to eliminate this failure, vibration control of the fan unit is required. However, a production line is a lot of time consumption for balancing a fan unit of these harvesters because operators must do both static and dynamic balancing processes for every single fan unit. According to the primary investigation, the variation in position and dimension of the fan blade is a major cause of its unbalance. In order to reduce this variation, a new standard procedure was introduced. This procedure was developed based on an assumption that the vibration of the fan unit can be significantly decreased if the standard deviation of the fan blade's weight is reduced. Experimental results indicated that the new procedure can reduce time consumption for doing static and dynamic balancing processes of the fan unit significantly. For example, in case of a 4-ft fan unit, the total assembly time of the fan unit can be reduced for more than 50%. Currently, this new procedure has been used in several production lines.

Keywords: Fan blade, rice harvester, combine harvester, vibration, product grouping

INTRODUCTION

More than 10 years that Thai's manufacturers have produced and exported their rice harvesters and combine harvesters (Figure 1) to the CLMV and South Asian countries. It was recorded that there were many catastrophic failures at the fan blade and a major cause of this failure was the vibration of fan blade unit. Hence, manufacturers attempted to reduce the vibration of fan blade unit by decreasing the variation of fan blade weight.

Figure 2 shows a solid model of the fan blade unit. Each unit consists of two sets of five fan blades, three ball bearings with vibration absorber, four sets of blade holder, and one shaft. A real fan blade can be seen in Figure 3.

According to the primary investigation, the variation in position and dimension of the fan blade is a major cause of its unbalance. Ideally, this problem can be fixed by doing the static and dynamic balancing processes introduced by several experts [1-5]. However, this method consumes a lot of production time. Hence, the other methods that spend less production time are required. The new method that can serve this requirement is therefore introduced in this paper.

Figure 1. An example of combine harvester

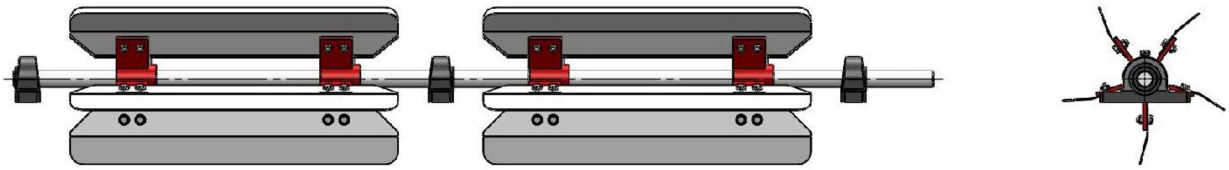

Figure 2. Solid model of fan blade unit

Figure 3. Example of fan blade

CASE STUDY

There are several models of rice harvesters and combine harvesters that are sold in the markets. However, in this research, a fan unit that is used in both 4-ft model of rice harvester and 4-ft model of combine harvester produced by a Thai's manufacturer was selected as a case study. The details of each fan blade used in the 4-ft model are shown in Figure 4, while the details of each set of fan blades are shown in Figure 5.

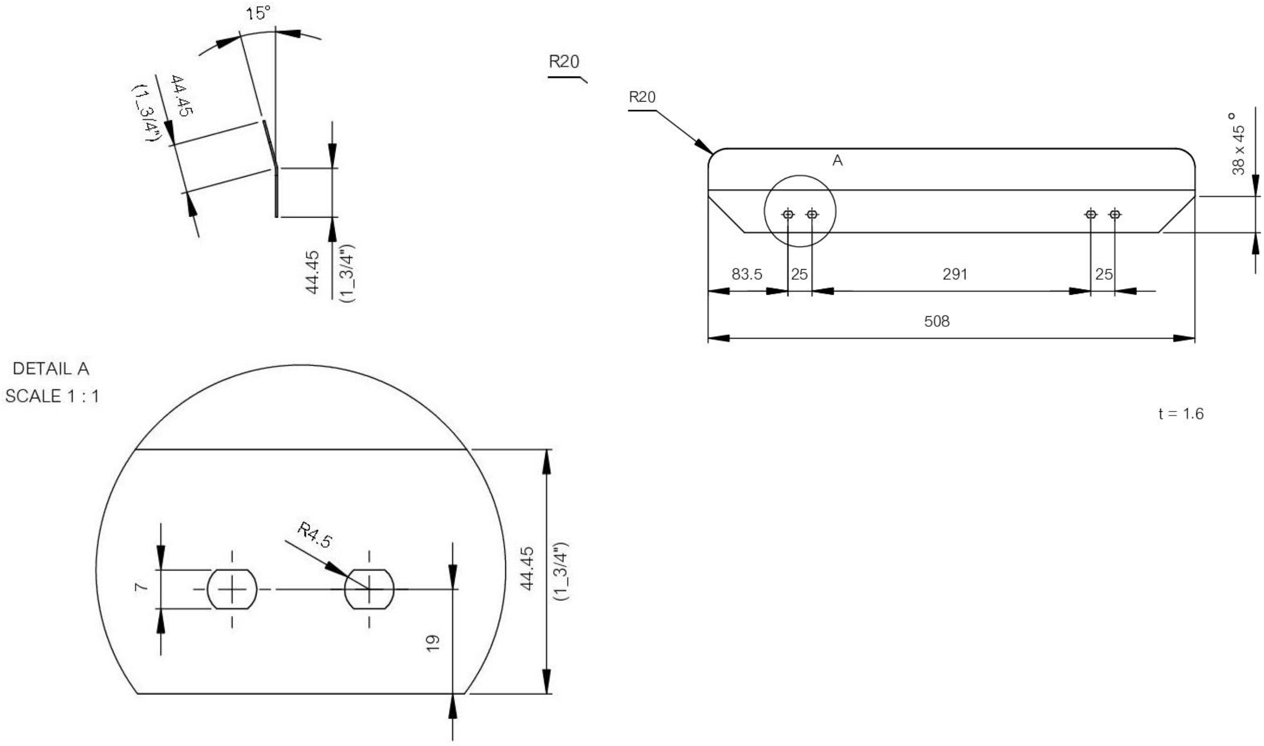

Figure 4. Drawing of each fan blade

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The GD&T of parts of 4-ft model of rice harvester, including dimension and angularity, meets the ISO 2768 Standard [6]. There is no any specific GD&T

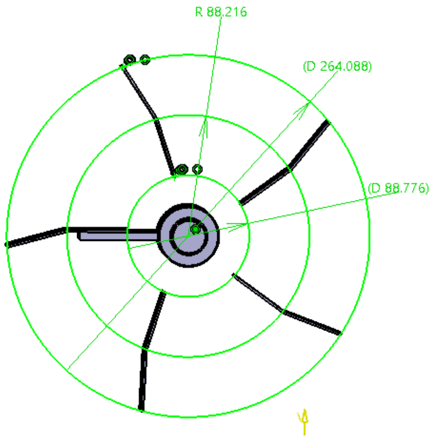

Figure .5 Drawing of one set of five fan blades

Schematic of case study

According to Figure 2, the schematic of 4-ft model of rice harvester can be expressed as shown in Figure 6.

Major assumptions for this schematic shown above are:

1. The center of mass of first and second five blades is assumed to locate in plane-1 and plane-2, respectively.
2. Plane-1 and plane-2 are parallel.
3. The source of vibration only comes from the rotation of unbalanced mass.
4. Only variation in angles at 15° and 90° of fan blade geometry is considered.
5. The production must be controlled under "Cp = 1.00".

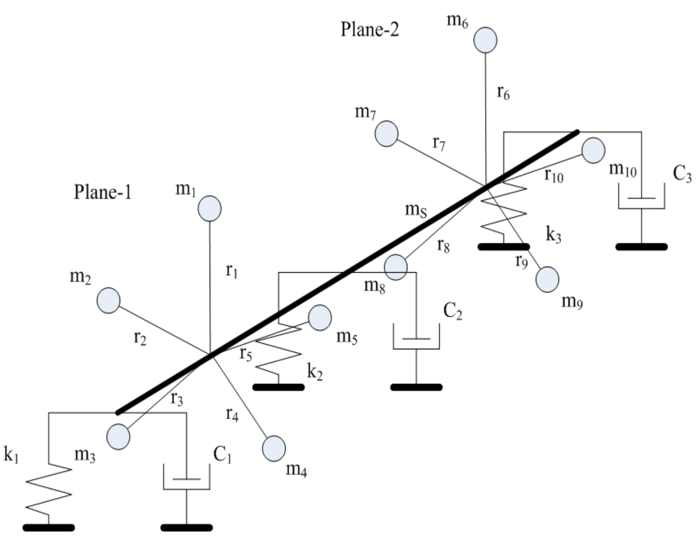

Figure 6. Schematic of case study

From the forth assumption, the schematic of mass representing the fan blade can be shown in Figure 7. It was also said that the variation in angles at 15° and 90° of fan blade geometry affects the distance "r_1 to r_{10}" and angle "Θ_1 to Θ_{10}" which is mentioned in Figure 5 and Figure 6.

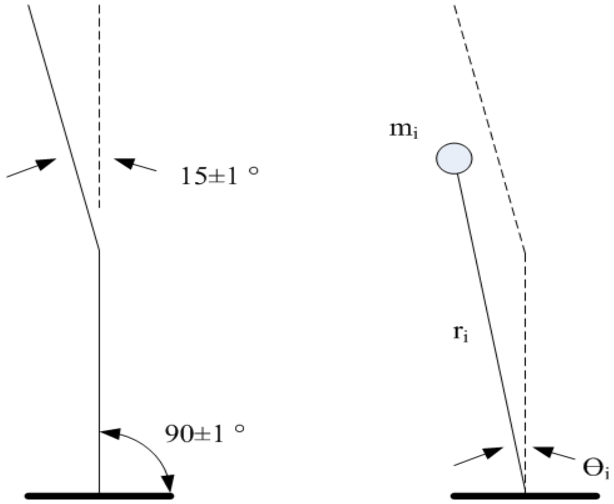

Figure 7. Schematic of mass representing each fan blade

The force vibration equation of motion that was developed by using the first, second and third assumptions can be expressed as follows:

$$M_t\ddot{X}+c_t\dot{X}+k_tX= \sum_{i=1}^{5} m_i r_i \omega \sin([(i-1)(\frac{2\pi}{5})+\theta_i+\frac{\pi}{2}]+\omega t) + \sum_{i=6}^{10} m_i r_i \omega \sin([(i-6)(\frac{2\pi}{5})+\theta_i+\frac{\pi}{2}]+\omega t) \quad (1)$$

$$M_t = m_s+\sum_{i=1}^{10} m_i \quad (2)$$

Where

$X(t)$	displacement (m)
M_t	total mass (kg)
$m_1 - m_{10}$	mass of blade no.1 to no 10 (kg)
m_s	mass of shaft (mg)
t	time (s)
Θ_i	deviation from perpendicular line (rad)
ω	rotating speed (rad/s)
k_t	total spring constant (N/m)
c_t	total dampling constant (N.s/m)

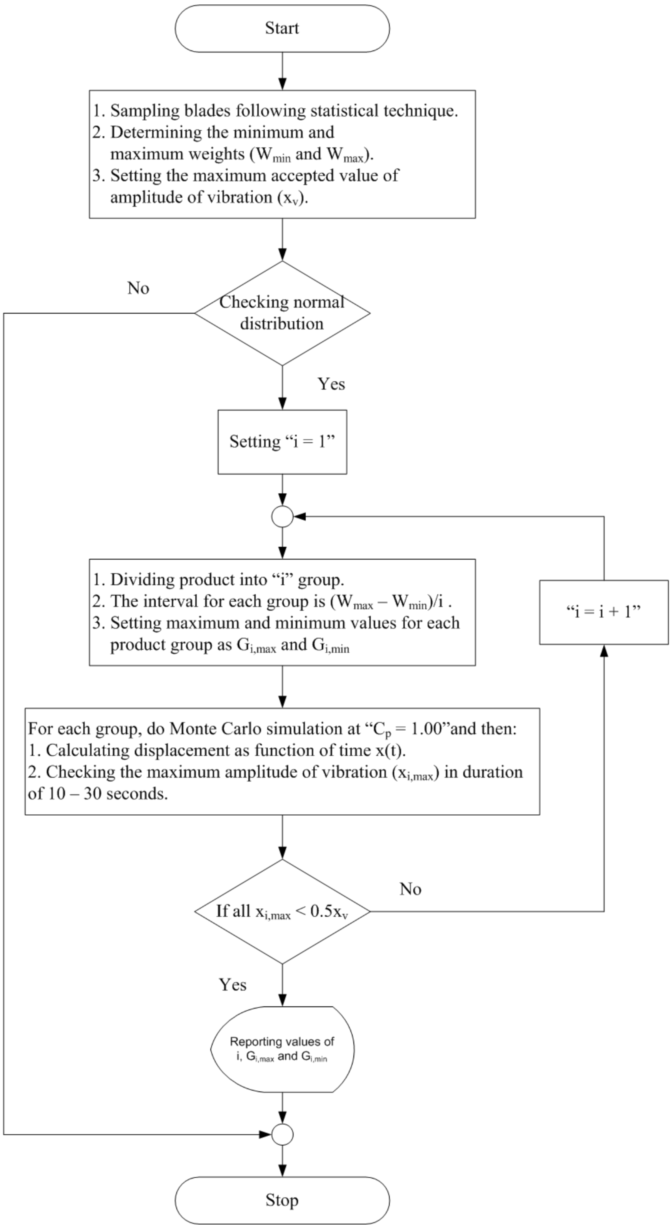

Figure 8. Flow chart of new procedure for reducing the effect of variation in position and dimension of fan blade in rice harvester and combine harvester

PROPOSE OF NEW PROCEDURE

The new procedure for reducing the vibration of fan blade in rice harvester and combine harvester was developed in this research and presented in Figure 8. The concept of this procedure was that the vibration of the fan unit can be significantly decreased if the standard deviation of the fan blade's weight is reduced.

For controlling the manufacturing cost, the product (fan blade) grouping method instead of making precision fan blade is selected. After finish fan blade production, hence, the fan blades need to be grouped. For each assembly of fan unit, all blades must be taken from the same group. Additionally, for each fan blade group, the variation in the fan blade's weight does not have to generate unaccepted vibration.

The Monte Carlo Simulation is used for finding the possibility of vibration of fan blade unit at different conditions. By employing the simulation results, the lower limit and the upper limit of the fan blade's weight for each group could be specified. However, this procedure can be used under a major criterion that the distribution of weight of fan blades must be normal.

EXPERIMENTAL SETUP

The experiment began with sampling the fan blades that were produced in the production line. Then, the simulation was carried out following the flow chart shown in Figure 8.

In order to verify the reliability of the new procedure mentioned in Figure 8, the experiment was set as a schematic shown in Figure 9. The maximum amplitude of vibration ($x_{i,max}$) in a duration of 10 – 30 seconds was collected by using a vibration analyzer model SKF Microlog CMXA 51-IS with a sensor attached at the middle ball bearing.

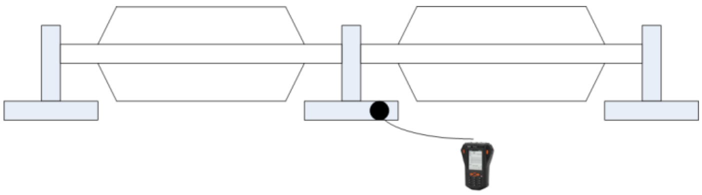

Figure 9. Schematic of testing apparatus

RESULTS AND DISCUSSION

<u>Preparing for simulation</u>

Since the manufacturer produces approximate 1000 fan blades for the 4-ft model every year, at least 278 fan blades must be sampled. This number of sample was calculated according to the statistical recommendations [7-9]. In this research, 278 fan blades were collected. It was found that the maximum and minimum weight of these sampled fan blades was 0.456 kg and 0.411 kg, respectively.

For checking the type of distribution of fan blade weight, all weights of sampled fan blades were analyzed for their distribution patterns by using the Microsoft Excel software. The analysis results showed that the patterns of distribution could be accepted as normal distribution. The mean value was 0.438 kg.

The value of vibration amplitude that the manufacturer can be accepted is 0.1 mm. This number was set as x_v. However, there were some errors in the vibration equation of motion amplitude (Eq. 1). Hence, the value of 2 was used as the safety factor.

Simulation results

The simulation process was carried out according to the flow chart shown in Figure 8. The Monte Carlo simulation was done by using the Microsoft Excel software. The example of using the Microsoft Excel software to do the Monte Carlo simulation was introduced by Jeges [10]. There were twelve parameters that must be employed in the Monte Carlo simulation. These were angle of 15°±1 shown in Figure 6, angle of 90°±1 shown in Figure 7, and weight of 10 fan blades ($m_1 – m_{10}$). The rotation speed was fixed at normal operation, which was 2,000 rpm.

The simulation results were shown in Table 1. In this table, if the manufacturer needs to produce the fan units that have the maximum vibration amplitude lower than 0.1 mm at C_p = 1.00, these fan blades must be divided into at least four groups. For each fan unit, all fan blades must be taken from the same group.

Table .1 Simulation results from proposed procedure

i	Group	Max. Amplitude of Vibration (mm)	Result
1	G_1 : 0.411 – 0.456	0.192	G_1 fail
2	G_1 : 0.411 – 0.436 G_2 : 0.436 – 0.456	0.106 0.117	G_1, G_2 fail
3	G_1 : 0.411 – 0.426 G_2 : 0.426 – 0.441 G_3 : 0.441 – 0.456	0.041 0.049 0.087	G_1, G_2 pass G_3 fail
4	G_1 : 0.411 – 0.422 G_2 : 0.422 – 0.436 G_3 : 0.436 – 0.445 G_4 : 0.445 – 0.456	0.037 0.040 0.048 0.043	All group pass

Note:

1. Amplitude of vibration that the manufacturer can be accepted is 0.100 mm.
2. Amplitude of vibration in case of using 2 as safety factor is 0.050 mm.

Table .2 Comparison between simulation and experiment

Weight of fan blades	Max. vibration amplitude in duration of 10 – 30 s. (mm)	
	New Procedure	Experiment
$m_1 – m_{10}$: case G_3 of i = 4 0.439, 0.443, 0.440, 0.438, 0.441, 0.442, 0.442, 0.445, 0.437, 0.440	0.048	0.872

Verification of new procedure for reducing the effect of variation in position and dimension of fan blade in rice harvester and combine harvester

In order to verify the reliability of the new procedure for reducing the effect of variation in position and dimension of fan blade in rice harvester and combine harvester shown in Figure 8, the testing apparatus was set as a schematic shown in Figure 9. Ten fan blades from the same group (in case of i = 4) were taken and then built as a fan unit. The comparison of the maximum vibration amplitude in duration of 10 – 30 s between the calculation following the new procedure and the measuring results were shown in Table 2. It can be said that the new procedure indicated in Figure 8 can be used in the production line for controlling the vibration of fan unit.

It should be noted that the vibration amplitude of duration of 0 – 10 s was not considered because it was the waiting time for steady state operation of the fan blade system.

CONCLUSION

According to the results in the results and discussion mentioned above, it was found that the new procedure for reducing the effect of variation in position and dimension of fan blade in rice harvester and combine harvester, which was introduced in this paper (Figure 8), can control the vibration of the fan blade into an acceptable level. Without the need of static and dynamic balancing processes, this procedure can therefore save the manufacturing time for assembling the fan blade unit significantly.

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