การวิเคราะห์และปรับปรุงเครื่องรีดพลาสติก
Analysis and development of plastic-rolling machine

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Abstract

The original idea of failure analysis of the transmission system of a Plastic Sheet Rolling Machine (PSRM) belongs to one of the plastic sheet manufacturer in Thailand initially comes from a frequent braking down of the machine. The firm has struggled with the failure of a main transmission shaft when it tries to increase the machine productivity. Up to the moment, the transmission has been broken down approximately once in two months which effects the productions plan tremendously. The engineer initially has improved the machine transmission system by adding number of transmission chain along with installing a support column at the end of transmission shaft. However, the transmission shaft failure is still exist. Therefore, the cause of the failure has been investigated, and it has been identified that the root of this problem comes from the fatigue load on the transmission shaft. The investigation has confirmed that the fatigue comes from the misalignment of the transmission shaft when it has been subjected to the heavy transmission load.

1. Problem statements

It has been revealed that the Plastic Sheet Rolling machine (PSRM) belongs to one of the plastic sheet manufacturer in Thailand brakes down very often when the firm intended to speed up the production rate. At the moment, the production rate of the machine (throughput) is 1300 Kg/hr, and it has been targeting to increase the production rate up to 1,500 Kg/hr in a near future. Base on the initial technical information of the machine, it has been designed to operate at the 800 Kg/hr throughput. However, there was no any machine technical document to verify the original design of the machine. Once the machine has been speed up at the 1300 Kg/hr throughput, its components (main transmission shaft, transmission chain, and sprocket) have started braking down.

The machine transmission system composes of a 45 kW AC electrical motor as the power source. It transmits the power trough a reduction gear box by a set of V-belts. The gear box transmits the power to a main transmission shaft by transmission chains, and the hot rollers have connected to a main transmission shaft by group of spur gears.

When the machine has been speed up to the set point. It's most likely that there is higher torque generated from the power motor through the transmission elements to the main transmission shaft. By this condition, the machine transmission has been broken down once in two months period.

The machine failure investigator team has measured all necessary parameters (main shaft operating torque, electrical motor power etc.) under several condition of the machine operation. The Finite Element analysis (FEM) is used to analyze the cause of the failure under various conditions such as direct applied torque, applied torque with impulse, and applied torque with impulse and misalignment in order to figure out cause of failure in the shaft.

2. Experimental work for measuring torque transmission

In order to investigate the cause of the failure in the shaft, the transmission torque should be measured by a torque transducer. At the moment, the cost of the torque transducer is quite high. Even though, the company can afford the torque transducer unit, it probably takes too long (at least three months) to obtain the measurement from the manufacturers. Therefore, the torque transducer should be invented to measure the applying torque from the main transmission shaft.

2.1 Basic Principle of the torque transducer

Typically, a torque transducer uses strain gauges to measure strain on the shaft surface. The signal from the strain gauge is connected to the bridge circuit to convert resistance to voltage signals. The signal from the circuit passes through the slip-ring to the display unit because the strain gauge on the shaft is rotated. However, this type of torque transducer is very expensive especially for the slip ring because all units except the display unit connect to the shaft. The accuracy of this type of transducer depends on the speed of rotation, the surface contact of the slip ring and the strain gauge installation.

To measure the torque in the main transmission shaft for analyzing the cause of failure, the torque transducer is invented. The principle of this torque transducer is based the twisting angle in the shaft. It consists of four main units: displacement transducer unit, conditioning circuit, display unit, and image transmission unit as shown in Figure 1. To measure the torque while rotating, all the units are connected to the outer shaft and rotated. The imaging transmission will send the current torque value to the receiver through antenna as shown in Figure 2

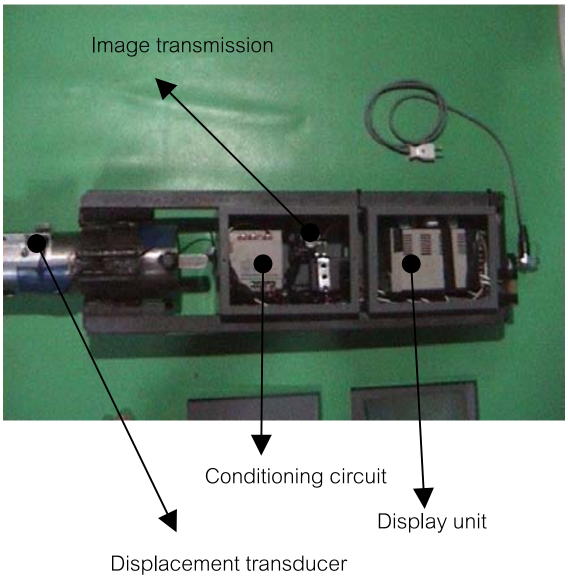

Figure 1: Torque transducer

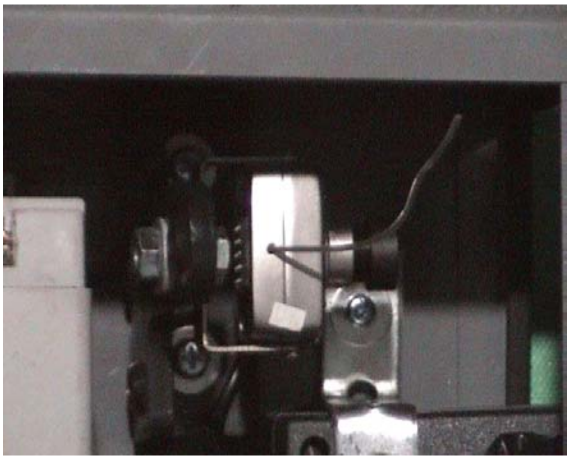

Figure 2: Image of transmission

The displacement transducer unit is fixed to the outer and inner shafts that are coaxial. The torque input is transferred from the sprocket by chain, the outer shaft, the key to the inner shaft for driving the rolling unit as shown in Figure 3.

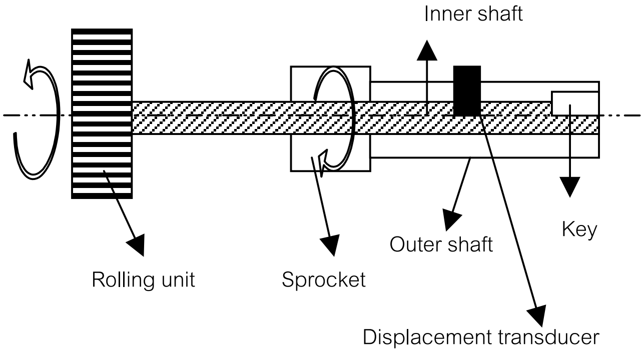

Figure 3: location of the displacement transducer and the shaft

2.2 Calibration and Result

To calibrate, the torque transducer, the input torque should be applied to the sprocket while the inner shaft is hold still. By using the hydraulic cylinder with the pressure gauge and the lever, the input torque can be applied and calculated. The calibration can be conducted by comparing the applying pressure in the cylinder to the output voltage from the conditioning circuit which can be read and calibrate by the display unit. As a result, the input torque in the form of pressure in the cylinder is linearly proportional to the output voltage as shown in Figure 4. This reveals that the torque transducer can be used to measure the torque in the rolling unit.

As a result of applying the torque transducer unit to the rolling machine while operating, the torque on the rolling machine is measured at 7415 NM. This valve is used for analyzing the cause of failure in the shaft.

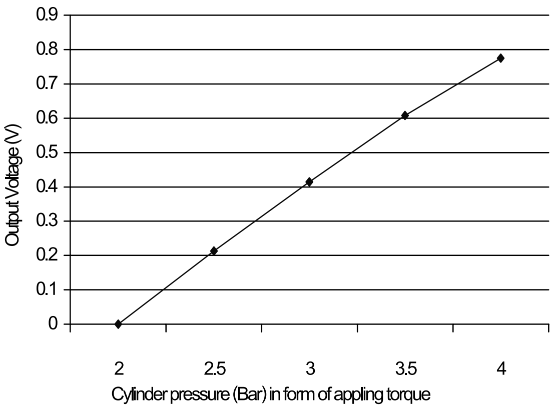

Figure 4: Calibration curve for torque transducer

3. Main transmission shaft analyses

The analysis of the main transmission shaft has been classified into two conditions. The first condition shows the stress analysis due to normal operating torque. The later condition emphasizes the effect of a misalignment of the main shaft.

3.1 Shaft analysis with impulse torque

Model Geometry

A main transmission shaft model has been built based on an actual transmission shaft. The model is built in three dimensional model using CAD programming[1], and has been meshed into 10,516 elements and used Algor[2] programming to do Finite Element analysis. The whole model is shown in Figure 5.

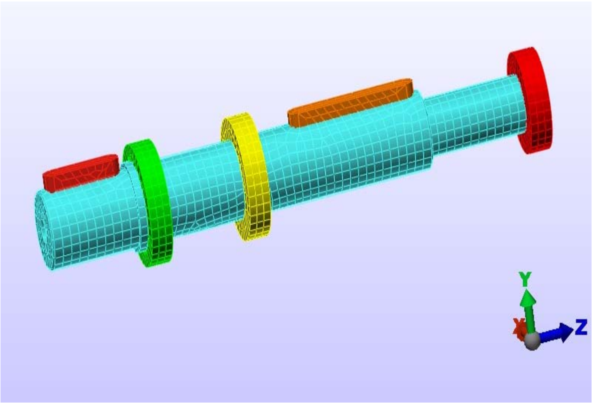

Figure 5: Main transmission shaft model for FEM analysis

Boundary and Load Conditions

- Shaft misalignment is zero.
- Applied torque is 7,415 N-m, which is equivalent to the 176 kN distributed force, subjected to a key on X-direction. (The applied torque has been computed from 26.8 kW measured power motor while the machine has operated at throughput 1,300 kg/Hr. The 45 kW maximum power motor is equal to 13,000 N-m transmission torque).
- Shaft has been subjected to an impulse torque, initiated from wrenching of the chain. Therefore, the impulse torque has been assumed to be twice of supplied torque, and applied in every half second as shown in Figure 6.

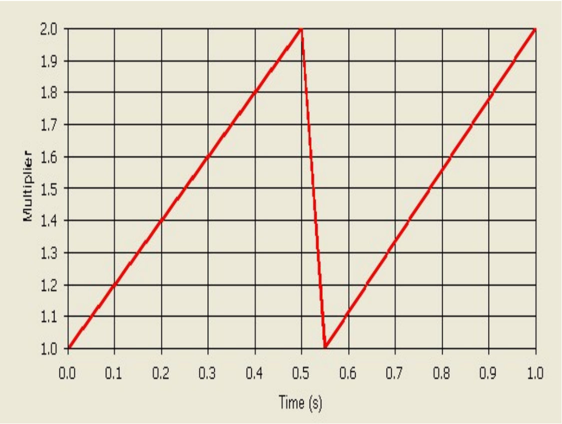

Figure 6: Impulse torques from wrenching of the chain

- A short key is fixed.
- Outer surface of the three support bearings are fixed.
- There is contact pair between inner surface of the bearing and the shaft surface.

The boundary and load condition of the main transmission shaft is shown in Figure 7.

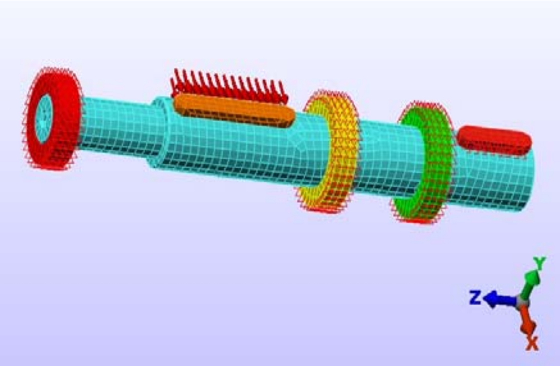

Figure 7: boundary and load condition of the main transmission shaft

Material Properties

The main transmission shaft, key, and support bearing are assumed to be Steel 4130. The FEM analysis will be elastic analysis, and plastic deformation does not exist.

Analysis Results

From FEM analysis as shown is Figure 8, It has been concluded that the main transmission shaft is subjected to the torque through the key. The type of load applied to the shaft is considered to be bending stress. Von Mises Stress on the small key is quite low (Area A), compares with the area on the middle bearing (Area B), and the whole shaft has been deformed due to bending stress. However, the maximum stress is occurred around the long key (Area C) due to the stress concentration at the shaft groove. In conclusion, the transmission shaft subjected to the transmitted torque is hardly failed from the fatigue, because the combined maximum stress is lower than the shaft yielding stress (800 MPa for Steel 4130).

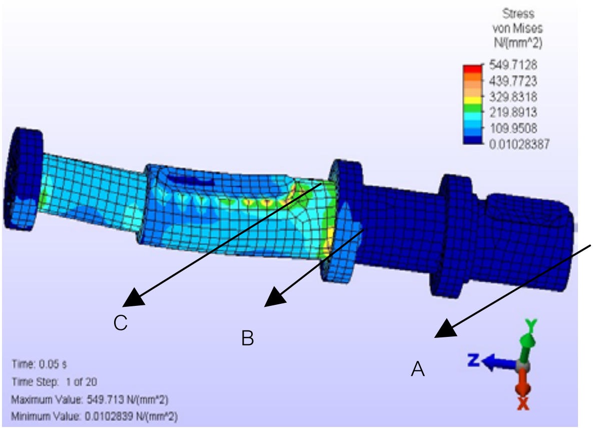

Figure 8: Von Mises Stress of main shaft subjected to operating torque

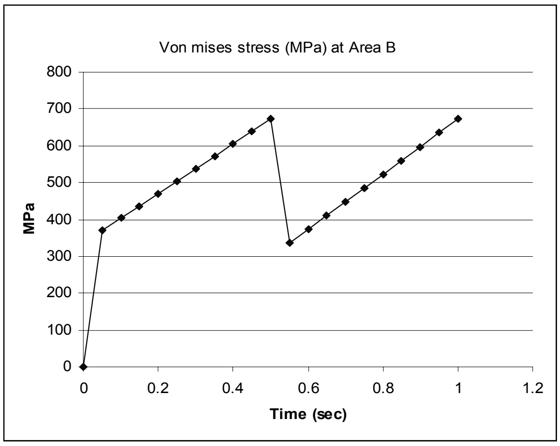

Figure 9: Von Mises Stress history on Area B

Once the shaft is subjected to the impulse torque, the trend of stress contour is likely the same as the previous analysis, except the increasing of shaft deformation and bending load. Stress around Area B continues to grow periodically in function of time as shown in Figure 9. The Von Mises stress is running between 330-670 MPa, which might cause the failure of the shaft due to fatigue load. Therefore, we should reduce this type of bending stress by

- Using tensioner to smooth transmission chain motion.
- Using self-alignment type of all support bearing.

3.2 Shaft analysis with impulse torque and misalignment

A main transmission shaft model is the same as previous analysis. However, the outer bearing offset (Area D) has been generated to monitor the effect of shaft misalignment as shown in Figure 10 and 11.

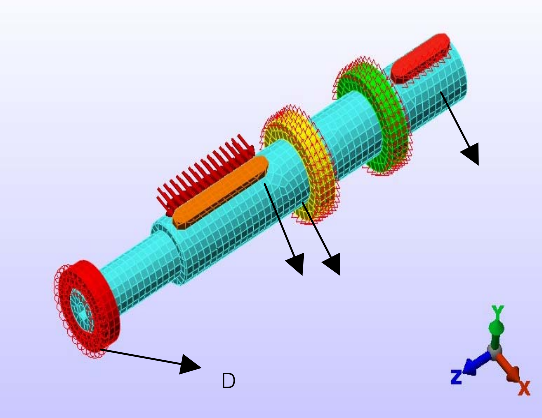

Figure 10: main transmission shaft modeling for FEM analysis

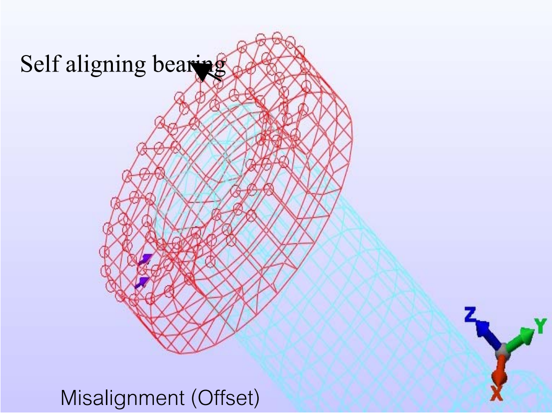

Figure 11: Outer bearing offset

Boundary and Load Conditions

- The outer bearing (Area D) is configured to be 0.5 mm offset in Y-direction and started from zero to maximum value by 0.5 second and keeped constant from 0.5 to 1 second.
- The bearing is constrained in X-direction only.
- Applied torque is 7,415 N-m, and equivalent to the 176 kN distributed force subject to a key on X-direction. (The applied torque has been computed from 26.8 kW measured power motor while the machine has operated at throughput 1,300 kg/Hr. The 45 kW maximum power motor is equal to 13,000 N-m transmission torque).
- Shaft has been subjected to an impulse torque, initiated from wrenching of the chain. Therefore, the impulse torque has been assumed to be twice of supplied torque, and applied in every half second similar to the previous analysis.
- A short key is fixed.
- Outer surface of the three support bearings are fixed.
- There is contact pair between inner surface of the bearing and the shaft surface.

Material Properties

The main transmission shaft, key, and support bearing are assumed to be Steel 4130 similar to the previous analysis.

Analysis Results

The FEM analysis is started from applying the transmitting torque on the shaft with 0.5 mm shaft offset distance. The maximum stress is 1,018 GPa, occurred at Area B and the stress mount 790 GPa also occurs at Area E as shown in Figure 12 and displacement contour as shown in Figure 13 at 0.05 second.

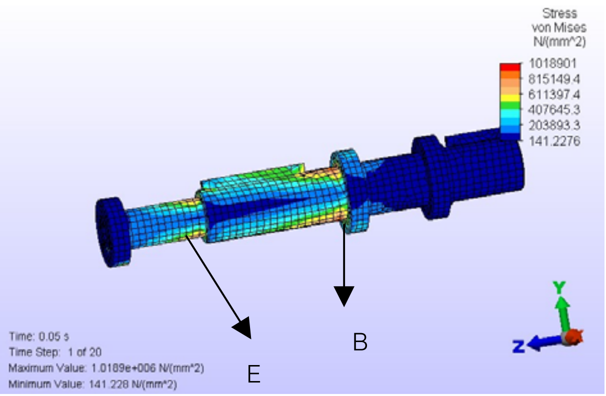

Figure 12: Von Mises Stress of main shaft subjected to operating torque and misalignment at 0.05 second

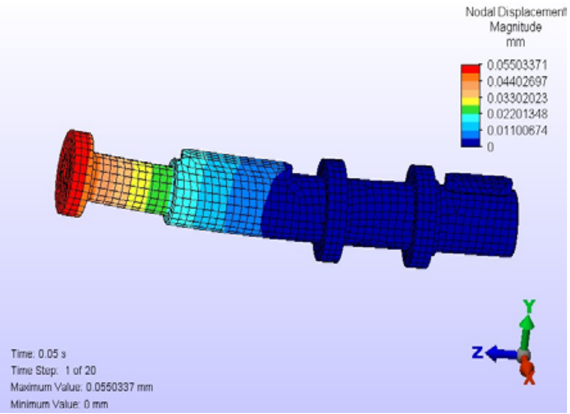

Figure 13: displacement contour of main shaft subjected to operating torque, impulse torque and misalignment at 0.05 second

When the impulse torque is applied to the shaft, the Von Mises Stress at area B and E have been increased related to the offset condition from zero to 0.5 mm offset displacement as shown on Figure 14. At the end of impulse cycle, the stress will be constant. Because the FEM analysis is considered as elastic problem, in reality, the plastic deformation will occur for the shaft. However, this periodic stress will create the switching between tension and compression, which speed up the fatigue of the main shaft, and the fatigue life will depend on the different between tension stress and compression stress. Therefore, the recommendations for correcting this type of problem are as follow:

- Reinforce the support column of the outer bearing.
- Install another long key opposite to the original one.

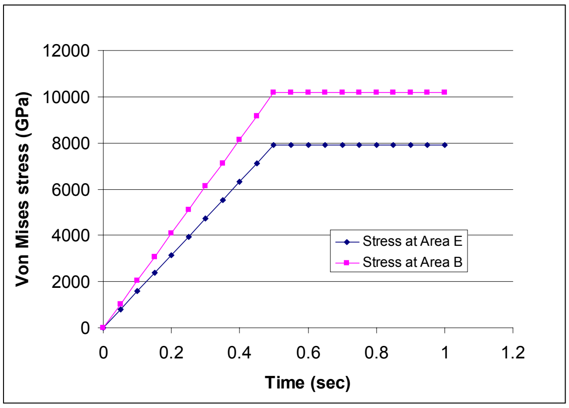

Figure 14: Von Mises Stress history on Area B and E

4. Conclusion and recommendation

- It is possible to add another transmission power directly to another connecting shaft. By installing a power hydraulic motor to drive the connecting shaft (as shown in the figure), and make the shaft revolution synchronize to the main transmission shaft. The power transmit through the connecting shaft could be as much as the power transmit through the main shaft. In this particular case, we can increase the production rate to the desired level, by let the two transmission shaft carry the transmission load equally.
- It is necessary to correct the misalignment of the main transmission shaft. Since the analysis shows that the main cause of the shaft failure comes from the fatigue from the offset shaft position. The support stand of the main shaft has to be strengthen and rigid enough for protecting the movement at the end of the shaft when subjected to higher bending.
- Install the tensioner to reduce the effect of the wrenching of the transmission chain. Therefore, the transmission force on the sprocket will be smoother.
- It is recommended to improve the main transmission shaft surface condition as well as redesign the shaft configuration (increase more fillet radius, bigger key). In doing so, one can extend the yielding limit of the shaft and it will increase the endurance of the main shaft.

Reference:

[1] Solid work Version 2003, http://www.solidwork.com

[2] Commercial finite element software: Algor version 13.28-win, http://www.algor.com