Corrective Maintenance of Worm Gear a Screw Press Machine with a capacity of 30 tons per hour using Wear Analysis and its response to Conus Pressure

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Abstract. Worm gear is one of the main components of a screw press machine that is very vulnerable to wear. Based on the survey, it was found that the lifetime of the worm gear of a screw press machine at a palm oil mill owned by PT. Perkebunan Nusantara 4, Adolina estate, is always lower (only 700 to 800 hours) when compared to the recommended lifetime of the manufacturer (1000 hours). The wear on this worm gear needs to be minimized because it affects the performance of the screw press machine and losses on palm oil. Corrective maintenance needs to be applied to worm gear as a repair solution. Temporary corrective maintenance that has been carried out by the operator is to re-weld the surface of the worm gear. Initial analysis has been carried out by calculating the response that occurs in the worm gear due to cone pressure. The analysis results obtained that the highest wear value is located at the end of the worm gear that is in direct contact with the cone pressure. Obtained the value of the rate of wear depth of the worm gear of 0.583 mm per day with the hardness value of the cast steel material that is 215 BHN. After that, at the end of the worm gear is modified by adding a coating plate that has been given surface hardening treatment using NiKaNa methods. The aims are to make the wear that occurs earlier on the part of the coating plate, so that repair becomes more leisurely. Based on the results of the study, it was found that the value of the hardness of the coating plates increased by 490 BHN, with the rate of wear depth decreasing to 0.256 mm per day.

1. Introduction

A company cannot avoid the process of maintaining a production machine because it is closely related to the smooth production process [1]. The basic concept of maintenance is to maintain or repair equipment or machinery so that it returns to its initial state with a short time and low cost [2]. The palm oil mill in Adolina estate has 4 screw press machines, which consist of 3 screw press machines with a capacity of 10 tons per hour, respectively, and 1 machine with a capacity of 15 tons per hour. A useful worm gear component determines the quality of oil pressed from oil palm fruit. Wear and damage problems are often found on screw press machines. Because, if the wear that occurs on the
screw part of a screw press machine is already of high value, then it can cause a wide gap on the outer side of the screw with the press cage. This certainly reduce the performance of oil presses and the impact on the loss of palm oil produced. This condition can be seen through the fibres, which still contain some oil after pressing [3]. Each manufacturer of a worm gear component must provide a lifetime recommendation because it is very vulnerable to wear and damage. The recommended lifetime of a worm gear component is 1000 hours. However, the lifetime provided by the manufacturer is not following the lifetime that occurs in the field, which is only around 700-800 hours. Therefore, intensive maintenance and repairs are needed to avoid undesired severe damage, so that in the future of the lifetime recommended by the manufacturer can be achieved. The focus of this study is (1) to find out the response of the worm gear to cone pressure; (2) analyse the wear that occurs in the worm gear which affects the reduced lifetime, and (3) implement corrective maintenance to minimize the risk of wear on the worm gear.

2. Method

This research was conducted at one of the palm oil mills located in the Adolina estate owned by a national company called PT. Perkebunan Nusantara 4, located at Jalan Perintis Kemerdekaan, Batang Terap village, Perbaungan sub-district, Serdang Bedagai Regency, North Sumatera province. This study was conducted from November to December 2018. The object of study was the worm gear component of a screw press machine located at the press station of the palm oil mill. Photograph of the worm gear is shown in Fig. 1. The specifications of the screw press machine used in this study are shown in TABLE I. The screw press machine includes two screw bars that rotate opposite each other. Palm fruit that has been crushed will be pushed and pressed by the cone on the other side so that the oil palm fruit becomes squeezed. Through the press cage holes, oil is separated from the fibers. The results of the pressing process are fibers and nuts that come out through the gap between sliding or adjusting cone and press cage, which then goes into the Cake Bake Conveyor. Crude palm oil, which still contains impurities such as fibers and water, will then pass the clarification stage through a Sand Trap Tank to separate the impurities from the crude oil. Then enter the Vibrating Screen to separate the fibers from the crude oil and finally transferred to the crude oil storage tank.

2.1. Wear Analysis

Wear of a machine component occurs due to friction between two or more surfaces of a material. This friction occurs between the surface of the worm gear, and the oil palm fruit is squeezed. The surface conditions of materials that are subjected to wear can be observed through surface enlargement using appropriate equipment. Worm gear material is cast steel with a hardness value between 200 to 230 BHN (Brinell hardness number). In this study, the average hardness value of worm gear material is 215 BHN. If converted in pressure units, the value of 1 BHN is equal to 1 kg/mm$^2$ and is equal to 9.8 MPa. Therefore, the hardness value of 215 BHN is equal to 2107 MPa. Based on Archard wear law, to find the value of the wear rate can be used the following equation [4]:

$$ V = K A_r L = K L \frac{W}{H} $$

Where $V$ is the rate of wear volume in m$^3$, $L$ as sliding distance in m, $W$ is the load in Newton, $K$ is the wear coefficient, then $H$ is the value of material hardness in MPa, and $A_r$ as the contact area in m$^2$. The value of wear coefficient $K$, adjusted for abrasive wear on two-component surfaces [5].
Figure 1. (a) The shape of a screw press machine, unit in mm. (b) The worm gear of a screw press

Table 1. The Specifications of The Screw Press Machine

| Parameter               | Value                                      |
|-------------------------|--------------------------------------------|
| Capacity                | 10 tons per hour                           |
| Type                    | Continuous double                          |
| Cone Pressure           | 30 to 40 Bars                              |
| Clearance               | 25 mm                                      |
| Rotation                | 9 to 11 rpm                                |
| Input Cycle             | Continuous                                 |
| Weight of Worm Gear     | 100 kg is equal to 981 N                   |
| Number of Screws        | 4 or 5                                     |

Furthermore, the rate of wear depth that occurs on the surface of the worm gear can be calculated using the following equation [6]:

\[ K_a = K \frac{W L}{H A_{ks}} \]  

(2)

Where \( K_a \) is the rate of wear depth that occurs in m, and \( A_{ks} \) is the actual contact area in m\(^2\).

2.2. Response to Conus pressure

To analyzing worm gear responses, three main factors must be considered, that is (1) dilution water temperature must be maintained at 90\(^\circ\)C; (2) moisture content of oil palm fruit is not more than 20%, and (3) cone pressure must be maintained between 30 to 40 bars. If the cone pressure applied when compressing is too small, then the amount of oil loss will be higher, and if the pressing pressure is too large will cause the number of broken nuts to be higher. The wear always occurs on the surface and the edges of the worm gear. The most critical area, which is often the area of wear, is shown in Fig. 2. In this study, the calculation of the wear rate is only on one screw, which is the outer screw under direct pressure by the conus. It is assumed that the critical point occurs at a maximum distance of 30 mm from the outer side of the screw. The response of the worm gear to the conus pressure can be used by finding the values of torque, nominal shear stress, axial stress, bending stress, and shear stress at the base of the screw. Torque can be calculated using the following equation:

\[ T = \frac{F \cdot dm}{2} \left( \frac{p + \pi \mu d_m}{\pi d_m - \mu p} \right) \]  

(3)

where \( T \) is the torque acting on the screw in N mm, \( F \) is the axial force acting on the screw in Newton, \( \mu \) is the coefficient of sliding friction between the material, the screw is 0.49, \( p \) is the screw pitch in mm,
and $d_m$ is the value average radius area of the screw. Then, the nominal shear stress is calculated using the following equation:

$$\tau_{nom} = \frac{16T D}{\pi(D^4 - d^4)}$$  \hspace{1cm} (4)

Where $\tau_{nom}$ is the nominal shear stress acting on the screw shaft in N/mm$^2$ or MPa, $D$ as the outer diameter of the hollow shaft in mm, and $d$ as the inner diameter of the hollow shaft in mm. Furthermore, the axial stress on the screw shaft due to load is calculated using the following equation [7]:

$$\sigma = \frac{4F}{\pi(D_r^2 - d_r^2)}$$  \hspace{1cm} (5)

Where $\sigma$ is the axial stress in N/mm$^2$, $F$ is the load acting on the worm gear in Newton, $D_r$, and $d_r$ represent the inner and outer diameters of the hollow shaft in mm, respectively.

![Figure 2. Photograph of the most critical area of the worm gear.](image)

The bending stress can be calculated using the cantilever beam principle, which is projected from the base of the screw beam with the following equation [8]:

$$\sigma_b = \frac{3F \cdot h}{\pi \Delta (D_r - d_r)nb^2}$$  \hspace{1cm} (6)

$\sigma_b$ is the bending stress in N/mm$^2$ or MPa, $h$ for the beam height in mm, $n$ represents the number of beams, and $b$ as the beam width in mm. Finally, the shear stress acting on the screw base is calculated using the following equation:

$$\tau = \frac{3F}{2(D_r d_r)nb\pi}$$  \hspace{1cm} (7)

$\tau$ is the bending stress in N/mm$^2$ or MPa.
3. Results and Discussion

The main cause of wear and tear on worm gear is the result of pressure that occurs on the surface of the screw. The rate of increase in screw pitch occurs because the rotation of the screw causes the oil palm fruit on the side of the screw to be pushed, and on the other side, the hydraulic pressure on the cone presses the crushed oil palm fruit. This certainly makes the oil palm fruit under high pressure on both sides, causing the outer side of the screw under pressure due to cone pressure.

3.1. Worm gear response

By applying equations (3) to (7), the values of torque, nominal shear stress, axial stress, bending stress, and shear stress is 6380707.916 Nmm, 26.95 N/mm², -9.58 N/mm², 65.515 N/mm², and 14.10 1 N/mm², respectively.

3.2. Wear rate and depth of wear

Based on equation (1), the value of the rate of wear that occurs for each oil palm fruit to the surface of the worm gear in each cycle along the 0.85094 m is 0.0118786 mm³. Referring to table 1, the worm gear rotates between 9 to 11 rpm (in this study, it is assumed to be 10 rpm). This means that each rotation of worm gear is equal to one circumference of the worm gear and has the equal value is 0.0118786 mm³. Under normal conditions, the palm oil mill operates for 22 hours per day or 1320 minutes per day. In 1 minute, the worm gear rotates as much as 10 rpm, so the number of worm gear rotations per day is 13200 rotations per day. So, it can be predicted that the rate of wear volume of worm gear that occurs in 1 day is 156.79752 mm³ per day.

In calculating the rate of dimensionality reduction due to wear, the first is to determine the actual contact area (Aᵣ) of the friction of the two materials. Based on the survey, the actual contact area is 0.0245862 m². The number of oil palm fruits in the critical area of the worm gear is 78. The weight borne by the whole oil palm fruit and worm gear is 269,143 Newton. Thus, the estimated rate of wear depth that occurs on the worm gear surface using equation (2) is obtained by 0.000037685 mm. The estimated value of the rate of wear depth obtained is the estimated rate of wear depth that occurs in the critical area of the worm gear for one screw rotation cycle. In one day operating of the screw press machine, there are 13200 rotation cycles, so the estimated depth of wear that occurs in 1 day is 0.497 mm per day. The value of the rate of wear depth based on operating time for 50 days is shown in Table 2.

Table 2. The Value of The Rate of Wear Depth

| Operation (day) | Time (hours) | The rate of wear depth (mm) |
|----------------|-------------|---------------------------|
| 1              | 22          | 0.497                     |
| 10             | 220         | 4.970                     |
| 20             | 440         | 9.940                     |
| 30             | 660         | 14.92                     |
| 40             | 880         | 19.90                     |
| 50             | 1100        | 24.84                     |

3.3. Corrective maintenance using NiKaNa methods

The NiKaNa method consists of a combination of three metallurgical processes, that is Nitriding, Carbonation, and Quenching using Sodium Chloride (sudden cooling in a salt solution). Three processes that were initially carried out separately, but with this method will get steel with a higher level of hardness. This hardening process occurs because of changes in the phase or atomic structure of the steel. The phase change is done by heating the steel at a specific temperature and cooling at a certain speed by adding new material to the steel [9]. In this study, the handling of worm gear hardening is carried out in three stages, that is (1) the initial treatment stage; (2) NiKaNa treatment stage; and (3) sample testing phase. The initial treatment stage is sanding and heating. A steel sample is heated in a Furnace with variations in temperature and heating time. At the NiKaNa treatment stage, nitrogen gas is
sprayed directly on the steel sample that has been heated (nitriding). Then the steel sample is reheated with the same temperature and heating time at the initial treatment stage and dipped quickly in a saturated concentrated oil liquid (carburizing). The steel sample is reheated at the same temperature and heating time at the initial treatment stage and dipped suddenly into a solution of saturated Natrium Chloride (Quenching).

In the process of nitriding, deposition of nitrogen atoms in steel that has been treated with heat, which results in stretching of the material atoms and emptiness, so that the nitrogen atom is filled so that the new atomic bond, that is Fe-N. The infiltrated nitrogen atom occupies the location of interstitials (insertions) and substitutes (displacement). With the entry of nitrogen atoms into the substrate results in changes in the microstructure of the atom, the steel is making atoms more dense and denser. In the carbonation process, the carbon atoms can diffuse into the steel material, and carbon atoms are very easy to infiltrate the substrate because the size of carbon atoms is smaller than that of Fe atoms. With increased carbon content, the hardness increases. The quenching process is very good at hardening metal materials. In the process of sudden cooling, a metal material does not have time to diffuse with its neighboring atoms but will be filled by the quenching media suddenly. This process causes the density of atoms on the surface of the material to be higher and the metal material to be harder.

3.4. **Surface Coating process**

The surface coating process is an economical method for producing materials, equipment, and machine components that require surface resistance to corrosion, erosion, and wear. The surface coating method used in this study is metal spraying. It is a process wherein a feedstock material is heated and propelled as individual particles or droplets onto a surface. Sprayed particles impinge upon the surface, they cool and build-up, splat by splat, into a laminar structure forming the thermal spray coating. A detonation gun unit mainly consists of a doubled walled barrel, a combustion chamber, a powder feeder, control panels to regulate gas flows and gas operation. The process produces noise levels that can exceed 140 decibels and requires particular sound and explosion-proof rooms. Depending upon the ratio of the combustion gases, the temperature of the hot gas stream can go up to 3890°C, and the velocity of the shock wave can reach 3500 m/s. Depending on the required coating thickness and the type of coating material, the detonation spraying cycle can be repeated at the rate of 1 to 10 shots per second [10].

3.5. **Impact of Corrective Maintenance**

The results of surface hardening using the NiKaNa method have increased the hardness of the worm gear material to 490 BHN (4802 MPa). Increased hardness of the worm gear, it turns out to have a good impact on reducing the rate of wear. Obtained the rate of wear depth decreased from 0.497 mm per day to 0.218 mm per day. The value of the rate of wear depth after corrective maintenance for 50 days of operation is shown in TABLE III. Decreasing the rate of wear depth will increase the lifetime of the worm gear. Lifetime recommended by the manufacturer will be appropriately achieved. The condition of this wear has been plotted in graphical form, as shown in Fig. 3.
Figure 3. The comparison of wear rate values.

4. Conclusion
The application of corrective maintenance will provide benefits for a company including (1) emergency maintenance requirements are reduced; (2) heavy downtime losses are reduced; (3) plant availability is increased; (4) results in better utilization of plant facilities; (5) safety level is improved, and hence there are fewer chances of accidents; and (6) provides sufficient information concerning the maintenance replacement and repair. More intensive studies are needed to find the latest methods in terms of improving the quality of materials, especially screw press machine components. In this study, it can be concluded that to extend the lifetime of the worm gear component from a screw press machine can be done by applying corrective maintenance in the form of increasing the hardness of the worm gear material using the NiKaNa method and coating the surface of the worm gear with metal spraying method.

Table 3. The Value of The Rate of Wear Depth After Corrective Maintenence

| Operation (day) | Time (hours) | The rate of wear depth (mm) |
|----------------|-------------|-----------------------------|
| 1              | 22          | 0.218                       |
| 10             | 220         | 2.180                       |
| 20             | 440         | 4.260                       |
| 30             | 660         | 6.540                       |
| 40             | 880         | 8.730                       |
| 50             | 1100        | 10.91                       |

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