Preliminary Design on Screw Press Model of Palm Oil Extraction Machine

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Abstract. The concept of the screw press is to compress the fruit bunch between the main screw and travelling cones to extract the palm oil. Visual inspection, model development and simulation of screw press by using Solidworks 2016 and calculation of design properties were performed to support the investigation. The project aims to analyse different design of screw press which improves in reducing maintenance cost and increasing lifespan. The currently existing of screw press can endure between 500 to 900 hours and requires frequent maintenance. Different configurations have been tried in determination of best design properties in screw press. The results specify that screw press with tapered inner shaft has more total lifespan (hours) compared existing screw press. The selection of the screw press with tapered inner shaft can reduce maintenance cost and increase lifespan of the screw press.

1. Introduction
A screw press is used to compress the fresh fruit bunch between the main screw and the travelling cones to extract the palm oil. It has been used in solid-liquid separation of extraction palm oil machine purposely is to separate between oil and non-oily solid (N.O.S). The effectiveness of the screw press is very critical in optimizing the oil extraction. Ineffective press will result in high oil loss and maintenance cost of the machine. There are various types of screw presses used for the extraction of palm oil. The earliest was introduced to the palm oil industry in the early 1960’s. This type of machine had been developed for a multitude of applications, both for extraction and extruding. The concept of the screw press is to compress the fruit mash between the main screw and the travelling cones to extract the palm oil [1]. The output from the screw press is crude palm oil and press cake. The extracted oil is mixed with fruit particles, water, sand and dirt. The press cake consists of palm fibre and nuts. Figure 1 shows the arrangement of each component. In the screw press, the stability of press cage pressure is an important factor in determining the oil loss and nut breakage in the press cake. A high pressure causes a better recovery of the oil but unfortunately produce a higher nut breakage. This study are carried out to analyze the different design of screw press which can increase effectiveness the machine to extract crude oil. Screw press with current design are originated to work between 500 hours until 900 hours. However, after this limit of time, it must be replaced with a new screw press which intermittent the production due to maintenance works.

Figure 1. Main component of screw press machine
This study will include the preliminary design of screw press with altered shape of screw and shaft. Four (4) configurations of pitch distance and shaft diameter are attempted using Solidworks2016 simulation and components design properties to estimate longer life span in screw press.

2 Literature review

Some types of screw presses machine can be obtained in [2] which have wide range of capacity to be processed. A straight screw shaft configuration is commonly used screw press and easy to produce. These following type of screw shaft configuration are used in processing seed oil industry over 50 years [3]. For first configuration of screw press, the pitch and the root diameter are constant through the screw press as shown in Figure 2. The pressure level in hydraulic presses will increase linearly. At one pressing, process flow in the screw press is continuously replaced after each stroke in a hydraulic press.

![Figure 2. Constant Pitch Screw](image1)

![Figure 3. Tapered Shaft and Constant Pitch Screw](image2)

![Figure 4. Variable Pitch Screw](image3)

![Figure 5. Tapered Shaft and Variable Pitch Screw](image4)

The second configuration of screw is tapered shaft and constant pitch. The annular area is decreasing through the length of the screw and takes its minimum value at the end of the screw which is shown in Figure 3. The volume swept by the screw thread in each turn is the multiplication of the annular area and the pitch distance. The rate of pressure increase in tapered screw press is higher than straight screw shaft type. This unusual part of tapered screw type requires a CNC machine.

The fourth type of screw is variable pitch with decreasing pitch screw type as shown in Figure 4. This unusual part of screw thread requires 5-axes CNC machine tool. Practically the total shaft is divided into several different sections with different pitch. Screws with a maximum pitch, which the palm kernel is fed, is useful in increasing in the total capacity of the kernel. Similar to the tapered shaft system, in this type of screw shaft system, volume is decrease by an amount in each turn. The main difference between them is the rate of pressure increase through each thread. In tapered screw, pressure increase linearly through the screw press shaft whereas in screw with variable pitches distance, pressure is constant through each thread and increase at the transitions [4].

The fifth configuration is a screw with tapered shaft and variable pitch which combine screw press types with variable pitch and tapered shaft as represented in Figure 5. Rate of pressure increase in this of screw is higher when compared with the other types of screw. The same pressure can be determined in a shorter time because the pressure attains its maximum value in fewer revolutions when compared with the same sized screw types [4].
In producing worm screw press particularly for palm oil mill, Cast Carbon Steel material typically used. The mechanical properties of this material shows in Table 1.

**Table 1** Physical and mechanical properties for material Cast Carbon Steel, [5].

| Property                | Value     | Units |
|-------------------------|-----------|-------|
| Elastic modulus         | 200000    | MPa   |
| Poisson’s ratio         | 0.32      | N/A   |
| Shear modulus           | 7600      | MPa   |
| Mass density            | 7800      | kg/m³ |
| Tensile strength        | 482549000 | N/m²  |
| Yield strength          | 248168000 | N/m²  |
| Thermal expansion coeff | 1.2x10⁻⁰⁵ | /K    |
| Thermal conductivity    | 30        | W/(m.K) |
| Specific heat           | 500       | J/(kg.K) |

In starting this study and research, industrial visit is required to expose the researchers with real problem. Preliminary studies was carried out in a crude palm oil processing plant where the company is owned by Kilang Kelapa Sawit Pertubuhan Peladang Negeri Johor (PPNJ), Kahang, Johor. This study focused on primary process to produce crude palm oil. Results from industrial visit has given the vital information related to the screw press machine. This include how the machine mechanism operates, dimension of machine, advantages and disadvantages using screw press machine. Figure 6 shows the new screw press and in Figure 7 shows after its lifespan, the screw press set becomes tear and wear.

![Figure 6. New screw press](image1)

![Figure 7. Used screw press](image2)

3. **Model Development and Simulation**

The results from industry visit on the operational of screw press are used to model the situation using a Solidworks 2016 software. Figure 8 shows the dimension of straight screw press shaft which screw shaft frequently used in palm oil mill.
Based on the simulation design, Solidworks 2016 software is used to identify the critical parts of screw press. The software displays the analysis results in contours of color to identify critical areas in screw press. The main purpose of this analysis is to evaluate the minimum and maximum value of Von Mises stress for screw press part. Figure 9-12 shows the Von Misses stress analysis on the screw press. It shows that higher yield strength are predicted in constant pitch both in straight and tapered shaft designs. The configurations of constant pitch yields higher in increase pressure than variable pitch as the variable pitch can cause different increasing pressure at each sections. Thus, it can be predicted variable pitch screw will damage earlier than constant pitch screw as lower in yield strength in variable pitch design.

Figure 8. Full dimension of straight screw press

Figure 9. Von Misses stress analysis of screw press part with Constant pitch

Figure 10. Von Misses stress analysis of screw press part with variable pitch
After run the simulation on each model, the result from simulation shows critical areas of screw press where values of minimum and maximum Von Misses stress are presented in Table 2.

| Physical Properties / Screw Press Type          | Max. Von Misses stress (MPa) | Min. Von Misses stress (MPa) |
|-----------------------------------------------|------------------------------|------------------------------|
| Constant pitch Screw                          | $1.071 \times 10^7$          | $7.882 \times 10^4$          |
| Variable Pitch Screw                          | $1.362 \times 10^8$          | $1.486 \times 10^5$          |
| Tapered Shaft and Constant Pitch Screw        | $8.104 \times 10^6$          | $1.046 \times 10^5$          |
| Tapered Shaft and Variable Pitch Screw        | $3.982 \times 10^8$          | $1.067 \times 10^5$          |

4. Result and Analysis

The effect of fatigue life is affected by the manufacturing process and component configuration. Several factors such as surface condition, size, stress concentration and temperature are significantly affect fatigue life of materials which being processed. The simulation results are used to find of design properties or design parameters for screw press components. The value of Von Mises provide $\sigma_{\text{min}}$ and $\sigma_{\text{max}}$ from estimated
simulation data using Solidworks software. These values are used to compute Stress Concentration Factor, $K_T$. Using interpolation in [6], $q$ can be found and $K_T$ can be calculated which used to find reliability factor, $k_e$ as refer in equation (1). All factors as surface condition, size, stress concentration and temperature are applied to calculate endurance limit, $S_e$, as summarized in equation (2). Then, total rotation of screw, $N$ applied the ultimate strength $S_f = 482.549 \text{ MPa}$ to complete the calculation of equation (3). Finally, total life span is valued through the ratio between total rotation of screw and total rotation within one hour as written in equation (4).

$$k_e = \frac{1}{K_T} \quad (1)$$

$$S_e = K_a \cdot K_b \cdot K_d \cdot K_e \cdot S'_e \quad (2)$$

$$N = 10^\frac{c}{S_f^{\frac{1}{b}}} \quad (3)$$

$$L_t = \frac{N}{N_p} \quad (4)$$

The steps of calculation and detailed values are given in Table 3 for example calculation of design properties in constant pitch screw type. Similar to these calculations are applied to other types of screw press configurations.

| Reliability factor, $k_e$ | Endurance limit, $S_e$ (MPa) | Total rotation of screw, $N$ | Total lifespan (hour) |
|---------------------------|-----------------------------|-----------------------------|----------------------|
| Stress Concentration Factor, $K_T$ | The ultimate strength, (use Table 1) $S_f = 482.549 \text{ MPa}$ | | Distance of pitch, $L = 173$mm |
| | $S_{ut} = 69987.8 \text{ psi}$ | | $N = 12 \text{ rpm}$ |
| Using interpolation, $4 - q = \frac{100 - 70}{100 - 50} = 0.8$ | Rotary beam test endurance limit, $S'_e = 0.504 S_{ut} = 35273.8512 \text{ psi}$ | | $v = \frac{173}{4.5} = 38.4 \text{ mm/s}$ |
| $K_T = 1 + q(K_T - 1)$ | Surface modification factor, $k_a = 0.766$ | | $t = \frac{2}{v} = \frac{1180 \text{ mm}}{38.4 \text{ mm/s}} = 30.73 \text{ s}$ |
| $= 1 + 0.8(135.9 - 1)$ | Size modification factor, $d = \sqrt{(957.33^2)} = 89.08 \text{ mm}$ | | $t_p = \frac{P}{v} = \frac{160 \text{ mm}}{38.4 \text{ mm/s}} = 4.17 \text{ s}$ |
| $= 108.92$ | Temperature modification factor $k_b = \frac{1.189 (89.08)^{-0.097}}{0.77}$ | | Time to complete one cycle $t_{total} = t + t_p$ |
| | | | $= 34.89 \text{ s}$ |
| $k_e = \frac{1}{K_T}$ | | | Total rotation within 1 hr $N_p = \frac{2600}{2600} = 2600 \text{ rotation}$ |
| $= \frac{1}{108.92}$ | $Se = K_a \cdot K_b \cdot K_d \cdot K_e \cdot S'_e$ | | $= 103$ rotation |
| $= 0.00918$ | $S_e = 190.99 \text{ psi @ 1.317 MPa}$ | | $N = 10^\frac{c}{S_f^{\frac{1}{b}}}$ |
| | | | $= 108.78 (482.549)^{-1.22}$ |
| | | | $= 320.69 (10^3)$ rotation |
| | | | $L_t = \frac{N}{N_p}$ |
| | | | $= \frac{320.69 (10^3)}{103}$ |
| | | | $= 3113 \text{ hours}$ |
Table 4 shows the overall results of design properties in four different types of screw press. From this table, constant pitch screw in both straight and tapered shaft give higher total life span compared with other two type in variable pitch. This result also agreed with simulation data which give higher Von Mises stress in both configurations. This comparison of different design of screw press type will be used to get a best design which can be applied to screw press machine palm oil mill.

Table 4. Result summary in each types of screw press

| Types / Properties          | Constant pitch Screw | Variable Pitch Screw | Tapered Shaft and Constant Pitch Screw | Tapered Shaft and Variable Pitch Screw |
|-----------------------------|----------------------|----------------------|----------------------------------------|----------------------------------------|
| Reliability factor, $k_e$   | 0.00918              | 0.001363             | 0.0161                                 | 0.00335                                |
| Endurance limit, $S_e$ (MPa)| 1.317                | 0.1955               | 2.303                                  | 0.4802                                 |
| Rotation of screw presses   | 320.69 ($10^3$)      | 75.39 ($10^3$)       | 612.66 ($10^3$)                       | 132 ($10^3$)                           |
| Total lifespan (hours)      | 3113                 | 731                  | 5948                                   | 1281                                   |

5. Conclusion
Investigation on the frequent occurrences of screw press failures in several palm oil screw press machines in a Malaysia palm oil mill company was presented. The findings indicate that screw press with tapered inner shaft has more total lifespan (hours) which is 5948 hours compared with others design of screw press. Which is screw press with tapered inner shaft has double the lifespan compared with existing of screw press. The selection of the screw press with tapered inner shaft can reduce maintenance cost, increase lifespan of the screw press and it can be decrease frequency of maintenance work to change screw press.

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