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AN INVESTIGATION OF FREQUENCY SPECTRUM ANALYSIS FOR THE DETECTION OF BEARING DAMAGE IN CENTRIFUGAL PUMP UNIT 731PU1205 F2

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ABSTRACT
This study explores the use of frequency spectrum analysis to identify bearing faults in centrifugal pumps, specifically focusing on the 731PU1205 F2 unit at PT Sari Dumai Oleo (SDS2). Vibration data were collected using the SKF CMDT 391 device, concentrating on velocity and enveloped acceleration spectra from two measurement positions (3V and 3H). The analysis examined characteristic bearing frequencies, including Ball Pass Frequency Outer (BPFO), Ball Pass Frequency Inner (BPFI), Ball Spin Frequency, and Fundamental Train Frequency, to detect defects related to the outer race, inner race, rolling element, or cage. The results revealed vibration spectra with frequency peaks corresponding to BPFO and BPFI, indicating early-stage wear in the bearing components. These findings demonstrate that frequency spectrum analysis serves as an effective predictive maintenance tool for the early detection of bearing faults, which has the potential to reduce both downtime and maintenance costs in industrial pump operations.

Keywords : : frequency spectrum analysis, vibration monitoring, centrifugal pump, bearing fault detection, SKF CMDT 391, predictive maintenance

1. Introduction

PT. Sari Dumai Oleo (SDS2) represents a specialized unit engaged in the production of various oleochemical products, including functional fats utilized in animal feed, raw materials for cosmetics, and components for the export-quality tire industry. Within the context of centrifugal pump operations, these machines exhibit characteristics akin to living organisms through their vibrational signatures. Direct observation of these vibrations with the naked eye presents challenges, rendering it difficult to discern changes in operational conditions without appropriate analytical methods. The vibrational dynamics of centrifugal pumps serve as critical indicators of performance within industrial applications. Even minor fluctuations can often serve as precursors to mechanical failures. As such, vibration analysis emerges as a fundamental tool for technicians, enabling the identification of potential defects, including those associated with bearings, shaft misalignments, and rotor imbalances. Moreover, the significance of analytical aids, particularly the Fast Fourier Transform (FFT), cannot be overstated. This technique facilitates the decomposition of complex vibration signals into more interpretable frequency components, empowering technicians to make informed decisions and implement preventative measures before mechanical failures escalate into catastrophic events.[1]

The operation of this pump is critical, as any failure would halt production at PT. Sari Dumai Oleo (SDS2). Therefore, it is essential to maintain the pump's performance to prevent operational issues. One of the key strategies for maintaining the pump's condition involves regular maintenance through condition monitoring, aimed at preventing damage to the equipment, particularly to the bearings. Despite the implementation of periodic monitoring, malfunctions in the pump can still arise due to various factors. [2].Condition monitoring activities on feed pumps involve periodic inspections and vibration analysis to assess the equipment's operational status. These vibration analysis activities also aim to predict the operating pump's vibration levels, determining whether they remain within safe limits or have exceeded alarm thresholds. Additionally, this analysis helps identify potential defects in the components that may be causing the observed vibrations. [3].In their research, Syafri and Firdaus [4] undertook an investigation into the degradation of the SKF-3213 bearing within the centrifugal feed pump at PT Pertamina Sungai Pakning. Employing a vibration analysis methodology, the study facilitated periodic monitoring of the bearing's condition, yielding results that indicated the capability of this technique to identify damage at an incipient stage, thereby preventing significant operational disturbances. This approach underscores the efficacy of vibration-based monitoring as an integral component of predictive maintenance programs [4].

Generally, the rotary dynamics inherent in pump operation can induce vibrations. When the intensity of these vibrations surpasses established normative thresholds, it poses a risk for damage to various components, notably the bearings. The detection of bearing damage is often imperceptible to human senses, given that these components operate at elevated rotational speeds and frequencies. Consequently, specialized analytical methods are requisite for their assessment. One prevalent technique is vibration signal analysis, which has been demonstrated to capture early indicators of bearing failure during the operational phase of the pump [5].Based on the results of vibration analysis, the bearing service life can be estimated and compared with its theoretical lifespan. If the actual life of the bearing has approached the theoretical life limit, then it is recommended for a replacement to prevent further damage [6].

2. Literature Review

This research was conducted during an internship at PT Sari Dumai Oleo from February 3, 2025, to April 26, 2025. The study took place at the Fractionation 2 facility, utilizing the SKF CMDT 391 pen vibration analyzer to assess the operational performance of centrifugal pump unit 731PU1205 F2. The analysis focused specifically on a type 6305 C3 bearing, with detailed specifications pertinent to the centrifugal pump outlined below.

a. Bore Diameter (in) : 25 mm
b. Outer Diameter (out) : 62 mm
c. Bearing Width : 17 mm
d. Number of Balls : 9 Piecese
e. Ball Diameter : 9 mm
f. Pitch Diameter : 43 mm
g. Rotation Speed (RPM) : 2964

The bearing specifications above are obtained from the specification of the centrifugal pump can be seen in Figure 1

Figure 1. Specification of centrifugal pump bearings

2.1 Vibration pen SKF CMDT 391

The SKF CMDT 391 vibration pen is the measuring instrument employed to analyze the vibration of bearings on the centrifugal pump, as illustrated in Figure 2. This portable device is widely utilized in predictive maintenance for monitoring the operational condition of the pump. The choice of the SKF CMDT 391 tool by the authors is due to its practicality and its capability to support FFT-based vibration monitoring. The accelerometer sensor within the device directly captures vibration signals, which are subsequently processed into frequency data. In practice, the tool collects real-time vibrational signals and transforms them into a frequency spectrum using the FFT method. This process aids technicians in identifying anomalies that may not be apparent through standard observations. The SKF CMDT 391 effectively captures vibration signals with its accelerometer sensor, processing them via the FFT method to deliver more precise diagnostic information[7][8]. Additionally, the tool measures three key parameters: velocity, enveloping signal (which facilitates early damage detection), and temperature.

2.2 . Vibration Measurement Procedure

The procedure for collecting vibration data on the bearing of the centrifugal pump unit 731PU1205 F2 is as follows:

1) Data is collected by placing a vibration sensor directly on the pump housing to record the actual condition.
2) By the measurement conditions, see Figure 2, the position of the sensor is adjusted based on the bearing type. In *non-driver end* (NDE) type bearings, namely bearing numbers 1 and 4, measurements are only made in the horizontal and vertical directions. Meanwhile, on *the driver end* (DE) type bearings, namely numbers 2 and 3, the measurements include horizontal, vertical, and axial directions. The primary focus of the test is directed at bearing numbers 3 and 4, which are types of deep groove ball bearings type 6305 C3.
3) The test starts from the number 1 motor bearing, which belongs to the NDE category, to record the initial vibration data.
4) The next step is the measurement of the DE bearing of the motor, marked with the number 2.
5) Next, data is taken from the DE bearing in the pump position marked number 3.
6) The last data collection process is carried out on the NDE bearing of the pump, which is numbered 4.
7) Once the entire measurement process is complete, the data obtained is analysed in a spectrum and overlay using the SKF Quick Collect application.
8) The data obtained initially is collected with the SKF CMDT 391 device. The recorded vibration data is then further processed to determine the bearing's operational condition, and the results are compiled into a table for easy analysis.

2.3 Calculation of Bearing Failure Frequency

The failure frequency of each bearing type exhibits variability influenced by its specific design or classification. This analysis focuses on the failure frequency associated with the 6305 C3 type bearing. The methodology for this calculation is articulated as follows:

a. Calculation of Ball Pass Frequency Outer (BPFO)

In bearing systems, defects located on the outer race generate a vibrational impulse each time a bearing ball traverses the compromised area. The frequency of these resultant impulses is referred to as the Ball Pass Frequency Outer (BPFO), serving as a critical parameter in the assessment of bearing condition for the early identification of potential damage. The BPFO can be quantitatively determined throughEquation1.

$$\mathrm{BPFO} = \frac{Z}{2} \times f_{rot} \times \left(1 - \frac{B_d}{P_d} \cos \beta\right) \quad [1]$$

$$\mathrm{BPFO} = \frac{9}{2} \times 49.4 \times \left(1 - \frac{9}{43} \times 1\right)$$

$$\mathrm{BPFO} = 4,5 \times 49,4 \times (1 - 0,2093)$$

$$\mathrm{BPFO} = 4,5 \times 49,4 \times 0.7907$$

$$\mathrm{BPFO} = 4,5 \times 39,07 \approx 175,81 \text{ Hz}$$

Frequency of BPFO in (Hz) = 4,5 x 39,07 Hz =175,81 Hz

b. Calculation of Ball Pass Frequency Inner (BPFI)

The Ball Pass Frequency Inner (BPFI) pertains to the frequency of impulse events generated when a rolling element traverses a defect located on the inner raceway of a bearing. This frequency is pivotal in the analysis of bearing health, as it is directly correlated to defects that may affect operational performance. BPFI can be quantitatively determined utilizing Equation 2.

$$\text{BPFI} = \frac{Z}{2} \times f_r \times \left(1 + \left(\frac{B_d}{P_d}\right) \times \cos(\beta)\right) \qquad [2]$$

$$\text{BPFI} = \frac{9}{2} \times 49{,}4 \times \left(1 + \left(\frac{9}{43}\right) \times 1\right)$$

$$\text{BPFI} = 4{,}5 \times 49{,}4 \times (1 + 0{,}2093)$$

$$\text{BPFI} = 4{,}5 \times 49{,}4 \times 1{,}2093$$

$$\text{BPFI} = 4{,}5 \times 59{,}75 = 268.88 \text{ Hz}$$

Frequency of BPFO in (Hz) = 4,5 x 59,75 Hz =268.88 Hz

c. Calculation of Ball Spin Frequency (BSF)

Ball Spin Frequency (BSF) is a characteristic frequency that arises due to a defect in the rolling element (ball) of a bearing. This frequency ndescribes the rotating motion of the ball against its own axis when the bearing is operating, in response to a defect in its surface. The magnitude of BSF can be calculated with equation 3.

$$\text{BSF} = \frac{Pd}{2Bd} \times fr \times \left[1 - \left(\frac{Pd}{Bd}\right)^2\right] \qquad [3]$$

$$BSF = \frac{43}{2 \times 9} \times 49{,}4 \times \left[1 - \left(\frac{9}{43}\right)^2\right]$$

$$\text{BSF} = 2{,}3889 \times 49{,}4 \times (1 - 0{,}0438)$$

$$\text{BSF} = 2{,}3889 \times 49{,}4 \times 0{,}9562 = 112{,}7 \text{ Hz}$$

BSF frequencies in (Hz) = 2,3889 x 49,4 x 0,9562 =112,7 Hz

d. Calculation of the Fundamental Train Frequency (FTF)

The frequency generated as a result of damage to the separator, commonly referred to as the cage, is defined as the Fundamental Train Frequency (FTF). The determination of the FTF magnitude can be accomplished utilizing the formula presented in Equation 4.

$$\text{FTF} = \frac{f_r}{2} \times \left(1 - \frac{B_d}{P_d} \times \cos\alpha\right) \qquad [4]$$

$$\text{FTF} = \frac{49.4}{2} \times \left(1 - \frac{9}{43} \times 1\right)$$

$$\text{FTF} = 24{,}07 \times (1 - 0{,}2093)$$

$$\text{FTF} = 24{,}07 \times 0.7907 \approx 19.54 \text{ Hz}$$

FTF frequency in (Hz) = 24,07 x 0,7907 =175,81 Hz

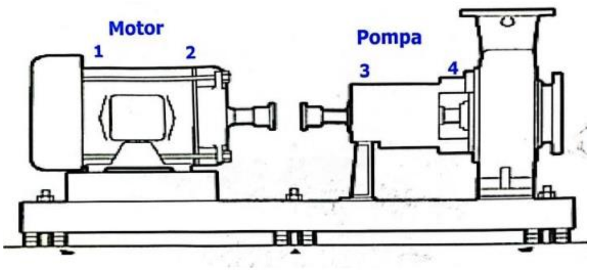

Figure 2. Vibration data capture position

Nb = Jumlah bola (*Number of balls*)

f_r = Frekuensi putaran kerja poros (Hz)

Bd = Diameter bola (*Ball diameter*) mm

Pd = Diameter pitch (*Pitch diameter*) mm

α = Sudut kontak (*Contact angle*) derajat

Figure 3. Description of BPFO, BPFI, BSF, and FTF formulas

3. Results and Discussions

The data used in this study was obtained through vibration measurement on centrifugal pumps using accelerometer sensors installed at two points: horizontal (3H) and vertical (3V) positions. This measurement aims to analyze the frequency spectrum to identify potential damage to the bearings. The results of the calculation of the frequency of bearing damage with the calculation of formulas from BPFI, BPFO, BSF, and FTF can be seen in Table 1 and Figure 4.

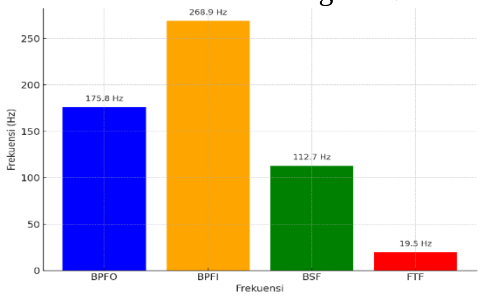

Figure 4. Results of calculation of BPFO, BPFI, BSF, and FTF formulas

Tabel 1. Hasil frekuensi

Frekuensi	Nilai (Hz)
BPFO	175,81
BPFI	268,88
FTF	19,54
BSF	112,7

3.1 Vertical position spectrum analysis (3V)

Based on the vibration analysis at the vertical position (3V) of the centrifugal pump, the velocity spectrum shows a peak vibration of around 295 Hz, which is close to the frequency of BPFO (175.8 Hz) and its harmonics. This indicates the potential for damage to the outer race bearing. The enveloped acceleration spectrum in this position shows a fairly high value of 11.91 gE, with many harmonic peaks between 50–300 Hz, including around 60.5 Hz which is close to the BSF value, which is the frequency of the rotation of the ball. This corroborates the indication of damage to the ball bearing. The analysis of the roughness on the 6305 C3 bearing can be seen in the overlay image of the velocity spectrum and the vertical position (3V) in Figures 6 and 7. The red dotted line indicates the harmonics of the characteristic frequency of the bearing (BPFO, BPFI, BSF, FTF).

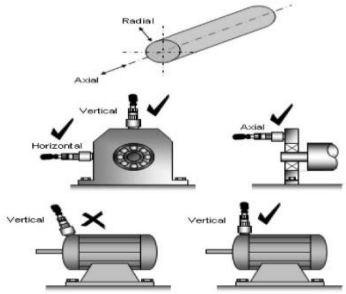

Figure 5. Spectrum Data Capture Position

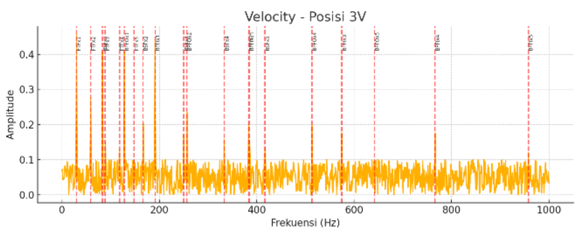

Figure 6. 3V Position Spectrum Velocity Overlay

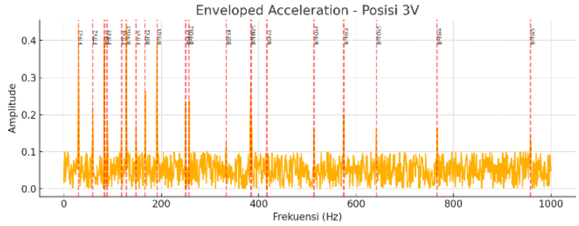

Figure 77. Overlay enveloped acceleration position 3V

3.2 Horizontal Position Spectrum Analysis (3H)

In the horizontal position (3H), the vibration speed was 2.18 mm/s. The frequency spectrum displayed a peak in the 268–270 Hz range, which corresponds with the BPFI frequency. It suggests the potential presence of damage to the inner race bearing. Furthermore, the enveloped acceleration value was notably high at 10.51 gE, with the dominant impulsive signal occurring at approximately 60–70 Hz. This pattern reinforces the suspicion of damage to the ball element or light spalling on the bearing surface. The roughness analysis on the 6305 C3 bearing can be observed in the vertical position spectrum overlay images (3V) presented in Figures 8 and 9. The red dotted line highlights the harmonics of the characteristic frequencies of the bearing (BPFO, BPFI, BSF, FTF)**.**

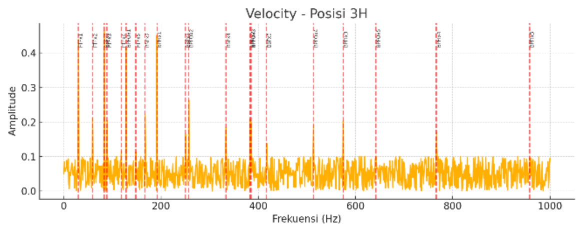

Figure 8. 3H position velocity overlay

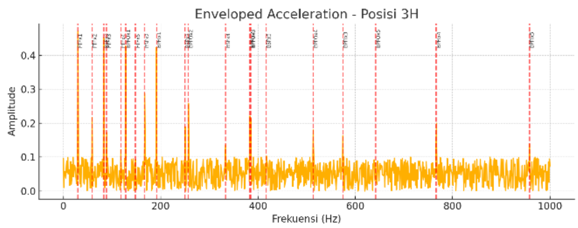

Figure 9. Overlay enveloped acceleration position 3H

3.3 Interpretation and indication of damage

Based on the results from the overall vibration spectrum analysis, several indications of damage to the centrifugal pump bearing have been identified, as outlined below:In the vertical position (3V), the vibration spectrum reveals a predominance of frequency components associated with the Ball Pass Frequency of the Outer Race (BPFO) and the Ball Spin Frequency (BSF). These peaks in the spectrum suggest potential damage to both the outer race and the bearing ball elements. Figure 10 illustrates the measurement data for the 3V position. Conversely, in the horizontal position (3H), the vibration spectrum is primarily characterised by a frequency component corresponding to the Ball Pass Frequency of the Inner Race (BPFI) and a consistent presence of BSF. The prominence of the BPFI frequency indicates suspected damage to the inner race bearing, while the recurring BSF frequency further supports the indication of degradation in the ball element. Additionally, the recorded enveloped acceleration values, which exceed the general threshold of 10 gE in both positions, suggest that the damage is at an intermediate to advanced stage. Therefore, it is recommended to promptly undertake maintenance actions or replace bearing components to prevent a complete system failure. Figure 10 shows the measurement data for the 3H position.

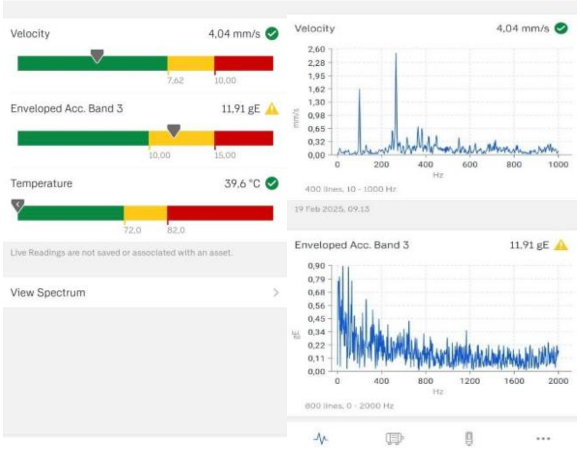

Figure 10. The Spectral Data of the position of 3V

The spectral data presented in Figure 10 for the position of 3V (vertical) demonstrate measurement results indicating a vibration velocity of 4.04 mm/s and an amplified acceleration of 11.91 gE. These values reflect the system's dynamic behavior under analysis, providing critical insights into its performance characteristics

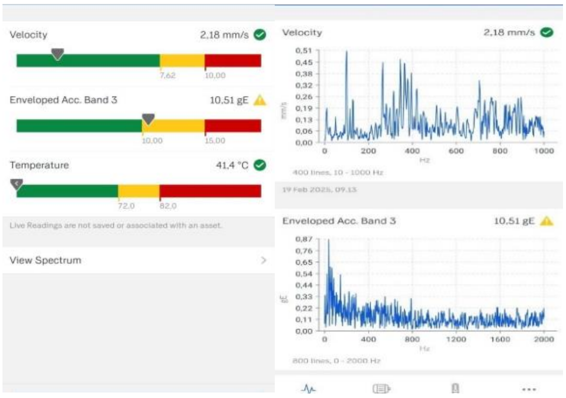

Figure 11. The Spectrum Data for 3H position

This section contains a complete and detailed description of the steps undertaken in conducting of research. In addition, the research step also needs to be shown in the form of flowchart of research or framework step in complete and detailed including reflected algorithm, rule, modeling, design and others related to system design aspect.

4. Conclusion

Based on the results of the vibration spectrum analysis conducted on the centrifugal pump using the velocity and enveloped acceleration methods at two measurement points (3V and 3H), coupled with the frequency characteristics analysis of the bearings, several conclusions can be drawn:

1) The frequency spectrum analysis successfully identified indications of bearing damage. The presence of characteristic bearing frequencies, such as the Ball Pass Frequency of the Outer Race (BPFO), Ball Pass Frequency of the Inner Race (BPFI), and Ball Spin Frequency (BSF), suggests potential damage to various bearing components.
2) In the vertical position (3V), a dominant frequency indicative of damage to the outer race and the ball bearing element was identified. This observation is further supported by a significantly high enveloped acceleration value of 11.91 gE.
3) Conversely, in the horizontal position (3H), the vibration spectrum indicates a tendency towards damage to the inner race and the associated frequency relating to the spherical element. The enveloped acceleration value of 10.51 gE reinforces the suggestion of structural damage in this area.

4) The vibration amplitude values recorded at both measurement points exceeded the acceptable thresholds, indicating considerable degradation of the bearing condition. Without prompt corrective action, there is a risk of system failure.
5) Overall, the frequency spectrum analysis method—especially via the enveloped acceleration approach—has effectively detected early signs of bearing damage. This method can successfully identify impulsive signals generated by microdefects, particularly through applying SKF Quickcollect, as illustrated in Figures 10 and 1. Consequently, this approach can be relied upon to assist technicians in making timely and informed decisions.

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