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Lifetime Analysis of Type E Tapered Roller Bearing on CC 201 Locomotive Bogie Based on ISO-281:2007

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Abstract **- PT. X conducts locomotive maintenance through workshop to ensure the reliability and safety of railway operations. As a component related to wheel propulsion, the maintenance of tapered roller bearings on locomotive bogies is critically important. Located on the outer side of the wheel assembly, these tapered roller bearings function to support both axial and radial loads exerted by the locomotive. Calculating the bearing lifetime is essential to determine its operational duration, thereby enabling the company to perform scheduled bogie maintenance in accordance with work instructions. Bearing lifetime directly affects maintenance effectiveness and the overall maintenance cost.**

Keywords: bogie, journal bearing, lifetime, maintenance, locomotive.

I. INTRODUCTION

Railways have become a preferred mode of transportation for the public due to their relative speed and efficiency. This was also the rationale behind the construction of railway lines in the 19th century by the Dutch East Indies government, which later became the foundation for the development of railway infrastructure in Indonesia [6]. In a diesel-electric locomotive, power from the diesel engine drives a generator, which produces electrical energy. This electrical energy is then distributed to electric motors and converted into mechanical energy, enabling the locomotive wheels to rotate [7].

The power of a diesel engine is generated through a combustion reaction between fuel and compressed air. This combustion increases temperature and pressure, causing the piston to move in a reciprocating motion and producing mechanical energy through the rotation of the crankshaft. With this working mechanism, electric transmission plays a crucial role in ensuring the efficiency of the output energy. This energy efficiency which includes both the electric transmission and technical design depends on the selection of the system's operating parameters [3].

The locomotive bogie consists of several components, one of which is the roller bearing, also known as a journal bearing. Roller bearings are mounted at each end of the train wheel axle. The type used is a tapered roller bearing, which functions to support the weight of the train and its load. These bearings are positioned within the pedestal jaw of the side frame. The moving elements within the roller bearing allow the axle to rotate smoothly [2]. The axle of a railway vehicle is equipped with a tapered roller bearing, which supports the entire load of the CC 201 locomotive. Tapered roller bearings have a limited operational lifespan, commonly referred to as their lifetime. A bearing is a machine element that supports the movement of other mechanical components by carrying radial loads, axial loads, or a combination of both [2].

II. RESEARCH OBJECT

In accordance with the definition of ABMA (American Bearing Manufacturers Association) what is meant by equivalent load is constant radial load acting on the rotating inner ring. In reality, bearings usually receive a combination of radial and axial loads and in a condition where the inner ring is fixed while the outer ring rotates [1]. So, the equivalent load equation (P) becomes:

$$P = X_2 V F_r + Y_2 F_a \qquad (1)$$

Description:

P: Equivalent load (kN)
F_r: Radial load (kN)
F_a: Axial load (kN)
V: Rotation factor (constant)
(1 for inner ring, 2 for outer ring)
X_2: Radial constant
Y_2: Axial constant

In the locomotive bearing specifications, the equivalent load is determined using the following formula:

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$$\frac{Fa}{Fr} \leq e\,, P = Fr + Y2Fa$$

$$\frac{Fa}{Fr} > e = 0{,}67Fr + Y3Fa$$

And for the equivalent static load, $P0 = Fr + Y0Fa$

The following steps are undertaken to determine the lifetime bearing:

1) Calculating value of Fr
2) Calculating value of Fa
3) Calculating value of n
4) Calculating lifetime bearing L10

Bearings that are analyzed are assumed to rotate with constant rotation, not contaminated by pollutant particles that are in the environment of PT. X, and lubrication is carried out using grease periodically, so the prediction of bearing life (expressed in hours) can be written with the following equation [3].

$$L_{10} = \left(\frac{C}{P}\right)^b \times \frac{10^6}{60n}$$

Description:

L10 : Lifetime bearing (jam)
C_{10} : Dynamic load (kN)
P : Equivalent load (kN)
b : Load bearing constant (b=10/3 for roller bearing bearing)
n : Shaft rotation (rpm)

2.1 Specification Locomotive CC 201

Table 1: Specification Locomotive CC 201

Track gauge	1067 mm
Bogie material	Bolster, Caststeel
Wheel diamete	905
Axle spacing	1.594 mm
(asimetri)	1.911 mm
Enginetype	GE 7FDL-8
Tractionmotors	GE Zqdr310 / GE 761 A19
Maximumspeed	120 km/h
Enginepoweroutput	1950 (140 Kw)
Forcetraction	17.640 kgf (173.000 N ; 38.900 lbf)
Gearratio	90 : 21
Fueltype	High-speed diesel
FuelCapacity	3.028 L (800 US gal)
Emptyweight	78 ton (17.208 Pon)
Ready tooperateweight	84 ton (185.000 Pon)
Maximum per	90 km/h

2.2 Specification Tapered Roller Bearing Tipe E

Table 2: Specification Tapered Roller Bearing Tipe E

d (Bore)	144,450 mm
D (Outside Diameter)	220,662 mm
Kt (Lebar)	120,6 mm
C (Outer race width)	163,512 mm
Radial load	195 kN
Axial load	50,7 kN
k Faktor	2,21
Y2	2,55
Y3	3,80
Y0	2,50
E	0,26
Basic dynamic load rating	667 kN
Basic static load rating	1380 kN

III. RESULTS AND DISCUSSIONS

The following is the calculation of the tapered bearing lifetime on the locomotive CC 201 PT. X using the following analysis method.

3.1 Free Body Diagram

Each type E tapered roller bearing on the CC 201 locomotive is subjected to both vertical and horizontal forces. The vertical force originates from the locomotive's weight, while the horizontal force arises due to lateral acceleration when the locomotive navigates a curve at a speed of 90 km/h with a turning radius of 440 meters. The following figure presents the free body diagram of the bearing:

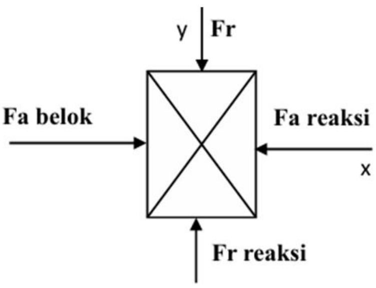

Figure 1: Free Body Diagram

Where the vertical or radial forces are applied:

$$\sum Fr = 0$$
$$0 = Fr\ locomotive - Fr\ reaction$$
$$Fr\ reaction = Fr\ locomotive$$

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Where the horizontal or axial forces are applied:

$$\sum Fa = 0$$
0 = Facorner - Fareaction
Fareaction = Facorner

Description:

Frlocomotive = Weight a locomotive
Frreaction = Radial force at the bearing
Facorner = Centrifugal force
Fareaction = Axial force at the bearing

3.2 Calculation Radial Force

The load is determined by considering the weight borne by the wheel, which typically includes the weight of the car body along with its carried cargo. Based on the maximum allowable axle load stipulated in the Regulation of the Minister of Transportation of the Republic of Indonesia No. PM 60 of 2012, for a track gauge of 1067 mm, the permitted maximum load per axle is 18 tons. Accordingly, the following equation is used to calculate the vertical load on a railway wheel during straight-track operation, under the assumption of a maximum axle load of 18 tons.

$$Fr\ lokomotif = P \times g$$

Description:

P = Weight of the locomotive
g = Gravitational acceleration

$$\text{Fr}\ locomotive = (84000\ kg \ \times 9{,}81 \frac{m}{s^2})$$

$$Fr\ locomotive = 824040\ N$$

Since there are 12 bearings on a locomotive, the vertical load on a single bearing can be calculated as follows:

$$\text{Fr bearing} = \frac{824040\ \text{N}}{12}$$

$$Fr\ bearing = 68670\ N = \mathbf{68,67\ kN}$$

3.3 Calculation Axial Force

According to the Regulation of the Minister of Transportation No. PM 60 of 2012, the centrifugal force acting on a train is defined by the following equation:

$$\text{Fcentrifugal} = \frac{\text{W}}{\text{g}} \times \frac{\text{v}^2}{\text{R}}$$

Description:

V = Maximum train speed on a curve (m/s)
R = Curve radius (m)
W = Train load (N)
G = Gravitational acceleration (m/s²)

Alternatively, if the velocity (V) is expressed in kilometers per hour (km/h), the centrifugal force equation can be reformulated as follows:

$$Fsentrifugal = \frac{W}{9{,}81} \times \frac{\left(V \times \frac{1}{3{,}6}\right)^2}{R}$$

$$Fsentrifugal = \frac{W \times V^2}{127R}$$

With the permitted locomotive speed of 90 km/h, the minimum allowable curve radius is 440 meters, based on PD No. 10 of 1986. The horizontal (axial) force acting on the locomotive can therefore be calculated as follows:

$$Fs = \frac{824040\ N \ \times (90\ km/jam)^2}{127 \ \times 440\ m}$$

$$Fs = \mathbf{119447,46\ N}$$

Since there are 12 bearings on the locomotive, the axial load on each bearing is:

$$Fa\ bearing = \frac{119447{,}46\ N}{12}$$

$$Fa\ bearing = 9953{,}95\ N = \mathbf{9,95\ kN}$$

Therefore, the horizontal or axial load acting on each bearing is approximately **9.95 kN**.

3.4 Calculation Dynamic Load

Based on the specifications of the E-type tapered roller bearing used on the locomotive, the value of e is known to be 0.26. The parameter e represents the threshold value for the ratio of axial to radial load Fa/Fr in the bearing load calculation, as defined by the bearing manufacturer. The governing equations are as follows:

$$\frac{Fa}{Fr} \leq e\ , P = Fr + Y2Fa$$

$$\frac{Fa}{Fr} > e, P = 0{,}67Fr + Y3Fa$$

For equivalent load, $P0 = Fr + Y0Fa$

After calculating the axial and radial loads:

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$$\frac{Fa}{Fr} = \frac{9{,}95}{68{,}67} = 0{,}14$$

The appropriate equation for dynamic equivalent load is:

$$\frac{Fa}{Fr} \leq e, P = Fr + Y2Fa$$

Using the value Y2 = 2,55, the dynamic load for the tapered roller bearing used on the CC 201 locomotive is calculated as:

$$P = Fr + Y2Fa$$

$$P = 68{,}67\ kN + (2{,}55)(9{,}95\ kN)$$

$$\boldsymbol{P = 94{,}04\ kN}$$

Therefore, the dynamic equivalent bearing load is **94.04 kN**.

3.5 Calculation Shaft Rotation (RPM)

The following equation is used to calculate the shaft rotational speed:

$$V = \omega . r$$

Where

V = Permitted linear velocity (m/s)
ω = Angular velocity (rad/s)
r = Wheel radius (m)

Given:

Permitted speed = 90 km/h = 25 m/s
Wheel diameter = 905 mm = 0.905 m

$$V = \omega . r$$

$$25 = \omega . (0{,}905)$$

$$\omega = 27{,}62$$

$$\boldsymbol{n = 269{,}75\ RPM}$$

3.6 Calculation Lifetime Tapered Roller Bearing

The following equation is used to calculate the lifetime (L_{10}) of the E-type tapered roller bearing used in the CC201 locomotive:

$$L_{10} = \left(\frac{C}{P}\right)^b \times \frac{10^6}{60n}$$

The basic dynamic load rating is given as 667 kN, with a calculated dynamic equivalent load of 94.04 kN. The shaft rotational speed is 269.75 RPM. The exponent *b* depends on the type of bearing; for tapered roller bearings, *b* is typically 10/3. Based on these values, the bearing lifetime is calculated as follows:

$$L10 = \left(\frac{667\ kN}{94{,}04\ kN}\right)^{\frac{10}{3}} \times \frac{10^6}{60(269{,}75RPM)}$$

$$\boldsymbol{L10 = 42357{,}59}\ \textbf{Jam}$$

The calculated lifetime of the E-type tapered roller bearing used in the CC201 locomotive is **42,357.59 hours**, which is equivalent to approximately **58 months** under continuous operation.

In practice, the locomotive operates for approximately 21 hours per day, from 03:00 to 00:00. The operational schedule consists of three shifts: the morning shift from 08:00 to 14:00, the afternoon shift from 14:00 to 20:00, and the night shift from 20:00 to 08:00 [4]. Accordingly, the calculated bearing lifetime under actual operational conditions is approximately **66 months**.

IV. CONCLUSION

From the analysis and discussion of the lifetime tapered roller bearing on the locomotive cc 201 motor PT. X, the following conclusions are obtained:

1) The type of bearing used on the wheels of the CC201 locomotive is a **tapered roller bearing**. Based on analytical calculations using the ISO 281 method, the estimated bearing lifetime is **42,357.59 hours**, or approximately **58 months** under continuous operation. Taking into account the locomotive's actual daily operating hours, the effective service lifetime is extended to approximately **66 months**.
2) Based on the analysis, the bearing maintenance and replacement schedule implemented by PT. X is in accordance with the recommended guidelines. Maintenance is performed during the P48 interval, which occurs prior to the calculated bearing lifetime of 58 months, and aligns with the operational service life of approximately 66 months based on actual locomotive working hours. The rationale for conducting P48 maintenance, as derived from both data analysis and interviews, is due to the occurrence of damage to several components, such as the bearing seal. In addition, P48 includes under frame maintenance, which often involves welding. The welding current can cause micro-damage to the roller bearings. Furthermore, exposure to dust and debris during operation can compromise the bearing seal, leading to potential leakage.

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