Optimization Stacker Reclaimer Slewing Bearing Assessment in Mechanical Inspection Combining with Advance Technology of Vibration Analysis

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Abstract. SKF Mechanical Service, Engineering Knowledge Company was entrusted to perform Life Assessment Of Slewing Bearing At Stacker Reclaimer for further Improvements Plan at one Power Plant Industry, suggest on best methodology and technique to be implemented in maintaining the reliability of slew bearing at the critical equipment in better maintenance functions, reliability and cost-effectiveness. SKF were awarded the work order for the assessment and recommend improvements plan with respect to the following scope of work. The objective of the assessment is to identify current condition of Slew Bearing installed at the critical equipment of Stacker Reclaimer and a way forward to prevent it from the catastrophic failure for another 15 years operation (expectation). The result of the mechanical service assessment is showing the evidence wear phenomena occurrence, as one of mechanical equipment/asset failure mode compared to suitable value of permissible wear or bearing height reduction, bolts, nut & washer integrity compared to OEM specification, gear drives backlash according to standardization and bearing grease contaminant observation in relation to Fe, PQ and Cr wear percentage, vibration pattern & level for conformance checking and recommendation maintenance procedure for improving bearing life.

1. INTRODUCTION
Stacker reclaimers have a critical function to store difference in material and consumption, to create stockpiles of the bulk materials, disruptions in transport systems, distance of plant from mines, the capacity of the stockpiles ranges from 7 to 45 days, coal is received by ships – stockpile of about 45 days. This mixing operation of more than one material is called blending. Stackers and reclaimers are also required for homogenization / blending of bulk materials.

There are some classifications of reclaimers from its arrangement which are linear, radial and mobile, from structure there are boom, portal & bridge, from device there are grab bucket, bucket chain & bucket wheel and from cycle duty there are cyclic and continues.

On this mechanical service assessment SKF performed on the mobile stacker reclaimer on coal yard. The typical problem of this equipment mostly harsh operating conditions (dirty, wet, abrasive, temperature extremes, heavy and vibrating loads), hard to maintain equipment due to of large or heavy
equipment (outdoor conditions, hard to assemble / align), high lubricant consumption (hazardous waste) and little warning of impending problems (input to automation). Implication of these problem are premature machinery failures and high repair costs, high lubricant consumption, poor reliability, high maintenance and repair costs, high machinery downtime, reduced equipment efficiency (increased energy consumption), risk of worker injuries, worker health risks (slips and falls, dermatitis), safety hazards (fire), higher environmental clean-up and waste disposal costs, greater equipment damage & downtime and reduced worker productivity.

Each slewing bearing type has different characteristic based on its design, which make it more, or less, appropriate for a given application. The size of a slewing bearing can be based initially on dynamic and static load ratings of the bearing, in relation with applied load and the requirements regarding reliability and service life. Value for the axial dynamic load rating C and axial static load rating Co are quoted in the product table. The loads and moment acting from slewing bearing from the inherent weight of the components that it carries, and other inertia forces, are either known or can be calculated. The resulting loads and moments applied to the bearing can be estimated, using the following equation:

\[ F_a = Q_a + G_1 + G_2 + G_3 \]  
\[ M_t = Q_a x L + F_r x H_r + G_3 x - G_1 x L_1 - G_2 x L_2 \]

Where:
- \( F_a \) = resulting axial load applied to the bearing, kN
- \( F_r \) = external radial load applied to the bearing, e.g. work/wind force, kN
- \( G_1 \) = weight fraction 1, e.g. the counterweight, kN
- \( G_2 \) = weight fraction 2, e.g. the weight of cabin, kN
- \( G_3 \) = weight fraction 3, e.g. the weight of the boom, kN
- \( H_r \) = distance from the bearing center point to the line of action of the radial force \( F_r \), m
- \( L \) = distance from the center of rotation to the center of the lifting load, m
- \( L_1 \) = distance from the center of rotation to the center of gravity of the weight fraction 1, m
- \( L_2 \) = distance from the center of rotation to the center of gravity of the weight fraction 2, m
- \( L_3 \) = distance from the center of rotation to the center of gravity of the weight fraction 3, m
- \( M_t \) = resulting tilting moment acting on the bearing, kNm
- \( Q_a \) = lifting load, kN

Slewing Bearings are vital and critical components of the machine. It takes skill and experience to maximize bearing performance and reduce the risk of premature failures. Experience means choosing the correct mounting method and using the correct tools for the job. As with all important machine components, slewing bearing should be cleaned and inspected regularly. Maintenance intervals depend entirely on the bearing conditions. In application where there are heavy loads and/or high level of contamination, decrease the time between inspections. To avoid accidents or injuries during the inspection process, be sure that the moving part of the slewing bearing arrangement is balanced and that no tilting moments or radial loads are present.

We have developed solutions in order to check the condition of the bearing during his service life and protect it against unexpected failures. We focus are avoid downtime and high expenses and the best combining solution are grease / oil Analyses, wear measurements and vibration analyses of the raceways & bearings components.

2. METHODOLOGY

SKF has set up several methods for this specific assessment which align with the best practice and experiences in industrial typical application.

2.1. Bolts inspection

Check for loose bolts on the inner and outer bearing rings. Tighten all bolts to the recommended torque values. This is the baseline activity before furthering any assessment done for the bearing. The
standard fastener can follow OEM specification on bolts, nuts & washers or it can be referred to ISO 898 standard fastener and tightening method.

Table 1. Bolt Tightening

| Tightening method | Wrench | Hydraulic torque |
|-------------------|--------|-----------------|
| type of bolts to ISO 898 | 6.0 | 10.0 |
| d (mm) | pitch (mm) | torque (Nm) | FM (N) | torque (Nm) | FM (N) | torque (Nm) | FM (N) |
| M 6 | 1 | 10 | 9000 | 14 | 13200 | 15 | 13400 |
| M 8 | 1.25 | 23 | 16300 | 34 | 24200 | 40 | 28300 |
| M 10 | 1.5 | 45 | 26000 | 67 | 38500 | 77 | 45000 |
| M 12 | 1.75 | 80 | 38500 | 115 | 56000 | 135 | 66000 |
| M 14 | 2 | 125 | 53000 | 185 | 77000 | 215 | 90000 |
| M 16 | 2 | 195 | 72000 | 285 | 106000 | 335 | 124000 |
| M 18 | 2.5 | 280 | 91000 | 393 | 129000 | 465 | 131000 |
| M 20 | 2.5 | 395 | 117000 | 560 | 166000 | 655 | 194000 |
| M 22 | 2.5 | 540 | 146000 | 770 | 200000 | 900 | 243000 |
| M 24 | 3 | 680 | 168000 | 970 | 239000 | 1130 | 280000 |
| M 27 | 3 | 1000 | 221000 | 1420 | 315000 | 1670 | 370000 |
| M 30 | 3.5 | 1360 | 270000 | 1930 | 365000 | 2260 | 450000 |
| M 33 | 3.5 | 1830 | 335000 | 2630 | 480000 | 3080 | 560000 |
| M 35 | 4 | 2380 | 395000 | 3380 | 560000 | 3960 | 600000 |
| M 39 | 4 | 3230 | 500000 | 4320 | 660000 | 4660 | 664000 |
| M 42 | 4.5 | 4450 | 610000 | 5290 | 799000 | 6080 | 840000 |
| M 45 | 4.5 | 5450 | 710000 | 6290 | 899000 | 7500 | 1070000 |
| M 48 | 5 | 6450 | 810000 | 7400 | 1050000 | 8400 | 1200000 |
| M 52 | 5.5 | 7450 | 915000 | 8500 | 1205000 | 9400 | 1350000 |
| M 60 | 6 | 11700 | 1666666 | 11900 | 2126666 | 13700 | 2533333 |
| M 64 | 6 | 12430 | 1809000 | 13200 | 2460000 | 15100 | 2970000 |
| M 72 | 6 | 20620 | 2052000 | 20520 | 3412000 | 22520 | 3812000 |

* Tolerances according to DIN 2510, sheet 2

2.2. Slew Drive Gear Inspection

a. Ensure all drive motors are functional and check the bolt torques on the drive base.

b. Isolate the slew drives and long travel.

c. Remove the covers and inspect the drive pinions and bearing gear teeth for wear and damage

d. Check the load distribution of the tooth meshing. Use bearing blue to ensure contact zones are correct

e. Check the gear backlash

f. Using feeler gauges, measure and record the backlash clearance between slew pinion and ring gear.

g. Re-install the guards for the slew gear and drive brakes, and reinstate power to drives for machine operation

Table 2. Backlash Guidance

| Module | incl. | backlash |
|--------|-------|----------|
| over | | from to |
| (µm) | (µm) | (µm) |
| 3,15 | 6,3 | 250 | 375 |
| 6,3 | 10 | 300 | 450 |
| 10 | 12,5 | 450 | 675 |
| 12,5 | 16 | 600 | 900 |
| 16 | 20 | 800 | 1200 |
| 20 | 25 | 1000 | 1500 |

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Table 2. Backlash Guidance
2.3. **Inspect Seals and Grease**
   a. Inspect the slew bearing labyrinth seals for signs of deterioration or tearing. Check the seals have not become dislodged
   b. Check the pre-packed grease
   c. Check that the inner seal has not become dislodged in operation

2.4. **Measure Wear - Slew Bearing**

2.4.1 **Procedure #1**
Measure the wear of the slew bearing as follows:
   a. Wind speed should not exceed 12 m/s. Ensure and conditions are satisfactory for accurate measurement
   b. Clean the slew area.
   c. Slew the machine into the same position for all bearing measurements as the measurement of the bearing wear is relative to measurement taken during commissioning (Customer expected to have the data). It is important the machine is positioned identically at each measurement (same machine position as at commissioning datum measurement) so, that result can be compared on an equivalent basis
   d. Use calipers or internal micrometers to measure and record the gap between the measuring blocks at four (4) points.
   e. Measure at the locations shown and record measurements.
   f. Replace slew bearing on or before the maximum acceptable wear value of …. mm. An order for the replacement slew bearing should be placed when wear has reached… (%) of the maximum value indicated above (ie wear = …mm)

![Figure 1. Cross Sectional of Slewing Bearing](image)

2.4.2 **Procedure #2**
With the machine in the same position as per above:
   a. De-isolate the luff cylinder hydraulic power pack and raise the boom to the uppermost position and record the luff angle.
   b. Take pressure readings from the cylinder/s and record.
   c. Lower the boom in sequence to the lower-most position taking pressure readings at each point.
   d. The results will be returned to SKF office for further analysis and report

2.5. **Vibration Analysis**
In complementing this work, SKF has also set up the vibration analysis to monitor the equipment. And for this specific work, we use several approaches to monitor the equipment:
   - Using Continuous Monitoring by installing SKF Online Monitoring (IMx-P) and OfflineMonitoring (Microlog AX)
   - Using Time Waveform, this is considering the low speed application at site
3. ASSESSMENT FINDING

3.1 Bolts Inspection

The slew bolts are an integral part of the bearing which facilitates the secure attachment of the bearing to the supports. This ensures maximum rigidity of the assembly and so avoids the risk of fatigue failure. If 20% or more of the total number of bolts of a single ring are found to have less than 80% of the prescribed preload, then all bolts should be replaced. Several bolts were identified & found to be loose and have lost their prescribed preload as outlined

From vibration analysis, we also found the alignment of above mechanical inspection, which have given the evidence of some looseness occurrence. Never loosen or exchange more than one bolt at a time. Use the same tightening method, the same tools and the same type of bolts employed for the original mounting/OEM specification”. (Inside Ring Bolt M24X260 ISO 4014 Ma=830Nm, Nut M24 ISO 4032, Washer 25 DIN 6916 and Outside Ring Bolt M24X180 ISO 4014 Ma=830Nm, Washer 25 DIN 6916)
For integrity purpose, SKF has taken two (2) bolts & washer for further material integrity check thru laboratory. And detail of the report of M24 x 260MM Hexagonal Bolts, Nuts & Washer could be found in Appendix D – Nata Test Result for Bolt.

Combining the finding between field assessment (Bolt looseness) and laboratory check of bolts material integrity, SKF comes up with some prejudice of following matters:

4. Only 11% bolt from inner side and 3% from outer side have looseness problem. And this phenomenon is suspected from corrosion of several bolts.
5. We presume, and it’s aligned with the report that one of possibility condition that made the occurrence of Bolt looseness, beside the corrosion, is washer material deformation (soft material)
6. Considering point#1 & 2, we suggest checking all the material of the Bolt, Nuts and Washer thru laboratory check, and using its laboratory data reference as guidance and for safety integrity operation purpose. This activity shall be done before any bolt, nut & washer replacement
3.2. Slew Drive Gear Inspection
The gear backlash was checked by lifting the brakes on the slew drives. Feeler gauges were used to measure and record the backlash clearance between slew pinion and ring gear. The backlash should be 0.03 to 0.04 x Module. The recommended allowable backlash is between 0.77 mm and 1.23 mm, as OEM data.

Measurements were done in original install position (ref) and in work zone area as depicted in the table below. Excessive backlash recordings were recorded and are not within specification for this application. In addition, some pitting corrosion occurs during the inspection is evident on the pinions.
| Module over | incl. | backlash from | to |
|------------|-------|---------------|----|
| -          |       | (μm)          | (μm) |
| 1.15       | 6.3   | 250           | 375 |
| 6.3        | 10    | 380           | 450 |
| 10         | 12.5  | 450           | 675 |
| 12.5       | 16    | 680           | 900 |
| 16         | 20    | 880           | 1200|
| 20         | 25    | 1000          | 1500|

**Figure 6.** Group Activities Backlash Measure

From Vibration analysis result, SKF also confirm…

**Figure 7.** Position Stacker for Vibration Measurement
a. Appears a repetitive impact signal in Time domain, as a periodic signal of fundamental ball pass frequency (BSF). This indication only cached by sensor no.3 which covering area 270° - 360° (bolt no.23 to 38) – reverse position where found wear value 1.2 – 1.9mm (90° – 135°) in zero degree of boom positioning
b. In sensor no.2 and no.4, specific frequency +/- 150CPM appears in many collected vibration data via Time and Freq. domains as possible indication of Gear Mesh Frequency (GMF)

3.3. Inspect Seals and Grease

From visual inspection, there are no signs of deterioration, ageing or tearing of the seals. The seals also appear to be intact and have not become dislodged.

We took the grease sample from the output side of the equipment. And from laboratory result, it could see an indication of degradation of grease function, which is normal phenomenon.

Under this assessment, SKF has taken several grease samples for laboratory check, and the following result for reference as depicted below:

- **Inside Boom 45d (sample A)**
  Iron elevated. Most likely indicating wear. PQ Ferrous debris index elevated. No significant wear >5um. Purge with fresh grease to remove build up. Monitor trend.
- **Inside Counterweight 45d (sample C)**
  Iron elevated. Most likely indicating wear. PQ Ferrous debris index elevated. No significant wear >5um. Purge with fresh grease to remove build up. Monitor trend.
- **Inside Boom 135d (sample B)**
  Iron elevated. Most likely indicating wear. Chromium elevated. Chromium is often alloyed with steel PQ Ferrous debris index elevated. No significant wear >5um. Purge with fresh grease to remove build up. Monitor trend.
- **Inside Counterweight 135d (sample D)**
  Iron elevated. Most likely indicating wear. No significant wear >5um. Purge with fresh grease to remove build up. Monitor trend.
• **Outside Boom 45d (sample E)**
  PQ Ferrous debris index elevated. No significant wear >5um. Purge with fresh grease to remove build up. Monitor trend.

  The occurrence of iron (Fe) and particle from grease analysis are showing the evidence of wear phenomenon, which is aligned with drop height measurement result.

  And the Chromium value is still under permissible value, which giving an indication that the Bearing material is in good condition, since Chromium is acknowledged widely as one of component that always used in bearing manufacture.

![Figure 9. Group Activities Grease Sampling](image)

### 3.4. Slew Bearing Wear

#### 3.4.1 Procedure #1 – Luffing Method

SKF used a combination of Tilting and Drop height measurements to assess the wear condition of this bearing. Measurements were taken in the original install position (0 deg) as a reference, then also in the work zone areas (45 deg & 135 deg) of the bearing. These measurements in the work zone are now baseline data to be compared with future inspections. Measurements were found to be within specifications of not more than 0.2mm. Customer suggested to frequently measurement of the Tilting for indication of bearing condition beside the Drop Height. Result of the reading are depicted in the tables below for references:

![Image of tilting and drop height measurement](image)
Figure 10. Group Activities Tilting Measurement vs Lifting Angle & Load Zone Area

The reference value for guideline on this tilting measurement we can find on SKF Kaydon Slewing Ring catalogue page 43 as follow:

Table 5. Allowable Tilting Value SKF Reference

| Diameter $D_{we}$ (in) | Rolling Element | Style |
|------------------------|-----------------|-------|
|                        | Ball (in)       | Roller (in) |
| 0.015                  | 0.030           | 0.010 |
| 0.750                  | 0.036           | 0.012 |
| 0.875                  | 0.040           | 0.013 |
| 1.000                  | 0.046           | 0.016 |
| 1.125                  | 0.050           | 0.018 |
| 1.250                  | 0.055           | 0.020 |
| 1.375                  | 0.060           | 0.022 |
| 1.500                  | 0.065           | 0.024 |
| 1.750                  | 0.075           | 0.028 |
| 2.000                  | 0.080           | 0.032 |
| 2.250                  | 0.090           | 0.036 |
| 2.500                  | 0.100           | 0.040 |
| 2.750                  | 0.110           | —     |
| 3.000                  | 0.115           | —     |

For diameter roller 32mm (1.250 in) then we got maximum tilting increase 0.020 in or 0.508mm. Another reference from other manufacturers we find on INA Slewing ring page 404.
Table 6. Allowable Tilting Value INA Reference

| Bearing type              | Maximum permissible increase in tilting clearance $\delta_{\text{ERR}}$ mm |
|--------------------------|--------------------------------------------------------------------------------|
| Four point contact bearings | $0.035 \cdot D_w^{(3)} + 0.6$                                                  |
| Crossed roller bearings   | $0.017 \cdot D_w^{(3)} - 0.024$                                                |

$D_w$ is the rolling element diameter in mm.

reference for roller bearing maximum tilting is $0.017 \times 32 - 0.024 = 0.52$mm

3.4.2 Procedure #2 – Drop Height

Upon installation of the slew bearing, drop height measurements were recorded to be 46.5mm. The machine was slewed into the positions as per sketch below. Vernier calliper was used to measure and record the gap between the measuring blocks at four (4) points. The measured locations and recorded measurements are shown below. Consistent readings were obtained, and maximum wear of 1.2 mm was recorded. It was opted to also record measurement from the edge of the bearing. These measurements will be baseline data for future readings. No anomalies detected. The existing slewing ring installed is LT30.3825.00A0/1/85, which means that this slewing ring has diameter roller element 30 mm with its pitch center diameter is 3825 mm. Unfortunately, this the only information SKF could be gathered & collected from customer.

Figure 11 Drop Height Measurement Point
Table 7. Measure Slew Bearing Wear – ‘Drop’ method / Top position outside:

| Boom at 0deg (ref) | A  | B  | Wear  | Surface       |
|-------------------|----|----|-------|---------------|
|                   | 4  | 4  | 1.8m  | Edge (baseline) |
|                   | 4.7| 4.7|       |               |
|                   | 4  | 4  | 0.7m  | Ref (rust)    |
|                   | 5.8| 5.8|       |               |

| Boom at 45deg (work zone, Stockpile #2) | A  | B  | Wear  | Surface       |
|----------------------------------------|----|----|-------|---------------|
|                                        | 4  | 4  | 1.9mm | Edge (baseline) |
|                                        | 4.6| 4.7|       |               |
|                                        | 4  | 4  | 1.2mm | Ref (rust)    |
|                                        | 5.3| 5.5|       |               |

| Boom at 135deg (work zone Stockpile#1) | A  | B  | Wear  | Surface       |
|---------------------------------------|----|----|-------|---------------|
|                                      | 4  | 4  | 1.9mm | Edge (baseline) |
|                                      | 4.6| 4.7|       |               |
|                                      | 4  | 4  | 1.2mm | Ref(rust)     |
|                                      | 5.3| 5.3|       |               |

Measurement data from the underside of the bearing was also collected using the feeler gauges. Consistent measurements were recorded as baseline data for future inspections. Reference measurement from drawing is 10 mm with 9.5 mm being measured. We found no anomalies detected from data collected.

Figure 12. Group Activities Drop Height Measurement

According to all fact finding above there are some comprehensively analysis as consideration as follows:

1. By comparing the data between measurement result of drop height and grease analysis, it is showing the evidence wear phenomena occurrence, as one of mechanical equipment/asset failure mode
2. Despite of several reference shown in this report, SKF recommends customer to obtain the best references for the suitable value of permissible wear or bearing height reduction. This could be as an input as proactive maintenance strategy using periodical measurement or monitoring of the bearing, such as every 6 month or 1 year. This activity will give more confidence to customer to operate the equipment, especially when consider 20 years operation.

3. From two (2) bolts, nuts & washer sample that been analyzed in laboratory and using NATA guidance, we know that the material of the washers was not comply and it is suspected that the washers may be too ‘soft’, which may contribute as one of factor that cause the bolts to lose their pre-load/tension. SKF recommends customer if possible, to check and analyze the bolt, nut & washer (used or spare) material integrity in laboratory. Or to replace the bolts, nuts & washer with the newest that match with OEM recommendation. This action would lead as a safety precaution for better operation integrity. Other precaution for customer would be to follow OEM specification for Bolt, Nut & Washer.

4. The gear drives have excessive backlash and need to be adjusted to around 0.8mm. Customer needs to evaluate if this is possible or if relevant modifications are required to achieve this correction. The pinion gear grease should be changed to reduce the pitting corrosion of the gears.

5. The level of Fe and PQ has shown a slightly above standard, which are evidence of wear phenomenon that still in the range considering 20 years operation. And the Chromium level is still normal, which indicate that the bearing material still in good condition (no sign of brittle condition). SKF recommends performing grease analysis in periodic basis to obtain the trend of grease parameter behavior. And customer suggested to add this activity in maintenance strategy, including the SOP of sample taken of the grease.

6. The auto lubrication system should also be checked for reliability of operations. Based on our SKF Dial set software this slewing ring required approximately 77 gram per day.

7. SKF recommend installing condition monitoring instrument (online system). The instrument has an objective to support customer to be able collecting any abnormality condition, which related to failure indication (mainly mechanical failure), especially for the wear condition. By doing this, customer expected can achieve information of P-F interval time for prognosis purpose.

8. The remaining life prediction is expected to help customer enable to plan in early stage process of procurement process of the new slew bearing. Most of the time, we achieve this by collecting, and analyzing the failure data related to the equipment/bearing for a periodic time, such as; wear data, failure data and inspection data. By combining periodic mechanical inspection and vibration analysis then it has baseline parameter to calculate and predicted remaining life.

4. CONCLUSION
With reference to all data, document, assessment result, SKF has come into the conclusion that the Slewing Bearing, LT30.3825.00A0/1/85, that been installed into Stacker Reclaimer, is still in good condition and permissible in operation within 6 monthly periodic regular inspections onwards.

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