P (+61 8) 9457 6297 E info@plant-wellness-way.com

Physics of Failure Analysis for Roller Bearing Failures

Let a Plant Wellness Way EAM System-of-Reliability halve your Annual Maintenance Costs

Abstract

Physics of Failure Analysis for Roller Bearing Failures: A tutorial explaining the Physics of Failure method applied to regularly failing roller bearings in a dewatering press. After three years of exhaustive efforts to solve the cause of the bearing failures it was decided to test Physics of Failure Analysis with the aim of finding a lasting answer.

Keywords: Physics of Failure Analysis, (PoFA) Root Cause Analysis (RCA), Root Cause Failure Analysis (RCFA), roller bearing failure investigation

Four 'twin wire' de-watering presses were used by a company in the paper making industry. Each machine had 8 rolls (4 against 4) running at 15 rpm. They had experienced endless bearing failures during the past four years, with a bearing in one of the machines failing every 3 months. Their worst rate of failure was when vibration analysis identified another failing bearing on three consecutive days. Six weeks previously the three bearings had been installed new.

Construction of Shaft Roller Bearing Arrangement

Figure 1 is the bearing arrangement at the roll ends. The bearing was a spherical roller tapered bore bearing 23236 CCK/W33 installed directly on the taper shaft. Old grease from the bearing purged out a pipe fixed on the front cover. Old seal grease purged past the axial V-ring.

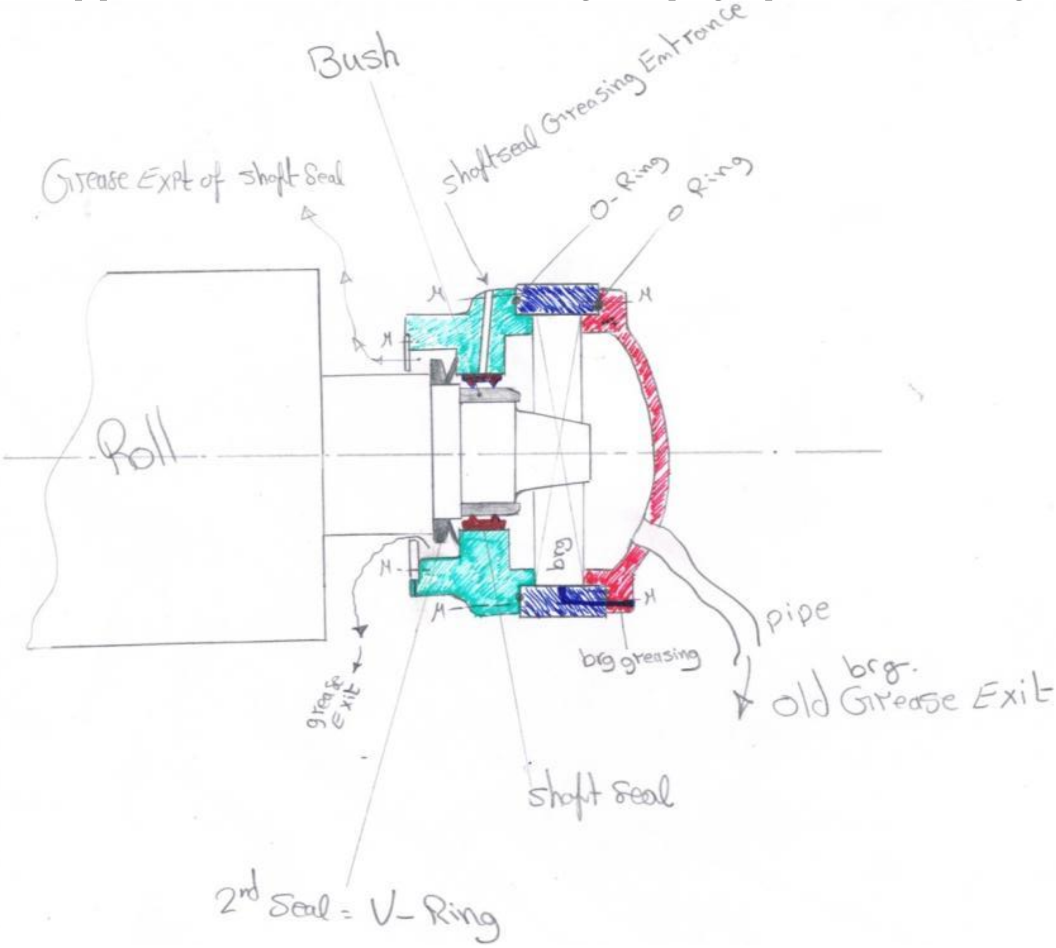

Figure 1 De-watering Press Roller Fixed End Bearing Arrangement

Figure 2 shows how the roll sets were driven by the wire, with no direct motor drive. Operating temperature ranged 50-70C. The pressing rolls were in a chamber with a vapour extraction system at the top.

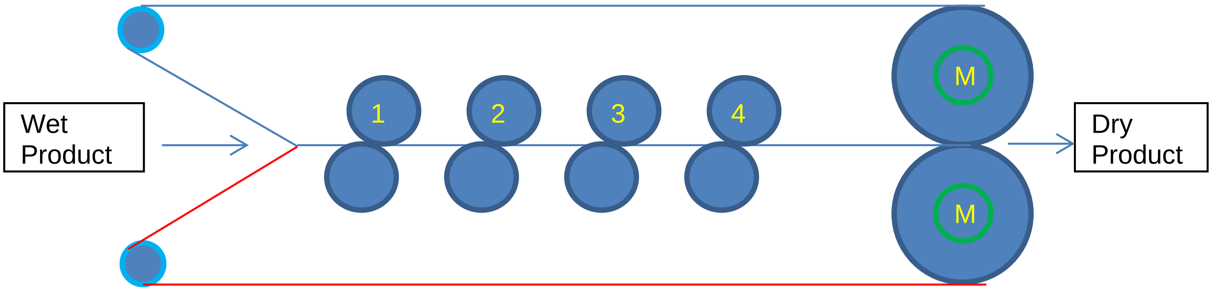

Figure 2 Roller Arrangement

The upper bearing housing was mounted to the press using two lugs, a left and a right, each with a hole for a retaining pin. The upper housing was unmovable and solidly fixed to a 5 cm thick machine frame by 4 cm pins that went through the lugs and frame and were secured by a collar at the ends. The lower bearing housing also had two lugs for hinged pins. One hinge was fixed to the frame as described above; the other had a hydraulic cylinder mounted to permit adjustment of roller pressure (not too unlike the lugs and pins shown in Figure 3).

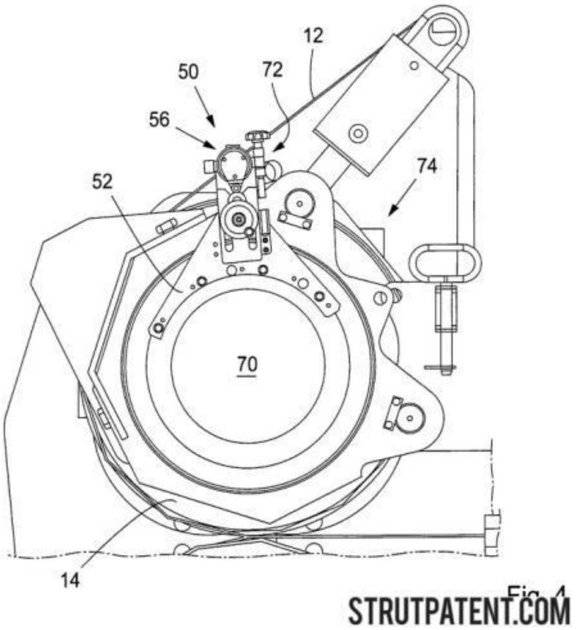

Figure 3 De-watering Press Adjustable Roller Bearing Housing

Seals were O-rings between each cover and housing; a primary shaft seal 240x270x15 V-ring made of NBR material DIN3760 running over a bush and greased; a secondary axial shaft seal V-ring VA-250 HNBR.

Bearing Failure History

The spherical roller bearing design details were as shown in Figure 4.

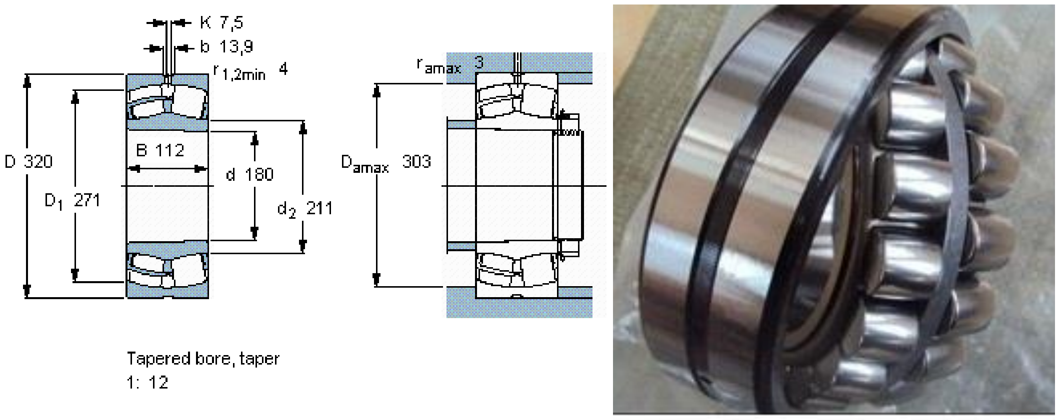

Figure 4 23236 CCK/W33 Bearing Details

When asked to provide information about the bearing failures the comments received were:

"The history of damage was that all but one failure happened in the bottom rolls—the adjustable rolls. Total failures were 11 in a period of 3 years at different machines:

- 6 failures on different machines at the drive side (fixed bearing): 3 failures @ roll number 3, 1 failure @ roll 1, 1 failure @ roll 2, 1 @ roll 4
- 4 failures on different machines at non-drive side (floating bearing): 3 failures @ roll number 3, 1 failure @ roll 4."
- 1 failure at non-drive side upper rolls

Figure 5 Elements

"The history of the failures shows that 80% of the damage is on one side of the outer ring, 20% of the bearings are damaged on the other side, which indicates an axial load (but the 4 press roll sets are driven by the wire, no direct driving motor.). The rolling elements always have minor damage—black spots and raceway contact damage, as shown in Figure 5."

"The bearing has normal clearance, replacement bearings are always like the old one—same supplier and same model number."

"The failures are happening to many rolls in different positions on the presses. If it was a shaft dimension problem it would limited to a shaft and not the random distribution of failures we have suffered for the past four years. Even with brand new housings, rolls and bearings, the failures continue to occur randomly—we do not know which roll will next fail!"

"Failures are detected by vibration measurement. When stripped the grease inside is black and smells bad. In the past we found that some automatic greasing modules / lines were not functioning. Since then the greasing system was checked and repaired; but we are still getting failures. The grease still is black and smells."

"We changed grease to a better quality— resistant to water and load—but it did not help, we still had bearing failures. The bearing failure on inspection is deep fatigue spalling and cracking; small pieces separate from the outer ring, then cage destruction, and finally total failure."

"From our early detection of bearing failure we noticed black spots (hydrogen attack) due, we thought, to aggressive environment (water and vapour) which made the surface very brittle and lead to cracking. There was something interesting that we found based on early failure detection: the bearing fails first then the grease fails later. We found black spots on the raceways but the grease was still in good condition. Maybe the vapour inside the bearing condenses to water after shutdown (for example, if we shut-down for a week)."

"Today I found the third defective bearing; this is the worst measuring cycle I have ever had. Maybe it will help you to know that two bearings have outer raceways defects and one bearing has an inner ring defect and a small defect on the outer raceway. (Most of the failures we have are on the outer race, the inner race usually has smaller spall.) Six weeks ago they were in good condition (no vibration signs), after detection they will not live more than 2 weeks!

The bearing is installed in the taper by hydraulic nut. The nut is turned on the thread of the shaft until it touches the bearing. A dial indicator tip touches the inner ring (axial direction); pumping oil the inner ring is pushed to the desired distance, as indicated by the dial gauge."

Physics of Failure Analysis

From the history of bearing failure events the evidence indicates:

- 10 out of 11 bearing failures were on the bottom rolls
- A common failure mechanism because the same failure mode was found in all failures
- Bearings always have black spots (hydrogen attack)
- The black spot appears while the grease is still in good condition
- Failure mode is spalling of outer raceway (80% one side of raceway, 20% the other side)

We look for common events and situations that happen to all bearings. These include:

- the process material,
- chemicals in the process stream,
- wash water,
- design of bearing,
- bearing materials-of-construction,
- bearing clearance,
- shaft design,
- shaft manufacture,
- shaft taper shape,
- housing design,
- housing installation
- shaft positioning system
- shaft seal material,
- bearing seal material,
- seal design,
- bearing installation and mounting,
- purchase of replacement bearings,
- storage of replacement bearings,
- building vibration,
- Equipment support and hold-down,
- grease type,
- grease supply, and so on.

Table 1 lists a range of PoF factors considered relevant to the situation. The list was developed from a table containing many more factors by removing those not judged to apply to the situation. For example, all manufacturing and electrical events were removed, since manufacturing errors and electrical discharges were not thought to be a cause of the bearing failure mode experienced. Many events noted in the table will not be a cause of the failures. But we still list them because at this stage we are not certain that they do not contribute to the bearing failures. Each of the issues listed are investigated in detail. If the reason has not been found after testing those failure causes believed to apply to these events, then the removed items can be included back into the investigation to be reconsidered.

Physics of Failure Guidewords - Roller Bearing

Factors that cause Atomic or Microstructure Failure	Component Manufacturing Events	Component Operational Stress Events (Horizontal, Vertical, Axial)	Component Environmental Events / Conditions	Electronic / Electrical Effects	Component Life Cycle Situations
Compressive force overload		Pressure	Corrosion (pitting, galvanic, crevice, etc)		
Cyclic stress fatigue		Interference fit tight	Humidity		
Shock force overload		Physical deformation (bend, twist, squash)	Contaminant ingress		
Chemical reaction		Shrinkage	Moisture ingress		
		Misalignment	Product ingress		
		Fracture	Chemical reaction		Installation
		Material fatigue	Lubrication degradation		
			Oxidisation		
			Hygro-mechanical (moisture absorption)		Operation
			Shock		Maintenance
			Humidity – Condensing and non-condensing		Overhaul / rebuild
			Immersion		
			Contamination by Fluids		
			Acidic Atmosphere		
			Hydrogen attack / embrittlement		

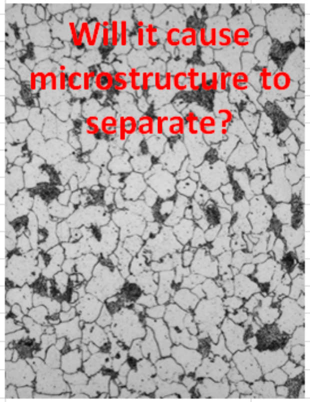

Table 1 Physics of Failure Analysis Bearing Failure Causes

The list still contains many factors that may be involved in the failure mechanism. Using the known facts we start to group those causes that that relate to each fact.

Black spot is known to be caused by the presence of hydrogen. One example is hydrogen embrittlement, where hydrogen builds up around the grain boundaries of the microstructure. Research of articles on the Internet indicated that it is related to the presence of high pressure and/or high temperature. In steels it occurs in those with high tensile strength properties. To have hydrogen attack hydrogen must be present. This can come from the steel itself, or it is in present in the local environment through suitable chemical reactions. Table 2 was developed from the list of PoF causes that are failure mechanisms related to black spot attack.

Item	Failure Facts	PoF Cause
1	Black spot (hydrogen attack) due to stress	Compressive force overload
		Interference fit tight
		Physical deformation
		Misalignment
2	Black spot (hydrogen attack) due to chemical reactions	Acidic atmosphere
		Humidity - condensing
		Moisture ingress
		Product ingress
		Chemical reaction
		Oxidisation

Table 2 Bearing Failure Mechanisms

We have reduced the bearing failure scenario down to two potential situations—high stress and hydrogen generating chemical reaction. Each of these is to be closely investigated before looking at other possible failure mechanisms. The question now becomes: What can occur to a roller bearing to create the two situations identified? Table 3 lists possible situational causes and how they can be tested. Figure 6 shows the type of problems that need to be checked.

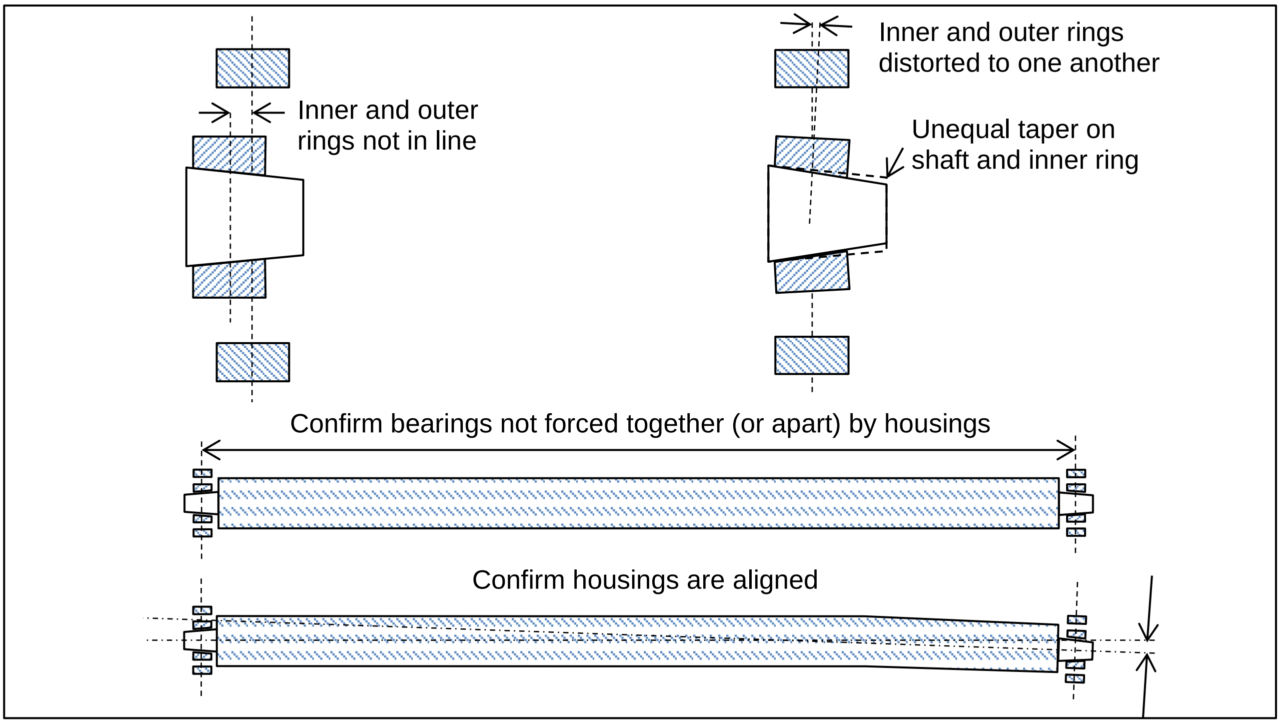

Figure 6 Possible Causes of Bearing Failures

No	Failure Facts	PoF Cause	Situational Causes	Test to Check Cause
1	Black spot (hydrogen attack) due to stress	Compressive force overload	• Bearing is too far up taper • Bearing is not far enough up taper • Bearing-to-bearing distance is too far • Bearing-to-bearing distance is too close	• Confirm shaft is truly to original press equipment manufacture's (OEM) measurements and tolerance (A non-OEM shaft may be machined wrong.) • Calculate from datum where bearing(s) should sit on taper and measure actual position • Check taper is to bearing OEM tolerance and form
		Interference fit tight	• Inappropriate bearing internal clearance for the application • Wrong shape/angle of taper • Skewed taper • Wrong size housing bore • Skewed housing bore	• Check housing bore is to the bearing OEM tolerance and form • Check taper is to the bearing OEM tolerance and form
		Physical deformation	• Housing(s) located in wrong position • Housing(s) not made to bearing OEM specs • Positioning ram distorts housing • Shafts are bent during operation	• Confirm housings are truly to OEM design and position on frame • Check position of housing locating pins in lugs and in frame are correct • Use dial gauges to see deformation of housing when fixed to frame in assembly • Use dial gauges to check housing distortion when rams force rollers together under operating conditions and pressures
		Misalignment	• Housings are out-of-alignment • Shafts are bent	• Calculate from datum where shafts and housings should sit on machine frame and measure actual positions are eh same on both sides of frame • Put shafts on flat datum and check extent of bending
2	Black spot (hydrogen attack) due to chemical reactions	Acidic atmosphere	• Process chemical in bearing chamber	• Confirm with seals' OEM that shaft and housing size, tolerance and finish is as required
		Humidity - condensing	• Vapour condenses in bearing chamber • Vapour enters up grease drain	• Check centre of bearing housing and centre of seal housing are identical • Check grease drain does not permit moisture/vapour ingress
		Moisture ingress	• Seals not sealing • Bearing housings hosed with water	• Confirm bearings are never hosed-down
		Product ingress	• Seals not sealing	• Confirm with seal OEM that shaft and housing size, tolerance and finish is as required
		Chemical reaction	• Chemicals entering with moisture and/or vapour	• Confirm chemical compatibility of seal material(s) with water and process chemicals found in product
		Oxidisation	• See 'Chemical reaction'	

Table 3 Potential Situational causes of Bearing Failure and Checks to Undertake

My best regards to you,

Mike Sondalini
www.plant-wellness-way.com