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Wind Turbine Gearbox Failure

By

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Subject

A 500KW wind turbine gearbox, identified as LK15, No. 421 104 802 – 001 – 1, was examined to determine the cause of failure. This was one of three gearboxes that failed within a 30 day period. The three turbine gearboxes had been in operation for 17 years, and were installed at approximately the same time. Each gearbox was inspected during tear-down at a maintenance facility. The maintenance personnel made measurements of gear end-play and back-lash during disassembly, and bearing race diameters after disassembly.

Examination of the LK 15 Gearbox

Figure 1 – LK 15 Gearbox Label

Figure 2 – LK 15 Gearbox

Figure 1 shows the Flender label on the LK 15 gearbox.

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The gearbox is shown in Figure 2. The bushing around the mounting pin had slipped about ½ inch. The slippage of this bushing could have resulted in unexpected stress in the gearbox. Figure 3 shows the slipped bushing from the low speed side of the gearbox. Figure 4 is a closeup of the bushing. The shock absorbing rubber around the mounting pin had been torn. The tear in the rubber likely compensated for any misalignment caused by the shifting of the bushing.

Figure 3 – Location of Slipped Bushing

Figure 4 – Slipped Bushing

Figure 5 – In-place Highspeed Shaft Bearing Retainer

Figure 6 – Properly Seated Set Screw on Highspeed Shaft Bearing Retainer

The highspeed shaft bearing retainer on the LK 15 unit was in place, Figure 5. Figure 6 shows that the set screw was properly seated. The retainer ring needed to be heated in order to loosen the set screw. There are indications of Locktite being on the set screw.

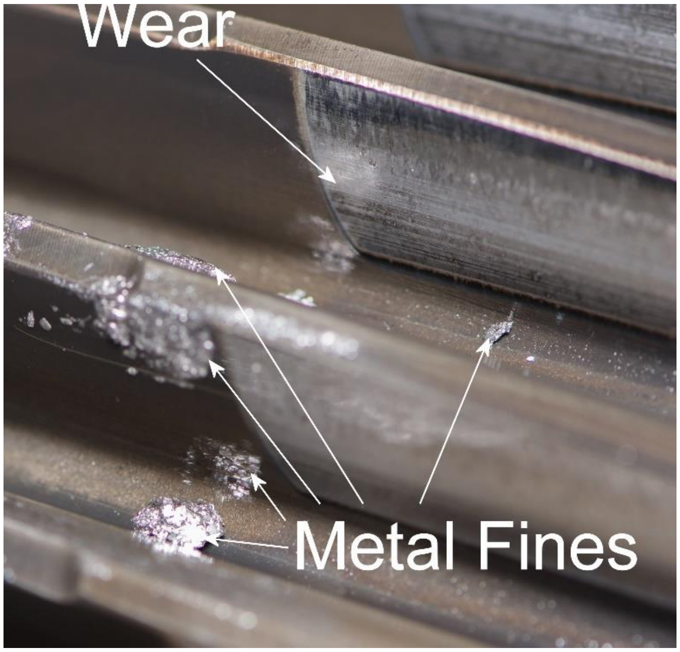

Figure 7 – Wear and Metal Fines on Highspeed Shaft Gear

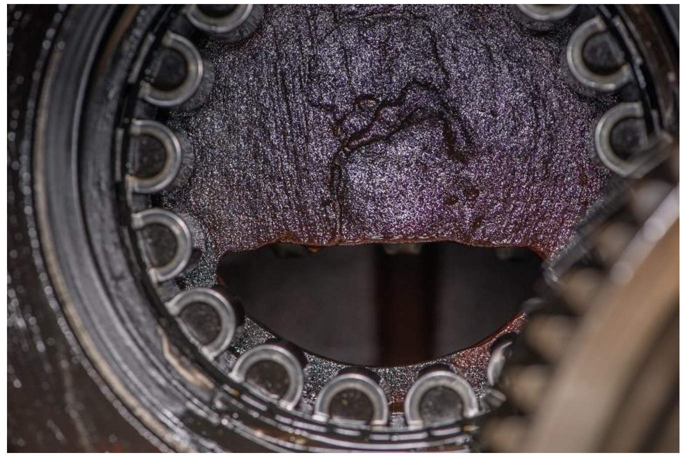
Figure 8 – Highspeed Shaft Roller Bearings and Gearbox Housing

The insides of the LK 15 gearbox and components were covered with metal fines. Figure 7 is an example of the metal fines buildup on the highspeed gear shaft. The photo also shows abrasive wear on the gear teeth. The cause of the abrasive wear is most likely the metal fines in the gearbox.

Figure 8 shows the roller bearings at the end of the highspeed shaft. There was no wear on the LK 15 gearbox housing that would have been caused by lateral movement of the highspeed shaft.

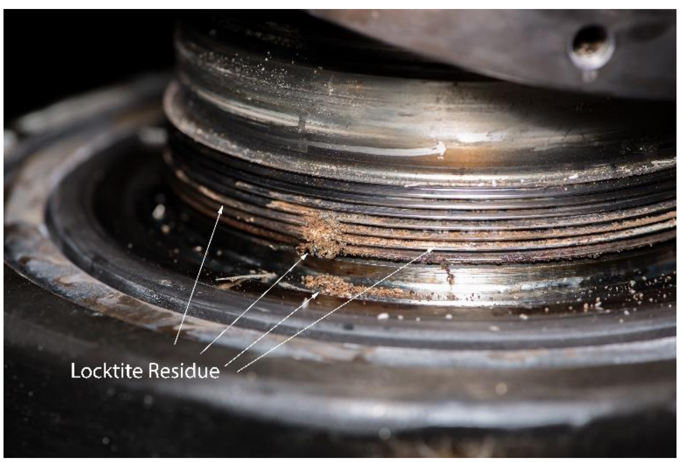

Figure 9 – Locktite Residue on Highspeed Shaft

Figure 10 – Locktite Residue on Highspeed Shaft Bearing Retainer Ring

The highspeed shaft bearing retainer ring was removed after the highspeed shaft had been pulled from the gearbox. Figure 9 shows Locktite residue in the set screw hole and in the threads of the LK 15 highspeed shaft. Figure 10 shows Locktite residue on the bearing retainer ring.

Figure 11 – Metal Fines

Figure 12 – Metal Fines

Figures 11 and 12 are examples of the large quantities of metal fines distributed throughout the interior of the LK 15 gearbox.

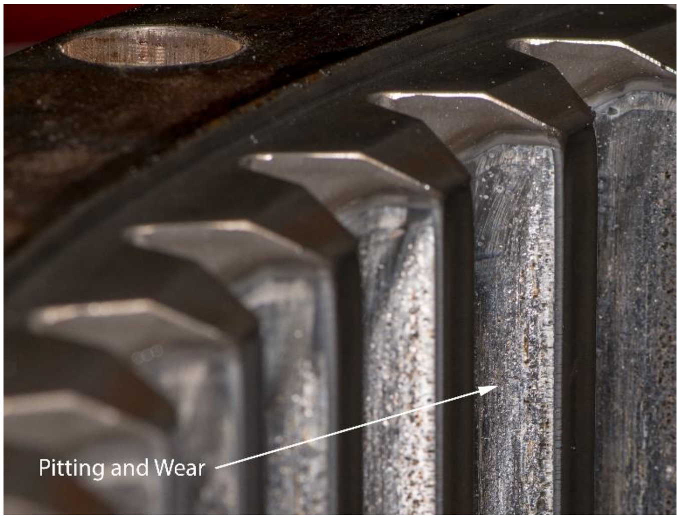

Figure 13 – Pitting and Wear on Ring Gear Teeth

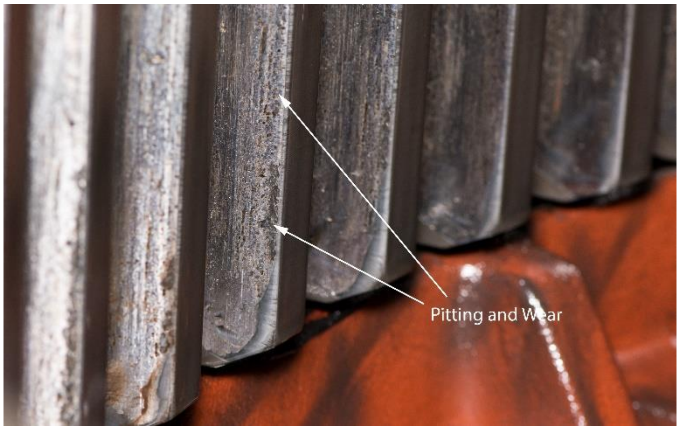

Figure 14 – Pitting and Wear on Ring Gear Teeth

The ring gear is a low speed gear, but it showed a considerable amount of pitting and wear; the wear was uniform on the teeth all the way around the circumference of the gear. Figures 13 and 14 are examples of the wear. This wear was likely the result of lubrication failure.

Wear consisted of extensive pitting of the gear teeth on the planetary gear, Figure 15. This pitting was the result of sliding contact fatigue resulting from gear overloading.

Figure 16 shows one of the bearing races. The bearing race appears to have spun in the planetary gear. This is indicated by the wear on the outside diameter of the bearing race.

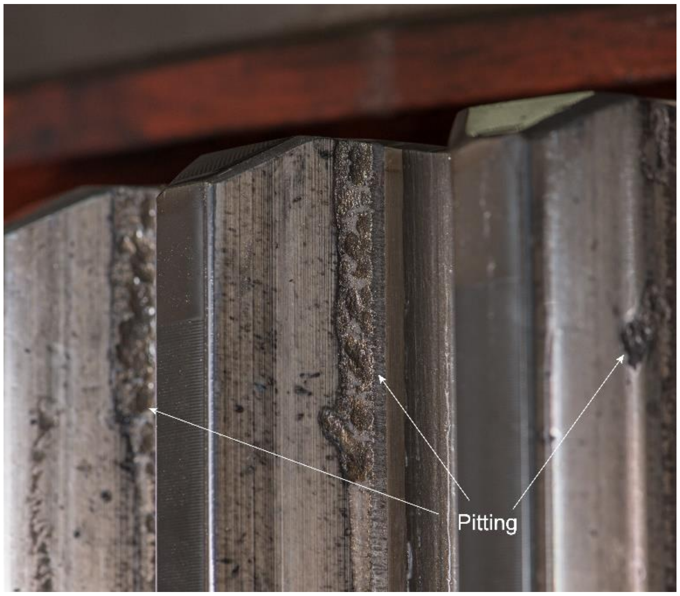

Figure 15 – Pitting on Planetary Gear Teeth

Figure 16 – Planetary Gear Bearing Race

Figure 17 – Wear on the Planetary Gear Carrier

Figure 18 – Wear on the Planetary Gear Carrier

There was wear on the planetary gear carrier. The wear is shown in Figures 17 and 18. The wear corresponds to the planetary gear labeled 2 during the disassembly of the gearbox. The wear of the bearing carrier was most likely the source of all the metal fines in the gearbox, resulting in the failure of the gearbox. It is my understanding that the shifting of the planetary gear bearing races is a typical problem with these gearboxes, therefore, this is normal wear and tear for this equipment.

Figures 19 and 20 show sliding/rolling contact fatigue on two of the bearing rollers removed from planetary gear #2. These two rollers were examined metallographically to verify the presence and extent of the fatigue. The conditions found on the bearing rollers are similar to the conditions on the gear faces. The presence of surface fatigue was caused by overloading and the presence of debris, namely metal fines, inside the gearbox.

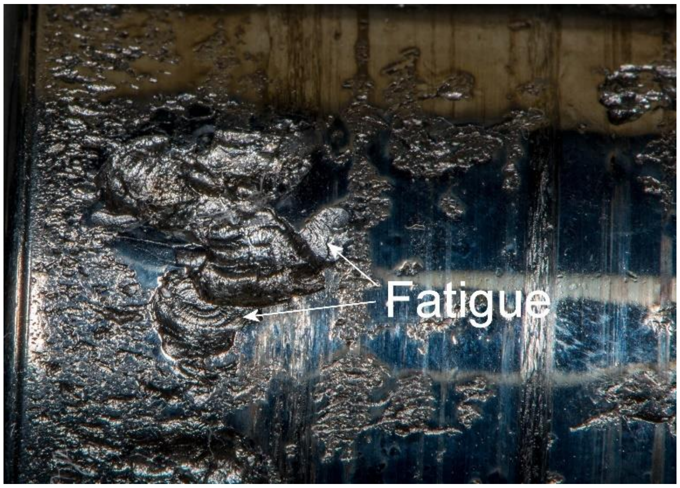

Figure 19 – Fatigue Failure Bearing Roller #1

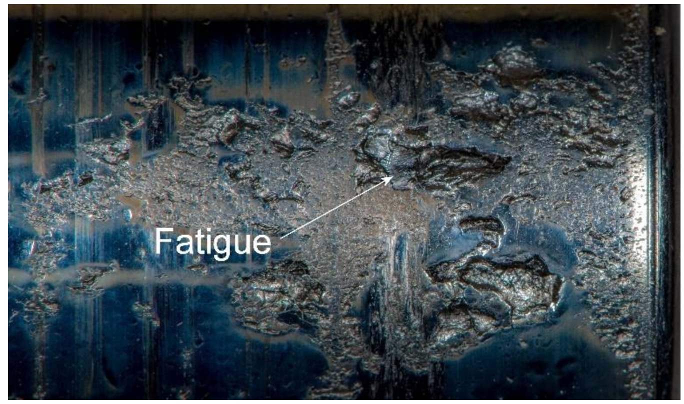

Figure 20 – Fatigue Failure Bearing Rollier #2

Hardness Testing

Hardness testing was done according to ASTM E384, using Knoop and Vickers indenters. In Table 1, the hardness of the retainer ring was determined using a Vickers indenter, and the hardness of the set screw was done using a Knoop indenter. In Table 2, the hardness of both bearing rollers was done using a Knoop indenter. The Knoop hardness was converted to Rockwell C scale, and Vickers hardness values were converted to Rockwell B scale.

Table 1
Hardness Test Data – Retainer Ring & Set Screw

Location	Vickers/Knoop	STD DEV	MAX VALUE	MIN VALUE	HARDNESS
Retainer Ring	146.00 Vickers	4.03	150.00	141.00	78.70 RB
Set Screw	524.00 Knoop	13.91	541.00	509.00	48.84 RC

Table 2
Hardness Test Data - Bearing Rollers
(Rockwell C Scale)

Location	Knoop	STD DEV	MAX VALUE	MIN VALUE	HARDNESS
Roller #1	730.00	19.23	749.00	694.00	59.82 RC
Roller #2	717.00	28.43	758.00	666.00	59.24 RC

The hardness of 59 on the Rockwell C scale on the bearing rollers, Table 2, is within the expected range for bearing rollers.

Metallographic Examination

The magnification shown for the photo is the magnification at which the photos were taken. The photos shown in this report may be smaller or larger in size than the originals.

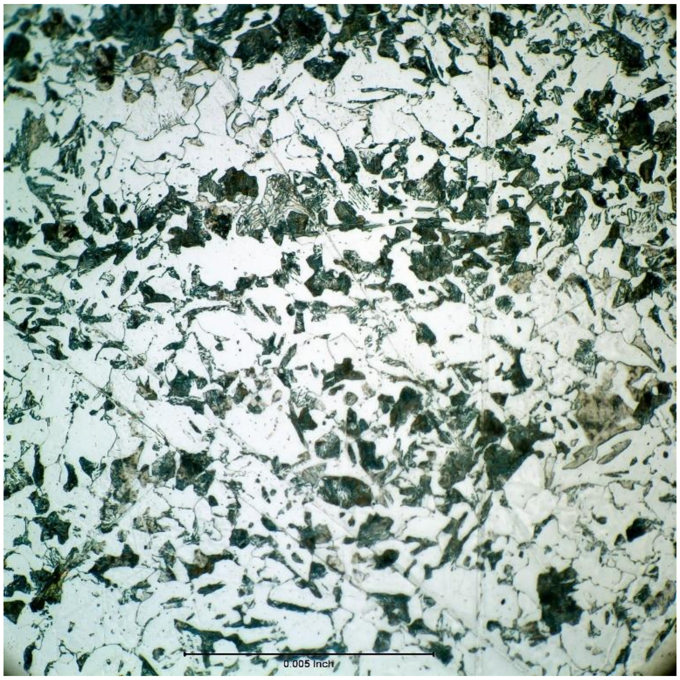

Figure 21 – 400X LK15 Retainer Ring Microstructure

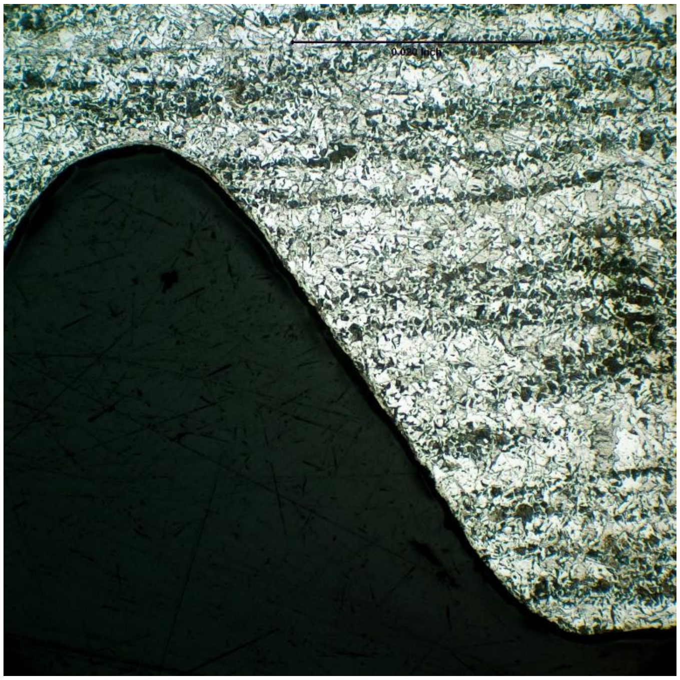

Figure 22 – 100X Retainer Ring Thread Form

The microstructure of the LK15 retainer ring is shown in Figure 21 and consists of very fine pearlite, the dark areas, and fine grained ferrite, the white areas. Figure 22 shows the retainer ring thread form.

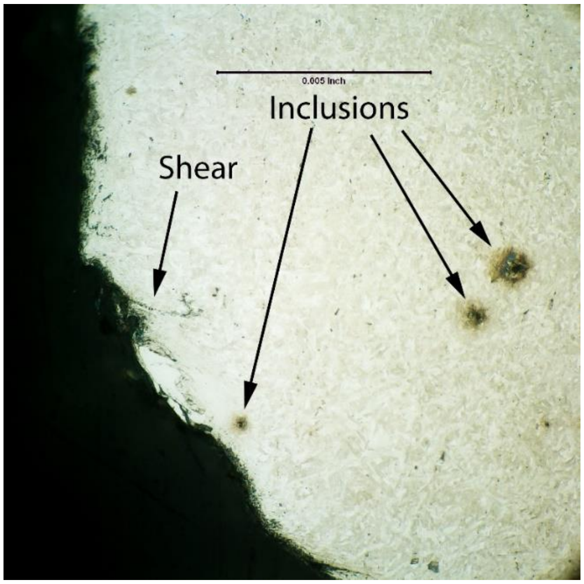

Figure 23 – 400X Tip of Set Screw

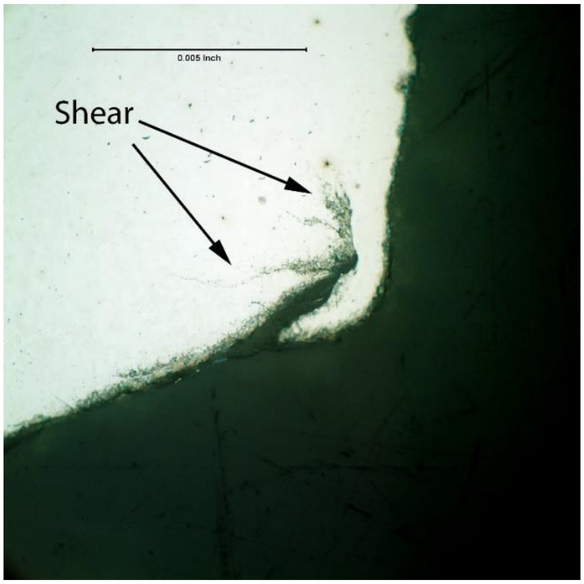

Figure 24– 400X Tip of Set Screw

Figures 23 and 24 show the tip of the set screw. The shear cracking was likely the result of forming of the tip of the set screw. Inclusions, Figure 23, are typical in the steels used to fabricate set screws.

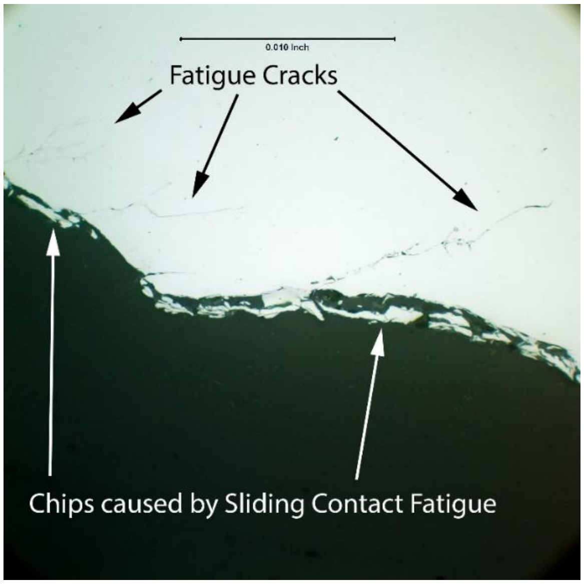

Figure 25 – 200X Fatigue Cracks in Bearing Roller #1

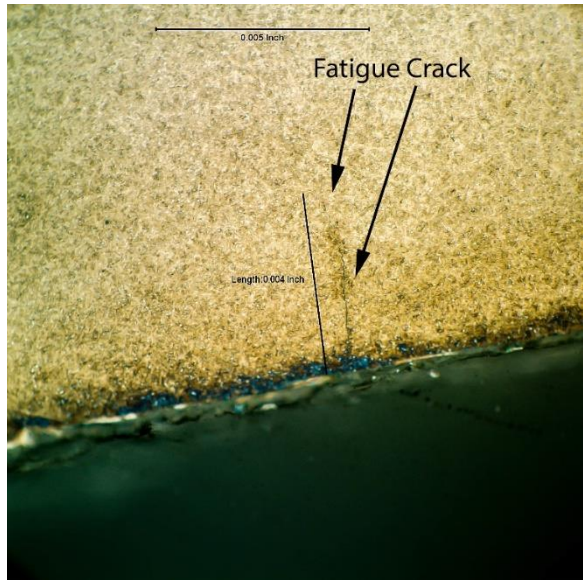

Figure 26 – 400X Fatigue Crack Perpendicular to the Roller Surface, Roller #1

Figure 25 shows a considerable number of fatigue cracks in a location where chips had formed in the bearing surface, similar to the locations indicated in Figure 19. Figure 26 shows a fatigue crack running perpendicular to the roller surface. The crack had penetrated 0.004 inches into the roller.

Opinion

It is my professional opinion to a responsible degree of scientific certainty that the LK 15 Gearbox failed by normal wear and tear. The initiation of failure was the result of the bearing race slippage of planetary gear #2, which resulted in wear of the planetary gear carrier, causing a significant amount of metal fines. The metal fines in turn caused wear and contributed to the fatigue of the gear and bearing faces by increasing the localized stress in these locations.