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FAILURES IN E- AND EL-TYPE PULVERIZER MILL MAIN DRIVE SHAFTS

by

Gary R. Wood
Senior Metallurgical Engineer
American Electric Power Service Corporation

and

Joyce M. Hare
Senior Metallurgical Engineer
Riley Stoker Corporation

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ABSTRACT

A series of drive shaft failures in ball type pulverizers prompted an investigation into the cause(s) of the fractures, particularly relevant since several of the failures had occurred within comparatively short shaft service lives. The investigation undertaken by American Electric Power included detailed metallurgical analyses, review of maintenance and operating histories, and interfacing with other utilities which had experienced similar failures.

The metallurgical study concluded that the fractures had consistently been initiated by fretting and were propagated by fatigue cracking at the shaft/yoke bushing contact point. Assessment of plant operating history and rebuild records revealed that fretting did not always cause an immediate failure but that several variables appeared to have potential effects on the transition from pure fretting to a fatigue failure of the shaft.

One corrective measure taken was to shot peen the contact zone of the shaft, but this technique was found to be ineffective in preventing failure. Correspondence with other utilities having similar experiences revealed genuine concern and strong interest in preventing future shaft failures. The formation of a database of operating history, maintenance practices, failure studies and corrective action plans is anticipated in order to pinpoint the root cause of the failures and to minimize premature failures of these pulverizer shafts.

This paper summarizes the status of ball type pulverizer shaft failures and presents our current understanding of the problem. The goal of the continuing study is to develop widespread utility participation in order to develop more stringent maintenance and operating procedures to prevent these failures.

INTRODUCTION

Ball pulverizer mills of the E- and EL-type designs are common components of many fossil-fired power plants. The failure of the main drive shaft of the pulverizer results in a forced curtailment of the unit. Thus, reliability and freedom from shaft breakage are critical to unit availability. American Electric Power (AEP) has 18 fossil power plants with a total of 56 units. Five of these plants, incorporating 20 units, are equipped with 111 E- or EL-type ball pulverizer mills.

AEP has experienced several failures of both new and rebuilt pulverizer shafts. All of the shafts have fractured in the yoke bushing-to-shaft contact zone. Inspections of shafts before failure have revealed the presence of fretting cracks in this zone, however, inspection of this area of the shaft is not easily accomplished without disassembly of the yoke/yoke bushing-to- shaft fit. Therefore, a method to predict failures is needed to minimize premature shaft breakage. Efforts to solve this problem have included metallurgical studies of the failed and cracked shafts to identify the root cause of the failures, an investigation into the sources of unanticipated loading of the shaft, and a survey of utility experience to define other possible solutions to the widespread occurrence of E- and EL-type pulverizer shaft failures.

Background

American Electric Power's Philip E. Sporn plant has experienced a series of ten pulverizer shaft failures. Some of these failures have occurred after rebuilding a failed shaft. The shafts have failed in the tapered section near the lower edge of the yoke bushing contact point. Although shaft failures have occurred at other AEP plants, the frequency of failure is markedly less at these plants than that experienced at Sporn Plant. Four additional shafts had been removed from service, three due to cracking in the keyway in the tapered section and one due to incipient cracking in the same area where all previous failures had occurred. This latter shaft, which had not failed, was submitted for metallurgical analysis to shed light on the initiation mechanism. Figure 1 shows a schematic of an E- type mill and the approximate location of the failures.

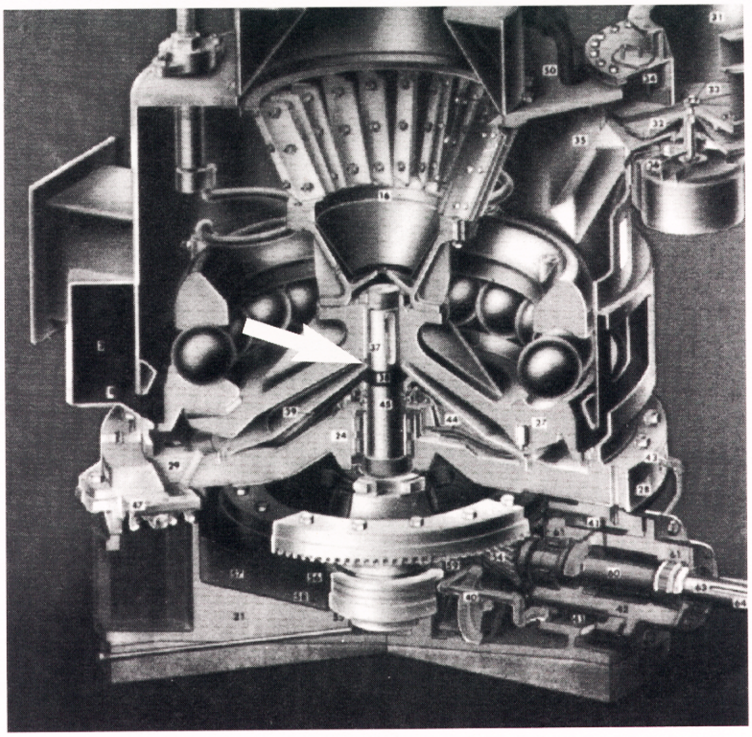

Figure 1 Schematic of an E-type Pulverizer and the Approximate Location of the Failures on the Main Drive Shaft

Initial steps taken to analyze the failures included a review of the following:

- rebuild practices which had been performed with the supervision of the OEM to oversee procedures and fit tolerances,
- rebuild histories of all 20 ball type pulverizers in service at the plant,
- control room log books for an estimate of the number of cycles (stops and starts) each pulverizer had experienced,
- maintenance department job orders for repair of operating problems such as oil pressure drops, plugged pyrite gates, foreign objects in the mill, etc.

Finally, a review of the loading on the four Sporn units and two similar units at AEP's Tanners Creek Plant was examined for possible correlation between system load requests and frequency of shaft failure.

The OEM reviewed the rebuild practices and provided several constructive suggestions in the following areas:

- optimizing percentage of contact between the tapered portion of the shaft and the yoke bushing,
- improving tight fit of the top bearing plate housing to the top bearing,
- reducing pyrite build-up that can cause uneven loading on the yoke.

All of the above listed areas can result in uneven loading on the shaft. Problems caused by pyrite build-up were thought to be germane since premature wear on the lower grinding ring kicker lugs was reported by the OEM.

The rebuild histories of the mills at Sporn Plant revealed no distinct pattern except for the recent series of failures at Sporn Unit No. 1. Control room log books showed no correlation between failure events and starts and stops. Several mills which had the greatest number of starts and stops had experienced no shaft failures. Maintenance department job orders for the previous two years showed that most pulverizers that had broken shafts had experienced foreign object damage and pyrite gate pluggage. The system load requests on all six units at the two plants were essentially equal with the exception that the average load on the Tanners Creek units was 25 MW higher than the four Sporn units.

These findings indicated that operating factors most likely had contributed to the failures.

METALLURGICAL INVESTIGATION

In response to the premature failures of several pulverizer shafts at Sporn Unit No. 1, failure analysis programs were conducted to learn the cause of the fracture. In all cases, the shaft fractured in the yoke bushing-to-shaft contact zone in the vicinity of the relief groove. The fractures were perpendicular to the axis of the shaft, but every fracture surface had been mechanically damaged by the continued rotation of the shaft following fracture (See Figure 2) and could not be used for fractographic analysis. AEP decided to check the replacement shafts nondestructively for any signs of cracking. After one of these shafts had been in service for approximately three weeks, the yoke was dismantled and the contact zone was examined by Wet Fluorescent Magnetic Particle Testing (WFMT). Several circumferentially-oriented indications were detected on the tapered portion of the shaft above the relief groove, well within the contact zone. The shaft was removed from service for metallurgical evaluation which included scanning electron microscope (SEM) analysis and optical microscopy.

Like the original shaft, the replacement shaft was fabricated from 4340 alloy steel with a nominal diameter of 7 inches. The bushing was made of 5150 alloy steel. The heat treatment and fabrication specifications were not made available.

Figure 2 Fractured Shaft in the Pulverizer Mill

Sample Designation

Figure 3 shows the tapered end of the replacement shaft and the location of the circumferential indications. Sample No. 1 was removed from this area and included some of the WFMT crack indications. This sample was examined in the SEM, the cracks were then mechanically opened, and the resulting fracture surfaces also examined in the SEM. A longitudinal metallographic section (parallel to the axis of the shaft and perpendicular to the crack indications) was prepared from Sample No. 1. Sample No. 2 was removed from the tapered portion of the shaft but away from the cracked area. Sample No. 3 was removed from the core of the shaft. Longitudinal sections were metallographically prepared from the latter two samples for optical microscopy.

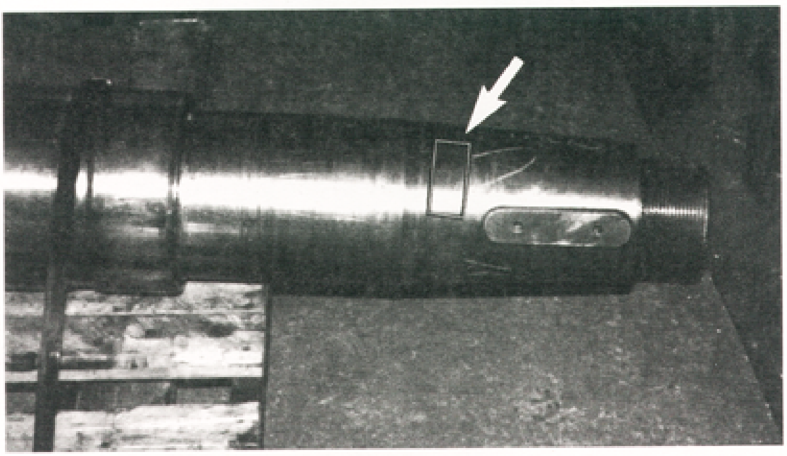

Figure 3 Replacement Shaft Recently Removed from the Mill with WFMT Indications inside the boxed area

Scanning Electron Microscopy (SEM)

SEM examination of the outside surface of the shaft contained in Sample No. 1 showed a locally roughened surface around the WFMT indications which clearly could be identified as cracks (See Figure 4). The roughness ranged from pit-like features to shallow abraded areas, typical of fretting damage. This type of damage results from the relative motion between two surfaces in contact, here the bushing and the shaft.

The fracture surfaces of the WFMT cracks are shown in Figure 5. The four dark thumbnail-shaped cracks, ranging from 17 to 29 mils in depth, originate at the outside surface of the shaft, are flat, and exhibit beach marks typical of fatigue.

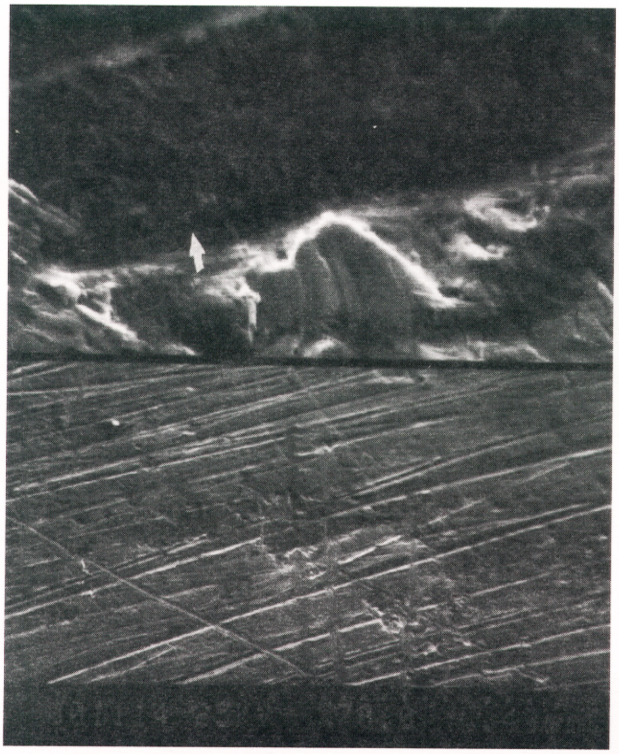

Figure 4 SEM Split Image Showing the WFMT Indication at 70X (Bottom) and 700X (Top)

Figure 5 Overview of the Fracture Surface Produced by Mechanically Opening a WFMT Indication. Four Fatigue Cracks (Thumbnail Features) Have Initiated at the Fretted Surface of the Shaft.

Optical Microscopy

Examination of Sample No. 1 revealed several shallow transgranular cracks that had initiated at the surface of the shaft, an example of which is shown in Figure 6. Since no surface decarburization was observed in either Samples No. 1 or No. 2 indicating cracking before heat treatment of the shaft, it could be concluded that the cracks had initiated during the three-week service period. The initial crack propagation direction is oblique to the surface, typical of fretting cracks that initially follow the deformed grain structure at the surface. Once the crack has grown beyond the influence of any fretting action, it propagates as a fatigue crack in a direction perpendicular to the principal alternating stress[1]. A discontinuous white layer was observed on the surface of the shaft which was found to be unique to the fretted area and associated with cracking (See Figure 6). Microhardness test measurements indicated

[1] R. B Waterhouse, Fretting Fatigue, 1981, pp. 209-211

that the white phase was harder than the matrix. It was concluded that the phase is untempered "white" martensite which is typically produced by fretting[2].

The general microstructure of Sample No. 1 in the cracked region is tempered martensite. Sample No. 2 exhibits a banded microstructure of tempered martensite dispersed with carbide particles (See Figure 7). Banding is the result of compositional segregation in the original cast ingot and is considered to be normal. The core microstructure of Sample No. 3 (Figure 8) is more highly banded and consists of spheroidized carbide dispersed in tempered martensite with some tempered bainite and ferrite.

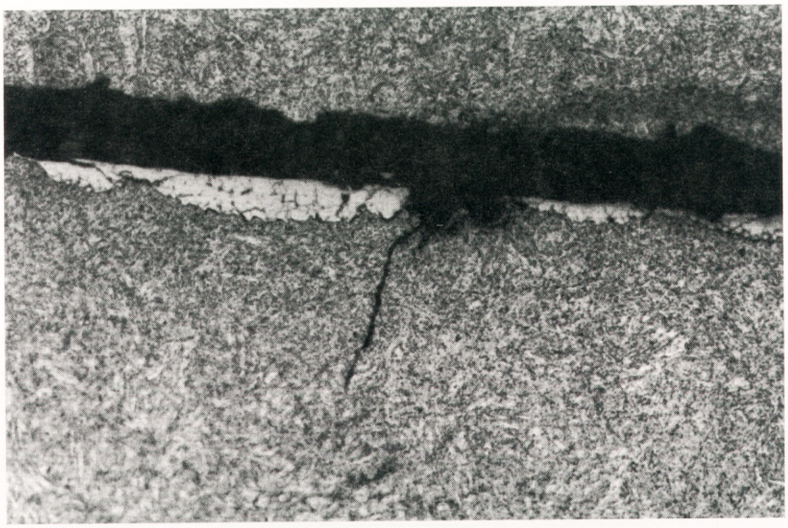

Figure 6 Typical Fatigue Crack Originating at White Layer of Martensite on the Fretted Surface of the Replacement Shaft

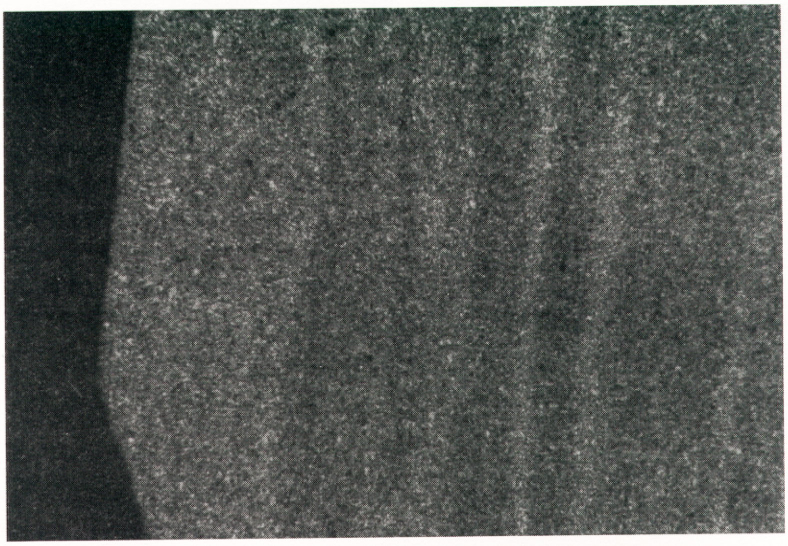

Figure 7 Banded Structure Near the Relief Groove of the Shaft. Note Absence of Surface Decarburization.

[2] ASM Handbook, Volume 18, Friction, Lubrication and Wear Technology, 1992, pp. 241-256

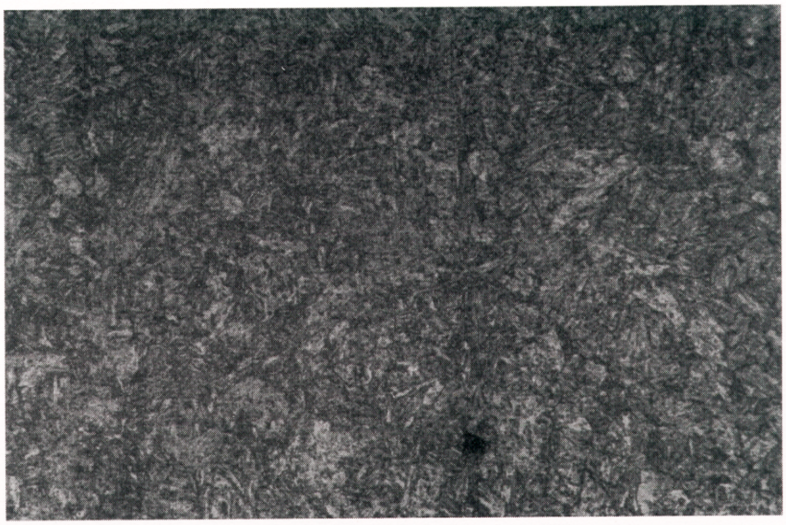

Figure 8 Detail of the Core Microstructure

Discussion of Metallurgical Findings

The incipient cracks detected by WFMT are concluded to be fine fatigue cracks which have initiated at surface-fretted regions on the tapered portion of the replacement shaft. This indicates that there has been relative motion between the bushing and the shaft which has induced, at localized points of contact, stresses of sufficient magnitude to initiate fatigue cracking. Within three weeks of service, the cracks had grown to a depth of 20 to 30 mils. The microstructure of the shaft is considered to be typical of quenched and tempered 4340 alloy steel. No evidence of material or fabrication defects were observed which could be linked to the cracking.

The observations made in this analysis were nearly identical to those made in metallurgical analyses of other failed shafts.

OPERATING HISTORY

Service Experience of Other Utilities

An informal survey was conducted to gain insight on the experiences of other utilities who operate similar ball type pulverizers of the E- and EL-type. The results showed that most respondents had nearly identical failures which were analyzed and concluded to be the result of fatigue crack propagation having initiated at fretting damage at the yoke bushing/tapered shaft interface. All attempts at solving the problems made by the utilities were aimed at either improving the fit of the yoke bushing to the shaft or at reducing the vibrational movement of the yoke bushing relative to the shaft during operation. The results of the survey are as follows:

- All utilities identified the type of cracking as either fretting or fatigue cracking.
- The target percentage contact between the yoke bushing and shaft was 80%. Most reported that a range of 75-95% was common.
- Some utilities increased the shaft diameter from 7-1/2 inches to 8-3/4 inches. The reasoning for this is to lower the stresses in the shaft. This change has apparently not improved the life of the shafts.
- One respondent has heated the shaft in order to provide a shrink fit to the shaft and therefore to improve the percent contact. There is no data at this time to show whether this works but AEP has tried this technique on one mill at Sporn with no failures to date.

- Another approach taken was to nitride the surface of the shaft in the tapered section to increase the surface hardness. An increase in surface hardness should improve the fatigue life of the shaft.
- One utility installed snubbers on the top grinding ring to limit relative movement between the yoke and the shaft (See Figure 9).
- Shot peening the shaft surface in the tapered section was also tried as a means to improve fatigue life and to minimize the chance for fretting. AEP tried this without success.
- One utility found that increasing the minimum coal flow rate drastically reduced failures. Maintaining an even and continuous coal bed is an OEM recommendation for reducing wobbling motion of the grinding rings.

In the approaches taken to solve this problem, the survey results show that the most effective steps are those which limit the possibility of uneven loading to the shaft. The survey results are summarized in Table 1.

Sporn Plant Case History

The study of the pulverizer shaft failures took a period of three years. During the time, shaft fractures occurred and cases of incipient cracking on the tapered section of the shafts were detected by magnetic particle inspection. Working together with the OEM and plant personnel, several tasks were undertaken which include:

(1) OEM involvement and closer quality assurance monitoring of rebuild steps:

- yoke fitup and percent contact was checked with a target of 80% contact as a minimum goal. In some cases, 100% contact on the upper surface and 80% contact on the lower surface could be achieved.

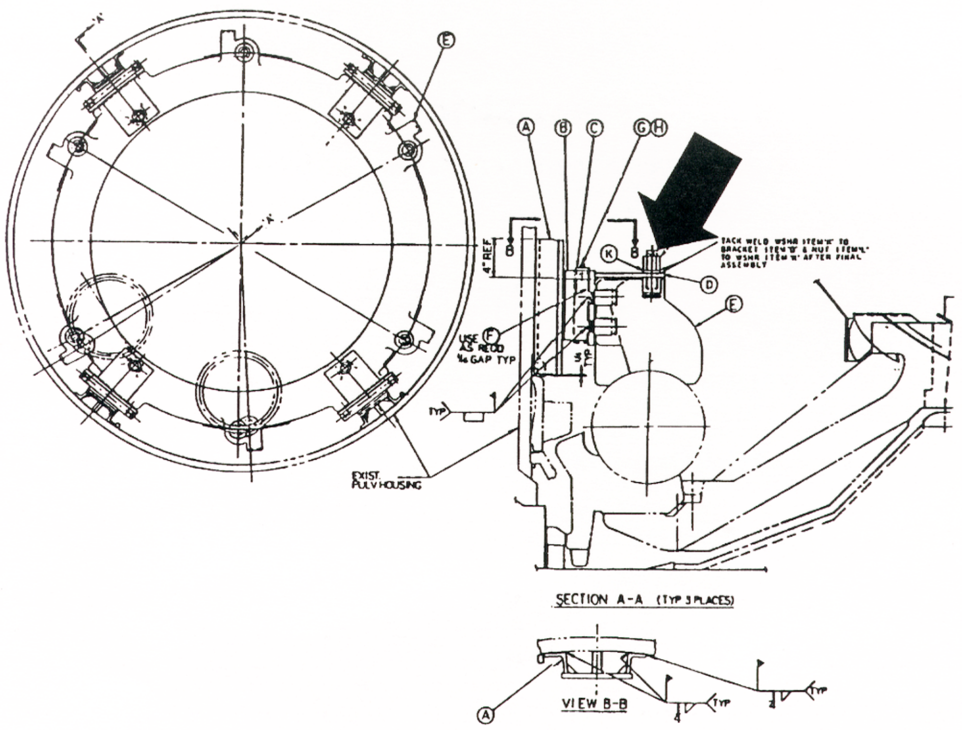

Figure 9 Drawing Showing a Typical Snubber Arrangement

	AEP (Sporn)	Utility A	Utility B	Utility C	Utility D	Utility E	Utility F
Type / No. / Year	EL70/10/1951	EL53/2/1957 EL70/2/1963	EL70/4/1963	EL56/4/1955 EL76/6/1966	EL70/4/1957 EL56/8/1951-2	EL76/5/1960	EL76/12/1964-5
Number of Failures	10 Failures in last 3 years	2-3 in last 10 years	None	3 in 1981, 1 repeat in '82	None	All 5 since 1968	7
Location	Relief Groove	Relief Groove	N/A	Relief Groove	N/A	Relief Groove	Relief Groove
% Contact	75-80	75-80	80-90	80	85	90+	95+
Vendor	B&W/AR	B&W	B&W	B&W	B&W	B&W	B&W
Shaft Diameter	7-1/2"	7-1/2"	7-1/2"	8-3/4"	7-1/2"	8-3/4"	8-3/4"
Heat Yoke	No	No	No	No	Yes	Yes	Yes
Modifications	Shot Peen	None	None	Shot Peen	None	None	Snubbers
Pre-Fail NDE	Yes	No	No	No	No	No	Yes
Cycle Mills	Yes	Yes	No	Sometimes	Yes	Sometimes	No
Pyrite Problems	Frequently	Sometimes	Sometimes	No	Rarely	No	No
Oil Problems	Sometimes	Rarely	No	No	No	No	Sometimes
Gate Problems	Sometimes	Rarely	Sometimes	No	Rarely	Yes	No
Lug Wear	Frequently	No	No	No	No	No	No
Backups	Sometimes	Rarely	Rarely	No	No	No	No

Table 1 Results of Utility Survey

- checks on the alignment of the top bearing plate to the gearbox showed misalignments that required boring and sleeving of the upper radial bearing.
- scrapped lower grinding rings from E70 series mills were examined. Excessive wear to the pyrite kicker lugs was seen. This type of wear was not present on EL76 rings previously removed from Sporn Unit 5.
- locknut torquing practices were reviewed since it was apparent that no measurable consistency was practiced. However, this line of investigation was discontinued when no correlation with the failures could be established.

(2) A review of shaft manufacturing practices in the areas of heat treatment, inspection and machining was undertaken. In addition, assistance from the OEM and other parts suppliers was enlisted to determine whether tolerances, materials, finishes or other shaft-specific items had been changed recently. This effort did not yield significant findings.

(3) The metallurgical study showed that fatigue crack propagation was initiated at fretting damage on the tapered surface of the shaft. One method to reduce the propensity of fretting damage is to shot peen the affected surfaces. This introduces compressive stresses to the outer fibers of the shaft which also promote resistance to fatigue cracking. Literature on the subject of fretting remedies makes it clear that if the vibrational movement between the two surfaces is significant, fretting cannot be avoided. This proved to be relevant in the Sporn shaft, as the shaft which had been shot peened failed after less than 100 hours of operation as a result of fretting induced fatigue cracking.

Based on OEM recommendations and the findings produced by the above tasks, it was decided that the most effective solution was to focus on reducing or removing the sources of the loads on the tapered section of the shaft which produce the vibration. Prior to receiving the results of the utility survey, the remedial steps were identified as:

(1) Build up of pyrites on the grinding surfaces causes uneven loading on the grinding rings and hence, the yoke. If the pyrite boxes are plugged and not emptied, the potential for problems is aggravated. A means to detect pluggage and to remedy the problem was needed. Excessive wear on the kicker lugs and the plugged, failed mills served as evidence to support this.

(2) The shape of the lower grinding ring and the orientation of the throat opening on the E-type mills was thought to dribble more than the EL mills, which can contribute to pyrite pluggage. A decision was made to complete an EL conversion on one mill to test this theory. At the time, AEP was unaware that other utilities had been experiencing shaft breakage with EL mills.

(3) Methods to improve the yoke bushing-to-shaft fit were explored. Shrink-fitting the yoke bushing to the shaft was employed on mills at the Sporn Plant.

SUMMARY

Industry experience would indicate that both E- and EL-type mills are prone to fretting/fretting fatigue failures at the yoke bushing to tapered shaft fit area. This is most likely caused by unbalanced forces experienced during grinding which produce bending stresses at this fit location. The lack of support between the upper radial bearing and the yoke bushing permits bending stresses to be imposed on the shaft. However, many operation variables can also produce the same result.

Snubbers are currently being used by one utility to dampen out the unbalanced cyclic loading on the grinding rings until wear in the grinding elements reduces their effectiveness. Other steps which have been taken to improve the fit of the yoke bushing to the shaft such as heat shrinking may also prove

effective. Surface treatments such as nitriding and shot peening of the contact zone of the shaft to improve fretting resistance may also prove effective in the case of lower cyclic stresses. These steps may extend the life of the shaft but may not address the root cause of the problem. Their effectiveness has yet to be proven by service hours.

To summarize AEP's actions to date, shot peening has been applied to the contact zone of shafts without success. The approach taken at the Sporn Plant was to convert the E-type mills to the EL-type. This was done to reduce pyrite dribble which is thought to be an improved feature of the EL-type mill. It is believed that pyrite build-up on the grinding rings led to many of the failures, but this has not been confirmed. A more detailed investigation of these shaft failures is planned including, among other steps, the role that the grinding rings may play in the failures. At this date, seven of the sixteen mills at the Sporn Plant have been converted from E- to EL-type mills. In addition, a shrink fit of the yoke bush ing was made on two of the converted mills. However, only one mill has been put into service since the rebuild. After only 900 hours of service, this mill has yet to experience failure. More service hours are required on the converted mills in order to judge the effectiveness of these steps.

The overall goal of this study is not merely to solve the immediate problem of shaft breakage, but also to develop a predictive maintenance model which could be used when mill rebuilds andlor inspections are required. AEP and Riley Stoker will continue to enlist other interested utilities to participate in this study.