Research Article

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Case study on the effectiveness of condition monitoring techniques for fault diagnosis of pumps in thermal power plant

https://doi.org/10.2478/mme-2019-0010
Received Mar 27, 2018; revised Oct 02, 2018; accepted Nov 20, 2018

Abstract: A case study was carried out to investigate the effectiveness of condition monitoring techniques in the early failure detection of pumps in a thermal power plant. Various condition monitoring techniques used in this case study involved vibration analysis, motor current signature analysis, noise monitoring and wear debris analysis. These techniques were applied on the three pumps, namely boiler feed water pump, auxiliary cooling water pump and condensate extraction pump, which have to work continuously for the operation of the thermal power plant. Vibration analysis of the auxiliary cooling water pump showed that there is a rising trend in the acceleration values at its driving and non-driving end indicating the deterioration of bearings. Motor current index range of all the pumps was found to be within acceptable limits. Wear debris analysis of lubricant in the hydraulic coupling of boiler feed water pump indicated the presence of sand, dirt and low alloy steel sliding wear particles in it. Condition monitoring techniques have been proved to be an effective technique in early failure detection of pumps.

Keywords: Maintenance, monitoring, spectrum, vibration, wear

1 Introduction

Condition monitoring is a maintenance technique for the diagnosis of defects in machineries, while it is in working mode so that its operation will not be interrupted [1]. It acts as an effective tool in the forecasting of maintenance and also avoids the chances of catastrophic failure [2]. Thermal power plants require continuous operation of a number of pumps for effective generation of electricity. Various pumps used in thermal power plants include boiler feed water pump, condensate extraction pump, auxiliary cooling water pump, ash disposal pump, seal oil pump and various other pumps [3]. Major condition monitoring techniques used in pumps are vibration monitoring, motor current signature analysis, noise monitoring and wear debris analysis [4].

Vibrations are produced due to the excitation forces generated in the machines during the operation [5]. Major reasons for vibrations in the pumps include rotor imbalance, shaft misalignment, bearing damage, wear ring dislocation, electrical and hydraulic defects. Vibrations in the body will be in axial, horizontal and vertical directions, which make it mandatory to measure the amplitude of vibrations in all three directions at the testing point [6]. The amplitude is expressed in terms of displacement, velocity and acceleration depending upon the frequency and operating speed of the machinery [7]. Vibrations are measured in terms of displacement when the speed range is less than 600 rpm and occurs mostly in dynamic stress conditions. When the operating speed ranges from 600 to 60000 rpm, the vibrations are expressed in terms of velocity, since it is developed under conditions of fatigue. In cases when higher frequencies are produced by forces and the speed is above 60000 rpm, vibrations are measured in terms of acceleration [8]. Vibration analyzers are used for picking up the characteristic vibration spectrum of machines and it also applies the fast Fourier transform technique to convert the original time signal [9]. The sensors are attached to the testing points and the data related to variation in vibration level is captured by the sensors, and it is sent to the analyzers where the spectrum is generated for analysis purpose.

Motor current signature analysis (MCSA) involves the monitoring of current in the induction motor by the analysis of the current spectrum for spotting the fault frequen-

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Table 1: Vibration readings of ACW pump before and after maintenance

Reading Point	Horizontal (mm/sec)		Vertical (mm/sec)		Axial (mm/sec)		Acceleration (g)	
	Before	After	Before	After	Before	After	Before	After
Motor non-driving end (NDE)	2.31	2.21	2.27	2.23	2.19	2.54	0.88	0.86
Motor driving end (DE)	2.67	2.43	2.15	2.37	2.52	2.29	0.93	0.77
Pump non-driving end (NDE)	3.43	2.21	2.25	1.67	2.14	1.45	2.73	0.71
Pump driving end (DE)	4.22	2.35	2.56	1.23	2.02	1.13	1.62	0.63

cies [10]. Higher resistance spots are developed in the location of faults, which give rise to harmonic fluxes inducing a current component in the stator winding [11]. This current component results in supply current modulation at pole pass frequency. Hall effect current sensor is used for capturing the current modulation by clamping it with the circuit and the readings are transferred to fast Fourier transform analyzer for generating the spectrum. In industries, the noise levels must be continuously monitored and maintained within limits in order to avoid its adverse effects on workers [12]. Noise levels are monitored by using the acoustic and ultrasonic noise meters.[13] Wear debris analysis is carried out to determine the concentration of wear particles in the lubricants used [14]. It is carried out by taking a sample of lubrication oil and subjecting it to ferrography for separating the wear debris and contaminant particles [15]. Then, the contamination levels are determined by using the particle count test [16]. Presence of the wear particles will also lead to corrosion of the components in the coupling [17, 18]. In this paper, a detailed study on the effectiveness of these condition monitoring techniques was carried out by applying these to the three pumps, namely boiler feed water pump, condensate extraction pump and auxiliary cooling water pump.

2 Condition Monitoring Analysis of Pumps

The condition monitoring of pumps was carried out by employing five techniques, namely vibration analysis, motor current signature analysis and noise monitoring using acoustic and ultrasonic noise meters.

2.1 Auxiliary Cooling Water (ACW) Pump

Auxiliary cooling water pump was used for pumping cooling water to the plate heat exchangers for cooling the Equipment cooling water (raw water). The cooling water used in ACW pumps was sea water and it was taken by tapping the condenser piping. A bypass was taken from the cooling water pumped by the CW pumps. Vibration readings were taken from points as shown in Figure 1.

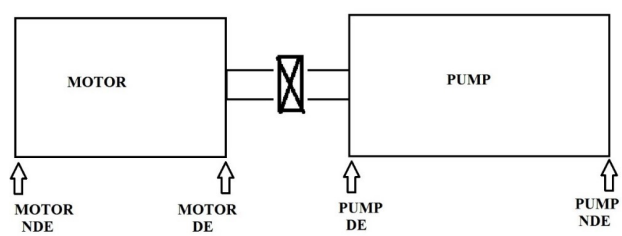

Figure 1: Vibration reading points of ACW pump

From the readings in Table 1, it can be seen that the acceleration values in pump DE and pump NDE are higher with a rising trend. It was observed that the "g" value was high on pump bearings and the frequencies got excited. The acceleration spectrum of pump DE bearing is shown in Figure 2. These high frequencies happen to be the bearing defect frequencies. Thus, it was suspected that the pump bearing's deterioration was in progress. Rechecking was done at regular intervals of one hour and it was observed that the pump NDE acceleration value rose to 2.9 g. Abnormal noise was also detected from the pump. The noise readings were taken with acoustic noise meter and it was found to be 130 dB, which is higher than the limits. Ultra-

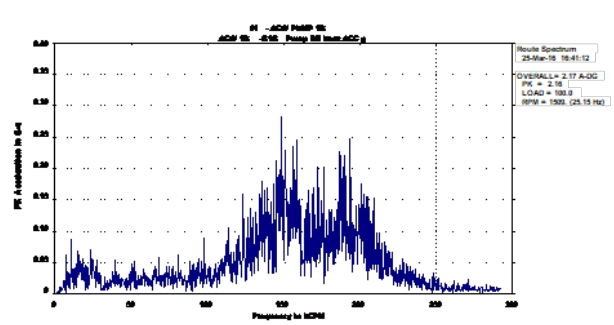

Figure 2: Acceleration spectrum of pump DE bearing

sonic noise meter was then used to detect the exact location of the noise source and to find the intensity of the flaw. Ultrasonic noise meter detected sounds of continuous hitting over shaft and it showed intensity level of 8 LEDs, which is supposed to be in limits of 5 LEDs. Looseness of bearing or wear ring in the pump was suspected with inference from the observed readings. Since motor vibration readings were well within limits, there was no need of maintenance on motor and electrical side. Mechanical maintenance of the pump had to be carried out.

Pump was then decoupled from the motor and the casing cover of the pump was removed. On removal of the cover, the wear ring of the pump NDE end was found to be dislocated from its position. Impeller and shaft were raised from pump casing and wear ring was inspected. The holding screw of wear ring was found to be corroded as shown in Figure 3 and it was replaced. Wear ring was refitted, and the impeller and the shaft were placed back to the casing. Pump bearings were checked for clearance and were found to be fine. Bearings were greased suitably. Pump shaft was then coupled with motor shaft and then checked for alignment using dial indicators. Noise readings were taken using acoustic noise meter and found to be 90 dB and ultrasonic noise meter showed intensity level of 3 LEDs. Motor current signature analysis of motor was carried out and the motor current index was calculated by substituting the values of line frequency and pole pass frequency in Eq. (1). Tongue tester indicated the pole pass frequency of 0.0315 Hz and line frequency of 17.25 Hz. Motor current index was found to be 64.76 dB.

$$\text{Motor current index} = 20\text{Log}\frac{(\text{Line frequency})}{(\text{Pole pass frequency})} \quad (1)$$

After restoring the pump NDE wear ring to its original location, acceleration values were reduced to normal level and no abnormal level sound was noticed from the pump. All the values of vibrations, noise meters and motor current index were found to be in limits. The probable reason of the problem, that is, the pump wear ring being loose, might have created excess load on pump bearing, which resulted in rise of acceleration of pump DE bearing.

2.2 Boiler Feed Water (BFW) Pump

Boiler feed pump is used for pumping the feed water from deaerator to the boiler wall tubes. The water in the deaerator is usually at a very low pressure of 5 kg. BFP requires a suction pressure of 23 kg, and in order to raise the pressure of the feed water in the deaerator, Booster Pumps (BP) are used as shown in Figure 5. The feed water at raised pressure of 23 kg will be then sucked by the BFP and is discharged to the boiler tubes at a pressure of 205 kg. Both BFP and BP are connected to a single motor drive. Motor rotates at a speed of 1500 rpm, which is the required rpm of the BP. So, the motor shaft is directly coupled to the BP. The required speed for the operation of the BFP is 5220 rpm and it is achieved by connecting the shaft of the motor to the BP via step up hydraulic coupling, which steps up the

Figure 3: Dislocated wear ring of ACW pump

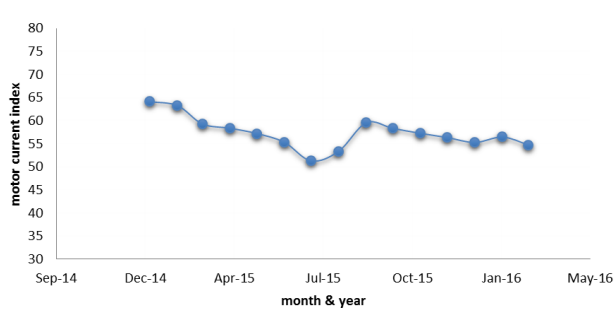

Figure 4: Dislocated wear ring of ACW pump

Figure 5: Boiler feed water pump

Table 2: Vibration readings of BFW pump

Reading Point	Horizontal (mm/sec)	Vertical (mm/sec)	Axial (mm/sec)	Acceleration (g)
Main pump NDE	2.31	2.82	1.93	0.72
Main pump DE	2.22	2.41	2.34	0.91
Hydraulic coupling-Main pump end	2.34	2.71	2.19	0.80
Hydraulic coupling-Motor end	3.12	2.53	2.61	0.93
Motor-Hydraulic coupling end	3.0	2.77	2.38	0.85
Motor-Booster pump end	2.81	2.51	2.46	0.89
Booster pump DE	2.23	2.48	1.97	0.73
Booster pump NDE	2.78	2.85	2.67	0.83

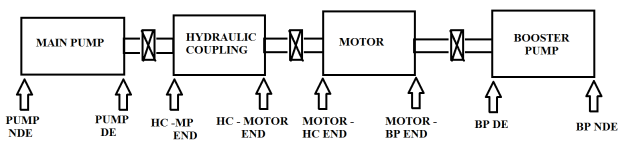

Figure 6: Vibration reading points of boiler feed water pump

Figure 7: Low alloy steel severe sliding wear particles

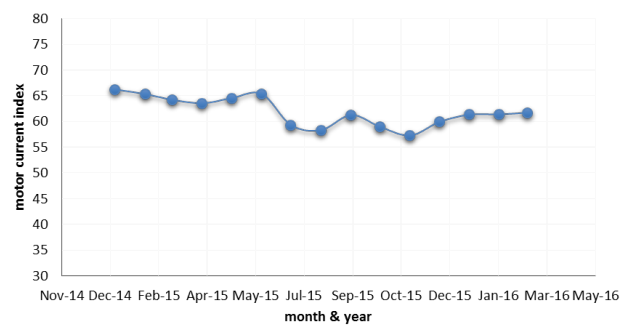

Figure 8: MCI trend of BPW pump

speed of the motor (1500 rpm) to the required speed of the BFP (5220 rpm). The main parts of a BFP are pump barrel, rotor, stator and mechanical seal.

Water passes through the suction branch into the intake spiral, and from there, it is directed to the first impeller. After leaving the impeller, it passes through the distributing passages of the diffuser, where it gets certain pressure rise. From there, it flows over guide vanes to the inlet of the next impeller, and from there, to discharge. A small part of the feed water, that is, 10% is taken from the space behind the last impeller for the operation of automatic balancing device to balance the hydraulic axial thrust of the pump rotor. Since the medium of the BFP is hot water, the operating temperature must be maintained in the pumps. Thermal equalizing lines are provided at both ends of the mechanical seals in order to meet this purpose. Vibration readings of the Boiler feed water pump was taken from points as shown in Figure 6 and was found to be within limits. The readings are given in Table 2 and it was found to be well within limits.

Wear debris analysis of the oil in the hydraulic coupling is done by collecting the oil sample from the hydraulic coupling oil bypass with the help of a vacuum pump. Ferrography is carried out on the collected sample of oil and the results of the tests are discussed below. The wear debris analysis of the oil sample showed the following results:

- Wear particle concentration (WPC) of the sample is 3.5 WPC (limit is 100).
- Normal rubbing wear particles were observed in small quantities.
- Low alloy steel severe sliding wear particles of the size range of 24 microns were observed in negligible quantities, as shown in Figure 7.
- Spheres were observed in small quantities.
- Sand/dirt particles were observed in small quantities.

Table 3: Vibration readings of BFW pump

Reading Point	Horizontal (mm/sec)	Vertical (mm/sec)	Axial (mm/sec)	Acceleration (g)
Motor non-driving end (NDE)	2.21	1.95	1.86	0.92
Motor driving end (DE)	2.82	2.37	2.53	0.97
Pump driving end (DE)	2.93	2.74	2.51	0.87

Motor current signature analysis of motor was carried out and the motor current index was calculated to be 61.72 dB, when the line frequency was found to be 15.9 and pole pass frequency was found to be 0.0125. The trend of MCI for a period of two years is shown in Figure 8. Noise monitoring of the boiler feed water pump was measured using an acoustic noise meter (110dB) and an ultrasonic noise meter (3–5 LEDs). The noise reading and the MCI index values were found to be well within limits.

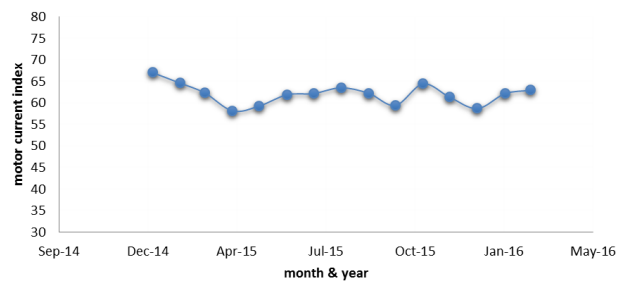

Figure 10: MCI trend of Condensate Extraction Pump

2.3 Condensate Extraction Pump (CEP)

Condensate extraction pumps are used to draw the condensate from the condenser hot well and feed it to the deaerator through low pressure heaters. It is a vertical double entry canister pump and it is provided with 5 impellers as shown in Figure 9. The liquid is sucked at a pressure of 0.5 bar and it is passed through the five stages of the impeller to produce a discharge pressure of 22 bar. Vibration readings of the condensate extraction pump were taken and were found to be within limits as shown in Table 3.

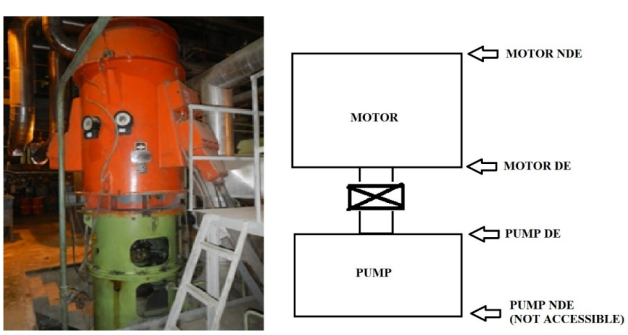

Figure 9: Condensate Extraction Pump

Motor current signature analysis of motor was carried out and the motor current index was calculated to be 60.8 dB when the line frequency was found to be 23.24 and pole pass frequency was found to be 0.021. The trend of MCI for a period of two years is shown in Figure 10. Noise levels of the boiler feed water pump was measured using an acoustic noise meter (100dB) and an ultrasonic noise meter (3–5 LEDs). The noise reading and the MCI index values are found to be well within limits.

3 Conclusion

Effectiveness of condition monitoring techniques in the early failure detection of pumps in thermal power plants has been studied in detail. Condition monitoring techniques like vibration analysis, motor current signature analysis, noise monitoring and wear debris analysis has been carried out in three pumps, namely auxiliary cooling water pump, boiler feed water pump and condensate extraction pump. The vibration readings of auxiliary cooling water pump shower a rising trend in its acceleration values both at its driving and nondriving end. It indicated that the deterioration of the pump bearing is taking place. Mechanical maintenance of pump was carried out and the wear ring of the pump bearing was found to be dislocated due to corrosion of clamps. This would have led to the catastrophic failure of the pump if not detected by condition monitoring techniques. Wear debris analysis of the lubricant in the hydraulic coupling of boiler feed water pump indicated the presence of sand, dirt and sliding wear particles in it. The lubricant oil has to be replaced to avoid the corrosion and also the failure of the coupling. Condition monitoring techniques have proved to be an effective tool in diagnosing the faults in the pumps at an early stage

so that the chances of catastrophic failure can be avoided completely.

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