PUMP COUPLING & MOTOR BEARING DAMAGE DETECTION USING CONDITION MONITORING AT DTPS

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Abstract. This paper shares a success story out of the implementation of Co-ordinated Condition Monitoring techniques at DTPS, wherein imminent Mis-alignment of HT auxiliary BFP – 1B and Motor bearing failure of ID FAN – 1B was diagnosed. On 30/12/2010, Booster Pump DE horizontal reading increased from 4.8 to 5.1 and then upto 5.9 mm/sec. It was suspected that Booster pump was mis-aligned with Motor. To confirm misalignment, Phase Analysis was also done which showed that Coupling phase difference was 180 Degrees. Vibration & Phase Analysis helped in diagnosing the exact root cause of abnormity in advance, saving plant from huge losses which could have caused total cost of £ 104,071.

On 06/01/2011, ID fan 1B Motor NDE & DE horizontal vibration readings deviated from 0.5 to 0.8 and 0.6 to 0.8 mm/sec (RMS) respectively. Noise level increased from 99.1 to 101.9 db. It was suspected that Motor bearings had loosened over the shaft. Meanwhile, after opening of Motor, Inner race of NDE side was found cracked and loosened over the shaft. Vibration Analysis & Noise Monitoring helped in diagnosing the exact root cause of abnormity in advance, saving plant from huge losses which could have caused total cost of £ 308,857.

1. Introduction

Dahanu TPS (2 x 250 MW) of Reliance Energy, India is one of the best operating coal based power stations in the country, in terms of all the major key performance parameters such as availability, plant load factor, specific oil consumption, heat rate, etc. The plant has strategically adopted Co-ordinated Condition Monitoring as one of the key maintenance management practices.

The main objective of adopting condition monitoring program is to:
1. Access the condition of equipment without stopping them.
2. Eliminate failures & identify the root cause(s) of any abnormality.
3. Extension of component life.

DTPS has set vision and mission for the sustainability of organization in today’s competitive environment. The vision is “to be amongst the world class power plants, delivering reliable generation of electricity at competitive costs”. Hence, to accomplish this, S.M.A.R.T objectives and targets are set, which are cascaded from top to bottom level of the organization. The strategic action plans are prepared to achieve the stated goals by using various analytical tools. The equipment criticality analysis is conducted to systematically determine the equipments, which have imminent influence on
the plant performance. The equipments are then prioritized for close monitoring on the basis of criticality index to ensure high plant availability. These critical equipments are monitored more attentively, to further improve the maintenance as well as operational performance.

2. Case Study-1: Mis-alignment of BOILER FEED PUMP – 1B

Following is a success story of the implementation of condition monitoring techniques at DTPS, wherein imminent Mis-alignment of HT auxiliary BOILER FEED PUMP – 1B due to damaged coupling bolts was diagnosed.

2.1. Pre-Maintenance History
1. In December 2010, during Unit overhaul, BFP servicing was done as per the schedule.
2. Bearing horizontal vibrations deviated from 2.9 to 4.8 mm/sec & 2.8 to 4.1 mm/sec (RMS) respectively, though the Motor, Hydraulic Coupling & Main Pump vibrations were normal.

3. Also, pump related parameters i.e. pressure and temperatures were normal.
4. It was decided to keep a close watch on vibration readings of Booster Pump (2 readings per shift).
5. On 30/12/2010, Booster Pump DE horizontal reading increased from 4.8 to 5.1 and then up to 5.9 mm/sec on same day.
6. Increasing trend observed in vibration of Booster pump DE bearing. It was decided to changeover the pump.
7. Detailed analysis was carried out as follows:
2.2. Vibration Diagnosis of Boiler Feed Pump 1B

On 30/12/2010, Booster Pump horizontal vibrations of DE & NDE reached 5.9 & 4.1 mm/sec respectively. (Same readings were normally in the range of 2.5 to 3.0 mm/sec.) The spectrum analysis for root cause is as follows:

**Figure 3.** The Horizontal Vibration Spectrum of BFP 1B Booster Pump DE. Total Magnitude: 5.90 mm/sec (RMS).

**Figure 4.** The Horizontal Vibration Spectrum of BFP 1B Booster Pump NDE. Total Magnitude: 4.10 mm/sec (RMS).
2.3. Frequency Analysis
1. There was increase in the amplitude of Booster Pump DE bearing vibration from 2.9 mm/sec to 5.9 mm/sec.
2. Earlier it was in the range of 2.5 to 3.0 mm/sec.
3. Spectrum analysis revealed that there is increase in 1x frequency.
4. It was suspected that Booster pump was mis-aligned with Motor.
5. To confirm mis-alignment, phase analysis was also done.

Figure 5. Phase Analysis of Booster Pump DE (Horizontal). Phase Angle = 306 Deg.

Figure 6. Phase Analysis of Motor DE (Horizontal). Phase Angle = 126 Deg.

Phase Difference across Coupling = 306 – 126 = 180 Degrees.

6. Above analysis shows that Coupling phase difference is 180 Degrees (which pinpoints Misalignment between Booster Pump & Motor.)
7. Decision taken to realign Booster Pump with Motor.
2.4. Observations during Maintenance work
1. No Scoring marks observed on both DE & NDE bearings
2. Condition of both bearing housings found OK.
3. While de-coupling, 6 Nos. bolts of flexible coupling found sheared.

![Figure 7. Coupling side view.](image1)

![Figure 8. Damaged Coupling Bolts.](image2)

4. Shims below suction strainer found loose.

![Figure 9. Loose shims.](image3)
2.5. Details of Maintenance work
1. Booster Pump de-coupled from rest of the drive group.
2. Before dismantling, initial alignment readings were taken for reference.
3. Sheared coupling bolts replaced with new coupling bolts.
4. 5 mm Shims added at all 4 corners of the suction strainer for smooth expansion.
5. Alignment reading taken but found disturbed.
6. Again, 5 mm shims removed & 4 mm shims added for precise alignment.
7. Alignment done with rest of drive group.
8. Readings are as follows (Dial Gauge on motor shaft & Clamp on booster pump shaft)

![Radial (All Units in mm)](image)

![Axial (All Units in mm)](image)

Figure 10a. Alignment readings (Before).
Figure 10b. Alignment readings (After).

9. Trial of BFP taken, all vibrations were found within limit.
10. BFP boxed-up and made available for operation.

2.6. Post-Maintenance Vibration Readings

| Point          | Position | Velocity (mm/sec) RMS | Velocity (mm/sec) RMS |
|----------------|----------|-----------------------|-----------------------|
|                | DATE     | Initial Readings      | After Re-Alignment    |
| Main (NDE)     | H        | 30/12/2010            | 03/01/2011            |
| pump           |          | 1.3                   | 1.5                   |
|                | V        | 1.6                   | 1.7                   |
|                | A        | 1.1                   | 1.0                   |
|                | H        | 2.1                   | 1.9                   |
| Main (DE)      | V        | 2.4                   | 2.4                   |
| pump           | A        | 1.7                   | 1.5                   |

Table 1. Vibration readings (Before & After).
2.7. Results and Discussion
The catastrophic failure of 'BFP – 1B' was avoided using Vibration & Phase Analysis Technique. The early detection of Mis-alignment between Booster Pump & Motor due to damage of Coupling bolts avoided costly catastrophic failure. The application saved the plant from huge losses in terms of generation, unplanned breakdown time and associated maintenance & spares costs.

Cost Saved by preventing catastrophic failure of Boiler Feed Pump 1B:
- Generation loss Calculation
  
  \[
  \text{0.25 MUs/hr (1 MU = 1,000,000 Units)} \\
  \text{Total saving for 1 hr} = 0.25 \times 1 \times 1,000,000 \\
  = 250,000 \text{ Units} \\
  \text{Cost per unit} = £ 0.05 \\
  \text{Total Saving} = 0.05 \times 250,000 \\
  = £ 12,500
  \]

- Cost of Main pump = £ 91,571
- Total Cost saving = Generation loss + Cost of Main Pump
  
  \[
  = 12,500 + 91,571 \\
  = £ 104,071
  \]
3. Case Study-2: Motor Bearing Failure of ID FAN – 1B
Following is a success story of the implementation of condition monitoring techniques at DTPS, wherein imminent Motor bearing failure due to looseness of bearing on shaft of HT auxiliary ID FAN – 1B was diagnosed.

3.1. Pre-Maintenance History
1. On 25.11.2010, during Unit overhaul, it was decided to replace ID Fan 1B motor with the serviced spare motor as per schedule.
2. On 26.11.2010, No load Decoupled trial was taken for 1 hour wherein Motor DE & NDE Bearing vibrations were found to be within limit. At the same time, DE & NDE bearing temperatures were found to be normal.
3. On 09.12.2010, when the fan was taken in service, vibrations of Motor, Hydraulic Coupling and Fan were within limit. Also, all the operating parameters were normal.
4. On 22.12.2010, abnormal sound noticed from NDE side of Motor. Vibration readings were taken and found to be well within limits. Noise level measured for reference which was 94 dB.

![Figure 11. Initial Noise Monitoring.](image)

5. The abnormal sound level was constant for next 10 days. No variations in vibrations were noticed.
6. On 05.01.2011, sound level increased to 99.1 dB though no deviation observed in Motor vibration.
7. In view of steep increasing trend of noise from NDE side of Motor, it was decided to stop the Motor for 2 hours to carry out internal inspection of Motor cooling fan and check for rubbing between stationary & rotating part.
8. Inspection was carried out. No abnormality was observed. Motor was taken in service.
9. On 06.01.2011, Motor NDE & DE horizontal vibration readings deviated from 0.5 to 0.8 and 0.6 to 0.8 mm/sec (RMS) respectively. At the same time, there was no deviation in Hydraulic coupling & Fan bearing vibrations.
10. On 08.01.2011, detailed vibration analysis report along with various probable causes was discussed in daily planning meeting.
11. It was decided to keep close watch on Motor vibration & Noise readings (3 readings per shift).
12. On 09.01.2011, Motor NDE & DE vertical vibration readings also deviated from 0.7 to 1.0 and 0.6 to 0.9 mm/sec (RMS) respectively.
13. On 10.01.2011, Motor NDE & DE horizontal vibrations increased to 1.3 & 1.2 mm/sec respectively and vertical vibrations increased to 1.1 & 1.3 mm/sec respectively.
14. On 10.01.2011 Noise level also increased from 99.1 to 101.9 dB

15. In view of Steep increasing trend of Noise from 94 to 101.9 dB, it was decided to stop ID FAN for Motor replacement.

16. Detailed analysis was carried out as follows.
3.2. Vibration Diagnosis of ID Fan 1B Motor

On 10.01.2011, Motor NDE & DE horizontal vibration increased from 0.5 & 0.6 to 1.3 & 1.2 mm/sec & vertical vibration increased from 0.7 & 0.6 to 1.1 & 1.3 mm/sec (RMS) respectively.

The spectrum analysis for root cause is as follows:

**Figure 15.** Spectrum of Motor NDE (Horizontal & Vertical) showing multiples of running speed frequency.

**Figure 16.** Spectrum of Motor NDE (H) showing bearing defect frequencies. Total Magnitude: 1.3 mm/sec (RMS).
3.3. Frequency Analysis
1. Initially the Motor NDE side noise level increased from 94.0 to 101.9 db.
2. Normally it is in the range of 89 to 90 db.
3. Increase in the amplitude of Motor NDE & DE bearing vibrations was also noticed from 0.5 & 0.6 to 1.3 & 1.2 mm/sec respectively.
4. Earlier it was in the range of 0.5 to 0.6 mm/sec.
5. Spectrum analysis revealed that there was increase in multiples of running speed harmonics from 1x, 2x, 3x ….. up to 10x frequency.
6. It was suspected that Motor bearings were loose on shaft.
7. Also, the spectrums showed Bearing Defect Frequencies at BSF, BPFO & BPFI which clearly pinpointed bearing defects.
8. When these frequency stress waves’ events occur at repeatable time intervals corresponding to a bearing defect frequency, then it is likely that a bearing defect is present.

**Stress waves:**

Stress waves are high frequency vibrations, caused due to:

- Impact of two metal surfaces with each other.
- Passing of bearing rolling element over any defect.
- Due to fatigue cracking, excessive friction & abrasive wear.

**Stress waves are:**

- Short in duration
- Micro seconds for fatigue cracking
- Milliseconds for Metal to Metal impact

9. Hence it was concluded that vibration of both Motor bearings increased due looseness of bearings on shaft & the deterioration of bearings was in progress.

10. So it was decided to stop the fan for Motor replacement.

### 3.4. Observations during Maintenance work

1. Condition of cooling fan found OK.
2. The bearing clearances were found on higher side than the original readings. There was a clearance of more than 0.5mm at NDE bearing inner race area.

![Loose Bearing on Shaft](image1)

**Figure 19.** Loose bearing on shaft.

![Checking NDE bearing clearances](image2)

**Figure 20.** Checking NDE bearing clearances which found on higher side.
3. Condition of DE bearing housing found OK.
4. Scoring observed on NDE side bearing housing cap.

![Figure 21. Scoring on bearing cap.](image)

5. NDE bearing grease found blackish with bearing burr particles inside & scattered over Stator Rotor.
6. Inner race at NDE side was cracked and got loosened over the shaft.

![Figure 22. Cracked Inner race.](image)  ![Figure 23. Dismantled cracked inner race.](image)

7. Scoring was observed over the shaft at NDE side due to relative motion between inner race of bearing and shaft. Due to this, the diameter of shaft was found 159.34 mm at bearing area instead of 160.03 mm.

![Figure 24. Scoring on Motor NDE shaft.](image)
8. Scoring was observed on both DE & NDE bearings rollers.

Figure 25. Scoring on Motor DE bearing.

9. Thorough inspection of Motor Winding and Stator rotor was done & found OK. No Scoring marks observed.

Figure 26. Scoring on Motor NDE bearing.

3.5. Maintenance work carried out
1. Gear coupling from DE side was removed.
2. Motor was replaced with the spare serviced Motor.
3. Gear coupling was then mounted on motor shaft.
4. Motor trial was taken at No load decoupled condition and vibrations found well within limit.
5. No abnormal sound noticed during the trial run of Motor.
6. ID fan alignment done with rest of the drive.

**Radial** (All Units in mm)

|       | South | North |
|-------|-------|-------|
| 650   |       |       |
| 718   |       |       |
| 774   |       |       |

**Axial** (All Units in mm)

|       | South | North |
|-------|-------|-------|
| 2.69  |       |       |
| 2.71  |       |       |
| 2.68  |       |       |
| 2.67  |       |       |

Figure 27. Inspection of Motor winding.

Figure 28. No Scoring on Motor stator Rotor.

Figure 29. Final Alignment readings.
7. ID fan was boxed-up and made available for operation.
8. ID fan was then taken in service.
9. At full load, all vibrations & Noise level found in well within limit.

3.6. Post Maintenance Vibration Readings

Table 2. Vibration & Noise readings (Before & After).

| EQUIPMENT  | DATE | VIBRATION REPORT OF ID FAN 1B |
|------------|------|-------------------------------|
|            |      | Initial Readings | After Replacing Motor |
|            | DATE | Motor @ full Load | Decoupled Motor Trial |
|            | 10/01/11 | 11/01/11 | 11/01/11 |
| Motor      |       | H | V | A | V | A |
| (NDE)      |       | 1.3 (1.0 g) | 0.3 (0.7 g) | 0.5 (0.6 g) |
| V          |       | 1.2 | 0.5 | 0.6 |
| A          |       | 1.0 | 0.3 | 0.4 |
| H          |       | 1.2 (1.3 g) | 0.3 (1.2 g) | 0.4 (1.0 g) |
| Motor      |       | V | 1.3 | 0.4 | 0.5 |
| (DE)       |       | A | 1.0 | 0.5 | 0.4 |
| Hyd.       |       | H | 1.3 | - | 1.2 |
| (DE)       |       | V | 0.9 | - | 0.8 |
| A          |       | 2.2 | - | 2.0 |
| Coup.      |       | H | 2.2 | - | 1.9 |
| (DE)       |       | V | 1.5 | - | 1.7 |
| A          |       | 2.1 | - | 1.7 |
| H          |       | 0.2 | - | 0.3 |
| Fan        |       | V | 0.2 | - | 0.3 |
| (DE)       |       | A | 0.3 | - | 0.3 |
| H          |       | 0.2 | - | 0.3 |
| Fan        |       | V | 0.3 | - | 0.3 |
| (NDE)      |       | A | 0.4 | - | 0.5 |
| Noise      |       | 101.9 dB | 89.7 dB |

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3.7. Results after Motor Replacement

Noise level at Motor NDE side

![Image](30.png)

**Figure 30.** Noise Level reduced from 101.9 to 89.7 dB.

![Image](31a.png)

**Figure 31a.** Reduction in Vibration level of Motor NDE (Horizontal) Total Magnitude: 0.5 mm/sec (RMS).

![Image](31b.png)

**Figure 31b.** Reduction in Vibration level of Motor NDE (Vertical). Total Magnitude: 0.6 mm/sec (RMS).

![Image](32a.png)

**Figure 32a.** Figure 32. Reduction in Vibration level of Motor DE (Horizontal) Total Magnitude: 0.4 mm/sec (RMS).

![Image](32b.png)

**Figure 32b.** Reduction in Vibration level of Motor DE (Vertical) Total Magnitude: 0.5 mm/sec (RMS).

Above Vibration spectrum does not show any abnormality such as Looseness & Bearing defect frequencies after replacement of Motor.
3.8. Results and Discussion
Vibration analysis & Noise Monitoring helped in diagnosing the exact root cause of abnormality at very early stage. The early detection of Motor bearing looseness on shaft of HT auxiliary ID FAN – 1B avoided costly catastrophic failure. The application saved the plant from huge losses in terms of generation, unplanned breakdown time and associated maintenance & spares costs.

Cost Saved by preventing catastrophic failure of ‘ID Fan 1B’:

- Generation loss Calculation
  0.09 MUs/hr (1 MU = 1,000,000 Units)
  Total saving for 48 hrs = 0.09x48x1,000,000
  = 4,320,000 Units
  Cost per unit = £ 0.05
  Total Saving = 0.05 x 4,320,000
  = £ 216,000

  Cost of Motor = £ 92,857

  Total Cost saving = Generation loss + Motor cost
  = 216,000 + 92,857
  = £ 308,857

Conclusion

- Co-ordinated Condition Monitoring helped in diagnosing the exact root cause of abnormality at a very early stage of HT auxiliaries BFP and ID Fan.
- It shows that early diagnosis has resulted in timely action and savings in cost and avoidance of unplanned shutdown.
- This has saved the plant from huge losses in terms of generation, unplanned breakdown of equipment and associated maintenance & spares costs.

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