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Predictive maintenance and fault diagnosis of hydraulic gear coupling of a boiler feed pump unit

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Abstract
Increasing demand for reliability and performance of today's most complex machines, and maintaining high productivity without sacrificing product quality have made it imperative for maintenance engineers to devise newer strategies in maintenance of plant and machinery. One of such strategies is condition monitoring, which has emerged as one of the most powerful technology in maintenance engineering. Condition monitoring and diagnostic engineering is a novel concept which enables us to detect in advance any incipient failure with ease and confidence in any part of a dynamic system before such failure trigger – off various types of failure mechanisms, which in turn may render the whole system uneconomical, unreliable, unhealthy, unsafe and even lethal. The present work highlights an experimental investigation to monitor the vibration behavior of hydraulic gear coupling, which is a part of Boiler Feed Pump train of a large utility Thermal Power Plant. The coupling is supported by 4 Bearings. Tri-axial measurements are made at the bearing supports for 12 months. Displacement and Velocity are measured along Horizontal, Vertical and Axial directions. The experimental data is plotted on Time domain for graphical analysis to ease viewing of vibration signals. Based on the experimental data, faults are diagnosed using ISO – 2372 standards and causes are predicted. It is observed that the front and rear bearings of Input and output shafts of coupling are experiencing excess vibration. The work is concluded by suggesting remedial measures to ensure vibration intensity, at the said points, within the safe limits.

Keywords: Condition based monitoring, Boiler Feed Pump, Hydraulic Gear coupling

INTRODUCTION

Machine condition monitoring is gaining importance in industry because of the need to increase reliability and to decrease the possibility of production loss due to machine breakdown. Traditional preventive maintenance not only leads to unnecessary machine downtime but also premature replacement of parts. Successful implementation of a condition monitoring programme allows the machine to operate to its rated capacity without stopping the machine at fixed periods for inspection [1]. In seeking to understand how they deteriorate, Collacot [2] states that, it is desirable to make a fresh approach to a new technology and in doing so, the present trend is at the frontier of new scientific discoveries useful in both safety and economic viability. As per Stipho [3] maintenance programming of industrial system in general aims at minimizing maintenance costs and maximizing the availability of the system.

According to Collacot [4] maintenance besides trying to better its own efficiency, must also solve the problem of preventing failure. Maintenance as suggested by Hensey and Nair [5] needs to and must be professionally managed by optimizing the four resources: men, machines, materials and money and thus ensuring the health of assets.

The maintenance management based on the operating condition of the equipment is termed as Condition Based Maintenance (CBM) with which overhauls are carried out only when the condition of the equipment has deteriorated to a predetermined level. Thus, overhauls or replacement of parts take place only when it has definitely been proved that a fault exists and if left unrepaired would result in unsatisfactory operating condition even leading to catastrophic failure.

A number of methods have been developed in the recent years to help the maintenance personnel for prediction of the health of equipment or system. These methods include, Vibration and Noise monitoring, Temperature monitoring, Oil monitoring, Leakage monitoring, Crack monitoring, Stress monitoring, Performance monitoring etc[6].

Of all these, vibration level measurements and signature analysis are the most commonly used methods for monitoring the health of a machine. Vibration is the language of the machines which if one can listen and is enough to diagnose their complaints and ailments. Machines vibrate because of defects or inaccuracies. Each kind of defect or trouble produce vibration characteristic in a unique way.

The vibration amplitude gives an idea about the intensity of vibration [7]. The convenient representative place of measuring its intensity is the bearing housing where the vibration is properly reflected. When the overall vibration level reaches or exceeds the limit, it may be because of unbalance, misalignment, looseness, damaged bearing, worn out gears, bent shaft or resonance etc. This can be identified and is to be rectified during the over haul [8]. Some of the recent works in the area are done by Shiroishi et al [9],

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McFadden [10] and Nandi [11].

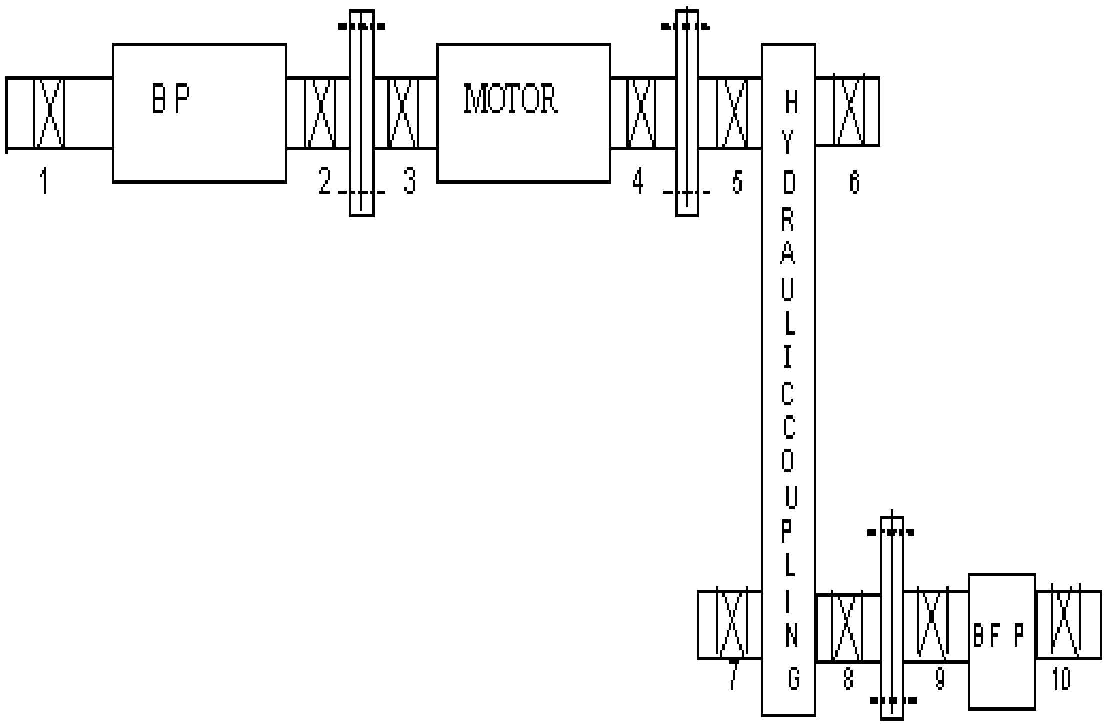
DESCRIPTION

Boiler Feed Pump (BFP) is used to pump the feed water to the boiler at high pressure. The boiler is at a high altitude compared to the level of the water. The feed pump is used to pump the water to the boiler. Pressurizing the water will be done in two stages. In the first stage, the water will be pressurized from 7.5 kg/cm^2 to 17.5 kg/cm^2 in Booster pump and from 17.5 kg/cm^2 to 180 kg/cm^2 at Boiler Feed Pump. The FK6D30 type BFP consists of FA1B56 Booster Pump (BP) directly driven from one end of the shaft of an electric motor with rated RPM of 1440 (28.8 Hz). BFP is driven from the opposite end of motor shaft through a variable speed turbo coupling. The drive is transmitted in each case through a spacer type flexible coupling. The line diagram of the entire unit of Boiler Feed Pump Train is shown in the Fig.1

Boiler feed pump is coupled with driving motor through a variable speed hydraulic coupling. The hydraulic coupling serves the purpose of controlling the speed of feed pump for maintaining definite delivery head and delivers the feed water as per the requirement of the boiler. This reduces the power consumption particularly at part load operation. A fluid coupling is basically a combination of pump and turbine connected in series.

In contrast to the constant filled type turbo coupling, the oil filling of the variable speed turbo coupling can be varied between fully filled and drained while in operation. In this way step less speed regulation of the driven machine over a large range is achieved. When the coupling operates against the load characteristics the regulating range is 4:1.

The present work deals with the diagnostic studies of Hydraulic Coupling shafts (both Input and Out put) which are supported by bearings 5, 6, 7 and 8.



1. Booster Pump Non – Driving end (BPNDE), 2.Booster Pump Driving end (BPDE), 3.Motor Booster Pump end (MBPE), 4.Motor main pump end (MMPE), 5.Input shaft Driving end (IPSDE), 6.Input shaft Non – Driving end (IPSNDE), 7.Output shaft Motor end (OPSME), 8.Output shaft Pump end (OPSPE), 9.Boiler Feed Pump shaft Drive end (BFPDE), 10.Boiler Feed Pump shaft Non – Drive end (BFPNDE)

Fig 1. Line diagram of Boiler Feed Pump Train

Experimentation

Measurements are made using “data PAC 1500”, single channel vibrometer with a frequency range of 10cpm to 4518000cpm (0.18Hz to 75.3 Hz), with A/D converter, VGA resolution screen data collector from ENTEK IRD, USA, over a period of 12 months at regular monthly intervals and recorded. The instrument is mounted on 4 bearing supports along Horizontal (H), Vertical (V) and Axial (A) directions, the axial direction is being in line with the axis of the shaft. The measurements are made for displacement and velocity. Accelerations have been computed for similar ratings. Regular logging of the data has provided the basis for performance trend monitoring of the rotating structure and prediction of faults to apply reasoning to trace the root cause

RESULTS AND DISCUSSIONS

Tri axial measurement of displacement, velocity and acceleration are recorded on time domain at regular monthly intervals near the bearing supports. The data is presented in Tables 1 to 8. This facilitated the computation of average values of displacement, velocity and acceleration corresponding to the rated speed of Input and Output shafts.

Table 1. Tri – axial measurements at Bearing 5

Month	DISP (µm)			VEL (mm/sec)			ACCEL (m/sec²)		
	H	V	A	H	V	A	H	V	A
JAN	16.2	15.34	19.52	8.62	6.98	7.24	4.59	3.18	2.69
FEB	15.2	18.48	17.32	5.83	6.35	7.42	2.24	2.18	3.18
MAR	18.49	21.42	17.84	5.78	6.49	7.36	1.81	1.97	3.04
APR	14.54	16.82	13.98	7.6	4.49	5.02	3.97	1.20	1.80
MAY	16.2	18.94	17.48	7.58	4.32	3.08	3.55	0.99	0.54
JUN	24.28	20.92	18.56	6.08	5.32	7.06	1.52	1.35	2.69
JULY	28.4	22.46	18.9	7.58	5.47	6.92	2.02	1.33	2.53
AUG	26.45	20.38	22.18	7.86	4.92	6.54	2.34	1.19	1.93
SEPT	22.46	19.38	20.56	7.82	6.43	7.02	2.72	2.13	2.40
OCT	20.44	18.36	22.5	7.48	6.03	6.75	2.74	1.98	2.03
NOV	26.04	24.98	21.56	5.32	4.98	5.76	1.09	0.99	1.54
DEC	30.68	29.48	27.06	5.62	4.96	6.03	1.03	0.83	1.34

Table 2. Tri – axial measurements at Bearing 6

MONTH	DISP (µm)			VEL (mm/sec)			ACCEL (m/sec²)		
	H	V	A	H	V	A	H	V	A
JAN	18.4	17.84	22.41	7.89	7.02	6.08	3.38	2.76	1.65
FEB	16.48	17.32	13.84	6.8	7.48	5.23	2.81	3.23	1.98
MAR	20.91	18.84	16.48	7.04	7.38	6.57	2.37	2.89	2.62
APR	15.86	17.04	14.38	7.48	6.04	6.98	3.53	2.14	3.39
MAY	15.08	14.02	16.48	3.58	6.9	5.07	0.85	3.40	1.56
JUN	21.36	20.82	18.92	4.58	6.32	4.92	0.98	1.92	1.28
JULY	24.68	19.56	22.08	9.02	8.3	7.58	3.30	3.52	2.60
AUG	22.98	24.56	20.36	7.02	6.58	5	2.14	1.76	1.23
SEPT	20.47	21.36	20.82	8.01	7.95	7.58	3.13	2.96	2.76
OCT	21.38	19.46	20.8	6.98	7.02	5.35	2.28	2.53	1.38
NOV	23.06	22.08	21.98	7.6	6.02	5.06	2.50	1.64	1.16
DEC	28.64	26.52	24.9	6.7	7.02	5.4	1.57	1.86	1.17

Table 3. Tri – axial measurements at Bearing 7

MONTH	DISP (µm)			VEL (mm/sec)			ACCEL (m/sec²)		
	H	V	A	H	V	A	H	V	A
JAN	17.52	16.8	17.56	8.2	7.59	7.48	3.84	3.43	3.19
FEB	14.96	13.94	15.08	7.18	6.59	5.98	3.45	3.12	2.37
MAR	21.46	19.98	18.28	4.58	5.27	7.18	0.98	1.39	2.82
APR	20.2	18.74	19.89	6.98	7.6	6.12	2.41	3.08	1.88
MAY	18.04	14.96	16.36	8.56	4.97	9.05	4.06	1.65	5.01
JUN	19.82	20.04	18.46	6.04	6.33	5.42	1.84	2.00	1.59
JULY	22.38	21.96	19.04	12.06	10.94	11.48	1.63	2.00	1.59
AUG	20.46	21.68	22.98	7.6	5.37	6.47	2.82	1.33	1.82
SEPT	24.06	18.98	20.52	5.95	7.08	6.53	1.47	2.64	2.08
OCT	24.76	22.4	20.84	3.98	6.45	5.78	0.64	1.86	1.60
NOV	25.98	23.06	22.08	8.14	7.87	6.02	2.55	2.69	1.64
DEC	31.08	26.94	24.76	6.6	6.02	5.98	1.40	1.35	1.44

Table 4. Tri – axial measurements at Bearing 8

MONTH	DISP (µm)			VEL (mm/sec)			ACCEL (m/sec²)		
	H	V	A	H	V	A	H	V	A
JAN	21.02	20.04	19.84	9.2	6.8	7.82	4.03	2.31	3.08
FEB	17.04	18.46	21.02	6.39	7.02	6.26	2.40	2.67	1.86
MAR	19.48	17.78	16.96	5.56	6.98	7.32	1.59	2.74	3.16
APR	16.9	18.48	20.02	5.48	6.08	7.19	1.78	2.00	2.58
MAY	21.76	19.52	20.06	7.06	6.38	5.92	2.29	2.09	1.75
JUN	22	19.48	21.36	7.61	6.17	6.98	2.63	1.95	2.28
JULY	26.54	21.78	23.6	9.8	8.88	10.2	3.62	3.62	4.41
AUG	18.08	20.42	22.96	6.64	7.08	5.4	2.44	2.45	1.27
SEPT	30.06	28.4	27.58	7.32	4.87	6.39	1.78	0.84	1.48
OCT	22.68	21.46	20.94	6.08	7.04	6.95	1.63	2.31	2.31
NOV	22.98	20.48	21.3	7	4.98	6.51	2.13	1.21	1.99
DEC	25.98	24.02	23.66	8.46	7.02	9.46	2.75	2.05	3.78

Table 5 gives the velocity measurement at bearing 5. The velocity trend on time domain is shown graphically in Figure 2.

Table 5.Velocity measurements at Bearing 5

MONTH	H	V	A	CONCLUSION
JAN	6.98	**8.62**	7.24	**V>H > A**
FEB	5.83	6.35	7.42	**A > V > H**
MAR	5.78	6.49	7.36	**A > V > H**
APR	7.6	4.49	5.02	**H > A > V**
MAY	7.58	4.32	3.08	**H > V > A**
JUN	6.08	5.32	7.06	**A > H > V**
JULY	7.58	5.47	6.92	**H > A > V**
AUG	4.92	**7.86**	6.54	**V > A >H**
SEPT	7.02	**7.82**	6.43	**H > A > V**
OCT	7.48	6.03	6.75	**V > H > A**
NOV	5.32	4.98	5.76	**A > H > V**
DEC	5.62	4.96	6.03	**A > H > V**

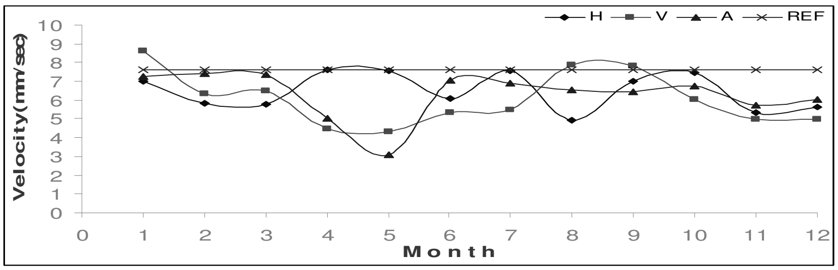


Fig 2. Velocity Trend at Bearing 5

It is observed that in the month of January, there is an excess velocity in vertical direction. Its intensity is less along horizontal and axial directions. The fault is diagnosed due to wiped bearing. An inspection of the sleeve revealed that there is some wear over the inner periphery at its bottom end. The replacement of sleeve resulted in reduction of vibration severity. The measurements during the month of August showed an excess velocity along vertical direction. Its intensity is less along axial and horizontal directions. The fault has been diagnosed as shell looseness. An inspection of the bearing revealed that there is an improper fit of sleeve in its housing. After proper fit is ensured, the velocity level is observed to be still high in vertical direction during the month of September. During this month the velocity along horizontal direction is high compared to the axial direction. The trend is attributed to the looseness in pedestal of the bearing. By strengthening the base as suggested by the investigators, the vibration levels are brought down to safe limits.

Table 6 gives the velocity measurement at the bearing 6 and the trend is shown graphically in the Figure 3.

Table 6.Velocity measurements at Bearing 6

MONTH	H	V	A	CONCLUSION
JAN	**7.89**	7.02	6.08	**H > V > A**
FEB	6.8	7.48	5.23	**V > H > A**
MAR	7.04	7.38	6.57	**V > H > A**
APR	7.48	6.04	6.98	**H > A > V**
MAY	3.58	6.9	5.07	**V > A > H**
JUN	4.58	6.32	4.92	**V > A > H**
JULY	**9.02**	**8.3**	7.58	**H > V > A**
AUG	7.02	6.58	5	**H > V > A**
SEPT	**8.01**	**7.95**	7.58	**H > V > A**
OCT	6.98	7.02	5.35	**V > H > A**
NOV	7.6	6.02	5.06	**H > V > A**
DEC	6.7	7.02	5.4	**V > H > A**

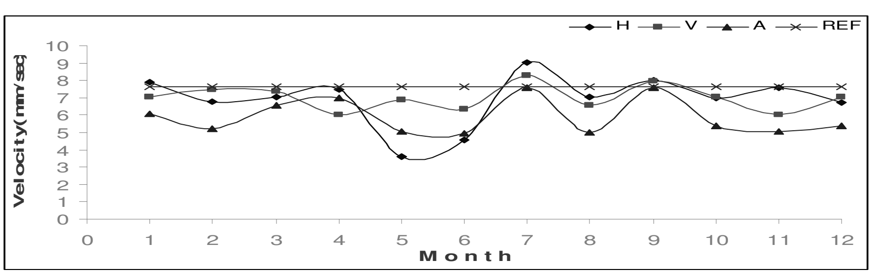


Fig 3. Velocity Trend at Bearing 6

It is observed that the velocity is exceeding the permissible limit along horizontal direction in the month of January. The measurements along vertical and axial directions are indicating that the velocity intensity is in the trouble free limit. This particular trend in velocity can be attributed that there are cracks in the shaft. It is suggested to balance the mass of the rotor. This has led to a reduction in the velocity. During the month of July and September, the same velocity trend is observed. It is suggested strongly to check the rotor during next immediate overhaul and replace the rotor if visible cracks are found.

Table 7 gives the velocity measurement at the bearing 7. The velocity trend on time domain is shown graphically in the Figure 4.

Table 7.Velocity measurements at Bearing 7

MONTH	H	V	A	CONCLUSION
JAN	8.2	7.59	7.48	**H > V > A**
FEB	7.18	6.59	5.98	**H > V > A**
MAR	4.58	5.27	7.18	**A > V > H**
APR	6.98	7.6	6.12	**V > H > A**
MAY	**8.56**	4.97	**9.05**	**A > H > V**
JUN	6.04	6.33	5.42	**V > H > A**
JULY	**10.94**	**12.1**	**11.5**	**V > H > A**
AUG	7.6	5.37	6.47	**H > A > V**
SEPT	5.95	7.08	6.53	**V > A > H**
OCT	3.98	6.45	5.78	**V > A > H**
NOV	8.14	7.87	6.02	**H > V > A**
DEC	6.6	6.02	5.98	**H > V > A**

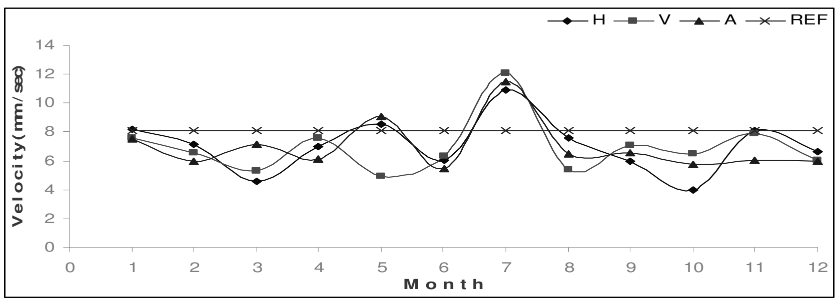


Fig 4. Velocity Trend at Bearing 7

It is observed that the key point is free of any excess vibrations till the month of May. During May, it is noted that velocity intensity is high along axial as well as horizontal directions. Its intensity is well below the permissible limit along vertical direction. Based on the measurements the probable fault has been diagnosed as soft footing. It is suggested to reinforce the basement of the bearing. The velocity levels have been brought down to the acceptable level. Again a similar trend has been observed during the month of July, during which velocity in all the three directions exceeding the permissible limit. The trend observed to be in the descending order along vertical, horizontal and axial directions. The root cause is predicted as loose pedestal. Tightening of the bolts reduced the vibration severity.

Table 8 gives the velocity measurement at the bearing 8 and the trend is shown graphically in the Figure 5.

Table 8.Velocity measurements at Bearing 8

MONTH	H	V	A	CONCLUSION
JAN	**9.2**	6.8	7.82	**H > A > V**
FEB	6.39	7.02	6.26	**V > H > A**
MAR	5.56	6.98	7.32	**A > V > H**
APR	5.48	6.08	7.19	**A > V > H**
MAY	7.06	6.38	5.92	**H > V > A**
JUN	7.61	6.17	6.98	**H > A > V**
JULY	**9.8**	**8.88**	**10.2**	**H > A > V**
AUG	6.64	7.08	5.4	**V > H > A**
SEPT	7.32	4.87	6.39	**H > A > V**
OCT	6.08	7.04	6.95	**V > A > H**
NOV	7	4.98	6.51	**V > A > H**
DEC	**8.46**	7.02	**9.46**	**A > H > V**

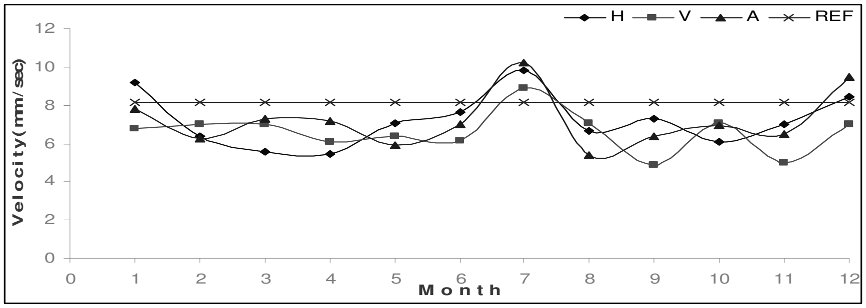


Fig 5. Velocity Trend at Bearing 8

During the month of January, a high velocity along horizontal direction is observed. Its intensity is less along axial and vertical directions. The fault has been diagnosed as bent rotor. It is suggested to measure the deflection and showed a magnitude of 0.32mm, which is over and above the prescribed value of deflection. The bend has been taken care. Subsequent measurements indicate that the bearing is experiencing vibrational velocities well within the limit. Again in the month of July the same trend is observed in which the velocity in all the three directions exceeding the acceptable limits. Since the problem is recurring it is suggested to take up the balancing of the shaft with all attachments. The measurements taken during December indicated that the velocity is exceeding the limiting value both in axial and horizontal directions and its intensity being less in vertical direction. This trend is due to soft footing. It is recommended to check the base frame and take the necessary action to rectify the fault.

CONCLUSIONS

In this paper an attempt has been made to highlight the application of condition based maintenance for diagnostic analysis of hydraulic gear coupling of Boiler Feed Pump train. The process has brought out a systematic investigation of the behavior of the rotor system. The measurements indicated that Bearings 5 to 8 are subjected to excess vibration on a few occasions. Suggestions given based on the overall trending on time domain as well as frequency to overcome the possible faults proved to be effective.

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