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VIBRATION DIAGNOSES FOR A DRY PIT RAW WATER SUPPLY PUMPING SYSTEM IN VERTICAL ARRANGEMENT

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Abstract. *The present paper pertains to the vibration diagnoses of a dry pit raw water supply pumping system in vertical arrangement for downstream treatment and supply of municipal drinking water in a metropolis in India. The pumping system was encountering the problem of excessive vibration, requiring frequent maintenance. To ascertain the probable causes of the excessive levels of vibration systematic vibration measurements of the pump-motor assembly were carried out under different combination of operating conditions for the pumps running in parallel.*

From the monitored frequency harmonics, the main sources of vibration were identified as: friction induced whirl, thrust bearing damage, unbalanced hydraulic force due to pump running under off-design condition, worn out impeller, casing and casing rings.

1 INTRODUCTION

Pumping systems with problem of excessive vibration is a commonly occurring phenomenon. Interaction of different causes of vibration often makes it difficult to pin-point the root causes of this problem. The present paper reports the incidence of one such incidence involving a dry pit raw water pumping system in vertical arrangement for downstream treatment for municipal drinking supply in a metropolis in India which was encountering the problem of excessive vibration, leading to recurrent wear of thrust bearings and impeller and casing rings of the centrifugal pumps requiring frequent stoppage for maintenance.

The pumping system under study comprised five nos. of dry-pit type mixed flow pumps in vertical arrangement with shaft length of 6 m with intermediate plummer block bearings. Each pump had a head, discharge and motor power rating as 5400 m3/hr, 27 MWC and 500 kW, respectively. The sets of pump were meant for pumping raw water from a river and supplying it to the water treatment plant situated a couple of kilometers away. The suction to individual pumps and delivery from individual pump were through common suction manifold and delivery manifold (Figure 1). Depending on the demand, either three or four pumps were run at a time**.** Excessive vibration was observed in one of these sets of pumps leading to frequent and elaborate mechanical maintenance requiring replacement of shafts, wearing rings and impeller rings.

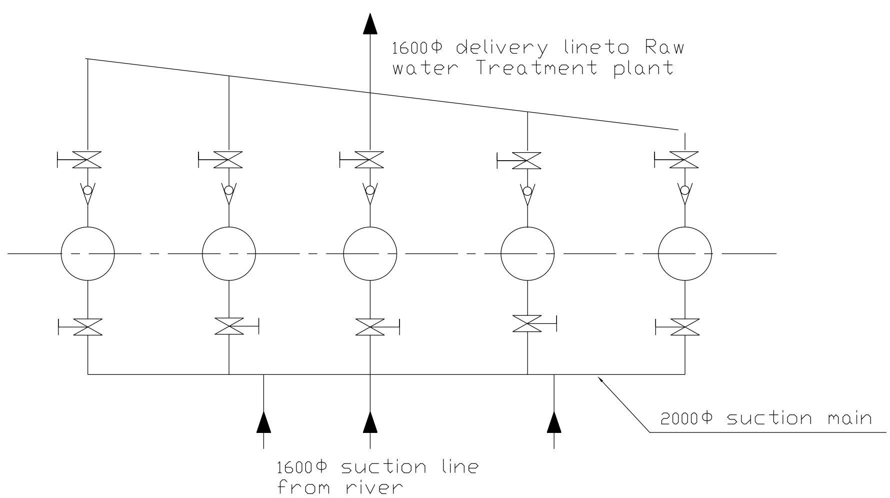

Figure 1 General arrangement of the system under study.

To ascertain the probable cause(s) of the vibration, systematic vibration measurements were carried out. To isolate the probable cause(s) of vibration, measurements were taken under varying hydraulic conditions at different stations along the shaft of the pump-motor assembly under study. A systematic analysis of the frequency harmonics were carried out to ascertain the probable causes of vibration. In the following sections the on-site vibration measurement process being carried out is described, test results furnished, data interpretation presented and suggestions for mitigation of vibration put forward.

2 DESIGN OF EXPERIMENTS

A study had been conducted to ascertain the probable causes of the excessive levels of vibration by carrying out systematic vibration measurements of the pumping system under different combination of operating conditions for the pumps running in parallel as already described [1].

Vibration measurements were conducted along X, Y and Z directions (Figure 2) at different stations (A), (B), (C) and (D) with combinations of inlet and delivery valve opening conditions [2] with the help of an 120 gram accelerometer (Figure 3) and 4-Channel FFT Analyzer (Make: OROS, Model: OR34) with proper signal conditioning [3]. Vibration measurements were taken under conditions of following combinations of valve openings.

1. Dry run of the pump with both suction and delivery valves closed.
2. Wet run of the pump put into the pumping system with suction valve open and varying degrees of delivery valve opening.

The different conditions as above were planned for the following reasons.

1. Dry run: To eliminate hydraulic factors with possible inclusion of vibration due to imbalance of the rotating elements
2. Wet run: With varying % openings: To ascertain effects of hydraulic factors and/or running under off-design condition

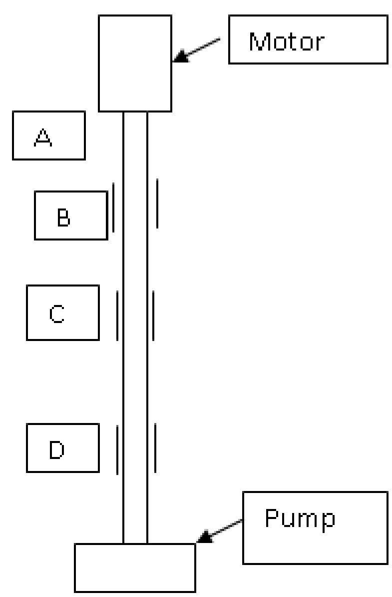

Figure 2 Schematic of vibration measurement stations.

Figure 3 View of accelerometer placed on the motor stool.

3 ANALYSIS:

The frequency domain analysis has been made using the FFT Analyzer [4]. The detailed results of the experiment are furnished in Annexure. Analyses of the systems based on the results are enumerated as follow:

1. The pump is run at no flow condition by closing the suction valve as well as the delivery valve fully. Low frequency component of magnitude 2Hz is observed. This is a sub-harmonic, which is less than 40% of the rotating frequency (12-13 Hz) of the impeller shaft. This frequency component is observed along two mutually perpendicular directions (X, Y) in the horizontal plane near the drive motor (station A, Figures 2 & 3). This could be due to friction-induced whirl. The friction induced whirl may be attributed to asymmetric frictional force between the stationary casing ring and the rotating impeller ring, which are subjected to severe contacts, as these rings undergo progressive corrosion, inducing unbalanced force on the shaft with an increasing magnitude.
2. Moreover, the same frequency component (2 Hz) is also observed at full flow condition in the axial direction (Z) at three different locations (Tables 2 through 5) along the shaft, viz., near the drive motor (A), near the impeller (D), and an in between position (C). This could be attributed to the effect of thrust bearing damage near the motor. It is also observed that there is a gradual decrease in level of vibration (axial direction) as we move from position (A) to (D). The maximum value was obtained at Position (A), near the drive motor. The gradually diminishing value is possibly due to cumulative stiffness offered by the intermediate bearing supports.
3. Significant frequency components like $1X$, $3X$ and higher multiples were also observed at all the locations mentioned above corresponding to different flow rate conditions. It may

be noted that nX indicates frequency value equal to the n times the rotating frequency of the shaft (12-13 Hz).

The frequency component 1X, which is equal to the rotating frequency of the shaft (12 Hz), may be due to any or combinations of (i) unbalance, (ii) shaft bow, (iii) coupling critical and (iv) distortion of casing.

Causes (ii) and (iii) do not arise because of the fact that 1X frequency was found to be absent in no flow condition. Notwithstanding this, we do not rule out the possibility of causes (i) and (iv), in view of the presence of 1X with flow condition.

Higher multiples may occur due to (i) coupling inaccuracy and (ii) aero/hydro forces. Coupling inaccuracy may be excluded, because, under no-flow condition, higher multiples were not observed. Hence, it possibly points to the presence of unbalanced hydraulic forces, in case of different flow situations.

4. Presence of unbalanced hydraulic forces can be attributed to (i) casing distortion and (ii) the pump running under off-design point.
5. The raw water handled by the pumping system has a pH value greater than 7.5, which indicates alkaline condition. Due to this alkalinity the impeller and the casing rings are subjected to a corrosive environment, leading to gradual wear of the rings. Once the dimensional tolerances of the rings get altered due to this, hydraulic unbalanced forces come into picture. The unbalanced hydraulic forces also appear due to pump running beyond the design point, due to formation of secondary rolls. It may be noted here that the pumps in the present system are run beyond their design conditions. During our measurements, we have observed that, when the pump is run with 75% delivery valve opening, the level of vibration is less that that obtained with delivery valve fully open, in some cases. To sum up, running of pumps beyond design point and frequent wear of impeller and casing rings, casing distortion may be probable causes of unbalanced forces and vibration.

4 OBSERVATIONS:

Based on the above analysis, the following observations are made:

1. From the monitored frequency harmonics at different stations along the length of the pump shaft with different valve opening conditions, main source of vibrations were identified as: (i) friction induced whirl arising out of worn out impeller/casing rings, impeller shaft end bush (ii) thrust bearing damage (iii) unbalanced hydraulic force due to pump running beyond design point, worn out impeller and casing rings as well as casing distortion.
2. To mitigate these problems following measures may be adopted, barring other considerations:

   i) Pumps are needed to be operated at the design point (in later experiments it was found that the pumps were running under off-design conditions).

   ii) In view of the alkaline nature of the raw water handled causing frequent corrosion of the impeller and casing rings, selection of alternative corrosion resistant materials needs to be addressed.

iii) The shaft, in the present design, had been quite long. Consequently, it was susceptible to unbalanced condition, bearing eccentricity, coupling inaccuracies etc. To avoid these problems, a better design might include shorter length of the shaft with a hollow cross-section to have better flexural rigidity.

REFERENCES

[1] J. K. Sinha and A. R. Rao, Vibration Based Diagnosis of a Centrifugal Pump, *J. Structural Health Monitoring*, **5**, 325-332, 2006.

[2] S Shahrooi, I H Metselaar, Z Huda, M Asayesh, Numerical and Experimental Vibration Analysis for Fatigue Failure Investigation in a Vertical Axis Pump Station, *Proc. International MultiConference of Engineers and Computer Scientists*, Hong Kong, **II**, 2009

[3] S. G. Brain and B. B. Seth, On the Extraction and Filtering of Signals acquired from rotating machines, *J. Sound and Vibration*, **65**, 37-50, 1979.

[4] E. O. Brigham, *The Fast Fourier Transform*, Prentice-Hall Inc, Englewood Cliffs, New Jersey, 1974

Annexure

Results from 4-Channel FFT Analyzer

Case 1: No Flow
Station A

Valve opening	Direction	Frequency Domain Peak frequency in Hz (Acceleration in m.s^{-2})	Time Domain Max. Level of Acceleration (m.s^{-2})	Remarks
Dry run with both suction and delivery closed	**X**	**2 (25)**	**80**	
	Y	**2 (110)**		

Case 2: Different Valve Opening Conditions
Station A

Valve Opening	Direction	Frequency Domain Peak frequency in Hz (Acceleration in m.s^{-2})	Time Domain Max. Level of Acceleration (m.s^{-2})	Remarks (Prominent Peaks in Hz)
Suction open-dely. closed	**X**	**2(7), 70(2), 85 (4), 96 (2.1), 108 (2.4), 117 (2.3), 145 (4.2), 180 (2.4)**	**110**	**2, 85, 145**
	Y	**12 (3.2), 24 (1.9), 37 (5.7), 100 (3.8), 110 (3.5), 112 (4.25), 117 (4.0), 119 (4.1), 126 (2.7)**	**80**	**12, 37, 100, 110, 112, 117, 119**
suction open-dely. 50% open	**X**	**2(5), 6(2.1), 68(1.8), 84(1.8), 112(1.7), 123(1.8), 146(2.9)**	**46**	**2, 146**
	Y	**12(3.8), 33(5.0), 36(6.2), 104(3.3), 110(4.6), 120(4.0), 146(1.5)**	**70**	**12, 36, 110**
suction open-dely. 75% open	**X**	**2(1.75), 13(0.7), 70(2), 85(2.2), 145(1.6), 174(1.5), 180(1.6)**	**35**	**2, 70, 85, 145, 174, 180**
	Y	**13(3.8), 28(2.0), 33(4.5), 37(5.8), 104(3.2), 112(5.6), 120(3.4)**	**62**	**13, 37, 112**

Valve Opening	Direction	Frequency Domain Peak frequency in Hz (Acceleration in $m.s^{-2}$)	Time Domain Max. Level of Acceleration ($m.s^{-2}$)	Remarks (Prominent Peaks in Hz)
suction open-dely. 100% open	**X**	**13(0.75), 75(2.5), 84(1.2), 112(1.3), 142(1.75), 180(1.6)**	**40**	**75, 112, 142, 180**
	X	**13(1.3), 33(4.5), 37(1.8), 103(3.2), 112(1.22), 120(4.45)**	**39**	**13, 37, 112**
	Y	**2(13.5), 13(2.4), 48(2.0)**	**138**	**2**

Station B

Valve Opening	Direction	Frequency Domain Peak frequency in Hz (Acceleration in $m.s^{-2}$)	Time Domain Max. Level of Acceleration ($m.s^{-2}$)	Remarks (Prominent Peaks in Hz)
Suction open-dely. closed	**X**	**13(8.5), 24(2.7), 37(5.0), 42(3.5), 52(3.3), 58(3.0), 73(2.5), 84(3.7), 96(3.5), 105(5.5), 110(5.3), 157(5.2), 168(9.0), 172(8.7), 188(3.8)**	**108**	**13, 37, 105, 168**
	Y	**13(2.3), 24(5.0), 37(23.5),42(13.5), 52(17.4), 72(7.5), 102(16), 117(11.5), 145(8.0)**	**175**	**37, 52, 102**
	Z	**37(14), 40(24), 43(31), 48(29), 106(19.5), 143(27.5)**	**175**	**43, 48, 106, 143**
Suction open-dely. 25% open	**X**	**13(7.5), 24(2.5), 37(3.5), 72(3.5), 84(5.5), 96(5.5), 110(7.8), 158(5.7), 170(10.25)**	**170**	**13, 110, 170**
	Y	**13(7), 24(5), 37(23), 52(14), 100(16), 122(13), 145(9.5)**	**175**	**37, 52, 100, 122**
	Z	**48(25), 105(17.5), 133(16.5), 143(34)**	**175**	**48, 105, 143**

Valve Opening	Direction	Frequency Domain Peak frequency in Hz (Acceleration in m.s^{-2})	Time Domain Max. Level of Acceleration (m.s^{-2})	Remarks (Prominent Peaks in Hz)
Suction open-dely. 50% open	**X**	**13(8.4), 24(2.7), 37(3.1), 155(4), 167(5.5), 188(3.1)**	**70**	**13, 37, 155, 167**
	Y	**13(7), 37(18), 52(9), 102(11), 120(7.5)**	**160**	**37, 52, 102**
	Z	**37(10), 48(17.5), 104(17), 132(13), 142(31)**	**175**	**48, 104, 142**
Suction open-dely. 75% open	**X**	**13(8.6), 37(7.7), 24(2.5), 48(2.4), 172(6.2)**	**100**	**13, 37, 172**
	Y	**13(3), 24(6), 37(24), 104(7), 120(9)**	**140**	**37**
	Z	**37(14), 50(16), 107(21), 120(12),130(12), 145(33)**	**170**	**37, 50, 107, 145**
Suction open-dely. 100% open	**X**	**13(6.8), 26(2.7), 37(6.5), 60(2.5), 93(3.7), 106(6.0), 118(2.1), 142(4.0), 168(6.3), 188(3.7)**	**80**	**13, 37, 106, 168**
	Y	**13(10.0), 37(20.0), 52(9.4), 104(8.0)**	**142**	**13, 37, 52, 104**
	Z	**37(14.5), 50(16), 108(18), 119(11), 130(12), 144(33)**	**170**	**37, 50, 108, 144**

Station C

Valve Opening	Direction	Frequency Domain Peak frequency in Hz (Acceleration in $m.s^{-2}$)	Time Domain Max. Level of Acceleration ($m.s^{-2}$)	Remarks (Prominent Peaks in Hz)
Suction open-dely. closed	**X**	**42(4.5), 65(6.3), 72(10.4), 84(5.0), 108(6.4), 117(6.8), 150(9.0), 155(7.5), 195(7.5)**	**175**	**72, 117, 150**
	Y	**2(50), 37(14), 40(15.5), 44(16), 55(55), 72(13), 102(10.5)**	**175**	**2, 55**
	Z	**2(30), 30(12), 38(12.5), 43(12), 158(32.5)**	**175**	**2, 158**
Suction open-dely. 25% open	**X**	**65(6.1), 72(14.8), 84(3.5), 117(6.0), 145(12.8), 150(8.1), 158(9.8)**	**175**	**65, 72, 117, 145, 150, 158**
	Y	**2(92), 56(25)**	**175**	**2, 56**
	Z	**2(66), 72(14), 155(36)**		**2, 155**
Suction open-dely. 50% open	**X**	**48(1.75), 68(4.4), 72(7.8), 108(3.6), 117(3.7), 122(4.4), 145(6.4), 149(6.4), 157(5.0), 183(4.0)**	**110**	**72, 122, 145, 149, 157**
	Y	**37(9), 48(18), 56(28.5), 68(6.5), 102(7.0), 122(8.0), 145(8.2), 164(7.5)**	**175**	**37, 48, 56**
	Z	**2(99), 72(11), 150(30.0)**	**175**	**2, 150**

Valve Opening	Direction	Frequency Domain Peak frequency in Hz (Acceleration in m.s^{-2})	Time Domain Max. Level of Acceleration (m.s^{-2})	Remarks (Prominent Peaks in Hz)
Suction open-dely. 75% open	**X**	**24(1.4), 37(1.0), 48(2.2), 58(2.2), 68(5.9), 72(6.7), 110(3.5), 118(3.7), 122(3.7), 145(6.9), 150(7.9), 158(5.0), 165(3.9), 190(3.8)**	**125**	**68, 72, 145, 150, 158**
	Y	**37(13.5), 50(17.5), 56(30), 102(7), 150(8), 163(9)**	**175**	**37, 50, 56**
	Z	**48(11.2), 58(12), 72(15), 148(46)**	**175**	**72, 148**
Suction open-dely. 100% open	**X**	**2(1.25), 24(1.2), 48(1.3), 68(3.2), 72(4.25), 104(2.5), 122(2.7), 145(5.4), 152(5.3), 158(3.6),164(2.7), 184(3.2), 190(4.2)**	**108**	**68, 72, 145, 152, 158, 190**
	Y	**37(14), 42(10), 48(21), 56(29), 68(6), 72(6.5), 102(6), 124(7.5), 148(7.5), 165(8.5)**	**175**	**37, 48, 56**
	Z	**2(8.5), 24(5), 48(10.5), 58(11.5), 72(13.5), 145(39.5), 150(48.5)**	**175**	**72, 145, 150**

Station D

Valve Opening	Direction	Frequency Domain Peak frequency in Hz (Acceleration in m.s^{-2})	Time Domain Max. Level of Acceleration (m.s^{-2})	Remarks (Prominent Peaks in Hz)
Suction open-dely. closed	**X**	**2(2.6), 37(1.8), 62(3.75), 72(7.8), 84(2.1), 98(2.1), 117(2.1),158(2.1), 192(2.25)**	**100**	**2, 62, 72**

Valve Opening	Direction	Frequency Domain Peak frequency in Hz (Acceleration in m.s^{-2})	Time Domain Max. Level of Acceleration (m.s^{-2})	Remarks (Prominent Peaks in Hz)
	Y	**2(2.35), 5(2.0), 52(1.8), 60(1.85), 72(1.9), 117(2.0), 122(2.0), 132(2.25), 145(3.25), 156(3.7), 168(3.6), 172(3.75), 182(3.4)**	**100**	**2, 132, 145, 156, 168, 172, 182**
	Z	**2(7.2), 39(6), 52(5.5), 68(5.8), 72(6.2), 160(12.2), 168(13), 175(11.2), 185(10.6)**	**175**	**2, 39, 72, 160, 168, 175, 185**
Suction open-dely. 25% open	**X**	**2(9), 13(2.2), 62(3.0), 72(10.2), 145(2.7)**	**110**	**2, 72**
	Y	**2(1.65), 8(1.5), 12(1.45), 26(1.42), 39(1.3), 45(1.5), 48(1.85), 72(1.8), 85(1.8), 96(1.8), 140(2.05), 145(2.8), 152(2.4), 163(2.4), 168(2.65), 180(2.65), 182(2.4), 185(2.4), 190(2.4)**	**97**	**2, 48, 72, 85, 96, 145, 168, 180**
	Z	**2(4.5), 68(5.5), 72(11.6), 84(7.5), 122(5.0), 133(5.5), 145(9.0), 160(10.0), 172(12), 175(10.6), 180(10.1)**	**175**	**2, 72, 84, 145, 160, 172, 175, 180**
Suction open-dely. 50% open	**X**	**5(1.25), 13(1.25), 48(1.6), 60(1.55), 72(3.875), 96(1.3), 145(1.75)**	**50**	**48, 60, 72, 145**
	Y	**2(12)**	**90**	**2**
	Z	**2(2.15), 13(1.6), 26(1.75), 42(2.0), 48(2.6), 59(2.5), 68(2.9), 72(4.25), 80(2.1), 84(2.2), 108(2.25), 155(4.15), 160(4.1), 168(5.4), 176(4.6), 190(4.0)**	**95**	**48, 59, 68, 72, 155, 160, 168, 176, 190**

Valve Opening	Direction	Frequency Domain Peak frequency in Hz (Acceleration in m.s^{-2})	Time Domain Max. Level of Acceleration (m.s^{-2})	Remarks (Prominent Peaks in Hz)
Suction open-dely. 75% open	**X**	**2(1.82), 10(1.35), 13(1.22),26(1.25), 48(1.45), 58(1.35), 72(2.32), 84(1.3), 96(1.3), 112(1.3), 122(1.38), 159(1.45), 183(1.3), 196(1.34)**	**48**	**2, 72**
	Y	**2(1.95), 12(1.45), 52(1.65), 96(1.4), 112(1.6), 122(1.55), 146(1.8), 147(1.75), 158(1.9), 170(2.45), 174(2.4), 180(2.35), 190(2.3)**	**80**	**2, 52, 112, 122, 146, 147, 158, 170, 174, 180, 190**
	Z	**2(13), 13(2.5), 48(3.0), 58(3.3), 72(5.5), 173(4.2), 180(4.2)**	**175**	**2, 72**
Suction open-dely. 100% open	**X**	**2(0.6), 26(1.15), 42(1.25), 58(1.2), 72(1.55), 84(1.2), 122(1.35), 136(1.2), 147(1.32), 153(1.25), 157(1.25), 165(1.21), 178(1.34), 183(1.35)**	**48**	**42, 72, 122, 147, 178, 183**
	Y	**2(22.5)**	**103**	**2**
	Z	**2(3.4), 41(2.15), 52(2.9), 58(3.45), 73(4.05), 172(4.2), 184(4.9), 192(4.4)**	**138**	**52, 58, 73, 184, 192**