Application of Modeling Techniques for Solving Misalignment Problem for Large Scale Pumping Stations

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Abstract— **In all types of rotating machinery application, misalignment is the major concern with machinery health monitoring. Usually, misalignment effects are seen at coupling, bearing and at support. Coupling misalignment is responsible for as more as 49% of all costs related to rotating machinery collapse. Precise aligning coupling can prevent a huge number of machinery collapses and reduce much of the unplanned downtime that results in a loss of production. Vibration analysis is the important tool for fault diagnosis in rotating machinery. In this paper, Vibration analysis using Fast Fourier Transform (FFT) spectrum is used to identify misalignment condition. From phase and magnitude, the fault type and position are commonly showed. Phase is of good importance and it is a strong tool that allows distinguishing which of many possible pump breakdowns dominate. The analysis of phase relations enables to diagnose the dominant cause of the breakdown before the corrective action is performed. Experimental results prove that FFT is an important solution for fault diagnosis and phase completes the explanation with how the pump vibrates. The FFT result confirmed that the vibration level became within acceptable condition after correcting misalignment deviation in Khayyam pump station. Overall vibration in Khayyam pump station level was decreased by 2.86 times in axial direction, 3.71times in vertical direction and 4.09 times in horizontal direction after applying alignment process. So, good alignment processing leads to increasing the operating life span of rotating machinery.**

Index Terms— **Misalignment, Fast fourier transform (FFT), Phase analysis, Vibration.**

I. INTRODUCTION

Misalignment is a condition where the coupling of the pinion motor and the driven pump are not on the same line. The non-coaxial condition can be parallel misalignment or angular misalignment or combined Rotating machinery plays a significant role in industrial applications. The multiple faults in rotating machinery are unbalance, misalignment, shaft crack, bent shaft, bearing fault, looseness or rubbing, etc. Unbalance and misalignment are most probable faults in rotating machineries [1]. These faults cause a machine to breakdown or reduce the life time of a machine. For fault diagnosis, different techniques are available such as oil analysis, acoustic emission and vibration signal, however, vibration based signal processing technique is most commonly used. As each fault generates identical vibration pattern and gives identical data of a pump condition, the vibration-depending on signal processing method is one of the most valuable method for fault diagnosis in machines[2]. The unbalance in rotor is the first most common fault in rotating machinery. Unbalance occurs when the mass center line of a rotor does not coincide with its shaft center line. Unbalance causes vibration and creates increasing force in the balls areas and reduces the running times of the balls [3]. Li W et al. [4] developed the expert system to diagnose unbalance using the backward propagation Artificial Neural Network (ANN). These problems affect performance and efficiency leading lo damage and requiring huge maintenance, replacement, and renovation expenses. The acoustic signals were used as input in ANN. the non-linear vibration analysis to study unbalance coupling that is supported on balls. They cleared the appearance of non-linearity as the rotation of the pump is varied [5]. Misalignment between driver and driven machine shafts is the second most common fault in rotating machinery. Rotor misalignment occurs because of improper alignment of couplings, thermal deflection of inner race supports and identical in the applied work [6]. Misalignment and unbalance faults of rotor using equations of motion. The certainty of the equation of motion by the curved pathway permits the analysis of vibration of non-rigid shaft subjected to exocentric and Non-pivotal [7]. the effect of misalignment parallel and angular on vibration signals of shaft. They found the misalignment couples vibration in bending, longitudinal and torsional modes and they carried out experimental investigation of misaligned rotors using vibration signals. The unique nature of misalignment fault was effectively reported using full spectra and orbit plots [8]. Algule and Hujare [9] they studied that the detection of the different effects of vibration signature such as unbalance, misalignment, and crack that may lead to downtime. Vibration result therefore helps in monitoring the quality of a rotating part. Vibration signature also helps to alert equipment operators of engine health condition. Jalan and Mohanty [10] they used a model based technique, which is based on residual generation technique, for identification of misalignment and unbalance faults. The fault condition and position of faults are successfully detected by using this method.

In this research, FFT spectrum technique for misalignment fault diagnosis is proposed. Phase and amplitude are obtained from FFT spectrum. The signal of phase analysis provides further insight into machine diagnostics in conjunction with the information initially provided by the FFT. Case study of fault diagnosis of Khayyam irrigation pump station is carried out as real application of laboratory test.

II. LABORATORY TEST FOR MISALIGNMENT PROBLEM OF MOTOR – PUMP UNIT REVIEW STAGE

The experiments were carried out on an experimental model in mechanical and electrical research institute lab as shown in Fig. (1). Experimental model contain a coupling 25.4 mm diameter and 750 mm length that is hanging using 2 row of balls SKF 6319. Two revolutions cylindrical of 150 mm diameter and 20 mm thick are mounted between two balls.

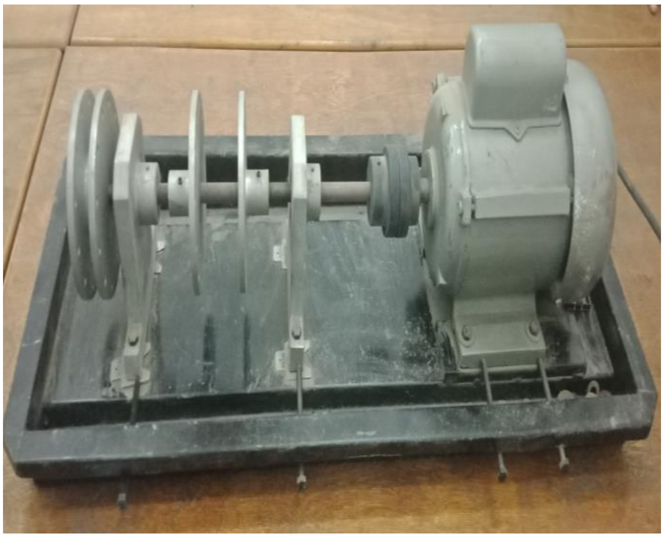


Fig. (1) Experimental model.

The rotor disk has twelve equally spaced holes of 10 mm diameters at 50 mm radius to create and unbalance by fixing weight. The shaft is driven by 1.5 horse power AC unit. The ruunig speed of shaft was setting at 1500 rev/min. The piezoelectric accelerometer Make: AMT; Model: AC100-2B is used to collect the vibration signature in horizontal (H), vertical (V) and axial (A) direction at inner race (Fig. 2). The four channel FFT analyzer Make: 01dB Movipack; XPR300 SW is used to collect vibration signals and carry out analysis. Velocity is the common parameter for vibration result, as all machines and their defects creates vibrations in the frequency domain of 2 Hirtz to 1 Kilo Hirtz.

Fig. (2) 01dB Movipack device and XPR 300 SW

III. RESULTS AND DISCUSSIONS OF THE LABORATORY MODEL

Permissible level up to 4.5 mm/sec. When power becomes more than 300 kW the good level of vibration, (RMS velocity level) is up to 2.3 mm/sec; with the allowable level until 4.5 mm/sec, and a restricted operation level up to 7.1 mm/sec. Angular misalignment of 0.95° is created in coupling and parallel misalignment of 0.25 mm was created in coupling this data as found in Khayyam pump station. RMS values of first order in vertical, horizontal and axial directions are (4.2 mm/s, 2.1mm/s and 6.45 mm/s) respectively. Vibration level along axial direction is high compared to vertical and horizontal vibration. The spectrum of angular misalignment at (DE) in vertical direction (Fig. 3) are showing, horizontal direction (Fig. 4) and axial direction (Fig. 5) were presented.

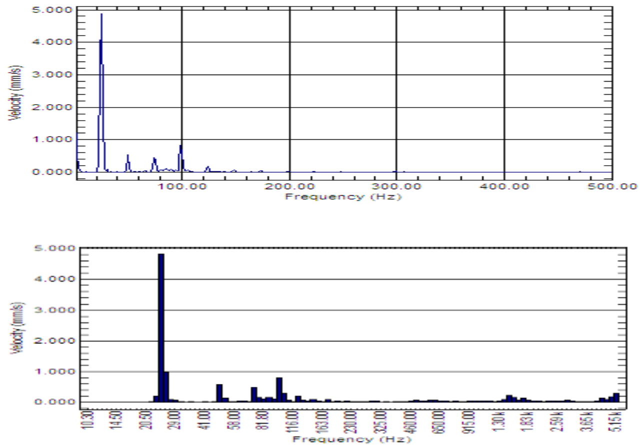


Fig. (3) (FFT) spectrum of angular misalignment at drive end in vertical direction (DE-V)

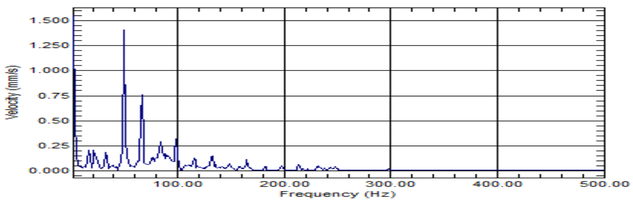


Fig. (4) (FFT) spectrum in horizontal direction

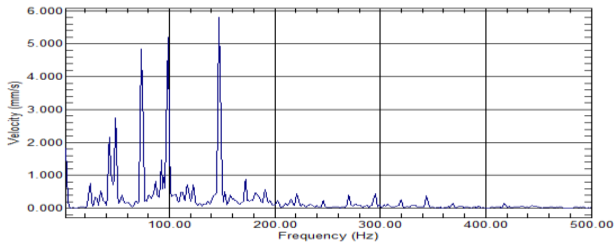


Fig. (5) (FFT) spectrum in axial direction.

Angular misalignment generates a strong vibration at first order (1X), i.e., 1500 rev/min and some vibration at second (2X), i.e., 3000 rev/min in the axial direction. There has also been fairly strong radial (vertical and horizontal) first order and second order vibration levels. Vibration levels at drive end in danger according to ISO 10816-3. Measurements at the drive end showed that the maximum overall vibration level measured reached 6.45 mm/s and 4.2 mm/s in the axial and vertical directions respectively. These levels exceed the permissible levels by 1.8 times and 0.82 times on drive side.

The phase values in horizontal, vertical and axial directions across coupling as shown in Table (1). A phase difference 160°, i.e., 180°±30° observed when axial measurements on the motor drive-end (MDE) bearing and DE bearing across the coupling. These results indicate that the angular misalignment present in the shaft. Misalignment causes an overload on bearings and results in shortening bearing life.

Table (1).Phase values in vertical, horizontal and axial directions at MDE bearing and DE bearing as found

Axial phase difference at MDE and DE bearing (degree)	Direction	MDE bearing (degree)	DE bearing (degree)
	A	75	-125
160	V	46.4	44.1
	H	-110.6	-110.7

This reduction depends on the degree of misalignment. Alignment process was done using (Laser Alignment device E530 with 2 Axis detectors from Easy Laser) and Alignment program (EASY TURN) to perform laser horizontal alignment between motor and bearing as shown in Fig. (6).

Fig. (6) Laser alignment device

Table (2).RMS values vertical, horizontal and axial directions at DE bearing

Drive end (DE) bearing	Direction					
	Vertical before alignment	Vertical after alignment	Horizontal before alignment	Horizontal after alignment	Axial before alignment	Axial after alignment
	4.2	1.3	2.1	1.24	6.45	0.622

The spectrum of parallel and angular misalignment at (DE) balls in (V) values sees (Fig. 7), (H) values see (Fig. 8) and (A) values see (Fig. 9) are presented. FFT spectrum show that the higher amplitude at second order (2X), (3000 rev/min) in the radial direction acceptable range after aliment was done. After applying alignment process between motor and bearing, the results indicated that vibration Levels are within the acceptable range according to ISO 10816 -3 as shown in Table. (2).

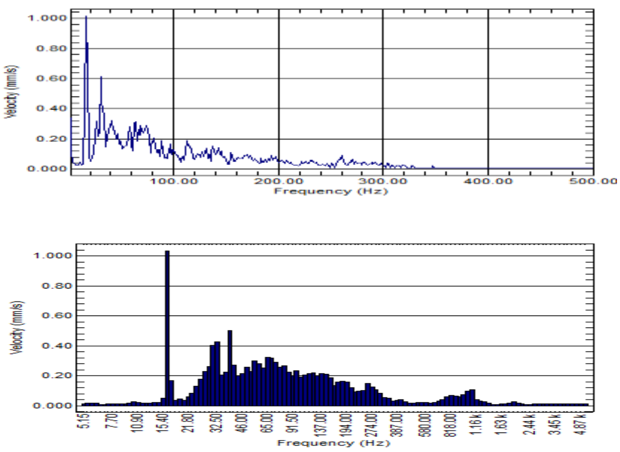


Fig. (7) (FFT) spectrum of angular misalignment at drive end in vertical direction (DE-V)

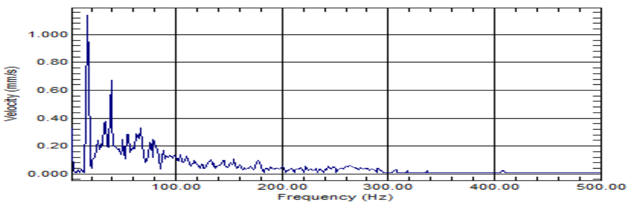


Fig. (8) (FFT) spectrum in horizontal direction

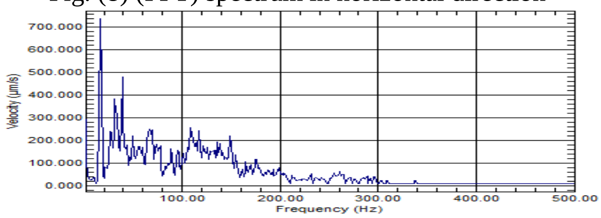


Fig. (9) (FFT) spectrum in axial direction

The measurements showed that the maximum overall vibration level measured reached 0.6 mm/s and 1.3 mm/s on drive end. Vibration levels decreased to 0.9 times and 0.69 times in the axial and horizontal direction on the relay. The FFT curves analysis indicates that maximum level magnitude reached 0.622 mm/s, and 1.3 mm/s at drive end respectively in the axial and vertical direction as shown. Phase values in horizontal, vertical and axial directions across coupling as shown in Table (3). A phase of 180° observed when vertical measurements on the motor drive end bearing and drive end bearing across the coupling. These results indicate that the parallel and angular misalignment disappeared in the shaft. The analysis result confirmed that the vibration level became within acceptable healthy condition after correcting misalignment problem. Therefor this will useful to extending pump running along the application of proactive maintenance scenarios

Table (3). Phase values at MDE bearing and DE bearing after alignment

Vertical phase difference at MDE and DE bearing (degree)	Direction	MDE bearing (degree)	DE bearing (degree)
	A	-3	113.2
180	V	120	60
	H	-66	-57

IV. CASE STUDY

Case study of fault diagnosis of Khayyam irrigation pump station is carried out. FFT analysis technique is used for fault diagnosis. Khayyam irrigation pump station consists of (6) pump units to lifting water to Nag Hamady canal for irrigation purposes in Aswan governorate as shown in Fig. (10). Specification of Khayyam irrigation pumps station shown in table (4).

Table (4). Specification of Khayyam irrigation pumps station.

Motor type	SCHORCH, GERMANY
Speed (RPM)	1482
Gear box type	Voith, three stage
Motor power (Kw)	1250, tilt
Pump speed (RPM)	494
Discharge (m^3/Sec)	14
Head (m)	7
No. of impeller	4

Fig. (10) Photograph of Khayyam irrigation pump station

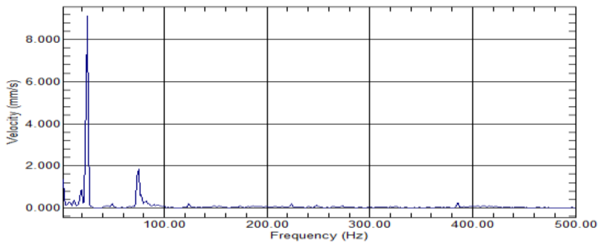
A. *Vibration response of Khayyam pump station*

RMS values of (FFT) in (V, A and H) values at drive end and GBDE gear box bearing drive end are given in Table (5).

Table (5). RMS values in horizontal, vertical and axial directions at DE and GBDE bearing

RMS amplitude (mm/s)				Speed (rev/min)
Measurement positions	Direction			
	Vertical	Horizontal	Axial	
DE	9.95	13.75	4.25	1482
GBDE	8.44	11.30	4.48	

The (FFT) spectrum at DE balls in V values, Fig. (11), H values, DE-H Fig. (12) and axial direction, DE-A Fig. (13) are shown. FFT curves show that the bigger magnitude happend at first order (1X), i.e., 1500 rev/min. Vibration levels at motor drive end and gear box drive end sides are in danger according to ISO 10816-3.



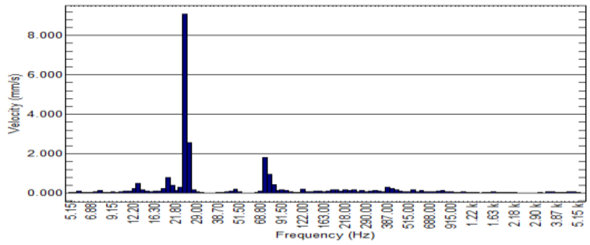


Fig. (11) (FFT) spectrum of angular misalignment at drive end in axial direction (DE-A)

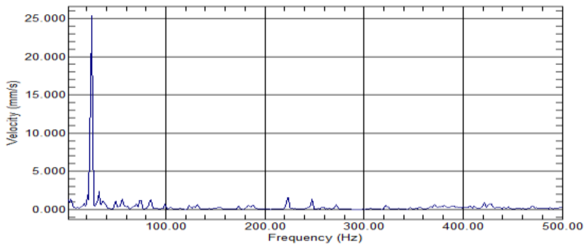


Fig. (12) (FFT) spectrum at drive end in horizontal direction (DE-H)

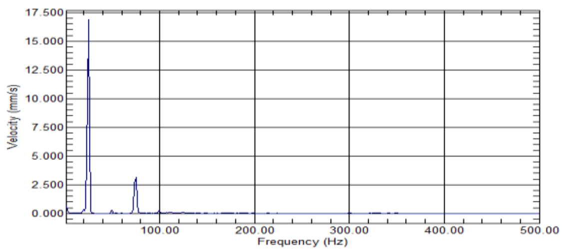


Fig. (13) (FFT) spectrum at drive end in vertical direction (DE-V)

Measurements at the motor drive end showed that the maximum overall vibration level measured reached 4.25 mm/s and 13.75 mm/s in the axial and horizontal directions respectively. These levels exceed the permissible levels by 0.84 times and 4.09 times on the motor and gear box drive sides. The FFT curves mode that have been measured showed that, there are instability nods appeared at unit rotating motion (1rev/min, 25Hz) in the axial and (V) values of the motor and pump. Vibration amplitude reached 4.25 mm/s, and 13.75 mm/s at the unit pinion end respectively in the axial and (H) values as shown in Fig.(11, 12 and 13). These high levels of vibration are in the danger area. The results indicated that the amplitude changed with directions. Also the amplitude in the axial direction is about 59 % of the biggest radial magnitude as showing in table (6). Depending on all these remarks, it is obvious that there is a misalignment problem. . Difference of phase observed between (H&V) direction on the balls is 99.5° i.e., 90°±30°. These results indicate the misalignment present in the system. Alignment process was done using (Laser Alignment device E530 with 2 Axis detectors from Easy Laser) and Alignment program (EASY TURN) to perform laser tilt and horizontal alignment between motor and gear box drive end. Measurements of overall vibration levels and frequency analysis are conducted and the FFT result confirmed that the vibration level became within acceptable condition after correcting misalignment deviation. Figures (14& 15 and 16) showing that the spectrums at drive-end balls of (V& H and A) and dynamic measurements are evaluated to determine the source of the high vibrations. After applying alignment process between motor and pump, the results indicated that vibration Levels are within the acceptable range according to ISO 10816 -3 as shown in Table (6).

Table (6). RMS values in horizontal, vertical and axial directions at DE and GBDE bearing after alignment

RMS amplitude (mm/s)			
Measurement positions	Direction		
	Vertical	Horizontal	Axial
DE	2.1	2.7	1.3
GBDE	1.99	2.5	1.01

The measurements showed that the maximum overall vibration level measured reached 1.3 mm/s, 2.1 mm/s and 2.7 mm/s at rotor unit (DE). Overall vibration in Khayyam pump station level was decreased by 2.86 times in axial direction, 3.71 times in vertical direction and 4.09 times in horizontal direction after applying alignment process the natural frequencies in the cross-discharge direction are very close to the frequencies in the discharge direction. The analysis result confirmed that the vibration level became within acceptable healthy condition after correcting misalignment problem. Therefor this will useful to extending pump running along the application of proactive maintenance scenarios.

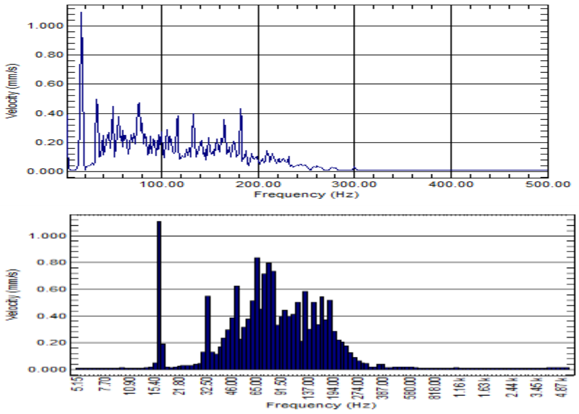
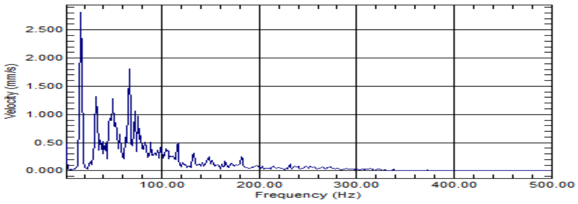
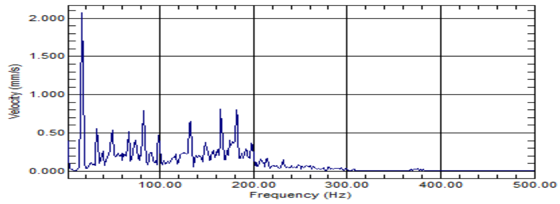


Fig. (14) (FFT) spectrum at drive end in axial direction (DE-A) after alignment





V. Conclusion

Experimental investigation on misalignment fault by FFT spectrum and phase analysis are carried out and following conclusions are listed:

- Phase result enables to recognize between the mono sources on misalignment shaft and thus choose the suitable alignment path away.
- Angular misalignment: It is showed that the largest magnitude at RMS peaks is generate in axial side as compared to vertical and horizontal direction. A 180°±30° phase difference observed when measuring the axial measurements on the motor drive end bearing and DE bearing across the coupling.
- Parallel misalignment: It is observed that the RMS value at second order is high. A phase shift is 180°±30° observed across the coupling.
- Similarity phases at the shafts enables to show out whether there is a misalignment when working and which order of dominated the misalignment was.
- Difference in phase at replacement of revolution running shows the exciting the reinforcement or prolongation of sound by reflection from a surface or by the synchronous vibration of a neighboring object. An instance of a particular situation, it is often worth to assess also the signal or a curve showing the shape of a wave at a given time, which usually use to clear the difficulties more surly.
- The analysis result confirmed that the vibration level became within acceptable healthy condition after correcting misalignment problem. Therefor this will

useful to extending pump running along the application of proactive maintenance scenarios.

- Overall vibration in Khayyam pump station level was decreased by 2.86 times in axial direction, 3.71 times in vertical direction and 4.09 times in horizontal direction after applying alignment process
- Vibration analysis and alignment process would be worked periodic come to a place with the pumping station to an excellent case that able to achieve efficiently of doing their rule in working and decrease the process of maintaining. otherwise mechanical work would be taken for observe working health of tilt clamp up units. Dismantling and refabricating for long shaft tilt pumping station would be taken exactly.

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