Numerical and Experimental Vibration Analysis for Fatigue Failure Investigation in a Vertical Axis Pump Station

[1] Shahram Shahrooi, [2] Ibrahim Henk Metselaar, [3] Zainul Huda, [4] Masood Asayesh

***Abstract*—In this study, failure in the pump main shaft, supports, couplings and bearings due to excessive vibration are investigated by experimental and numerical modeling of the system behavior. The origin of fatigue failure is shown by the vibration measurement and its analysis as well as for the modification of system from any failure source finite element method is utilized. Finally, using of model based diagnosis and its analysis the modification of system will be done accurately without any more expenses.**

***Index Terms*— Vibration analysis, fatigue failure, model based diagnosis, force model updating, vertical pump**

I. INTRODUCTION

Many signal processing techniques have been introduced for vibration data processing and fault diagnosis. Recently, method of decays vibration analysis has been well known as one of the methods for failure analysis and fault diagnosis in the machinery and structural systems [1].

Every fault in rotating machinery has its own characteristics. Some of these specifications are common for two or more faults and will make the diagnosis process difficult. However, application of vibration analysis method is preferred; also it is used widely today.

The first step in the vibration analysis is the knowledge of the machinery components and operational data. Each part of the machine and as well as every faults in its components will produce some specific characteristics and need to be measured and analyzed in appropriate points of the machine [2]. In this paper, the vibration analysis procedure and verification points will be introduced for a vertical water pump station. Moreover, the causes of fatigue failure in the pump components will be presented by vibration analysis. Based on the analysis data the main excitation sources of pump are detected and applied in the model based analysis. In addition, the correction effects of any part of pumping systems during operation on vibration of pump were investigated using of a finite element model by ADAMS software.

This work and research has been supported by Khuzestan power research and standard center. The authors appreciated them for supporting and preparing necessary data for measurement and analysis.

[1] PhD student University of Malaya, Kuala Lumpur, Malaysia and faculty member of Islamic Azad university, Ahvaz , Iran (corresponding author phone: +60173923190; e-mail: shahramshahrooi@ perdana.um.edu.my).

[2] Dept. Mechanical Engineering, University of Malaya, UM, Kuala Lumpur , Malaysia, (e-mail: h.metselaar@um.edu.my).

[3] Dept. Mechanical Engineering University of Malaya, UM, Kuala Lumpur, Malaysia, (e-mail: drzainulhuda@hotmail.com).

[4] Dept. Mechanical Systems, Niroo Research Institue, Tehran, Iran, (e-mail: masayesh@nri.ac.ir)

II. SPECIFICATION AND SYSTEM VIBRATION MEASUREMENT

A. *Pumping systems*

The pump under study is used to cooling water systems in a steam power plant. The main characteristics of this pump system are presented in Table 1.

TABLE 1- PUMP SYSTEM CHARACTERISTICS

No.	Characteristics	Value(s)
1	Head	1.5(m)
2	RPM	1470(rpm)
3	Power	55 (kw)
4	Bearing Lubricating	Water
5	Pump mass	3670 (kg)
6	Motor mass	4650 (kg)
7	Systems Dimension	1(m)×1(m)×15.7(m)

The pump is installed vertically and driven by an electric motor which it has installed at the top of the pump. The components of motor-pump system are electromotor, pump, main shaft, five interface shafts, pump shaft, and impeller. These parts are with their bearings and couplings are included in the modeling.

B. *Vibration Measurement*

Vibration of pump system is measured in full load condition. The measurement points are shown in Figure 1. The vibration measurement has been done on foundation lower and upper bearings of motor. Other parts of the system were not accessible.

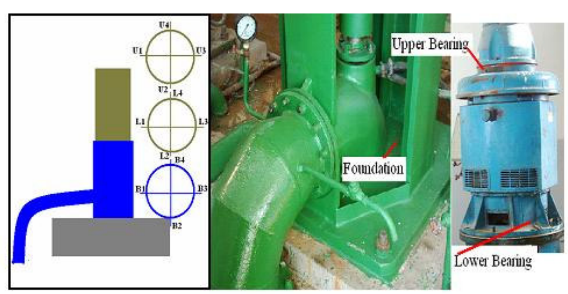

Figure 1. Measurement point of pump systems

Vibration at lower and upper bearings of motor was in good zone but at foundation high amount of vibration has been

ISBN: 978-988-17012-7-5

seen. The spectrum of vibration at foundation is shown in Figure 2.

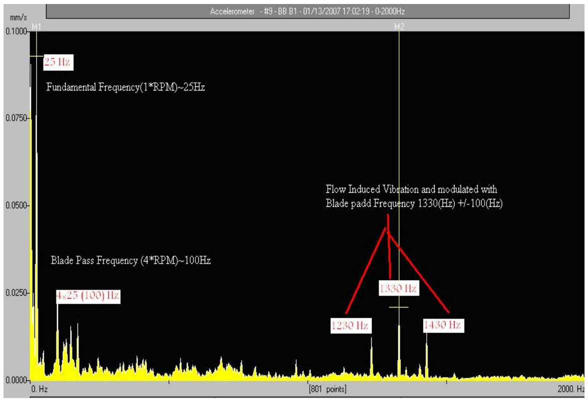

Figure 2. Vibration Spectrum at motor-pump foundation

Figure 2 shows clearly that the main excitation is due to fundamental frequency, blade pass frequency and flow induced frequency that is also modulated with blade pass frequency with 100 Hz. Any modification of systems for reducing the failure should be done by considering these excitation sources.

III. Methodology

As stated, a model based method is used for fatigue failure analysis in a vertical axis water pump.

At first, the source of excitation and consequently the root of failure in systems have been diagnosed by using vibration analysis technique. For analyzing for proper design and also any improvement in system component, a finite element model has been developed for system. A correlation between vibration measurement and analysis with finite element modeling was used to estimate forces in the system. Vibration analysis showed that fundamental frequency and blade pass frequency were the origins of excitation. Then any correction should be done for the cancellation of their effects.

Different hypothesis were used to improve the system design and then their model have been considered in finite element model of system. The improvements have been analyzed with two main excitation sources and the results checked in different points.

A. *Finite element modeling*

A finite element model has been developed for free and forced vibration analysis of pump systems.

The main components of pumping systems are included in the modeling. The shafts are modeled using beam elements. Also the bearing is treated as a stiffness and damping element in the model. The stiffness and damping coefficient of bearing are determined experimentally. The outer pipe that surrounding the mentioned shaft is considered as a hollow beam element and it will be interfaced with the rotating shaft by bearings. Figure 3 shows the finite element model of the systems. The system has been considered as a clamped beam and only translational vibration in horizontal plane is put under observation. In this modeling the steel alloy mechanical properties is considered for all parts of pumping system. The damping ratio for bearings is 0.14 and their stiffness is calculated from following equation in two perpendicular directions in horizontal plane

$$K_X = K_Z = \frac{AE}{h}$$

Where h is the thickness, A is the area of bearing in contact with shaft and E is 8.27MPa [3], [4].

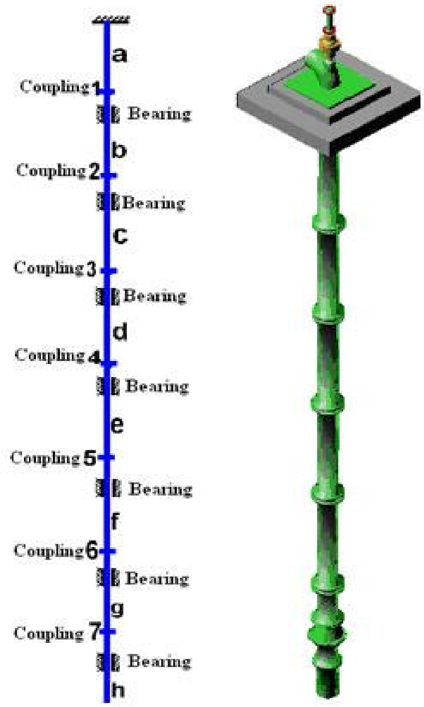

Figure 3. Finite element modeling of pump system

For better estimation of real system behavior, all the parameters of systems like damping ratio, young modulus and density have been changed from 80 to 110 percent for sensitivity analysis and the deviation in lateral natural frequency in all cases were less than 3%. It shows that small error in experimental determination of mechanical properties of bearing and metal used in construction has negligible effects on results.

B. *Model updating for force estimation*

After designing an appropriate model of systems and doing some sensitivity tests in the model, a correlation between forces in motor, impeller, responses at foundation and motor bearings are developed [5],[6]. Amount of force amplitude with the known frequency applied and its response has been calculated in foundation and compared with the responses that are measured with a Vibro-meter at the same frequency till desirable results have been found.

IV. Results of Systems Improvement

Different cases for reducing the amount of vibration have been proposed. The effect of each correction considered in model and analysis again has been done with the same amount of forces and frequencies estimated and measured in the previous part. The modifications cases and their gotten results are as follows:

The first recommendation was improvement in base plate stiffening. In this case, it has considerable effect only upon fundamental frequency but the vibration amplitude due to 100Hz (blade pass frequency) frequency will increase.

The second solution for vibration problem of system is reinforcing the shaft casing. Stiffening of shaft casing has the same effects of base plate stiffing.

One of the appropriate solutions for the system vibration problem is the use of stiffer bearings. The stiffness of twice of origin for bearing has been included in the modeling. The results in Figures 4 and 5 are shown that with reinforce of rubber bearing or in other words increase to their stiffening will decrease to vibration amplitude in the excitation frequencies of 25 and 100 Hz.

The final solution that is considered for improvement of vibration behavior of the system is simultaneously stiffening of bearing, casing near the impeller and base plate. The results of solution are illustrated that resonance will accrue near of 100 Hz excitation frequency.

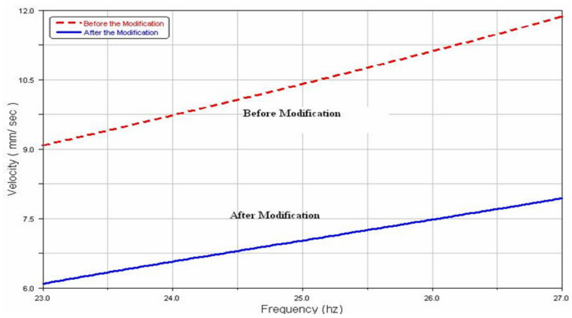

Figure 4. System response at 25 Hz before and after bearing stiffening

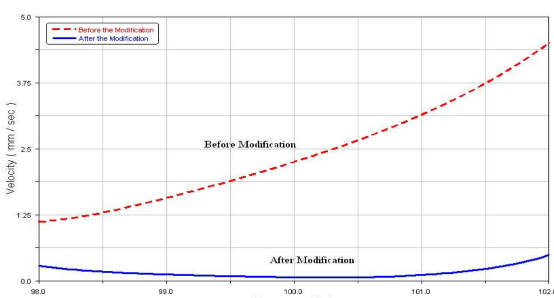

Figure 5. System response at 100 Hz before and after bearing stiffening

V. CONCLUSION

The finite element method with vibration analysis was used for modeling and analyzing of system. As expressed, in this pumping system the frequencies of 25 and 100 Hz are excitation frequencies. Indeed, for modification of this system the solution is appropriate which it can decrease both of mentioned frequencies. The finite element analysis used here to investigate the effect of each modification on system vibration behavior. Therefore, by referring to results of vibration analysis have been indicated that stiffening of foundation and shaft casing individually and compound will cause to increase the frequency amplitude near 100 Hz. Whereas, Stiffening of bearings has considerable effects on vibration amplitude at both frequencies. The bearing used here was made from rubber with stiffness of 80 in Shore A. It can be easily improved and the final stiffness of bearing can be increased about twice.

Finally, the analysis reveals that vibration analysis with model based diagnosis is more important in failure investigation and also any correction in system design. The model based diagnosis and correction will assist in prediction of system behavior without any more costs that arise from in site modifications.

REFERENCES

[1] T. DeMatteo, "*Operational Deflection Shape and Modal Analysis Testing To Solve Resonance Problems*", CSI RBM University, 2001.

[2] A. Rama Rao , " *Vibration Based Diagnosis of a Centrifugal Pump*", J. Structural Health Monitoring, Vol. 5, No. 4, 2006, pp. 325-332.

[3] Mechanical Packings Manual: A Handbook on Leather and Synthetic Rubber Packings, Graton and Knight, Worcester, MA 1945, Digitized Apr 2008.

[4] Bertil Häggström, Sveriges gummitekniska förening, Rubber Handbook, Swedish Institution of Rubber Technology Published 1996, ISBN:918643070X

[5] Jones, W. Keith, " Finite Element Model Updating Using Antiresonant Frequencies", AIR FORCE INST OF TECH WRIGHT - PATTERSONAFB OH SCHOOL OF ENGINEERING,MAR 2000

[6] R. M. Lin, J. Zhu, *"Finite element model updating using vibration test data under base excitation*", Journal of Sound and Vibration, Vol. 303, 2007, PP. 596-613.