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Experimental Determination of Unbalance in a Multi-Rotor System using Order Spectrum Technique

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***Abstract*—The work deals with the experimental determination of unbalance in a multi-rotor system by using the method of order spectrum. The test is conducted on a simulator which consists of two rotors in which we can introduce unbalance. Two types of unbalance such as static unbalance, couple unbalance are introduced into the simulator. The order spectrum technique helps in determining the unbalance from the peak value of first order. Theoretical prediction for the two unbalance and the experimental outputs are compared.**

Keywords—Order Spectrum; Unbalance; First Order.

I. INTRODUCTION

Rotor dynamics is the branch of engineering that studies the lateral and torsional vibrations of rotating shafts. It is commonly used to analyse the behaviour of structures ranging from huge jet engines and steam turbines to small auto engines. At its most basic level rotor dynamics is concerned with one or more mechanical structures (rotors) supported by bearings and influenced by internal phenomena that rotate around a single axis.

Rotating machines are the most unavoidable component of the industries. A rotating machinery will be subjected to various faults like unbalance, misalignment, whirling of shaft, bearing stability, looseness, eccentricity of rotor or stator, grounding faults or tuning faults, phase loss etc. during its lifetime. Shaft misalignment and disk unbalance are the two main sources of rotating machinery vibration. The vibration due to such sources affects critical parts of the system such as bearings, gears, motor, seals, couplings etc. Disk unbalance is a condition in which the centre of mass of a rotating disk is not coincident with the centre of rotation. Unbalance in a rotor system is unavoidable and it cannot be completely eliminated. In practice, balancing is done to balance the rotor system but due to some reasons, such as porosity in casting, non-uniform density of material, manufacturing tolerances, and gain or loss of material during operation, rotors can never be perfectly balanced. The effects of the faults can be catastrophic in case of large machinery.

The composition of the modern rotating machinery is of complex rotor–bearing system which needs accurate and reliable prediction of its dynamic characteristics. M Xu,R and D Marangoni [2] developed a theoretical model of motor, flexible coupling, rotor which was capable of describing the vibration characteristics due to misalignment and unbalance. Later Arun Kr. Jalan and A.R. Mohanty [1] used a model based technique for fault diagnosis of rotor–bearing system. These could be used to predict the dynamic behaviour of these machinery faults. These results are useful for comparison with the experimental results.

M. Duchemin, A. Berlioz and G. Ferraris [4] used an experimental model to study the dynamic behaviour and stability of rotor under base excitation. An experimental setup similar to that is designed so that it can be used to simulate these faults. The simulator designed is exclusively for the study purpose and is different from the industrial setup in terms of size and cost. This simulator works in combination with software's like labview, ME scope,Matlab. There are many setup in the industry from which we can directly obtain the readings for the presence of these faults but these are relatively costly. Main advantage of the simulator developed is that it is cheaper and can be used to study these faults so that there occurrence in the real machinery can be easily understood.

Surendra N. Ganeriwala,Brian Schwarz and Mark H. Richardson[4] described about the methods of inducing different kinds of unbalance within the system. They described how tests could be conducted for static, couple unbalances using Operational Deflection System (ODS). Similar method of adding additional weights at different position is followed in order to create the required type of unbalance

The entire work is divided into two sections- design of simulator and simulation of various unbalance in the multi-rotor system. Different methods can be employed for testing unbalance (1) phase shift (2) order spectrum (3) Operational Deflection system (O.D.S). We are using the method of order spectrum to determine the kind of unbalance present in the multi-rotor system.

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II. THE TEST RIG

The test rig developed for the purpose of fault simulation is shown in Fig. 1. It consists of a long shaft made of steel supported on two bearings placed inside suitable housing. The bearings are locked within the housing by means of sir clip to resist motion in the axial direction. One end of the shaft is free while the other end is connected to the electrical system to provide rotation. The electrical system involves a universal motor and a variable frequency drive which is connected to the shaft using a love jaw coupling. Two rotors are mounted on to the shaft at a distance. The rotor has 36 numbers of threaded holes at 10 degree drilled in it whose purpose is to fix the rotor on to the shaft and provide for unbalance. The whole system is assembled on to an aluminum base plate. This whole assembly is then mounted on to large base with dampers provided in between to avoid vibrations.

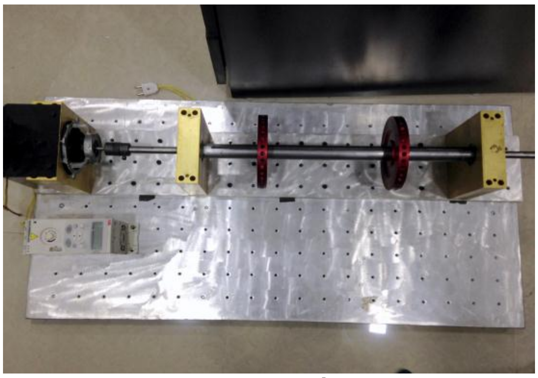

Fig 1. Experimental Setup

III. TEST FOR UNBALANCE

The experimental setup used for checking unbalance is shown in Fig. 2. The setup involves using a tachometer, 3 industrial accelerometers and a tri-axial accelerometer. Tachometer is used to determine the rotational speed and accelerometer is used for measuring acceleration. Two industrial accelerometers are fixed on to the bearing holder at non-drive end. A tri axial accelerometer and an industrial accelerometer are mounted on to the bearing holder at the drive end.

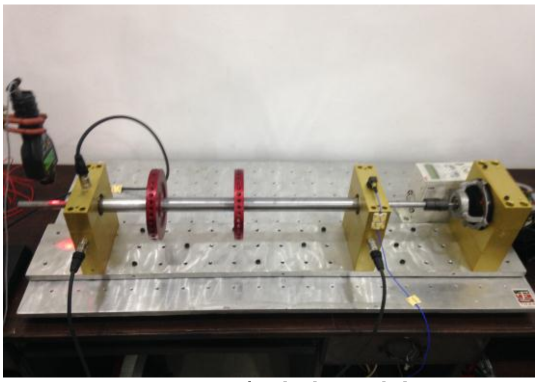

Fig. 2. Test setup for checking Unbalance

Signal from Tachometer is used as the input signal for the software Labview 2012. These transducers provided a total of 6 vibration signals that were simultaneously acquired with an 8 channel data acquisition system. These signals are used to develop the order spectrum corresponding to the speed of rotation.

Unbalance is introduced into the system through the rotor discs. In the rotor disc there are 36 threaded holes drilled at 10° respectively. Among these three holes at 120° each are used for fixing the disc on the shaft. Its behaviour is like that of a three jaw chuck which helps in fixing the disc tightly on the shaft. Remaining 33 threaded holes are useful for inducing imbalance. There are screws each weighing 2.2 grams which can be fitted into these holes. These were tested for two different conditions of unbalance at 2000 rpm.

A. *Static unbalance*

In this setup we will be introducing an unbalance of 11 gram into each rotor. This is achieved by means of inserting screws into the holes drilled on the rotor disc. They were added at the same radial position on both rotors (with 0° difference between them). The test is conducted at 2000 rpm.

B. *Couple unbalance*

In this setup we will be introducing an unbalance of 11 gram into each rotor. This is achieved by means of inserting screws into the holes drilled on the rotor disc. They were added at the same radial position on both rotors (with 180° difference between them). The test is conducted at 2000 rpm.

IV. THEORETICAL PREDICTION

Unbalance is the most common rotor system malfunction. Its primary symptom is 1X vibration which can lead to fatigue of machine components. In extreme cases it can cause wear in bearings or internal hubs that can damage seals and degrade machine performance. Unbalance can produce high rotor and casing vibration and it can produce vibration in foundation and piping systems. 1X vibration can also contribute to stress cycling in rotors which can lead to eventual fatigue failure. Vibration induced due to unbalance can also cause internal rubs in machinery especially when passing through resonances. There are two types of rotating unbalance, static and couple unbalance.

A. *Static Unbalance*

In static unbalance, all the unbalanced masses lie in a single plane resulting in an unbalance of single radial force. Static unbalance can be detected by placing the shaft between two horizontal rails and allowing the shaft to naturally roll to the position at which the unbalance is below the shaft axis. We can experimentally determine static imbalance by using the chart in Fig. 3.

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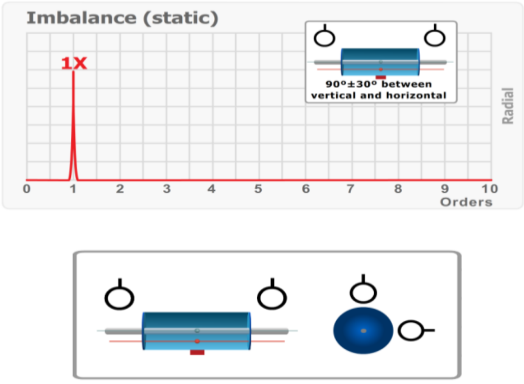

Fig 3. Static Unbalance.

A large peak can be seen in the spectrum at the shaft turning speed (1X) in the vertical and horizontal axis whereas Axial 1X vibration will be low. The simplest type of unbalance is equivalent to a heavy spot at a single point in the rotor. This is called a static unbalance because it will be present even if the rotor is not turning and if placed in frictionless bearings the rotor will turn so the heavy spot is at the lowest position. Static unbalance can be corrected with a single-plane balance.

Static unbalance results in 1X forces on both bearings of the rotor, and the forces on both bearings are always in the same direction. The vibration signals from them are in phase with each other. The main symptoms of static unbalance are

a) High value of 1X in the radial directions and low value in the axial direction.

b) The waveform will be very sinusoidal when viewed in units of velocity. If it is not sinusoidal then there may (also) be misalignment, cocked bearing, a bent shaft or some other fault condition.

c) Compare vertical to horizontal vibration on a horizontal machine. If horizontal 2X is greater than vertical 2X amplitude then suspect foundation looseness or resonance.

d) Look for 90° phase shift between vertical and horizontal. For pure static unbalance, phase at bearings at either end of the rotor will be in-phase

B. Couple Unbalance

Expect to see a large peak in the spectrum at the shaft turning speed (1X) in vertical and horizontal axis. Axial 1X vibration will be low. A rotor with couple unbalance may be statically balanced (it may seem to be perfectly balanced if placed in frictionless bearings), but when rotated, it will produce centrifugal forces on the bearings, and they will be of opposite phase.

We can experimentally determine static imbalance by using the chart in Fig. 4. The main symptoms of couple unbalance are

a) High value of 1X in the radial directions and low value in the axial direction.

b) The waveform will be very sinusoidal when viewed in velocity. If it is not sinusoidal then there may (also) be misalignment, cocked bearing or some other fault condition.

c) On comparing the vertical to horizontal vibration on a horizontal machine, If horizontal 2X is greater than vertical 2X amplitude then suspect looseness or resonance.

d) Look for 90° phase shift between vertical and horizontal. For pure couple unbalance, phase at bearings at either end of the rotor will be 180° out-of-phase.

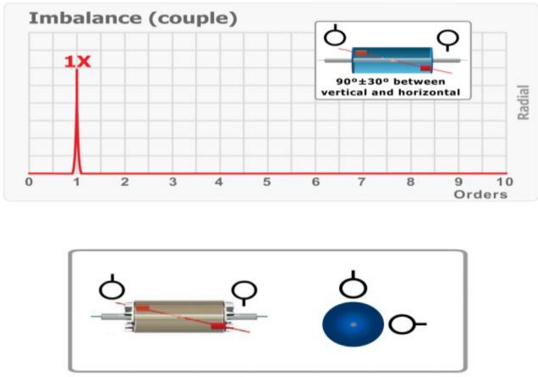

Fig. 4. Couple Unbalance.

V. RESULTS AND DISCUSSIONS

Fig. 5 shows order spectrum in various colours for a balanced system at 2000 rpm. These colours correspond to the signals from the 5 channels of the accelerometer. Importance should be given to the value of 1X. The magnitude of 1X will low as it comes to around 120 units.

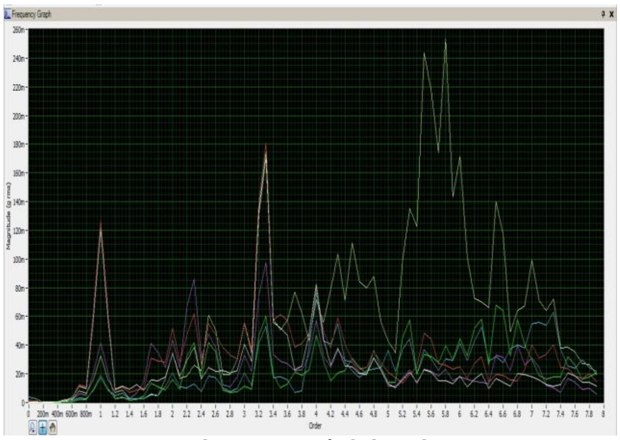

Fig. 5. Order spectrum of a balanced system

Fig. 6 shows order spectrum in various colours for a static unbalanced system at 2000 rpm. These correspond to the signals from all the 5 channels of the accelerometer. Importance should be given to the value of 1X. The magnitude of 1X will low as it comes to around 580 units.

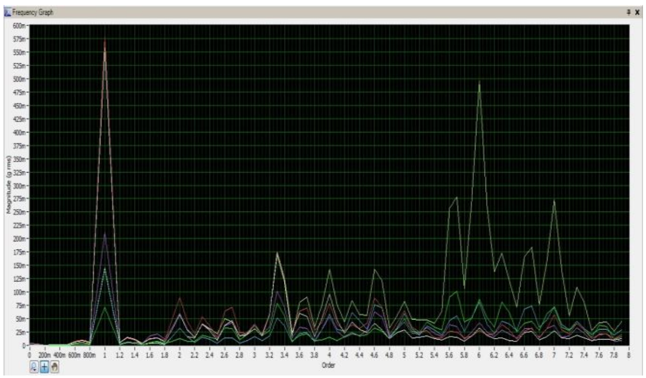

Fig. 6. Order spectrum of a couple unbalance system

Fig. 7 shows order spectrum in various colours for a couple unbalance system at 2000 rpm. These correspond to the signals from all the 5 channels of the accelerometer. Importance should be given to the value of 1X. The magnitude of 1X will low as it comes to around 260 units.

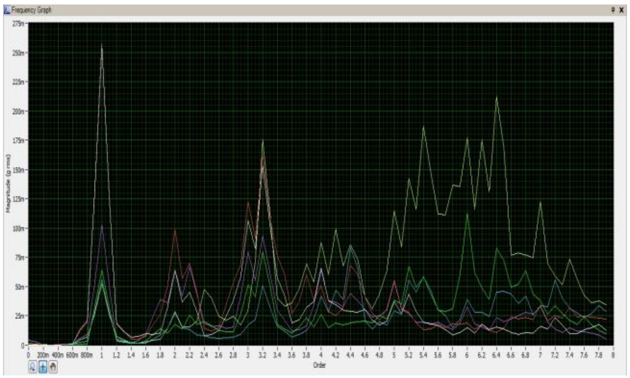

Fig. 7. Order spectrum of a couple unbalance system

From the three order spectrum we can draw the conclusion that the value of 1X will be minimum for a balanced system. The value of 1X will be high for a system with unbalance. Under the two different condition of unbalance the highest value will be the one with 0° difference and a much lower value for the one with 180° difference.

VI. CONCLUSIONS

A multi-rotor system was developed which can be used for simulating faults like unbalance, misalignment, rotor and stator eccentricity etc. By adding weights at different positions on the rotor causes different kind of unbalances to be introduced in the system. Order spectrum technique in Labview helps in identifying the kind of unbalance. The primary symptom of unbalance is the 1X vibration. From the magnitude of 1X vibration in the order spectrum we can determine the kind of unbalance because the value will be different for each case. It will be minimum for a balanced system while the highest value will be for static unbalance and value of couple unbalance will be in be lesser than static unbalance but higher than a balanced system.

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