Misalignment of Shaft on Gearbox Test Rig Leading to Failure in Diagnosis of Noise and Vibration in Gearbox

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ABSTRACT

Misalignment is considered as important cause of noise and vibration of rotary machines like Gearbox. On the gearbox test rig different type of vibration and noises are observed to ensure safety of the gearbox. In the setup considered it was observed that misalignment of shaft laid to failure in diagnosis of noise and vibration of the gearbox. The paper deals with the study of shaft misalignment and its types and effects of misalignment on various components. It also includes study of sources of noise and vibrations in gearbox. Thus there is a requirement in industry for rapid and reliable techniques to measure shaft misalignment so that condition of rotating machines can be monitored and shafts can be adjusted to achieve proper alignment.

Keywords*: Angular Misalignment, Vibrations, Condition monitoring, Thermal Expansion.*

1.0 INTRODUCTION

Misalignment of shaft is the most common problem occurring in any type of machine. Misalignment causes various effects and may damage working components of the machine such as bearings, oil seals etc. It may also cause unwanted vibrations and excessive loads on the machine components. Detection of the misalignment and fixing it at correct time will reduce the cost incurred. [1][7]

Gearbox is a mechanical device used to transmit motion by change of speed and torque in given ratio. The main parts of the gearbox include gears, shafts, bearing, housing and oil seal. Motion is transmitted by gears by means of successive engagement of teeth. Gearbox test rig setup underwent a misalignment. Test rig is used to determine proper gear ratios; different noises in gearbox and vibrations. These observations are necessary to avoid gearbox failure. Gearbox drive shaft is coupled with motor input shaft of the rig. Angular misalignment was observed between these two shafts. Gearbox is guided on the rig with help of plate, which bend due to weight of the gearbox. Due to this misalignment there was oil seal damage which resulted in oil leakage. This misalignment leads to excessive noise and vibration which laid to failure in diagnosis of gearbox noises and vibration.

1.1 LITERATURE REVIEW

In paper, "Laser based measurement for the monitoring of shaft Misalignment", written by Anthony Simm, Songling Huang, Wei Zhao laser based technique for misalignment monitoring is discussed. Method uses non-contact type laser to identify shaft misalignment. Tolerances considered are more than the actual shaft tolerances for misalignment. Also paper discusses various methods to identify shaft misalignment. [1]

In paper, "Misalignment as a source of vibration in rotating shaft system", written by Irvin Redmond, Khaleel Al- Hussain misalignment and its types are discussed. A mathematical model is studied in this paper to analyse effect of parallel misalignment on vibration response. It was observed that vibration response is synchronous and similar as that of obtained for shaft bow. It is also observed that vibration response is zero at high speed. [14]

In paper "Effects of motor misalignment on rotating machinery", written by J. W. Hines, S. Jesse, A. Edmondson various effects of misalignment are discussed. It includes study of effect of misalignment on seals, bearings, couplings, etc. [3]

In paper "Alignment pitfalls- how to identify and eliminate them" written by Robert D. Skeirik various problems faced for proper alignment are discussed. In this paper, sweep technology for proper alignment and method for reduction in soft foot is discussed. Sweep technology makes use of internal inclinometers to automatically calculate misalignment. Sweep curve is used to determine working condition of machine and also to

diagnose shaft bind. Soft foot is gap between machine foot and foundation. Author also discusses importance to reduce soft foot, types of soft foot and its effects. Importance of building good foundation is also mentioned. [13]

2.0SHAFT MISALIGMENT

Shaft is essential part of rotating machine used to transmit power and motion. Shaft misalignment occurs when center lines of rotation of two or more machines are not in line with each other. Shaft misalignment consists of three types (referring figure 1):

i) Offset misalignment: It is also referred as parallel misalignment. Offset is the distance between shaft centres of rotation measured. Parallel misalignment occurs when two shaft centres are parallel and not in same line. The two planes of parallel misalignment may be offset vertically, horizontally or both.

ii) Angular misalignment: Angular misalignment or gap is the difference between slopes of shaft, usually of movable machine, as compared to slope of other shaft. This misalignment occurs when motor shaft is at an angle with driven component shaft.

iii) Combination misalignment: Combination misalignment occurs when motor shaft suffers from angular misalignment in addition to parallel misalignment. In most of practical cases such type of misalignment is observed [2].

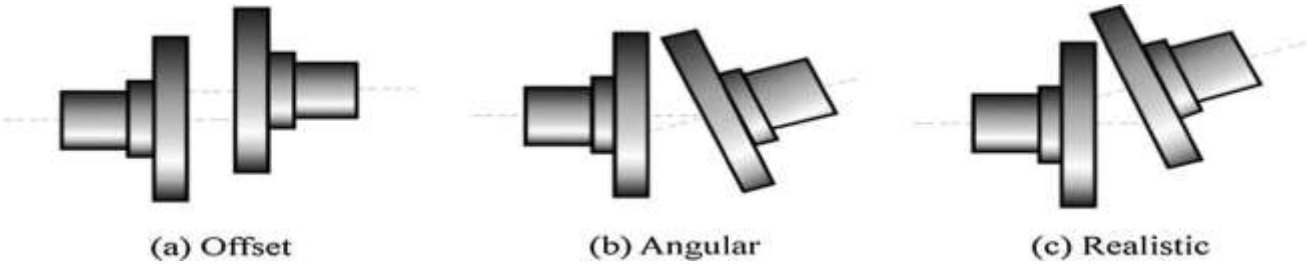

Figure 1 Types of shaft misalignment [1]

2.1 EFFECTS OF SHAFT MISALIGNMENT ON ROTATING MACHINERY:

If components such as couplings, bearings are operated in misaligned state, these components consume more power. Misalignment leads to increase in coupling and bearing temperatures. These components are designed to work at certain temperature limits. Elevated temperatures due to misalignment thus lead to failure of bearings, couplings, seals. Also, bearing load is increased as a result of misalignment. About 0.01% of output mechanical power from motor is required to drive such detrimental loads. Thus life span and reliability of bearings is reduced to misalignment. Efficiency is expected to reduce due to misalignment; however the variations observed in efficiency are within limits. [3]

Misalignment causes wearing of seals due to shaft loading. Seals have precision ground and honed components with finished accuracy of two microns and thus they don't tolerate operation in poorly aligned conditions, elevated temperature. Seal failure is often catastrophic giving little or no pre warning. Seal failure may cause failure of bearings. Bearings cannot withstand contamination caused by seal failure which allows ingress of dirt, grit, metallic particles, etc. Removal of damaged seals and refitting of new seals causes bearing damage. Thus both seals and bearings have to be replaced. [7]

Misalignment leads to generation of reaction forces in coupling. This is one of the major causes of vibrations. Flexible couplings are mostly used to connect shafts. These couplings transmit driving torque while accommodating unavoidable misalignments. Restoring moments of these couplings tend to bow the machine shafts. This amount of shaft bowing increases with torque and speed of machinery thus increasing vibrations.[5]
Misalignment is one of the major causes of vibrations.90% of machine vibrations are due to imbalance and misalignment. [4]

3.0 PRACTICAL CASE STUDY:

Flushing machine is used for testing gearbox on the assembly line of GB40 gearbox in Tata Motors, Pune, India. The gear box drive shaft is rotated by motor at constant speed of 2080 RPM (Motor Rpm) so that the chips which remain after the machining of the gears and various operations on the main, counter and the drive shaft are removed during the flushing operation. As the gearbox is filled with oil during flushing it splashes inside the gear box hence removing the left over chips dirt etc. Also noise and vibration and shifting mechanism is tested on the machine.

3.1 VARIOUS NOISES CHECKED ON FLUSHING RIG:

When the gear box is tested at various speeds there is noise check. This is an important factor which needs to be tested. This ensures proper functioning of the components in the gear box. Various noises may occur due to improper assembly or improper manufacturing of the parts which may lead to disturbance in working of the system and may create noise. Hence to prevent wear and tear of any component and preventing further accidental damage, test of noise is done.

• High Point Noise: This type of noise occurs when the high point on gear on main shaft meshes with the high point on gear on the counter shaft. This gives a peak noise after a particular interval of time. It is the most unfavorable type of noise. This noise is to be eliminated because it may lead to gear tooth failure. This causes wear and tear of the tooth and may shear the tooth rapidly.

• Crushing Noise: This type of noise is detected while shifting the gear. When a large shifting force is required to shift the gear then there is a probability of such type of noise. This noise mainly occurs if there is a variation in the synchro ring or the synchrocone diameters. Angle variation in the cone may also lead to such type of noises. These noises if not eliminated may tend to wear the synchrocone and make the shifting arrangement more rough.

• Whistling Noise: This type of noise is generated due to improper gear profile generated. When the gears are manufactured if they contain s curves or irregular profile can lead to the whistling sound. This reduces the life of the gear tooth and speeds the wear rate.

• Rubbing Noise: These types of noise are generated by basically two reasons. If the gears on the counter shaft are not pressed properly there is rubbing noise. Also if there is bending occurring in the shifting fork then this type of noise may occur.

• Humming Noise: If the countershaft is bent during pressing operation or while the assembly humming noise may occur. Also if there are errors in the profile of gears, if gear pitch circle diameter is large there are chances of producing humming noise.

The misalignment problem was observed on the flushing machine. On this machine the gearbox is located on a single frame which has its support on the base. On the frame the gear box is rested with drive shaft connected to the motor spindle. Due to the weight of the gear box, the frame on which the gearbox is located undergoes bending. This caused misalignment of the shafts. The misalignment of the frame on flushing rig was measured using a Dial gauge method. It was observed that the angular misalignment of the frame was 0.7mm. This misalignment was due to heavy weight of the gearbox which is 122kgs. The permissible angular misalignment for a motor with speed of 2880 rpm is 0.4mm. As the detected misalignment is higher than the permissible limits, hence it is necessary to take corrective actions. (Referring Schematic figure 2a) and 2b))

It was found that the problem of oil seal leakage was due to misalignment on gearbox flushing rig. This misalignment resulted in excessive load on the oil seal and causing it to damage. On the flushing rig gear shifting and gear noise is also checked simultaneously. It was also noticed that there was excessive noise and vibrations than earlier due to the misalignment. Thus noises and vibrations on gearbox were not analyzed properly. Hence modification of the gearbox flushing rig was necessary to reduce misalignment. Due the modification i.e. improvement done on the flushing rig, excessive noise and vibrations would reduce. Also it will cause reduction of excessive loads on motor spindle and gearbox oil seal, thus helping to resolve the issue.

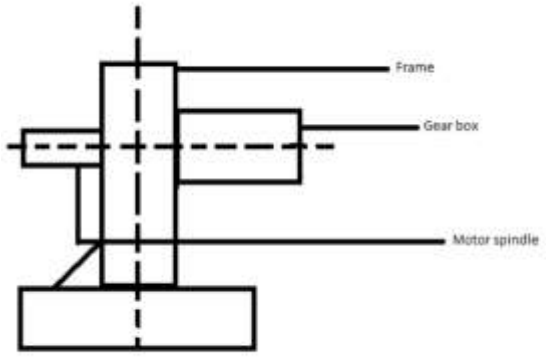

Figure 2a) Without misalignment

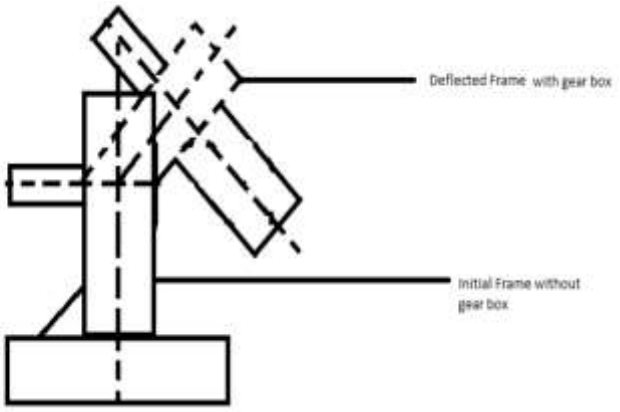

Figure 2b) With misalignment

4.0SHAFT ALIGNMENT:

Shaft alignment is a process in which two or more machines are positioned such that at point of power transfer from one shaft to another, axis of rotation of both shafts must be collinear when machine is in running under normal conditions.

4.1NECESSITY OF SHAFT ALIGNMENT:

i) Improve reliability and operating life of components.

ii) Reduces maintenance and labor costs, costs of consumed spare parts as seals, bearings.

iii) Reduces cost of power consumption and loss of production due to standby machines and product failure.

iv) Improves operating efficiency and safety.[7]

4.2 METHODS OF SHAFT ALIGNMENT:

a) Straight edge method:

It is first stage of inspection to get approximate reading before any accurate method. Misalignment is determined by placing the straight edge on shaft. This is not accurate method; however is cheapist method to determine referring Figure 3a)

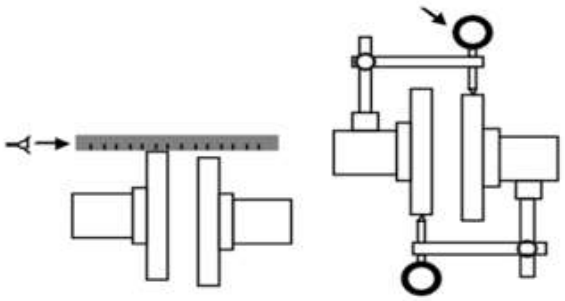

Figure 3a Straight Edge Method [1]

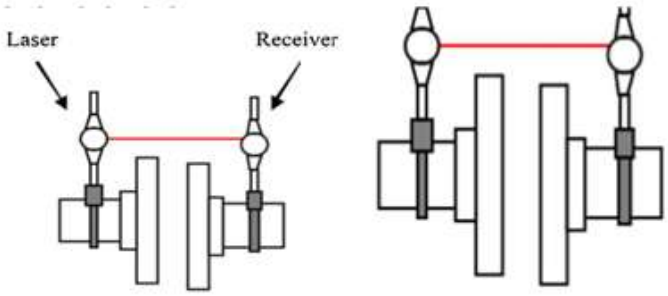

Figure 3b Laser Indicator Method [1]

b) Laser indicator method:

Method is more accurate and automated to measure shaft misalignment. This method reduces energy costs and improves bearing and seal life. (Referring Figure 3b)

c) Dial Indicators:

This is most commonly used method to measure misalignment.

i) Rim and face method (Trial and Error Method)

This is trial and error method. Bracket sag and shaft float are ignored. Rim and face indicator touch machine coupling. This method leads to various significant errors. Thus this method has limitations in application. (Referring Figure 4a)

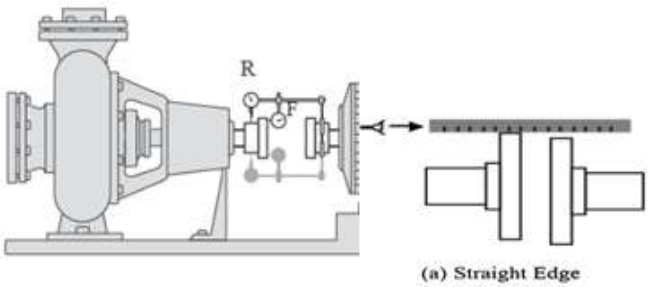

Figure 4 a) Rim and face method. [7]

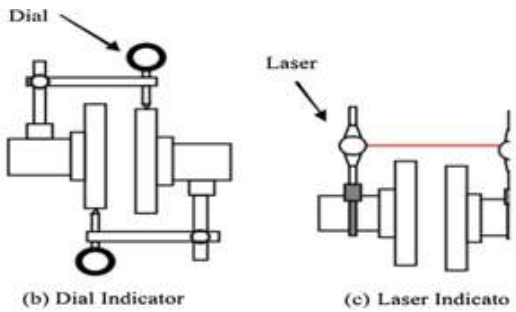

Figure 4 b) Reverse Indicator Method [1]

ii) Reverse Indicator Method:

In this method; indicators positions are opposite of one another on opposite couplings halves (Figure 4b). [1][7]

5.0 CONDITION MONITORING:

It is monitoring physical parameters associated with operation of machine such as vibrations, temperature, and pressure to determine operated condition of machine. This is necessary to avoid failure of machines, take remedial actions if problems are detected. There is a requirement in industry for rapid and reliable techniques to measure shaft misalignment so that condition of rotating machines can be monitored and shafts can be adjusted to achieve proper alignment.

Following are few methods for monitoring misalignment:

a) Laser based measurement for monitoring shaft misalignment-

This method uses non-contact laser technique to capture positional changes of shaft for improved shaft monitoring. This technique can be used to measure both angular and offset shaft misalignment between 0.5 and 2.5 mm. These values are larger than practical shaft misalignment tolerances which are based on rotational speed of machine and vary between 0.02mm and 0.3mm. [1]

b) Use of Co-ordinate Measuring Machine for shaft misalignment monitoring –

CMM are used for quality control, design projects where higher accuracy is necessary compared to other conventional methods of misalignment monitoring like dial indicator, gauges, callipers: CMM are precise and high degree of repeatability. It uses a highly sensitive touch probe which is moved on part to be measured. [2]

c) Misalignment Fault diagnosis using signal processing technique-

This technique uses vibration analysis for misalignment monitoring. It is frequency domain analysis which uses Fast Fourier Transform. FFT spectrum is recorded in radial and axial direction for drive and non-drive end of the motor. FFT analyzer is used to measure velocity in RMS with help of accelerometer. The velocity frequency spectrum shows dominant frequency corresponding to rotor speed. Higher values obtained for harmonics of frequency denote problem of angular misalignment. Increased variation in vibrational values denote misalignment problem of the system. Thus, vibrational analysis provides quick and reliable information of condition of mechanical system. [4]

d) Coast down time analysis for analysis of effect of misalignment on rotating machinery-

When power supply to any rotating machinery is cutoff, system begins to lose momentum gained during sustained operation and finally comes to rest. Behavior of system during this period is coast down phenomenon. Exact time between power cutoff time and time at which rotor stops is called coast down time. Coast down time is analyzed to study the effect of misalignment. Coast down time decreases with increase in level of angular misalignment. Impact of percentage reduction in coast down time is very high and there is specific correlation between percentage reduction, cut off speeds and level of introduced angular misalignment. [12]

6.0 CONCLUSION

Misalignment was found out to be important cause of noise and vibration in mechanical systems. About 70%of vibrations are caused due to misalignment. Detection of misalignment and remedial actions to reduce and avoid it are necessary. In order to reduce noise and vibrations on flushing rig, reduce oil seal leakage, issue of misalignment needs to be resolved. Also proper condition monitoring is important to avoid misalignment and its effects. Thus alignment is important as it improves reliability and operating life of components. It also reduces maintenance and labor costs, costs of consumed spare parts as seals, bearings. It reduces cost of power consumption and loss of production due to standby machines and product failure and also improves operating efficiency and safety.

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