Axial Vibration Analysis of Pivot Bearing using LDV/SLDV and Identification using FEM

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Abstract

A hard disk drive (HDD) is a storage component, which is commonly used in computer, electronic device etc. It has been continuously developed by means of either capacity or size to achieve the customer's requirements. This paper is aim to study and to analyze the vibrations of the pivot bearing, one important part of Head Stack Assembly (HSA) in HDD by using FEM (Finite Element Method) software, LDV (Laser Doppler Vibrometer) and SLDV (Scanning Laser Doppler Vibrometer) to find out the natural frequencies. The results of the natural frequencies from FEM, SLDV and LDV show a good agreement and this information can also be used for further study the vibrations of Head Stack Assembly (HSA) and to develop the finite element model of the actuator arm.

Introduction

Hard disk is a non-volatile data storage device, which stores digitally encoded data on a magnetic surface layered onto hard disk platters by magnetically reading data to and writing data from a disk via a read/write head (r/w head) fixed to an actuator arm. A head disk assembly for a hard disk drive employs a rotary actuator apparatus including a pivot shaft that defines an actuator axis of rotation. A pivot bearings which are frictionless bearings are assembly including a pivot bushing having a plurality of fingers supports rotation of the actuator about the pivot shaft.

The fact in reading and writing process is that the actuator arm and the r/w head will oscillate slightly in a horizontal direction as they move back and forth. Too much oscillation will result in the very real possibility of an improper alignment of the r/w head. Moreover, during a point of maximum oscillation, vibration and resonance will take place meaning a failure to read or write data properly causing severe data loss and unprofessional data recovery attempts results further damage to the remaining data. Thus, with the limitation that the phenomena of hard disk failure is raising higher and higher as to increase the read and write speed then, vibration in HDD is one of the crucial physical factor that must be concerned (Jintanawan,2001).

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This article will study the vibration characteristics of bearing by using finite element analysis, which is useful for predicting the behavior of a hard disk drive (HDD) subject to adverse conditions. The effects of a vibration load on a hard disk drive is simulated for several frequency bandwidths and amplitudes, in order to obtain vibration mode shapes and natural frequencies of bearing considerably only in axial direction(Eric,2004). For more accuracy, simulations from Finite element method (FEM) will be compared with experimental results using Laser Doppler Vibrometer (LDV) and Scanning Laser Doppler Vibrometer (SLDV).

Vibration Analysis

In mechanical vibrations, the system in both forced vibration and free vibration are dynamic system, which have the excited forces (inputs), and responses as a variables depending with time. The analysis of vibration in engineering always involves with the mathematical modeling by imitating physical substances in order to represent all the important features of the system for deriving the mathematical or analytical equations governing the system's behavior. As demonstrated in Figure 1, after we obtained the mathematical modeling, we have to derive the equation of motion and then, the equation of motion must be solved to find the response of the vibrating system. The results would reveals type of mode shapes and conclusions about behavior of the system. Besides that, this model can be applied for solving another similar problem in the future. The equation of motion can be acquired using Newton's second law as shown in Equation (1).This is an Eigenvalue problem which solving for Eigenvalue vector so as to analyze the behavior of the vibration system and make a comparison between the experimental results (Singirese, 2004).

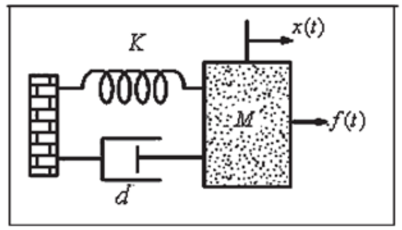

Figure 1. Mathematical Modeling of vibration system

Equation of motion [4]

$$[M]\{\ddot{x}(t)\}+[D]\{\dot{x}(t)\}+[K]\{x(t)\}=\{f(t)\} \qquad (1)$$

Which $[M]$ is Mass Matrix

$[D]$ is Damping Matrix

$[K]$ is Stiffness Matrix

$\{f(t)\}$ is Vector Force

$\{\ddot{x}(t)\}$ is Vector Acceleration

$\{\dot{x}(t)\}$ is Vector Velocity

$\{x(t)\}$ is Vector Displacement

Finite Element Methods

The finite element method is numerical analysis technique which widely used for obtaining approximate solutions in many kinds of engineering problems by modeling a body. This model is divided into an equivalent system of smaller units (finite element) interconnected at points common to two or more elements (nodal points or nodes) and /or boundary lines and/or surfaces is called discretization (Saeed, 2008). The solutions of the whole body can be derived by combine each equation of finite element together. In general problem, excitation forces are typically, variables of time-dependent. Inertia force and damping force will be generated follow upon the variation of time. These two forces have opposite direction to the movement. From Equation (1), stresses and strains which included in load vector $\{f(t)\}$ are also time-dependent variables. By using these known properties for the material making up the structure, every others element in the structure can be defined the behavior of a given node. Then, equations of finite elements which varied with time can be solved by using the principle of Modal Superposition. The processes of the principle are finding Eigenvalue, Eigenvector and finally, solving for Transient Response (Tachaumpo, 2004).

Vibration Measurement

In the experiment, LDV (Laser Doppler Vibrometer) and SLDV (Scanning Laser Doppler Vibrometer) are used for vibration measurement. The operation of LDV is that detecting laser beam to the desired position, only single point for each. Then, the reflected light going backward to the LDV receiver in form of alternated phase angle. These data are processing and showing the results on Dynamics Signal Analyzer (DSA. The operation of SLDV can tells a number of vibrating mode shape measurement by automatically collect complete vibration data from up thousands of individual points on a user-defined area. And established the results through computer.

Vibration Testing

This article emphasize on the structural vibration measurement of Pivot Bearing in HSA (Head Stack Assembly). Fixture was designed to fix bearing with shaker which being the exciter in this experiment. The input of excited frequency range that might be effect HSA is between 500 Hz – 18,000 Hz. The apparatus setting is shown in Figure 2, the transducer (sensor) is overhang, pointing to the vibrating surface of bearing during vibration measurement. Figure 2 shows the 5 positioning measurement of vibration by using LDV (Laser Doppler Vibrometer) to detect vibrating at sleeve of pivot bearing then converts mechanical motion into electrical signal. The Dynamic Signal analyzer is then used to sample this electrical signal and make various calculations based on the electrical signal finally, show output in form of FRF (Frequency Response Function). The illustration of Figure 3 is the defined surface area for SLDV which has similar apparatuses setting as in LDV testing excepted that DSA is not to be used and we have to create detecting mesh with SLDV's software.

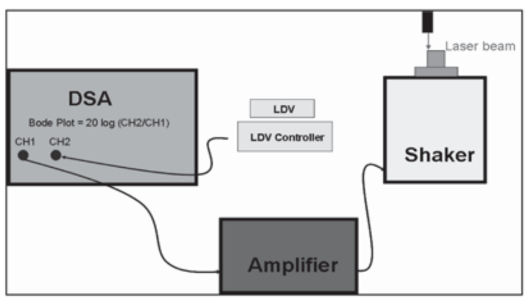

Figure 2. LDV Setting

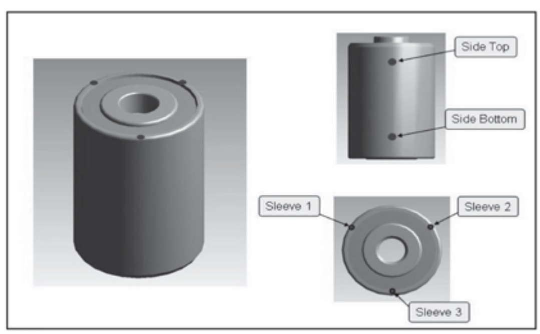

Figure 3. LDV detecting points.

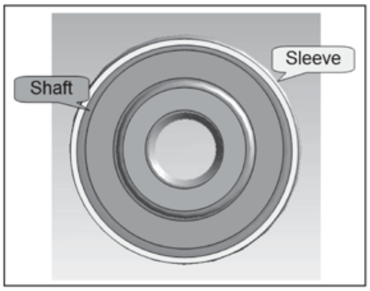

Figure 4. User's defined area

Experimental Results and Discussions

SLDV Results and Discussions

The results obtained from experiment using SLDV are given in two forms; graphical result and animation results. From the detecting areas, the experiment found that there are three distinctive peaks occurred in the operation range of Vibration Generator (500 Hz to 22,000 Hz). These peaks are as follows; 7.625 kHz, 13 kHz and 15.94 kHz approximately, as shown in figure 5. However, the actual axial vibration of the pivot bearing is not yet classified.

LDV Results and Discussions

To identify the axial vibration mode shape of the pivot bearing, LDV experiment is necessary.

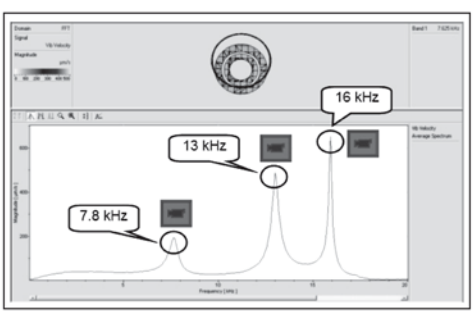

Figure 5. SLDV results

First, Vibration Generator and pure fixture are needed to perform in this experiment to ensure the vibration generating range of the shaker and check for resonance of the fixture itself. The graphical result is showed in Figure 6, proves that the shaker can generate vibrating signal up to 22,000 Hz. Moreover, peaks on a blue line identify resonance frequencies of fixture at around 13 kHz and 16 kHz.

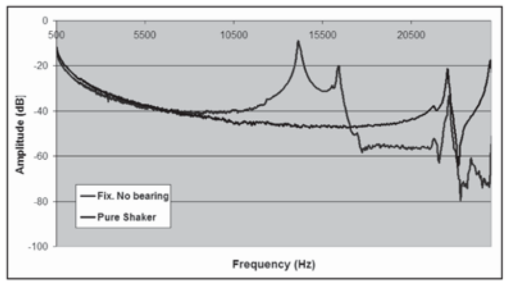

Figure 6. LDV graphical result of detection at fixture and shaker position.

Second, sleeve positions are experimented and the graphical results are showed in Figure 7. It illustrates three classifiable peaks at 7.8 kHz, 13 kHz and 16 kHz approximately. These results from detection on the sleeve are incorporated with the results from SLDV; therefore, axial vibration frequency of the pivot bearing shall be identified. From Figure 8, it clearly illustrates that graphs of sleeves and pure fixture are showed peaks at 13 kHz and 16 kHz respectively. Therefore, we can conclude that peaks that occurred in the sleeve vibration detecting graphs at frequencies of 13 kHz and 16 kHz are transferred from vibrating resonance of the fixture. Consequently, the axial vibration mode shape is occurred at the frequency of 7.8 kHz. The Results of LDV testing are shown in Table 1.

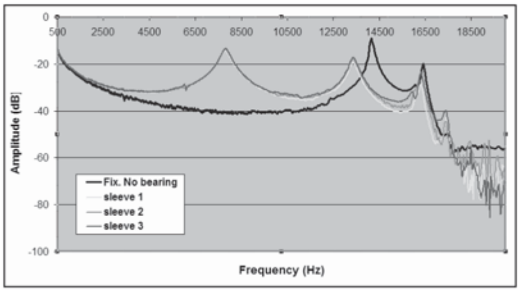

Figure 7. LDV graphical result of detection at sleeve positions comparing with fixture position.

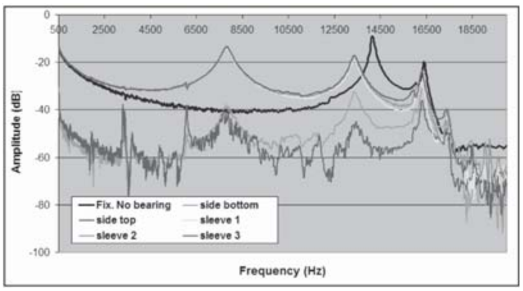

Figure 8. LDV graphical result of detection at sleeve positions, fixture position and side view positions.

Table 1 Natural Frequencies from LDV testing

(Mode)	(Natural Frequencies) Hz
1. Sleeve 1	7,788
2. Sleeve 2	7,808
3. Sleeve 3	7,808
4. Fixture1	14,140
5. Fixture2	16,410
6. Side-Top	7,788
7. Side-Bottom	7,788

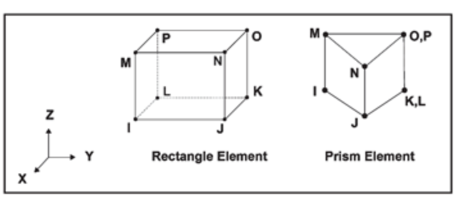

Figure 9 Element type Solid 185

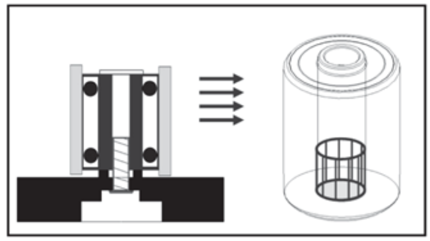

Figure 10. Boundary conditions and restrained position.

Finite Element Analysis

The finite element method is a numerical analysis which yield approximate values of the unknowns at discrete numbers of point in the continuum. Thus, this process of modeling a body by dividing it into an equivalent system of smaller bodies or units (finite element) interconnected at points common to two or more elements (nodal points or nodes) and /or boundary lines and/or surfaces is called discretization. In the finite element method the equations for each finite element and combine them to obtain the solution of the whole body (Saeed, 2008). As shown in Figure 9 , is the example of element types Solid 185 .In this study, we selected to use Solid 185 which is the instant software and appropriate to three dimensional solid element. Each element has 8 interconnected (Node) and 3 Degree of Freedom which are movement on plane X, Y and Z

After we set the boundary conditions and the restrained (Fixed) position at shaft as shown in Figure 10, then running the program to obtain the results. In this paper, the essential part in analyze and derive the natural frequencies is the properties all bearing's components or select the material for the components. In diving element, we used Solid mesh with 0.4 mm for each. There are 79,092 elements and 128,984 interconnected points (Node). The amount of elements vary with sizing the element.

Simulation Results

From the results, we get 2 modes that are in the range of shaker operation which are 7657.1 Hz and 7932.3 Hz, as shown in the Figure 11 and Figure 12, respectively.

Figure 11. The mode one of the bearing simulation at frequency of 7657.1 Hz.

Figure 12. The mode two of the bearing simulation at frequency of 7932.3 Hz.

At mode 1 (at the frequency of 7657.1 Hz), the bearing shaft has no movement and the bearing sleeve moves in one direction (moves upward and downward). From the vibrating mode shape of this mode, it can be concluded that this mode is axial mode.

Another, for mode 2 (at the frequency of 7932.3 Hz), the bearing shaft is also stay still and the bearing sleeve is compressed in the horizontal view and move up just a little if compare to the deformation of mode 1 of the bearing model.

Although there is the deformation in vertical direction at the 7932.3 Hz frequency, it cannot be noticed in LDV and SLDV results because the vertical displacement in mode 2 is a lot less than mode 1.

In addition, there is the peak at around 7932.3 Hz in the result of LDV of the detecting at the side view of the bearing sleeve; this is showed in Figure 8. Hence, it can be verified that mode 2 from Finite Element Method might be correct as well.

Comparison between Experimental and Simulation Results

The result of axial vibration frequency of the pivot bearing from experiment (SLDV) and simulation (COSMOS) are 7,625 Hz and 7,657.1 Hz respectively. The percentage of error is 0.42 percent, which is very little. In conclusion, results from both experimental and simulation are incorporated well with a very small difference.

Conclusion

According to vibration analysis of Pivot Bearing in HSA the results of natural frequencies and vibrating mode shapes from FEM are close to experimental results of LDV and SLDV which exposed the correspondingly incorporated well of both methods. As a result, a merely percentage different between experiments and simulations results, could be affirmed that simulations designed can be recommended for further vibration failure analysis as well as to develop the performance of HSA in the future.

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