Finite Element Analysis of a Reworking Process of a Tolerance Ring in a HDD's Actuator Arm

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Abstract— **The paper proposes the use of finite element simulation for a rewoking process of a tolerance ring. The purpose of this simulation is to examine the possibility to reuse the tolerance ring by checking solution information of total deformation including both insertion and tear down of tolerance ring. Moreover, this simulaton compares natural frequencies before and after reworking process to make sure that they do not affect the mechanical vibration. The result shows that the tolerance rings can rework process in HDD's actuator arm manufacturing because it has a little natural frequencies is changed which does not affect mechanical vibration in modal analysis and total deformation does not change so much. However, the process engineer has to generate mechanical parameter to measure mechanical data of tolerance ring and increase visual inspection at the top and bottom wave row. Therefore, researcher recommends reworking tolerance ring only one cycle.**

***Keywords*— Hard Disk Drive, Natural Frequency, Vibration, Finite Element Method, Tolerance Ring, Reworking**

I. Introduction

Hard Disk Drive (HDD) inidustry is a vital electronic inidustry in Thailand. They have many competition in business to increase capacity of data storage. Therefore, it is very important to improve the manufacturing process and testing method for this electronic equipment. During the read and write process of HDD, the HGA (Head Gimbal Assembly) is controlled to move back and forth on the spinning disk. Vibration problem often occurs during this process, which results in read/write errors, and potentially reduces the life time of HDD.

Deformations and vibrations are the important problems in HDD which affect the ability of reading and writing operation. These vibrations lead to off-track motion of the read and write heads as they follow the data tracks on the recording surface of the magnetic disk during reading and writing operation [1].

Generally in HDD, the actuator arms are fixed to the pivot bearing with a tolerance ring. The tolerance rings are made of steel and provide a stiff outer shell for the ring assembly to resist axial rocking of the actuator body relative to the pivot, especially during structural resonance mode [2].

The tolerance ring is used in HDD for many reasons, depending on the design of the tolerance ring. For example, the torque ripple is reduced for a pivot bearing in an actuator arm assembly, the tolerance ring requires high axial static friction and provides a low consistent installation force profile.

A tolerance ring is configured to reduce torque ripple for a pivot bearing in an actuator arm assembly. The tolerance ring has a cylindrical shape with a predetermined length, and a plurality of contacting staggered over at least two rows around the cylinder [3].

For applications requiring high axial static friction, the tolerance ring generally has a contacting portion. The multiple contacting portions to increase rigidity and provide directional grip that increases axial static function [4].

A tolerance ring provides a low consistent installation force profile as a rotatable member. A tolerance ring has a substantially cylindrical base portion from which a plurality of spaced apart raised portions radically extends. Each raised portion has a contact surface with a substantially elliptical cross-sectional shape in a direction parallel to the axis and a pair of transition portions between the contact surface and base portion [5]. As the result, researcher should try to rework tolerance rings because they are varieties of advantages.

The reworking process of tolerance rings can save cost for manufacturing process. This research aims to analyze mechanical vibration of APFA (Actuator Pivot Flex Assembly) in modal analysis and total deformation of tolerance ring in static analysis.

Finite element analysis is one of the methods to analyze deformation and vibration of tolerance ring because it is suitable for complex geometry such as HGA (Head Gimbal Assembly), APFA and HSA (Head Stack Assembly). Furthermore, finite element simulations still save cost for analysis without actual experiment. The finite element simulations in this research are performed using ANSYS software.

II. APFA Mechanical Vibration

The APFA mechanical vibration has various mode shapes such as coil bending, coil torsion, 1^{st} pivot butterfly, pivot rocking, arm torsion, arm scissor, 2^{nd} pivot butterfly and 3^{rd} pivot butterfly. Each mode shape has different natural frequency. In this research, the validation of finite element analysis will be considered only for 1st, 2nd and 3rd pivot butterfly as shown in Fig. 1(a), (b) and (c) respectively because these mode shapes have exact specification. The natural frequencies are measured by LDV for 5 Arms as shown in Fig. 2.

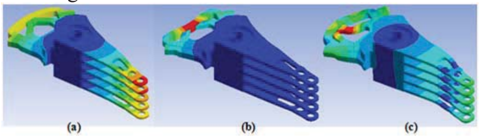

Fig. 1 Pivot butterfly mode

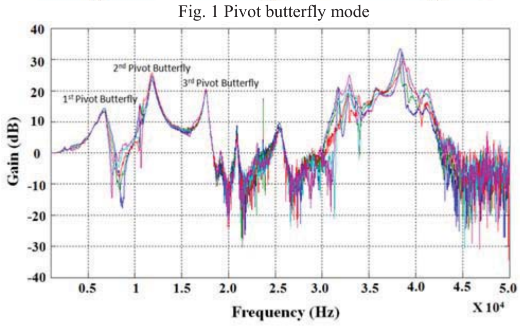

Fig. 2 Natural frequencies are measured by LDV for 5 Arms

III. Finite Element Models

The finite element analyses in general have three main components; Defining geometries, material properties and boundary conditions. Fig. 3 illustrates the finite element model of APFA with 285,337 nodes and 137,285 elements.

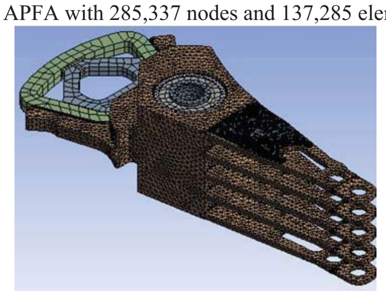

Fig. 3 Meshing of APFA

A. Geometries

Actuator Pivot Flex Assembly consists of coil, pivot bearing, damper, tolerance ring and E-block. All of them are modelled using solid elements as shown in Fig. 4.

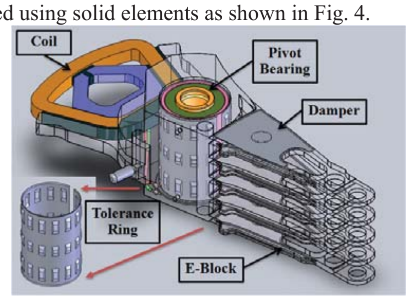

Fig. 4 Component of APFA

B. Material properties

Material properties used in the simulation are defined in Table I. Damper, pivot, and tolerance ring are made of stainless steel. E-Block and coil are made of aluminum alloy and copper alloy respectively.

TABLE I
MATERIAL PROPERTIES

Type of Materials	Material Properties		
	Modulus of Elasticity (GPa)	Poisson's Ratio	Density (kg/m^3)
Stainless Steel	197	0.30	7,750
Aluminium	69	0.33	2,700
Copper	100	0.33	8,500
Epoxy	8.5	0.30	1,400

C. Boundary conditions

The pivot shaft is fixed in all directions. All contact bodies are bonded type which means no sliding or separation between faces.

IV. Finite Element Analysis

The natural frequency obtained from the finite element analysis is compared with the data measured by LDV (Laser Dropper Vibrometer) and the specification for validation.

Fig. 5(a) shows the graph of natural frequency which is measured by LDV. The first pivot butterfly occurs at 6,740 hertz, the second pivot butterfly occurs at 11,800 hertz and the third pivot butterfly occurs at 17,560 hertz.

Fig. 5(b) shows the graph of natural frequency obtained from FEA (Finite Element Analysis). The first, second and third pivot butterfly modes occurs at 6,324 hertz, 11,836 hertz and 17,744 hertz, respectively.

The percentage errors of the finite element of the first, second and third pivot butterfly mode is approximately 0-6 percents. The lower percentage error means the better reliability of finite element modeling as shown in Table II. According to Fig. 5, we compare the natural frequencies (X-axis) specifically at the 1st, 2nd and 3rd Pivot Butterfly modes, because these mode shapes have exact specification. In this case, we do not compare the magnitude of mechanical vibration (Y-axis) since these values are in the different scales.

TABLE II
THE VALIDATION OF FINITE ELEMENT METHOD

Mode Shape	Frequency (Hz)			% Error (LDV)	% Error (Spec.)
	LDV	Spec.	FEA		
1st Pivot Butterfly	6,740	6,240	6,324.3	6.17	1.35
2nd Pivot Butterfly	11,800	11,870	11,836	0.31	0.29
3rd Pivot Butterfly	17,560	17,610	17,744	1.05	0.76

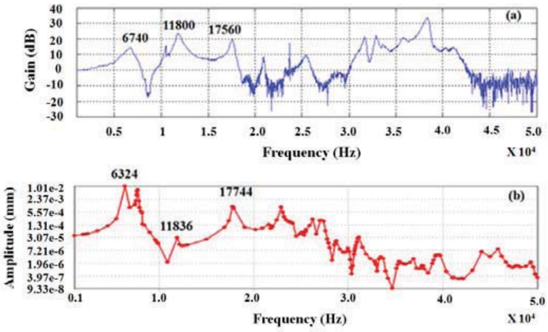

Fig. 5 Natural frequency for upper arm
(a) Natural frequency from LDV
(b) Natural frequency from FEA

V. Process Reworking of Tolerance Ring

Fig. 6 shows the flow chart of the reworking process of a tolerance ring. The first four step of prime assembly is step (a) to (d). These four steps are pivot assembly and tolerance ring which are combined and inserted into E-Block. The last eight step of reworking assembly is step (e) to (l). These eight steps are torn down of pivot assembly and tolerance ring. Then, the repeat step of prime assembly is pivot assembly and tolerance ring inserted into E-Block.

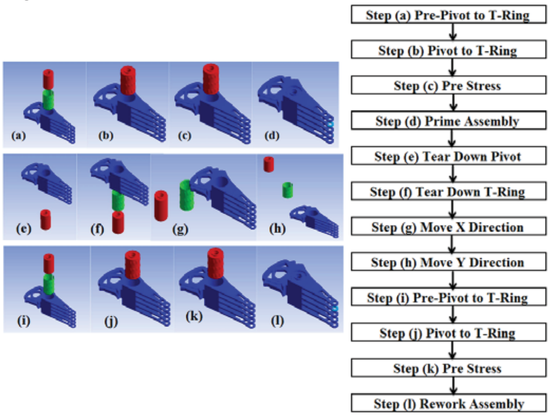

Fig. 6 Flow Chart Process Reworking of Tolerance Ring

VI. Static Structural and Modal Analysis

A. *Total Deformation*

According to the finite element analysis, the maximum total deformation of the top and bottom wave row of T-Ring is 5.0699 microns before reworking condition (step (d) Prime Assembly) as shown in Fig. 7(a). For reworking process, there are only two steps, in which the deformation of T-Ring is of interest, namely pivot tearing down (step (e)) and reworking assembly (step (l)). The maximum total deformations for both steps are 11.390 and 5.0970 microns, respectively, as shown in Fig. 7(b) and 7(c).

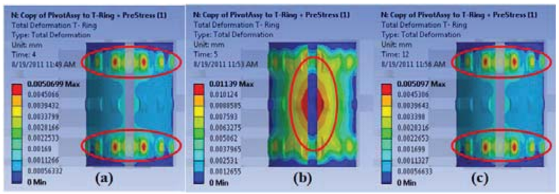

Fig. 7 Total Deformation

B. *Equivalent (von-Mises) Stress*

The maximum equivalent von-Mises stress shows 267.24 MPa before reworking (step (d) Prime Assembly) and located on the top and bottom wave row of T-Ring as shown in Figure 8(a). In this case, the T-Ring is made from stainless steel, which has yield strength 207 MPa. The von-Mises stress value obtained from the analysis reaches the yield strength which means the material will yield and has plastic deformation. For reworking process, as shown in Figure 8(b) and 8(c), the maximum equivalent von-Mises stresses are 227.32 and 266.96 MPa respectively. Thus, these areas should be carefully inspected in the manufacturing process.

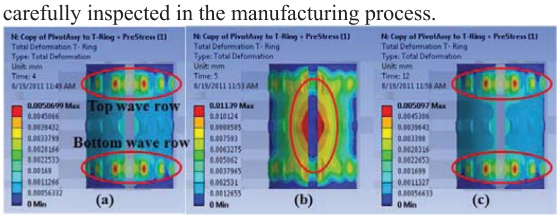

Fig. 8 Equivalent (von-Mises) Stress

C. *Safety Factor*

The safety factor on the top and bottom wave row of T-Ring less than one is 0.77447 (step (d) Prime Assembly) as shown in Fig. 9(a). For the reworking process, as shown in Fig. 9(b) and 9(c), the safety factors show 0.91045 and 0.77529 respectively. These areas should be carefully inspected in the manufacturing process.

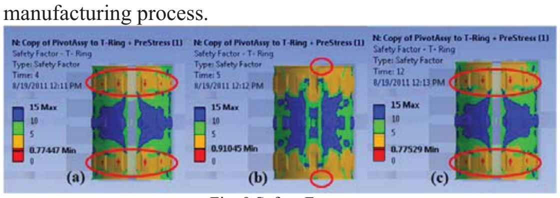

Fig. 9 Safety Factor

D. *Equivalent Plastic Strain*

The maximum equivalent plastic strain is 8.9522E-04 which appears on the top and bottom wave row of T-Ring before reworking (step (d) Prime Assembly) as shown in Fig. 10(a). This number means small displacement when compared with original shape of tolerance ring. For the reworking process, as shown in Fig. 10(b) and 10(c), the maximum values of equivalent plastic strains are approximately 1.6367E-03 and 1.2349E-03 respectively. The two steps of reworking process are deformed more than prime process.

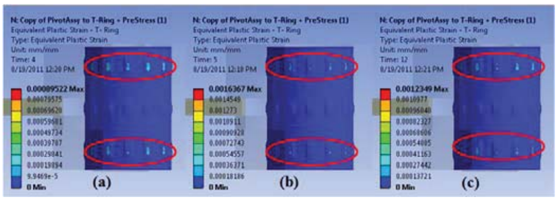

Fig. 10 Equivalent Plastic Strain after Reworking

E. *Modal Analysis*

Modal analysis is the method of simulation in order to analyze mode shape and natural frequency of an object of interest. This simulation examines the change in natural frequency of APFA before and after reworking. The results show that the percentages of change in natural frequencies for different mode shapes are slightly different for approximately 0-5 percents. Furthermore, the most important mode shapes such as the first, second and third pivot butterfly are still within the specification. Therefore, the reworking process of T-Ring in the manufacturing does not affect with mechanical vibration.

TABLE III
NATURAL FREQUENCY COMPARISON BEFORE AND AFTER REWORKING

Mode Shape	Natural Frequency (Hz) before Reworking	Natural Frequency (Hz) after Reworking	Percentage of frequency changing
Coil Bending	2425.4	2423.7	0.070
Coil Torsion	4524.3	4532.1	0.172
1st Pivot Butterfly	6324.3	6207.0	1.855
Arm Torsion	7670.3	7262.1	5.322
2nd Pivot Butterfly	11836	11746	0.760
3rd Pivot Butterfly	17744	17321	2.384

VII. Conclusions

The reworking process of tolerance ring in the manufacturing does not affect mechanical vibration in modal analysis. Moreover, the maximum total deformations of the tolerance rings are very small. The maximum equivalent plastic strain is deformed for small displacement when compared with original shape of tolerance ring. However, the maximum value of equivalent von Mises stress on the top and bottom wave row reaches the yield strength and the safety factor less than one. As the result, these areas should be very carefully inspected in the manufacturing process after reworking. It is recommended that the process engineer should generate mechanical parameter to measure mechanical data of tolerance ring and increase visual inspection on the top and bottom wave row.

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