DESIGN OF HIGH-SPEED AUTOMATIC VISUAL INSPECTION MACHINE FOR HEAD GIMBAL ASSEMBLY (HGA)

Prathan Ch[1,2,*], Sorada K[1] , Jiraphon S[1]

[1]School of Mechanical Engineering, Suranaree University of Technology,

[2]Western Digital (Thailand) Co., Ltd., Bang Pa-In, Phra Nakhon Si Ayutthaya, Thailand

Contact E-mail:*Prathan.chomuangpuck@wdc.com

ABSTRACT Nowadays, automation machine and system are widely used in Hard Disk Drive (HDD) industry for high production and inspection process. Western Digital (Thailand) Co., Ltd. (WDTH) also uses auto inspection machine to inspect Head Gimbal Assembly (HGA) by 2,700 HGAs per hour. However, the machine should operate at units per hour (UPH) of 3,600 HGAs. The bottleneck in HGA automation process was occurred. In order to eliminate the bottleneck, this research aimed to design the high-speed automatic visual inspection machine in HGA automation process to achieve machine Units per Hour (UPH) of 3,600 HGAs. Consequently, the driven components of machine had to operate at high speed and this caused the vibration taking place in machine which raised from the dynamics responses in machine component. Moreover, the large amplitude of vibration responses affected to the resolution of images and it decreased machine efficiency to justify whether HGA has defect or not. The vibration isolation approach is demonstrated in this research by changing the boundary condition or adding the isolator into traditional machine to reduce the force transmissibility from vibration sources. After the isolator are installed, the results shown that the amplitude of vibration responses decreased to 85-98%, 30-95%, and 54-98% of displacement transmissibility for X, Y, and Z axes, respectively. However, the machine cannot refrain the low speed of driven components. Nevertheless, it can operate at high speed to examine 3,600 of HGAs per hour. The standard deviation of HGA's reference hole is reduced from 1.70 microns to 0.50 microns or about 70.59% of machine's precision increased and it can ensure that the machine can examine 3,600 of HGAs per hour.

1. INTRODUCTION

In modern Hard Disk Drive (HDD) technology, there are couple types of data storage principle available. They are conventional HDD and Solid State Drive (SSD). Currently, the conventional HDD continues to dominate for more than 70% of market share of total data storage business which the key motivation is cost per storage capacity. The technology of conventional HDD now a day is still developing to implement the Heat Assisted Magnetic Recording (HAMR) instead of Perpendicular Magnetic Recording (PMR). HAMR technology has been demonstrated in the experiment at over a trillion bits per square inch or about a 30% improvement of PMR technology (Rosenthal, 2013). Due to the conventional HDD technology growth, the manufacturers has developed the process themselves to achieve the goal of business. In addition, the high speed automatic process plays an important role to produce HDDs corresponding to market's requirement.

The conventional HDD's key components consist of mechanical base components integrated with advance electronics control system. In addition, one of the important mechanical part is Head Gimbal Assembly or HGA which is the key component of read/write module. HGA perform the function of sustain the read/write head and control the flying behaviour during transferring digital information into storage media and gathering them from storage media. The production process of HGA has seven processes as illustrated in figure 1. The bottleneck of HGA process is inspection machine with machine Unit per Hour (UPH) about 2,700 HGAs. In addition, the current machine has Non Value Added (NVA) process from pick and place robots and a lot of variations to control (e.g. workpiece variations, machine vision variations, and vibration). Accordingly, those of NVAs and variations have to be eliminated as much as possible in order to achieve the UPH and the bottleneck in HGA process will be eliminated also.

Therefore, this research aimed to design the high speed automatic inspection machine that can achieve the desired UPH. The resolution of image taken by machine which define by the standard deviation of HGA's reference hole diameter should be lower than 1.5 microns.

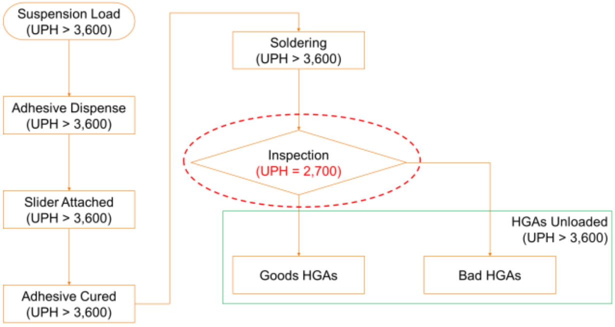

Fig.1 Head Gimbal Assembly Process Flow

2. MACHINE APPEARANCE & ITS OPERATION

HGA Inspection machine as illustrated in figure 2 consists of five main components i.e. machine table, clamping module, transportation module, camera holder frame, and camera adjusting module. Machine table perform to support all components as well as to steady machine part while it is operating. Clamping module is used for both clamp and unclamp HGA for inspection and stabilize HGA during the camera takes an image to examine HGA's defect. Transportation module has a duty for transport HGA on its carrier through the inspection zone. Camera holder frame is used for carry the camera setting module and stabilize the camera while inspecting the HGA, and camera adjusting module for setting the camera corresponded to its focus and field of view (FOV).

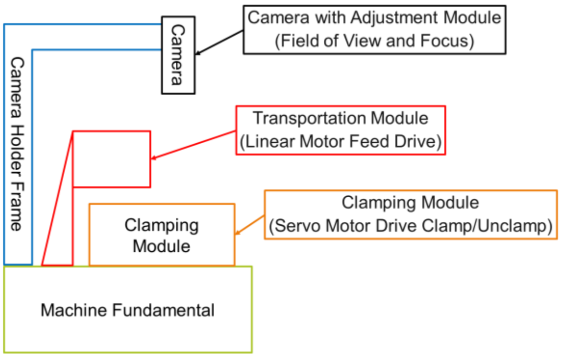

Fig.2 Machine Appearance

There are four processes in the inspection machine which are continuously work as a cycle related to the amount of HGAs in HGA's carrier as shown in figure 3. The process starts from Index which is performed by transportation module. After index step is accomplished the clamping module will starts to clamp HGA and stabilize it. Then, the camera can take an image for inspect, and finally unclamp step and the next loop started to inspect the next coming HGA. In order to achieve machine UPH, all of the four processes need to finish within 1 second as illustrated in figure 4. Due to the performance of linear motor and machine vision, the process cycle time of index process and inspection process are fixed to 150 millisecond and 200 millisecond, respectively. Although, those two process cycle times are fixed but the clamp and unclamp process cycle times are variable by varying the speed of servo motor. Therefore, the machine can achieve 3,600 of HGAs per hour by changing the servo motor speed to 150 RPM.

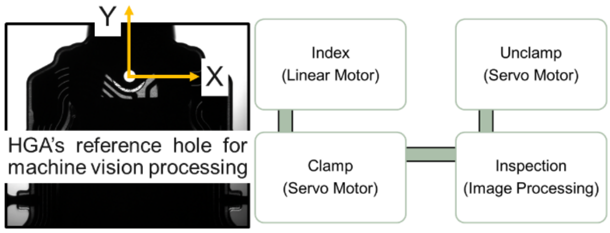

Fig.3 Operation Procedure and Reference Hole of Inspection

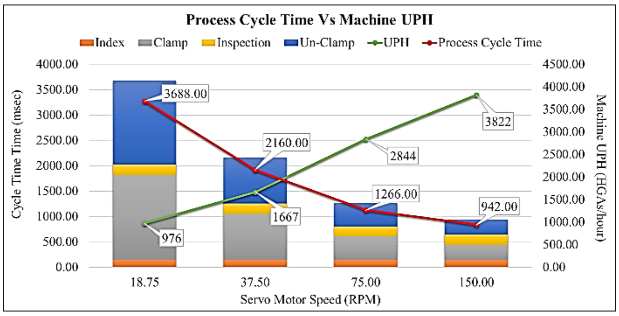

Fig.4 Machine UPH & Process Cycle Time VS Servo Motor's Speed

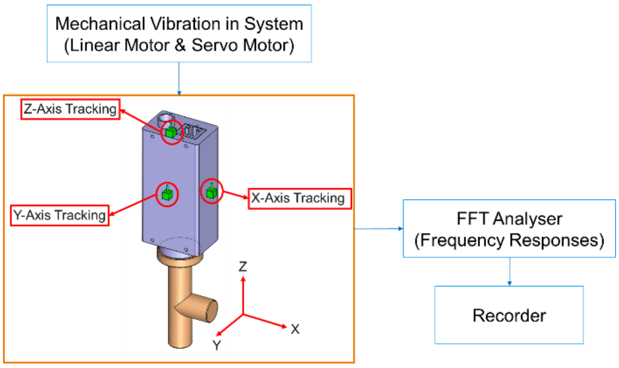

Fig.5 Frequency Tracking Position at Camera

3. EXPERIMENT

3.1 Experimental Apparatus & Procedure

In this research, the vibration waveform in frequency domain of X, Y, and Z axes are measured by the vibration handheld analyser with accelerometer probe mounted onto the measuring location by wax as illustrated in figure 5. The vibration waveforms of all axes are collected while the machine operating for all experiments. There are two experiments in this research. The first experiment was set to define the vibration responses at 150 RPM of servo motor's speed. The second experiment demonstrated the results after installed the vibration isolator components at 150 RPM speed of servo motor. The results of these two experiments were compared with each other in order to ensure that the machine can withstand the vibration load in system. In addition, machine can get the high image quality at high speed running which can observed by the standard deviation of diameter of reference hole.

3.2 Location of Vibration Isolator

Due to the dynamics responses in X, Y, and Z axes, the vibration isolators are used for restrict the transmissibility whether the force or the displacement (Rivin, 2010) (A.A. Hanieh, et al., 2002) and it located in the position as illustrated in figure 6 and 7. Machine is divided into two zones i.e. the source of vibration and the camera holder frame or the critical system (see figure 6). The vibration in machine is generated by linear motor in transportation module and servo driven motor in clamping module. Based on the movement behaviour of these two motors, the vibration force from linear motor has very little influence to the dynamics responses in machine. In addition, the linear motor is moving smoothly in machine which driven by the magnetic field. On the other hand, the vibration force is mostly generated by servo motor, because of its movement and the cyclic load from the clamping module. Therefore, it need to separate from each other between these two driven components and the camera holder frame to achieve both of machine UPH and image quality.

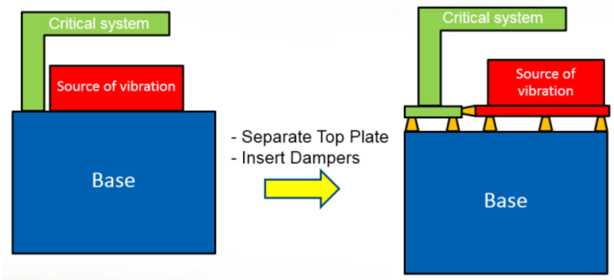

Fig.6 Location of Vibration Isolator Equipment

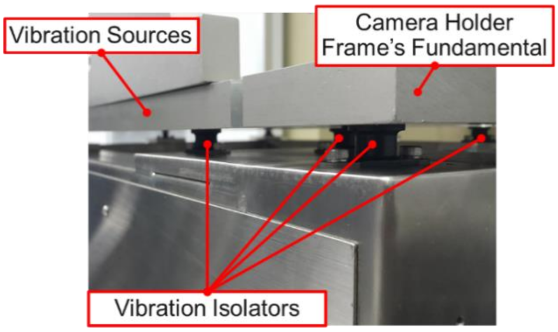

Fig.7 Vibration Isolators Installed to Machine

3.3 Vibration Isolator Selection

The vibration isolators are selected based on the equation of vibration transmissibility (Inman, 2007) in equation (1).

$$\text{T.R.} = \sqrt{\frac{1+\left(2\zeta r^2\right)}{\left(1-r^2\right)+\left(2\zeta r^2\right)}} \tag{1}$$

In addition, the frequency ratio (r) is given by the natural frequency and critical frequency in system. The critical frequency in system is defined by the dynamics responses measured by vibration handheld analyser. Furthermore, the dynamics responses, in term of displacement responses, can be observed by the frequency which shown the large amplitude while the machine was operating. The mass and stiffness in system are related to natural frequency so, in this case, it is determined by the mass or weight of machine components and machine's structure which installed on machine table. The transmissibility is determined by an acceptable maximum amplitude of displacement (J.C. Golinval & M. Geradin, 1999) which is defined by the lens's focus and FOV (Long Cui, et al., 2011) (Ö. Tomas, 2013). The primary parameter for controlling machine vision is lens's focus and its acceptable amplitude is about 10 microns. Regarding to the figure 8, Z-axis shown the maximum amplitude about 20 microns thus it has to reduce the amplitude from 20 microns to lower than 10 microns or about less than or equal 50% of transmissibility. In addition, there are three dampers available from vendor, i.e. 5%, 10%, and 15% of transmissibility, therefore the damper which has 15% of transmissibility is selected to install in machine.

4. RESULT & DISCUSSION

4.1 Dynamics Responses before Install Isolators

The dynamics responses of X, Y, and Z axes are demonstrated in figure 8. The results shown that the maximum amplitude of displacement is occurred at 35 Hz for X and Z axes about 10.96 microns and 19.77 microns, respectively. While the displacement amplitude of Y-axis shown the smallest amplitude about 1.67 microns at 50 Hz compare to other axis and it is acceptable. As a results, the image quality of inspected picture shown that it has low quality of image as illustrated in figure 9. Furthermore, the standard deviation of diameter of reference hole was about 1.70 microns.

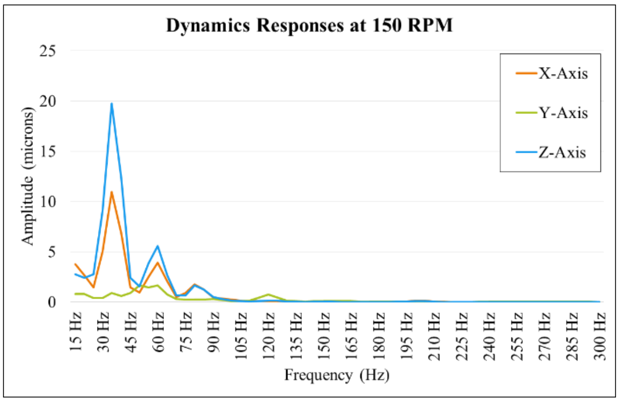

Fig.8 Dynamics Responses before Install the Isolators

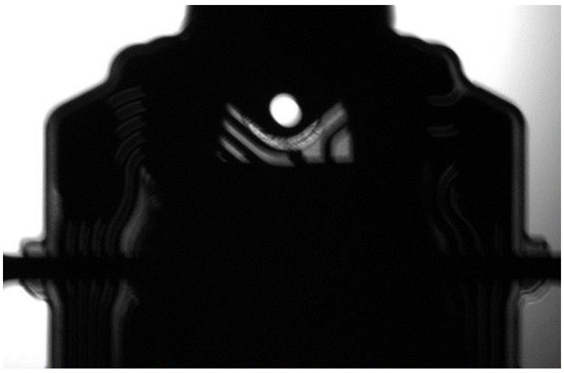

Fig.9 HGA before Install Isolators

4.2 Dynamics Responses after Install Isolators

The results of isolation approach as illustrated in figure 10. It is show that the displacement amplitude of X, Y, and Z axes reduce to 4.67 microns, 6.00 microns, and 5.79 microns, respectively. Moreover, the peak of frequency are shifted to 45 Hz, 40 Hz, and 80 Hz of X, Y, and Z axes, respectively. In addition, the frequencies are shift due to the installation of an isolators and the changing of boundary condition in conventional machine. Furthermore, the isolators do not have only the damping ratio but the stiffness also involved in itself. The result of reference hole's diameter was found 0.50 of standard deviation. The image taken by machine after install the vibration isolators is demonstrated in figure 11.

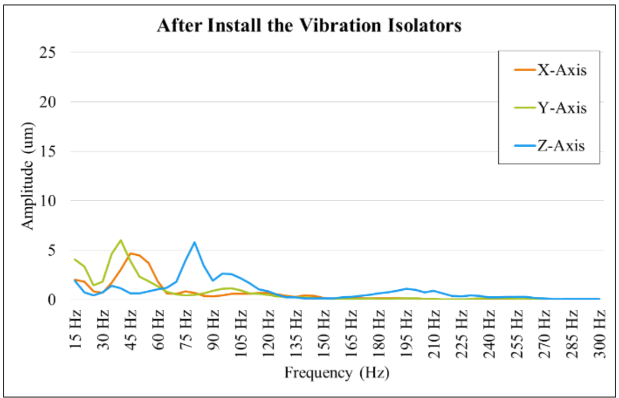

Fig.10 Dynamics Responses after Install the Isolators

Fig.11 HGA Image taken by Machine after Install Isolators

4.3 Vibration Transmissibility

The conventional machine has been divided into two zones as illustrated in figure 6. Then, the isolators are installed into machine to restrict the transmissibility by 15% of transmissibility regarding to the specification of damper from vendor. In table 1 presented that the isolators can be applied at both of 75 RPM and 150 RPM of servo motor's speed. These two speeds of servo motor shown that the transmissibility are: 14.83% and 4.16% of X-axis, 16.26% and 11.38% of Y-axis, and 39.90% and 2.34% of Z-axis, respectively. However, the 150 RPM of servo motor's speed is selected, as it is mentioned in figure 4, in order to meet the requirement of UPH. Therefore, the transmissibility at this speed is acceptable.

Table.1 Displacement Amplitude Reduction.

Servo Motor's Speed (RPM)	Amplitude Reduction (%)		
	X-Axis	Y-Axis	Z-Axis
18.75	-160.02	-118.78	-80.72
37.50	-56.31	-167.30	-32.13
75.00	85.17	83.74	60.10
150.00	95.84	88.62	97.66

CONCLUSION

The HGA's reference hole diameter measured by the inspection machine shown the standard deviation about 0.50 microns which is decreased from 1.70 by the vibration isolation approach or, on the other hand, about 70.59% of machine's precision increased. As a results, it can ensure that the machine can examine the HGA and justify whether HGA has defect or not.

Moreover, the transmissibility as presented in table 1 shown the results accordingly with the principle of vibration isolation transmissibility (Inman, 2007) (J.C. Golinval& M. Geradin, 1999) (Yan Wen-bing, et al., 2009) (Zhixing Li, et.al, 2011) (Thanh Danh Le, Kyoung Kwan Ahn, 2013). There are two regions of the transmissibility i.e. amplification region and isolation region which can be described the transmissibility at 18.75 RPM and 37.50 RPM of servo motor's speed. Thus, the machine can operate at 150 RPM of servo motor's speed to achieve the required UPH.

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Prathan Chommuangpuck received the B.S. (2000), degrees in Teacher Training in Mechanical Engineering from King Mongkut's University of Technology North Bangkok.

He is a Principal Engineer, HGA Process Development, Western Digital (Thailand) Co., Ltd. and currently studying in M.E., degree in Mechatronics Engineering, Suranaree University of Technology. His current interests include vibration, system and control.

Jiraphon Srisertpol Received the M.E. (1998) degree in Technical Maintenance Aviation Electrosystems and Pilot-Navigation Complexes, D.E. (2003) degree in System analysis, control and processing information from St. Petersburg State Academy of Aerospace Instrumentation.

He is an Associate Professor, Department of Mechanical Engineering, Suranaree University of Technology. His current interests include adaptive system, system identification and vibration control.

Sorada Khaengkarn Received the B.E. (1997), M.E. (2002), and D.E. (2014) degrees in mechanical engineering from Suranaree University of Technology

She is a Lecturer, Department of Mechanical Engineering, Suranaree University of Technology. Her current interests include robotics and automation system