Improvement of Hard Disk Drive's Arm Bending Machine using Fuzzy Logic

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Abstract: Hard Disk Drive's arm (HDD's arm) is one of the key elements in the HDD assembly. This element has to have the height of the arm measured from the reference be in the required range. To get such requirement, HDD's arms have to pass to a bending machine in order to measure and adjust the height of the arms accordingly. Currently, if needed, a pre-defined bending force is applied to the arm. In this paper, the fuzzy logic rule to control the bending force is proposed. From the experimental data, it is found that the performance of the proposed technique in terms of the process capability index of the arm height error is superior to the conventional technique.

Keyword: Hard Disk Drive, Fuzzy Logic, Force Control.

1. Introduction

Hard disk drives (HDD) have been one of the major electronic devices required in most of the current world applications. HDDs are combined of two major parts; that is, a head disk assembly (HDA) and a printed circuit board assembly (PCBA). For HDA, there are three main components included; that is, the magnetic disk, the spindle motor to rotate the disk, and the head stack assembly (HSA). Considering the HSA, three primary components are combined; that is, the actuator assembly which is moved as control by the servo control system, the head gimbal assembly (HGA) which is mounted to the end of the actuator to access the disk, and the flex cable assembly which provides the electrical interconnection to the system. It is seen that there are many components in a HDD and each component has to have the characteristics, size, and dimension as required by the standard. To get such requirements, the production process becomes very important.

Considering the actuator assembly, one of the main components in the actuator assemble is the actuator arm or HDD arm, which is used to support the HGA. The arm has to have the correct size and dimension since it has to support the HGA and lead the HGA to the precise tracks on the magnetic disk. Not only be able to lead the HGA to the precise location of the disk but the arm also has to have the correct height so that the HGA does not physically touch the disk to prevent the damage on the disk.

It is seen that the size and dimension of the HDD arm are very crucial. The height of the arm measured from the reference point is also important. In the actuator assembly production line, the HDD arm has to be passed through a checking process to determine whether the height of the arm meets the requirement. If not, some adjustments have to be done. Conventionally, the HDD arm adjustments are done by using a bending machine, which will bend the arm over and over in order to make it meet the height requirement.

The problem of the currently used bending machine is that the bending force is fixed to some values without taking into account the input height error. Hence, some HDD arms still do not meet the height requirement even if they had passed the bending process. It is seen that there should be some alternatives to solve such problem. In [1], it was found that the required bending force and the input height error are not linearly proportional. And, from the collected data, it was also shown that fuzzy logic might be a promising approach to solve the problem in adjusting the HDD arm height. Therefore, in this paper, the further research and experiments are done to determine whether the designed fuzzy logic rule for controlling the bending force will help reducing the height error of the arm and to compare the performance from different fuzzy logic rule and the currently used method in the industry.

In the following sections, the related theory and experimental results are given. The HDD arm measurement system, basic theory on fuzzy logic and the performance measurement are describes in Section 2. In Section 3, different designed fuzzy logic rules are applied to the bending system and the results of such rules are determined. And, finally, the discussion and conclusions are given in Sections 4 and 5, respectively.

2. HDD Arm Measuring System, Fuzzy Logic and Process Capability Index (C_{pk})

As discussed previously, HDD arms have to be measured whether they have the correct height. The measuring system is done by putting the arm on the nest and using the laser gage to measure the height of the arm, as shown in Figure 1. The height of the arm is measured from the reference point. If the measured height is not in the required range, such arm has to pass through the bending process.

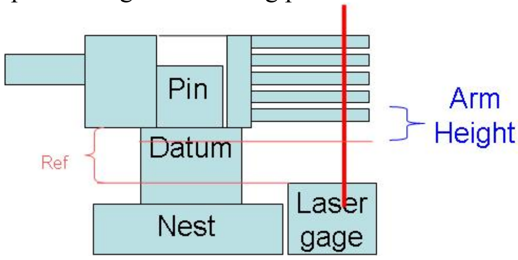

Figure 1. Diagram of HDD's arm height measurement using laser scanner.

The bending process currently used in the industry has a problem of fixing the bending force to some values as described before. In this paper, a technique called fuzzy logic is adopted to help solving the problem by assigning the bending force as a function of the input height error. The fuzzy logic [2 – 5] is based on the decision of human. There is no completely white or black in most sense for the human. The fuzzy logic is categorized into one of the expert system used in many applications. There are three main processes; that is, fuzzification, inference, and defuzzification. Fuzzification is the process where the input is gathered and grouped into fuzzy set described by the membership function. Inference is the decision process at which the decision is made logically by using the fuzzy logic operator. And, finally, defuzzification is the outcome from the fuzzy logic. Normally, there are two main approaches to perform this process; that is, central-gravity method and singleton method [6 – 9]. In this paper, the singleton method is chosen.

To evaluate the capability of the manufacturing process in making the final product within the required specification, some key performance indices are needed. In the HDD arm manufacturing process, the performance is measured by using an index called process capability index (C_{pk}), which is one of the most common indices being applied by manufacturing industry [10]. To determine C_{pk}, the statistical data of the process has to be collected. And, it is assumed that the statistical distribution of the tested products is normal. This index is calculated by using the following equations; that is,

$$C_{pu} = \frac{USL - \overline{X}}{3\sigma}, \quad C_{pl} = \frac{\overline{X} - LSL}{3\sigma} \qquad (1)$$

$$C_{pk} = \min\{C_{pu}, C_{pl}\} \qquad (2)$$

Where USL and LSL are the upper and lower specification limits. $\overline{X}$ and σ are the mean and standard deviation of the process, respectively. These parameters are graphically described in Figure 2.

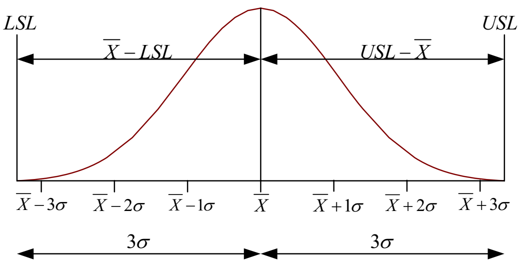

Figure 2. Diagram of normal distribution used in C_{pk} calculation.

The process capability index is needed to be as high as possible, which is approximately 3. This will then means that the mean of the process is almost exactly in between USL and LSL. In general, an index of 1.5 to 2 is assumed to be acceptable for being used in industry [11].

For HDD arm bending process, the arm height required by the considered HDD arm specification is 0.1300 inches. And, the required USL and LSL are 0.1315 and 0.1285 inches, respectively. The value of this index achieved from the HDD's arm bending machine used in the industry is 0.80, which still does not meet the requirement; that is, 1.33.

In the next section, the fuzzy logic rule to control the bending force is applied. The process capability index from different designs of fuzzy logic will be determined.

3. Experimental Results

In the following experiments, the data from [1] is used as the main information for designing the fuzzy logic rule to control the bending force. The average height difference and the standard deviation of the achieved height difference as a function of the bending force is shown in Figure 3. It is clearly seen that the height of the arm does not increase linearly proportional to the bending force. Hence, applying this to the bending process, it can be concluded that for different input height error, the bending force must be varied, accordingly. Using such information, the fuzzy logic rule to design the bending force as a function of the input height error could be obtained. In the following sub-section, three designs of fuzzy logic rule are described and the performance of those designs is evaluated.

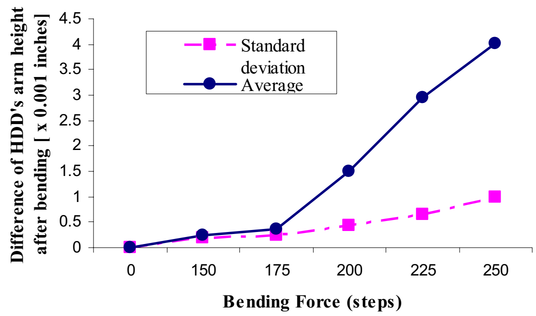

Figure 3. The HDD's arm height difference as a function of the bending force.

3.1 Experiment I

From Figure 3, the input height error is divided into three groups; that is, the groups with small, medium, and large errors, respectively, as shown by the error height membership function in Figure 4.

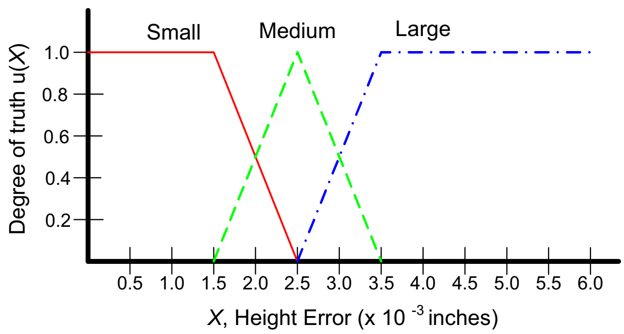

Figure 4. Error height membership function for 3-value Fuzzy singleton.

It is seen that since the singleton method is adopted, the coverage areas of these three groups are partly joined with a triangular boundary; for example, the input height error between 0.0015 and 0.0025 inches is under the small and medium areas. The bending forces for these three groups are 150, 200, and 250 steps, respectively. Note that the bending force here is in the unit of steps since the force is control by stepping motor. To get the bending force for a particular input height error, Figure 4 and these bending forces have to be used.

The designed fuzzy logic rule is applied to some samples of HDD arms. The number of arms used in the experiment is 24 arms. The heights before and after bending process with this design of 3-value Fuzzy singleton are shown in Figure 5.

It is seen that for all HDD arm samples, after bending, they are in the acceptable range (between 0.1285 to 0.1315 inches). The average and the standard deviation of the height after bending are 0.1299 and 0.000732 inches, respectively. Applying these numbers to the equations (1) and (2), it is found that C_{pk} for this design is 0.64. This achieved index is not as good as the one achieved from the industry. Dividing the height error into only three groups might not help improving the performance of the process.

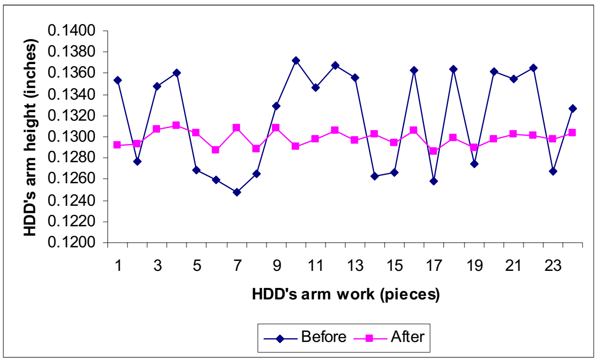

Figure 5. The heights before and after bending process for 24 HDD's arms: with 3-value Fuzzy Singleton.

3.2 Experiment II

In this experiment, the input height error is divided into five groups to explore whether by doing this the performance could be improved. The error height is divided in to five groups; that is, very small, small, medium, large, and very large, respectively. In Figure6, the error height membership function for this design is given. The bending forces for these five groups are 125, 160, 185, 210, and 250 steps, correspondingly.

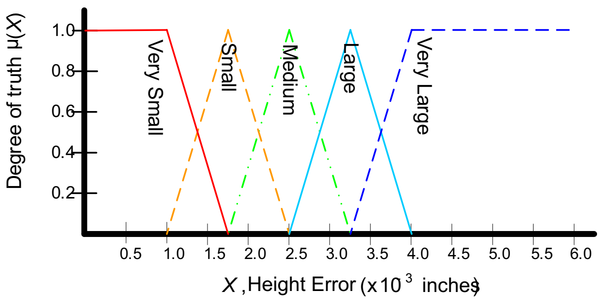

Figure 6. Error height membership function for 5-value Fuzzy singleton.

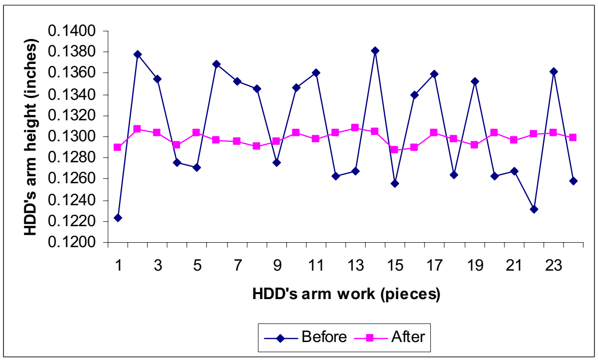

Figure 7. The heights before and after bending process for 24 HDD's arms: with 5-value Fuzzy Singleton.

Similarly, the designed fuzzy logic rule is tested with 24 samples of HDD arms. The result is shown in Figure 7. It is also seen that after bending, the height of the arms are in the acceptable range. The mean and standard deviation of the height after bending are 0.1299 and 0.000619 inches, respectively. Consequently, C_{pk} for this design is 0.75, which is better than the C_{pk} achieved from previous design. However, comparing to the C_{pk} achieved from the industry, this C_{pk} is slightly lower.

3.3 Experiment III

To get an improvement on the bending process performance comparing to the previous design of 5-value fuzzy singleton, an adjustment on the output bending force has to be done. The error height membership function is identical to the one shown in Figure 6 but the bending forces for different groups are changed to 160, 170, 190, 220, and 240, respectively. With these new assigned bending forces, 20 HDD's arms are tested. The heights of these arms before and after bending are given in Figure 8.

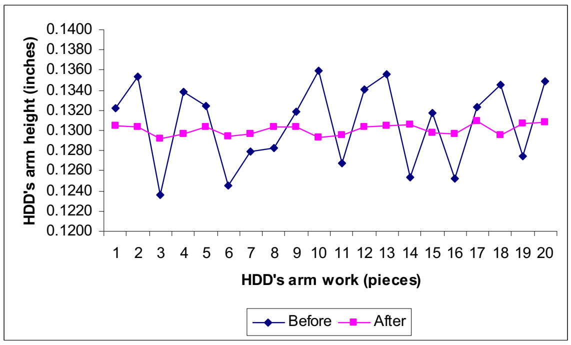

Figure 8. The heights before and after bending process for 20 HDD's arms: with new 5-value Fuzzy Singleton.

Considering Figure8, it is found that the average and the standard deviation of the HDD arm heights after bending process are 0.1301 and 0.000550 inches, respectively. It is seen that the standard deviation from this design is lower than those from the previous two designs. The process capability index, C_{pk}, from this design is 0.85, which is better than the previous designs and better than the index achieved from the industry.

4. Discussion

From the designs of fuzzy logic to control the bending force shown in the previous section, it is seen that dividing the error height into three groups does not help improving the capability index of the bending process comparing to the capability achieved from the industry. To get a better performance, the error height should be divided into more number of groups. Five groups of error height are designed. It is found that with 5 groups separation, the capability index is better comparing to the index achieved from 3-group separation. The reason is that with 5 groups, the assigned bending forces can take care of the input error height more appropriately since the height and the bending force are not linearly proportional as seen from Figure1. However, the capability index of this design is not higher than the index from the industry. Taking into account of the bending force, it is found that the bending force used in the 5-value fuzzy singleton might not be suitable since there are some forces which are too low or too high, for example, 125 and 250 steps. Hence, in the last design of 5-value fuzzy singleton, the bending forces are adjusted. With this new 5-value fuzzy singleton, the achieved capability index is 0.85, which is higher than the index achieved in the industry. It is seen that with fuzzy logic, the performance of the bending machine can be improved.

5. Conclusion

In this paper, the concept of fuzzy logic is applied to the HDD's arm bending machine. Applying different values of bending force to the arm, the arm height is changed but not linearly proportional to the value of the force. Using this information, some fuzzy logic rules to determine appropriate bending force for a particular input error height of the arm can be achieved. Three designs of fuzzy logic are given. Dividing the input error height into 5 groups and assigning 5 corresponding bending forces has been shown to have a better process capability when comparing to the case of 3. Moreover, with some bending force adjustments, the 5-value fuzzy singleton design performs better in terms of the process capability index comparing to the capability achieved from the conventional bending method used in the industry. In conclusion, it is seen that fuzzy logic is a promising alternative in help improving the performance of the HDD's arm bending machine.

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