# Design of Fuzzy Logic for Hard Disk Drive's Arm Bending Machine

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## Abstract

The HDD arm is one of the key elements in HDD head assembly industry. The HDD arms are required to have a correct height measured from the reference. The HDD arms produced in the industry have to pass an inspection process to check whether the requirement is met. If some do not meet the requirement, the adjustment has to be done. The HDD arm adjustment is done by bending the arm up or down in order to make it be at the correct height. The problem of bending process currently adopted in the industry is that some of the bended HDD arms still do not meet the requirement since the bending force is fixed to some values and not adaptively adjusted. In this paper, a technique called Fuzzy logic is proposed to be used as a predefined scheme to control the bending force. From the experimental data in bending HDD's arms for various cases, the Fuzzy logic to control the bending force is designed. Comparing to the technique used currently in the industry, this proposed technique can help reducing the rejection rate of the HDD arms passed through the bending process.

**Keywords**: HDD, Fuzzy Logic, Material, Force Control.

## Introduction

In Hard Disk Drive (HDD) industry, the HDD's head is very important since it is the part that used to read and writ the information to the media. The HDD's head is assembled from several elements. One of the elements in the HDD's head assembly is HDD's arm. This element has to meet the required specifications. One of the required specifications is the height of the arm itself that has to be at the correct value measuring from the reference point. The measure is done by using laser scanning. If the height of the HDD's arm follows the specification, such arm can then be passed through the next assembling process. If the height of the arm is not at the correct one; for example, it is up-bended or down-bended; such arm has to be inversely bended in the bending process to make it be at the right height.

However, there are some problems in adjusting the HDD's arm to the right height; that is, the problems from the material characteristics and the structure of the HDD's arm. Because of the

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flexibility property of the material forming the HDD's arm and different characteristics between HDD's arms, it is quite difficult to define a straight relationship between the height error and the required bending force. Conventionally, in industry, the bending force is fixed to a certain value for a particular model of HDD and used as the pre-defined force with every HDD's arm if needed. This fixed bending force causes the unavoidable error for the case of having small error height and consumes more time to bend the HDD's arm back and forth to get the correct height.

Considering these problems, it is seen that there should be some alternatives to improve the bending process. An intelligent system can be adopted in order to adaptively adjust the bending force optimally. Fuzzy logic system is a promising approach for using with this work since it can make use of the input error height to set the required bending force appropriately. In this paper, the data from many HDD's arms with different values of bending force is collected. The data is analyzed and used in the Fuzzy logic design to get the decision curve for defining the bending force used in the bending process.

The system overview and concepts of Fuzzy logic are given in Section 2. In Section 3, the data from different experiments is shown. The collected data is analyzed and used as the basic information in forming the Fuzzy logic membership functions, which is described in Section 4. Finally, the conclusions are given in Section 5.

## System and Fuzzy Logic Overview

The diagram of HDD's arm inspection is given in Figure 1. The HDD's arm is placed on top of the machine and is scanned by the laser to measure the height of the arm. If the height does not meet the requirement, the arm is bended with some pre-defined force in order to adjust the arm to be at the required height. The bending force is achieved from the stepping motor and the force is defined by the number of steps used.

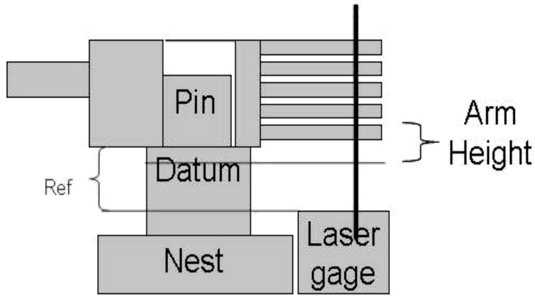


**Figure 1.** Diagram of HDD's arm height measurement using laser scanner.

As mentioned previously that Fuzzy logic can be used here to help improving the bending process to get the proper bending force for a given input error height. The concept of Fuzzy logic is from the human decision, which is based on the experience. In Fuzzy logic, there are two important parameters; that is, Fuzzy set $(x)$ and membership function $(u(x))$ (Zadeh, 1994;Klir, 1995; Ramot and et al., 2003). Fuzzy set is the set of the uncertainty or the input data from the system and the membership function is a graphical representation of the magnitude of participation of each input. There are many operators used in the Fuzzy logic; for example, complement, intersection, and union. It is seen that these operators are identical to those used in the set operation. However, the difference between these is the output of the operation; that is, in general Boolean logic, the output is binary logic (i.e., only 0 or 1) while, in Fuzzy logic, the output is ranging from 0 to 1 (Zadeh, 1994; Ramot, et al., 2003;Coleman, 1994; Rich and Knight, 1991;Russell and Norvig , 2003)

## Experimental Results

In this section three different experiments are done in order to get the information regarding the adjustable height as a function of bending force and the number of times applying the force to arm.

**- Experimental I**

In this experiment, the average and standard deviation of the height difference from two values of bending force are studied. The bending forces used are 200 steps and 250 steps, respectively. For each value of bending force, 5 HDD arms are used in the experiment. The height of each HDD arm is measured for both before and after bending 1 time. After bending, each arm is placed into the conventional bending machine to make it back to its original height. Then, the same process is repeated for the same HDD arm for another 49 times. The results of this experiment are shown in Figure 2 and 3.

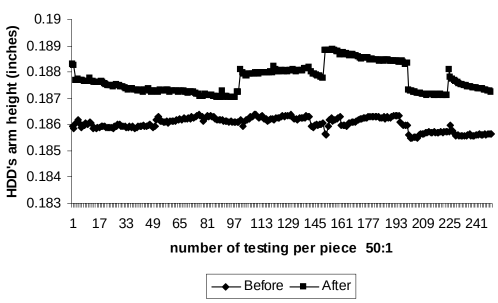


**Figure 2.** The heights before and after bending process with 200-step bending force.

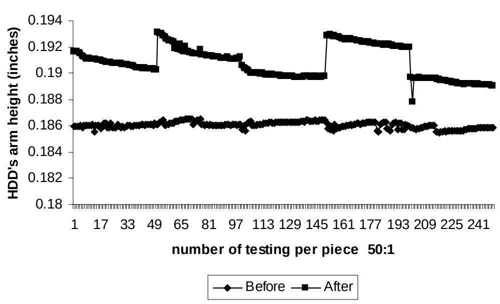


**Figure 3.** The heights before and after bending process with 250-step bending force.

From Figure 2 and 3, it is seen that the height after bending for both values of force is increased. The larger force applied, the higher height achieved. However, considering in both figures, it is seen that the achieved height are not identical for a particular bending force. There are some variations of the achieved height. These variations are from the property of the material itself and from the fact that the HDD's arms used in each bending force are different (that is, 5 arms are used in each case). From these two figures, the difference height between before and after bending is determined and the average and standard deviation of the difference are calculated and given in Table 1.

**Table 1.** The HDD's arm height difference from 200-step and 250-step bending forces

| Bending Force | HDD's arm Height Difference (inches) | |
|---|---|---|
| | Average | Standard Deviation |
| 200-step | 0.00156 | 0.000216 |
| 250-step | 0.00481 | 0.000442 |

It is clearly seen from Table 1 that the larger height difference is achieved from the stronger bending force. However, as the force increased, the standard deviation of the height difference is also increased.

**- Experiment II**

From Experiment I, it is seen that the standard deviation of the height difference is quite large and might become problem if the arm is bended only 1 time. In this experiment, the effect of number of bending is studied. The bending force is now set to 200 steps. The number of HDD arms is 50 pieces. Each HDD arm is bended 1 time with 200-step force and measured the height before and after bending.

The difference height between before and after bending is shown in Figure 4. Similar process is repeated but each with 5-time bending. The difference height is shown in Figure 5.

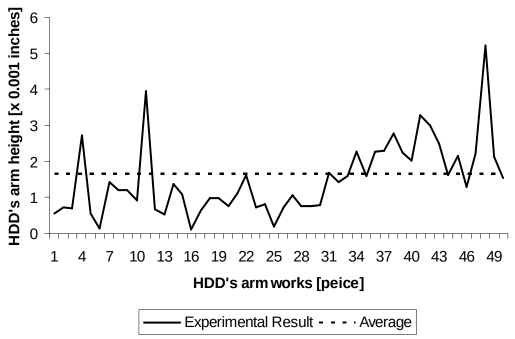


**Figure 4.** HDD's arm height difference for 50 HDD's arms: with 200-step bending force and 1-time bending

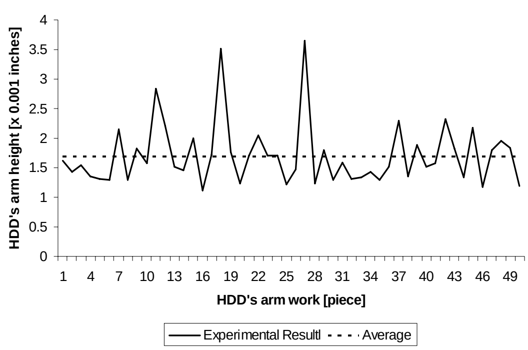


**Figure 5.** HDD's arm height difference for 50 HDD's arms: with 200-step bending force and 5-time bending

From Figure 4 and 5, as the number of bending times increases, the average height difference is slightly increased (see the dotted line in both figures). And, variation of the height difference for the case of 1-time bending is quite large while the variation for the case of 5-time bending is smaller.

**Table 2.** The HDD's arm height difference from 200-step force with 1-time and 5-time bending.

| Number of Bending | HDD's arm Height Difference [inches$\times 10^{-3}$] | |
|---|---|---|
| | Average | Standard Deviation |
| 1-time | 1.65 | 1.08 |
| 5-time | 1.69 | 0.50 |

The average and standard deviation of the height difference from Figure 4 and 5 are given in Table 2. It is clearly seen that as the average is slightly increased as the number of bending time increases from 1 to 5. The significant result is from the decrease of standard deviation (from 1.08 x $10^{-3}$ to 0.50 x $10^{-3}$) as the number of bending time increases. This result shows that to get more reliable bending height, the number of bending time should be high. However, if the number of bending time is too high, the process becomes time-consuming and might not useful in practice.

**- Experiment III**

In this experiment, the effect of bending force on the height difference is studied. The bending forces are 150, 175, 200, 225, and 250 steps, respectively. For each bending force, 50 HDD's arms are used. Each arm is bended 5 times and the height difference between before and after bending is determined. The HDD's arm height difference for different bending forces is shown in Table 3. And, the plot of the average height difference as a function of bending force is given in Figure 6.

**Table 3.** The HDD's arm height difference from different bending forces.

| # of Steps | Difference of HDD's arm height after bending [inches x $10^{-3}$] | | | | |
|---|---|---|---|---|---|
| | 150 | 175 | 200 | 225 | 250 |
| AVG | 0.30 | 0.42 | 1.69 | 3.45 | 5.14 |
| STD | 0.19 | 0.24 | 0.50 | 0. 84 | 1.24 |

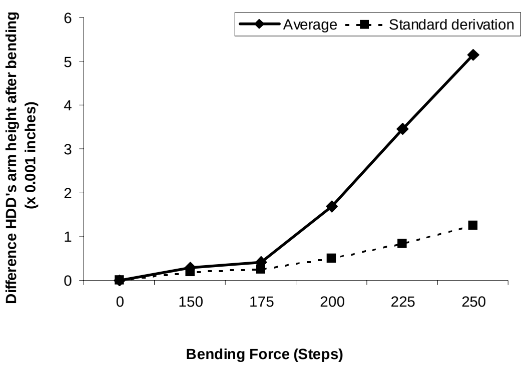


**Figure 6.** The HDD's arm height difference as a function of bending force.

From Table 3 and Figure 6, it is seen that as the bending force increases, the arm height difference is increased. However, the increase of the height difference is not linearly proportional to the bending force. Considering the standard deviation, we get that as the bending force increases, the standard deviation of the height difference increases but not linearly proportional to the bending force.

The experimental results in this section can be used as the basic information in the designing of Fuzzy logic to control the bending force. This is shown in the next section.

## Fuzzy Logic Design

From the data achieved from Section 3, especially from the average curve in Figure 6, the membership function for Fuzzy logic can be designed. There are two types of membership function defined; that is, the one with the error height as the input and the one with the bending force as the output as shown by Figure 7 and 8, respectively.

For the error height membership function, three groups can be formed; that is, small = 0 to 2.5 x $10^{-3}$ inches, medium = 1.5x$10^{-3}$ to 3.5 x $10^{-3}$ inches, and large $\geq$ 2.5 x $10^{-3}$ inches, respectively. The membership function is shown in Figure 7. And, for the output bending force, three groups can be formed in Figure 8; that is, light = 150 steps, normal = 200 steps, and heavy = 250 steps, respectively.

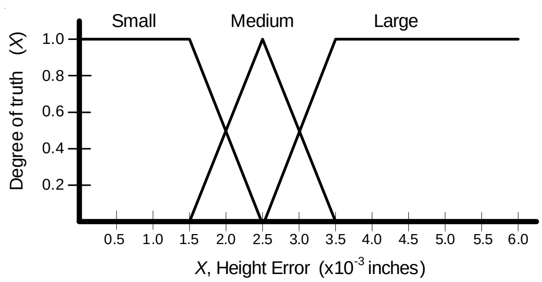


**Figure 7.** Error height membership function.

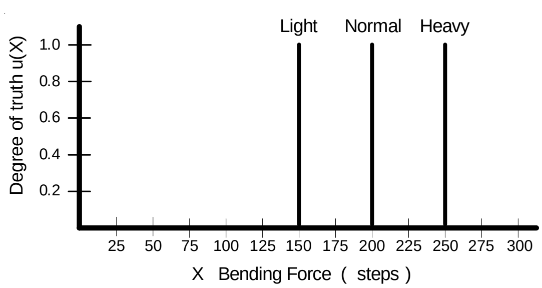


**Figure 8.** Bending force membership function.

## Conclusions

The HDD's arm is a crucial element in HDD's head assembly since it is the part holding the media and accessing to the data recorded in the media. The major error in HDD's arms is the height of the arm that might not follow the specification. The height has to be adjusted appropriately. Conventionally, HDD's arms with this error are sent to a machine called bending machine to bend the arm with a pre-defined force in order to make the arm be at the correct height. The problem associated with the pre-defined force is that some errors could not be reduced since the force used is too strong. In this paper, the achieved heights from different experiments are collected. It is shown that putting more bending force to the arm, the achieved height difference becomes large. However, the relationship between the height difference and the input bending force is not linearly proportional. Using the collected data, the Fuzzy membership functions are designed as shown in Figure 7 and 8. These two figures can be used as a guideline in controlling the bending force associated with the input error height so that the HDD's arm bending process can be improved since the bending force is now not pre-defined but depending on the input error height of the HDD's arm.

## Acknowledgement

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## References

Coleman, C.P. 1994. "A comparison of robustness: fuzzylogic, PID, and sliding mode control," *the Third IEEE Conference on Fuzzy Systems*, June 26 - 29.

Klir, G. J. 1995. "Fuzzy logic," *IEEE Potentials*, Vol.14, Issue 4, Oct - Nov: 10 - 15.

Ramot, D. and et al., 2003. "Complex fuzzy logic," *IEEE Transactions on Fuzzy Systems*, Vol.11, Issue 4, Aug : 450 - 461.

Rich Elaine and Knight Kevin, 1991.*Artificial Intelligence*, McGraw-Hill.

Russell Stuart and Norvig Peter, 2003.*Artificial Intelligence: A Modern Approach*, Prentice Hall.

Zadeh, L. A. 1994. "Fuzzy logic: issues, contentions and perspectives," *1994 IEEE International Conference on Acoustics, Speech, and Signal Processing* (ICASSP - 94), April 19 - 22.