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Reduction of Bending Defects in Hard Disk Drive Suspensions

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Abstract: - The objective of this research was to reduce the rate of bending defects in hard disk drive suspensions by applying the Six Sigma method. The study first defines the problem, gives the project objective and scope. Then, the Attribute Agreement Analysis was performed to ensure the reliability of the inspection results. Process Mapping then lists the Process Input Variables that lead to bending defects. Then, the effects of various variables on bending defects were analyzed using the Cause and Effect Matrix. The criteria of the Failure Mode and Effects Analysis technique were then used to reduce the number of variables and prioritize the Key Process Input Variable (KPIV) for further analysis. Following this, process factors were improved by changing tray design in Laser Welding, Cutting, Forming, Final Trim, Damper Attachment and Backend processes. The tooling die was modified in the forming process. The handling tool was modified in the Final trim and Damper Attachment processes. Finally, the creation or revision of standard work instructions (Do/ Don't) were done and the operators were trained. After that, a control plan was set up to control production processes. The results show that the bend defect rate decreased from 15649 PPM to 9263 PPM.

Keywords: - *Bend Defect, Hard Disk Drive Suspension, Six Sigma, Hypothesis Testing, Defect Reduction*

I. INTRODUCTION

A suspension is a component of a hard disk drive designed to record and write data on a hard disk. Suspension manufacturers need to focus on the costs of production as well as the performance, reliability and stability of the system. As a result, manufacturers must find ways and means to improve quality in order to remain competitive in terms of cost and quality in a highly competitive industry.

This research was designed to reduce production costs by reducing waste generated from the production of defective suspensions and to produce quality products to meet the needs of consumers. Bending is one of the top three defects and generates the highest scrap costs in suspension system production. Bend defects in suspension systems occur from improper assembly processes. Thus, there is a need to understand each factor in the process that creates bending defects in order to reduce defects. To determine this relationship, effective experiments have to be performed to obtain experimental results. Hypothesis testing is a technique used to test the significance of factors analyzed and post-process improvement.

Hard disk drive suspensions consist of five main parts: a mount plate, load beam, hinge, damper and flexible circuit (flexure). The suspension assembly process starts with cleaning, cutting and forming raw material (load beam and flexure), then laser welding assembly of components (formed load beam, formed flexure, mount plate), cutting suspension, pre-gram load and statistic forming suspension, final trim suspensions, cleaning, annealing, damper attachment, gram load and static attitude adjustment, final visual inspection, quality audit and packing. In the assembly process there are many factors that may affect disk bending such as machine tooling, the die contacting the suspension directly and incorrect operating procedures. There will be a reduction of defects if these factors are corrected.

II. LITERATURE REVIEW AND METHODOLOGY

This research aims to study and improve all types of factors affecting bend defects in hard disk drive suspensions. Thus, a systematic method was utilized to prioritize, select, and improve the most important factors leading to such defects. The principle objective was to decrease defects, reduce production costs, and create value [1]. The Six Sigma approach consists of five steps known as DMAIC which represents Define, Measure, Analyze, Improve, and Control. This paper implemented the DMAIC procedure of the Six Sigma approach. In the Define phase, a project charter and process map were written to describe the problem and current processes. In the Measure phase, the measurement system and process capability were analyzed to ensure that the current performance of the process was correctly understood. In the Analyze phase, key process input variables (KPIVs) were identified and reduced for further investigation in the next phase using the Cause-and-Effect Matrix and the criteria from the Failure Mode and Effects Analysis. In the Improve phase, the design of experiment technique was used to test for the significance of the selected factors and to determine optimal levels of significant factors. In the Control phase, a control plan and other control tools including control charts and check list, were set up to maintain performance after improvement [2].

Many studies have applied the Six Sigma approach and shown that it can help companies worldwide save costs and effectively achieve targets for the reduction of defect rates in production [3],[4],[5]. Also, the Six Sigma method is an effective way to perform quality improvement in various industries as has been shown by Ruthaiputpong and Rojanarowan [6] who used the Six Sigma approach to increase the read/write area of hard disk drives. Sonphuak and Rojanarowan [7] applied DMAIC steps in a case study to improve the strength of modulus of rupture (MOR). Artharn and Rojanarowan [8] presented methods to reduce dent defects in the flexible printed circuit manufacturing process by applying the Six Sigma quality improvement method. Finally, Kaewon and Rojanarowan, [9] applied the Six Sigma method to study the effect of assembly process factors on seal strength of a VRLA battery.

III. RESULTS

3.1 Define Phase

In the Define Phase, the project charter was written. The project charter consists of the Problem statement, Objective Statement, Project Scope, Project Metrics, Project constraints, Project assumptions, Team members and Timeline. Table 1 shows the project charter. The rate of bend defects in hard disk drive suspensions was reported at 15649ppm. This defect rate amounts to 9,944,224 THB/year in losses. The research goal is thus to decrease the defect rate to 13800ppm (70% reduction from entitlement 13000ppm) by December 2013.

Table 1 Project Charter

Project Title:	Reduction of bend defects in hard disk drive suspensions
Business Case:	Suspension product defects cause a significant scrap cost and customer claims.
Problem Statement:	Based on the hard disk drive suspension yield report of product S+M, there was a high bend defect rate of 15649 ppm from January-June 2013. This led to losses of suspension products on average of 9,944,224 THB/year.
Objective Statement:	To reduce bend defects from 15649 ppm to 13800 ppm (70% from entitlement 13000 ppm) of product S+M by end of December 2013 as measured by a hard disk drive suspension yield report.
Project Scope:	Study of product S+M
Project Metrics:	● Business metric: Customer satisfaction ● Primary metric: Bend Defect rate ●Secondary metric: machine UPH ●Consequential metric: Investment in resources ● Financial Metric: Cost of scrap and rework
Project Assumption:	The champion supports the project and team has authority to do experiments and implement solutions.
Project Constraints:	Team meets two hours/week with information updates by email.
Team Member:	• Director/ Manager/ Engineers: Manufacturing, Tooling, Equipment, Product and Quality

3.2 Measure Phase

In the Measure Phase, the Measurement System Analysis (MSA) of bend defects is performed to make sure that measurements are reliable. The measurement system is tested by visual inspection for Attribute data. Then, an Attribute Agreement Analysis was performed to study 42 operators and two replicates. In this study the Repeatability results within Appraiser for each operator was more than 95.0% while the value between Appraisers (Reproducibility) was 90.0%. The Kappa was >0.90 which shows that the measurement system had sufficient reliability from inspection agreement to measure the process [10].

In order to understand the process before the Analyze phase, a study of problems and preliminary data analysis was performed. Bend defects were defined then a failure analysis was performed by characteristics and Zone.

The pie chart in Fig. 1 shows major defect characteristics by zone. The contribution on defects from the four zones was as follows: BE1 (48%), BE2 (13%), BE3 (16%), and BE4 (23%). Thus, BE1, BE3, and BE4 zones were chosen to be improved further since they contributed 87% of total defects.

Following that, the defect analysis by operation was done to find out which main operations created the defect by visual mapping before and after each process. A sample size (n) of greater than 708 pieces was needed to ensure the power of the test was >80% [11].

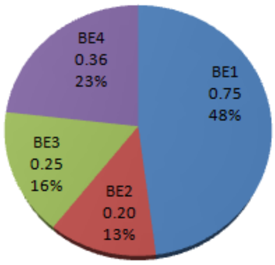

Fig. 1 Pie Chart showing Contribution on Bending Defects

Table 2 Defect Data by Process

Process	Qty Inspect		BE1	BE3	BE4	Total
Flexure Forming	1600	Defective	0	0	0	0
		%Defective	0.00%	0.00%	0.00%	0.00%
Laser Weld	1600	Defective	0	6	2	8
		%Defective	0.00%	0.38%	0.13%	0.50%
Cutting	1592	Defective	0	6	0	6
		%Defective	0.00%	0.38%	0.00%	0.38%
Forming	1586	Defective	6	7		13
		%Defective	0.38%	0.44%	0.00%	0.82%
Final Trim	1573	Defective	0	2	0	2
		%Defective	0.00%	0.13%	0.00%	0.13%
Cleaning	1571	Defective	0	0	0	0
		%Defective	0.00%	0.00%	0.00%	0.00%
Annealing	1571	Defective	0	0	0	0
		%Defective	0.00%	0.00%	0.00%	0.00%
Damper Attach	1571	Defective	0	12	3	15
		%Defective	0.00%	0.76%	0.19%	0.95%
Backend	1556	Defective	0	1	0	1
		%Defective	0.00%	0.06%	0.00%	0.06%
FVMI	1555	Defective	0	0	0	
		%Defective	0.00%	0.00%	0.00%	0.00%

The results shown in Table 2 found six processes created bend defects including: laser welding, cutting, forming, final trim, damper attachment and backend. Next, process mapping was performed to list Process Input Variables (PIV) that affected bend defects. Then each factor was prioritized using the Cause & Effect Matrix and the score rating from FMEA [12], [13] led to six process variables for analysis of significance in the analysis phase.

3.3 Analyze Phase

In this phase, the KPIVs which affected the bend defect of each process were identified and prioritized. The variables are listed according to 5M categorization (man, machine, method, material, measurement). The six process factors were selected to be analyzed further to see if they statistically affected bend defects of suspension systems. Hypothesis testing was done to test the significance of those factors. The details of experiments from visual inspection of each KPIV with a sample size of 1000 pcs (power of test>80%) was noted [11] and then analyzed using a proportion test to establish whether and which KPIVs created bend defects or not [14]. See the results in the Hypothesis of list KPIVs in Table3.

Π : Proportion of bend defects
$H_0 : \Pi = 0$,
$H_a : \Pi > 0$

Table3 Hypothesis Testing Results for KPIVs with α = 0.05

Process	KPIVs	Hypothesis Test	Gage	KPOVs	Result	Action Plan
Laser Weld	Position to lift the TG out of tray	Proportion	Visual inspection	Bend Defect	Significant	Revise WI Do Don't
	Clearance between part and tray	Proportion	Visual inspection	Bend Defect	Significant	Design New Tray
	Clearance between part and hand tool	Proportion	Visual inspection	Bend Defect	Not Significant	-
Cutting	Clearance between part and hand tool	Proportion	Visual inspection	Bend Defect	Not Significant	-
	Clearance between part and tray (strip level)	Proportion	Visual inspection	Bend Defect	Not Significant	-
	Clearance between part and die	Proportion	Visual inspection	Bend Defect	Significant	Modify Die
Forming	Clearance between part and hand tool	Proportion	Visual inspection	Bend Defect	Not Significant	-
	Clearance between part and tray (strip level)	Proportion	Visual inspection	Bend Defect	Significant	Design New Tray
	Clearance between part and die	Proportion	Visual inspection	Bend Defect	Significant	Modify Die
Final Trim	Position to hand carry the tray	Proportion	Visual inspection	Bend Defect	Not Significant	-
	Die condition	Proportion	Visual inspection	Bend Defect	Not Significant	-
	Clearance between part and die/pin	Proportion	Visual inspection	Bend Defect	Not Significant	-
	Clearance between part and tray (strip level)	Proportion	Visual inspection	Bend Defect	Significant	Design New Tray
	Clearance between part and tray (piece part level)	Proportion	Visual inspection	Bend Defect	Significant	Design New Tray
	Clearance between part and hand tool	Proportion	Visual inspection	Bend Defect	Significant	Design New hand tool
	Position of part in tray	Proportion	Visual inspection	Bend Defect	Significant	Design New hand tool
Damper attach	Clearance between part and tray	Proportion	Visual inspection	Bend Defect	Significant	Design New Tray
	Handling	Proportion	Visual inspection	Bend Defect	Significant	Design New Tray
	Clearance between part and hand tool	Proportion	Visual inspection	Bend Defect	Significant	Design New hand tool
	Position of part in tray	Proportion	Visual inspection	Bend Defect	Significant	Design New hand tool
Backend	Position to hand carry the boat	Proportion	Visual inspection	Bend Defect	Significant	Revise WI Do Don't
	Clearance between part and tray	Proportion	Visual inspection	Bend Defect	Not Significant	-
	Handling	Proportion	Visual inspection	Bend Defect	Not Significant	-

3.4 Improve Phase

In the improvement phase, KPIVs which displayed significant differences were included in improvement plans to reduce bend defects which have four actions in table 4. Action 1- Design a new tray to solve the problem of clearance between parts and the tray where the upper tray directly presses on the parts; a small lump makes the part bend. Action 2 - Design a new hand tool to solve the clearance problem between parts and the hand tool which tends to get stuck with the upper tray during unloading from the final trim tray by the strip below. This either presses the part into its correct position or makes it drop outside its correct position which creates bends. Action3 - Modify the die to solve the problem of clearance between parts and the die by tooling the die to operate with direct contact with the work piece. Action4 - Revise work instructions to train the operator in the correct operating method.

Table 4 Improvement Plan

No.	Action Plan	Cause of Problem	Concept Improvement	Implement Process	Hypothesis Test	Result
1	Design New Tray	1. The lump on the center bar presses on the suspension make the bend defect 2. The upper tray sticks to the strip of the lower tray, causing a bend defect. 3. Location of pin at tail causes bend defect.	Design new tray to prevent lumps on the center bar pressing on the suspension and to keep the upper tray from sticking to the strip of lower tray and allocate the locating pin to correct position.	Laser, Cutting, Forming, Final Trim, Damper and Backend	Proportion	Significant
2	Design New hand tool	Locating cavity is oval so the position is not so accurate. This causes the part to fall outside its cavity.	Design locating cavity alignment by circle hole.	Final Trim, Damper Attachment	Proportion	Significant
3	Modify Die	Clearance between the part and die is close which creates opportunities for bend defects while the tooling die operates.	Relief tooling material to avoid direct contact while die operates to prevent bend defect.	Forming	Proportion	Significant
4	Revise Work Instruction	The problem caused by operator error such as mistake in load-in and re-loading.	To reduce this problem, Do/Don't WI is created.	Laser Weld, Backend	Proportion	Significant

3.5 Control Phase

In the control phase, the control plan was created as shown in Table 5.

Table 5 Control Plan

Process	Checking Method			Sampling Plan		Triggering point		
	Equipment	Product Characteristics	Specification / Disposed by	Sample Size/ Frequency	Response	Trigger Limit	Action	Response
Laser Weld, Cutting, Forming, Final Trim, Damper Attach and FVMI	Micro scope 10X	Bend defect	Refer to visual inspection document	10Pcs./ 2 Lots	QC	Out of spec	1,2	Process/ Maintenance Engineer

Legend: Action: 1 = Stop Machine, 2 = Adjust / Fix/ Change

The result after implementation on the production line is the Bend defect decreased to 9263 ppm as seen in Fig. 2 Bend defect trends.

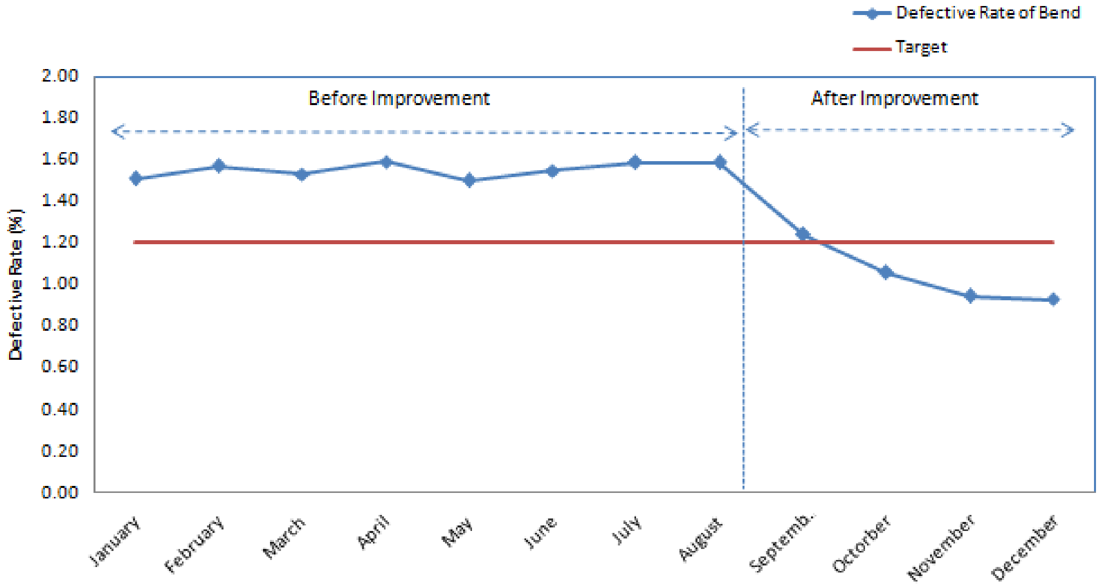

Fig.2 Bend Defect trends

Table 6 shows the comparative results before and after improvement. It shows that the defective rate from bend defect decreased from 15649 ppm to 9263 ppm, which achieved the target of 13800 ppm. The cost reduction of 9,944,224 THB/year to 4,583,970 THB/year (5,360,254 THB/year saving) was realized.

Table 6 Bend Defect Before-After Improvement

Item	Before Improve	After Improve (Forecast Input)	Improvement
Input (Piece/ Year)	38,797,932	30,000,000	-
%Bend Defect	1.56	0.93	0.63
Bend defect (Pieces)	605,248	279,000	326,248
Price / piece (Baht)	16.43	16.43	-
Loss / Year (Baht)	9,944,224	4,583,970	5,360,254

IV. CONCLUSION

This paper presented a method to reduce bend defects in suspension systems in hard disk drives. The Six Sigma approach with DMAIC steps was applied. In the Define Phase the problem, the objective, and the scope of project were identified. In the Measure Phase, the attribute agreement analysis was performed. Then, the Process Input Variable (KPIV) of bend defects were prioritized by using the Cause and Effect Matrix and the criteria of FMEA. Next in the Analyze phase, the Hypothesis Testing was used to test for significant causes of bend defects. In the Improve phase, steps were taken to design a new tray, a new hand-tool, modify the die and revise the work instructions to improve the bend defect. Finally, in the Control phase, the control plan was set up by document control and responsible technicians assigned. The results after implementation is bend defects were reduced from 15649 ppm to 9263 ppm (better than target 13800ppm).

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