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YIELD ENHANCEMENT WITH SIX SIGMA METHODOLOGY IN SPINDLE MOTOR HUB ASSEMBLY FOR HARD DISK DRIVE PRODUCTION

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Abstract. *This paper presents a systematic improvement using Six Sigma methodology for increasing process yield in a spindle motor hub assembly for hard disk drive (HDD) production. A data-driven DMAIC (Define, Measure, Analyze, Improve, Control) approach is utilized to improve the existing process for press fitting a hub assembly into a bearing assembly. A Six Sigma defect is defined as any hub/bearing assembly that fails the axial run-out testing for high rotational speed of 7,200 rpm. Optimization of process parameters for defect reduction to enhance process yield is based on the use of Minitab software with Taguchi method. Statistically significant results confirm that the manufacturing yield can be increased from 99.28% up to 99.78%.*
Keywords: Six Sigma, Yield enhancement, Production defect, DMAIC, Taguchi method

1. **Introduction.** Six Sigma is an improvement methodology for providing a framework to make an organization more competitive by focusing on variation reduction and waste reduction that lead to less defect rate and increase efficiency. One of the major tools in Six Sigma approach is the use of the five-step cycle known as DMAIC, which represents Define, Measure, Analyze, Improve, and Control, for reducing defects in production processes to enhance yield outputs [1,2], for solving problems to improve quality performance [3], and for analyzing restrictions to improve testing process capability [4]. Moreover, the Six Sigma DMAIC approach is also applied to identifying defects and variations in production processes and to determining how to reduce them for increasing process yield in hard disk drive (HDD) manufactures [5,6]. However, we develop this idea in different aspects to yield improvement for press fitting a hub assembly unit and a bearing assembly unit together during the production of spindle motor hub assembly for an HDD manufacturer when considering the concept of 'zero defects' for maximization of profitability and improvement in quality.

This paper aims to propose an implementation of step-by-step DMAIC procedures to solve the underlying problem of defect elimination for enhancing process yield. In Define phase, the rolled throughput yield was used to assess the true yield of the interesting process, and the project goal was set. In Measure phase, validating measurement systems using measurement system analysis (MSA) and gathering root causes such as fishbone diagram analysis and failure mode effects and analysis (FMEA) were focused. In Analyze phase, key process input variables (KPIVs) were identified and reduced by using the variable screening method based on hypothesis testing. In Improve phase, the design of experiment (DoE) with Taguchi's method was utilized for testing the significance of the selected KPIVs and for determining optimal levels of the significant factors. In Control phase, a control plan was set up to assist in tracking and correcting the performance of the KPIVs and key process output variable (KPOV).

The remainder of this article is organized as follows. Section 2 describes a case study for enhancing the manufacturing process yield, and Section 3 discusses the research results that illustrate the application of the Six Sigma DMAIC approach in the case study. Finally, Section 4 concludes the paper.

2. **Case Study.** This case study was executed in the HDD base plate and spindle motor manufacturer in Thailand. It deals with the reduction of significant defect in the production process of spindle motor hub assembly, sometimes called motor base assembly (MBA) as shown in Figure 1, which consists of bearing assembly unit, spindle hub assembly unit (rotor), and bracket assembly unit (stator). The MBA is assembled by two major processes. The first process is press fitting of the spindle hub assembly unit to the bearing assembly unit. The hub/bearing assembly unit is crucial to the HDD performance in terms of precision and reliability. It demands a high center run-out precision of 0.014 mm at the outside periphery of the rotor york. The axial run-out measurement and judgment are then performed on the production line for quality control. In the next process, the hub/bearing assembly passing the run-out testing is combined with the bracket assembly unit.

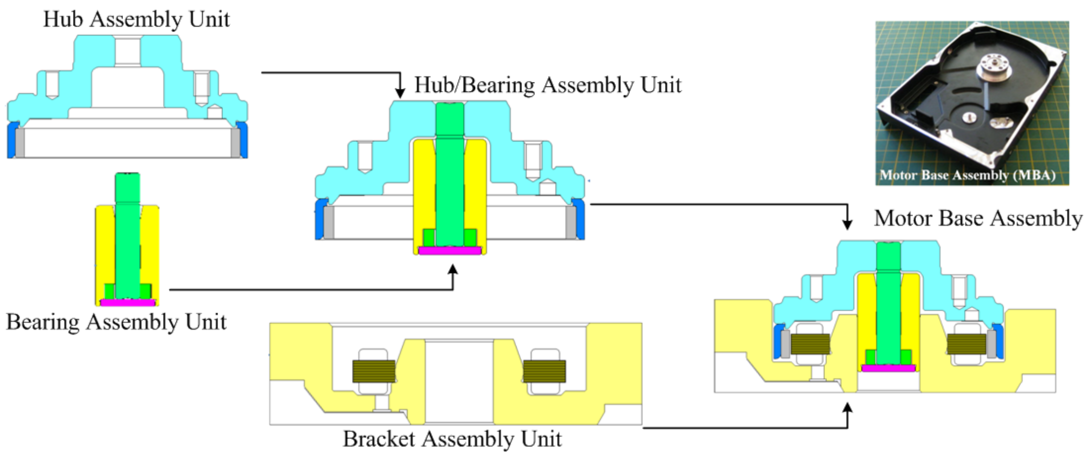

Figure 1. Schematic view of spindle motor hub assembly (or motor base assembly)

3. **Results.** Since the rejection level of the hub/bearing assembly unit after axial run-out testing for high rotation speed was high, and the function of this component in the finished product was highly critical, it was required to do 100% inspection. The Six Sigma DMAIC methodology was recommended for solving the interesting problem to discover the root causes.

3.1. **Define phase.** In the Define phase, the rolled throughput yield was used for true assessment of the process effectiveness. It was a large number of defects in hub/bearing assembly units from the process of press fitting the spindle hub assembly unit and the bearing assembly unit together at yield baseline of 99.28%. This defect rate amounts to 1.1 million THB/year in losses. The hub/bearing assembly that fails the axial run-out testing for high rotational speed of 7,200 rpm (see Figure 2) is defined as the defect. Thus, yield enhancement was set as the project goal.

3.2. **Measure phase.** In this phase, the MSA of defects was performed in order to assess the validity of the measurement systems. The team decided to carry out the gauge repeatability and reproducibility (GR&R) study, one of the tools in the MSA, to assess the precision errors. Results of the GR&R study and correlation with master tester are summarized in Table 1, where the acceptable criteria levels are %Contribution $\leq$ 1%, %Study Variance $\leq$ 10%, %Tolerance $\leq$ 10%, and Number of Distinct Category (DC) $\geq$

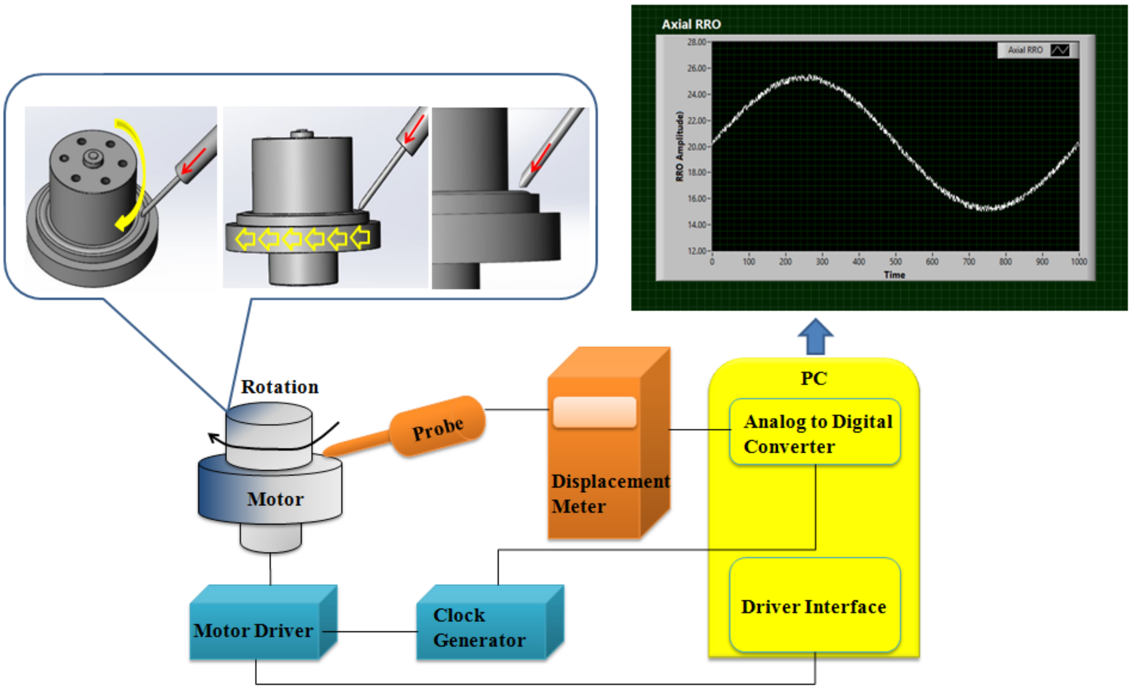

FIGURE 2. Axial run-out testing

TABLE 1. Results of the GR&R study and correlation with master tester

AxRRO Tester	%Contribution	%Study Variance	%Tolerance	No. DC	R-square	Pair-T-Test
TFX46021	0.02%	1.56%	4.31%	90	99.9%	P = 0.956
TFX57184	0.02%	1.44%	4.02%	97	99.9%	P = 0.644
TFX57190	0.03%	1.63%	4.63%	86	99.8%	P = 0.828

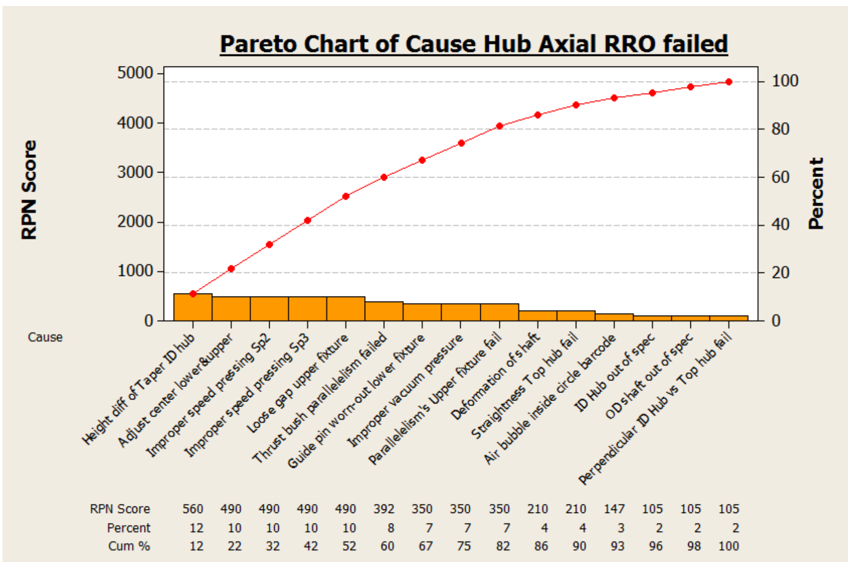

FIGURE 3. Pareto chart to display the potential causes of the defects

4. In order to identify the true root cause of the problem, the cause and effect diagram (or fishbone diagram) for team brainstorming possible causes was utilized to focus on the possibilities grouped into five categories: tester, bearing assembly, part, hub/bearing assembly, and hub assembly. Moreover, the FMEA was used as a tool to concentrate on

assessing the effects and process controls for the root causes related to the given failure modes. Figure 3 shows the Pareto chart to display the potential causes of the defects.

3.3. **Analyze phase.** In the Analyze phase, the nine KPIVs were identified as shown in Figure 4 providing significant impacts for the defects from axial run-out testing. In order to narrow down and verify the root causes of defects, the hypothesis testing was done for validating the relationships between KPIV and KPOV. The axial repeatable runout (RRO) rotor was defined as the KPOV. The sample size was 84 pieces for testing each KPIV (power of test $> 90\%$). Table 2 gives the hypothesis testing results for KPIVs with $\alpha = 0.05$.

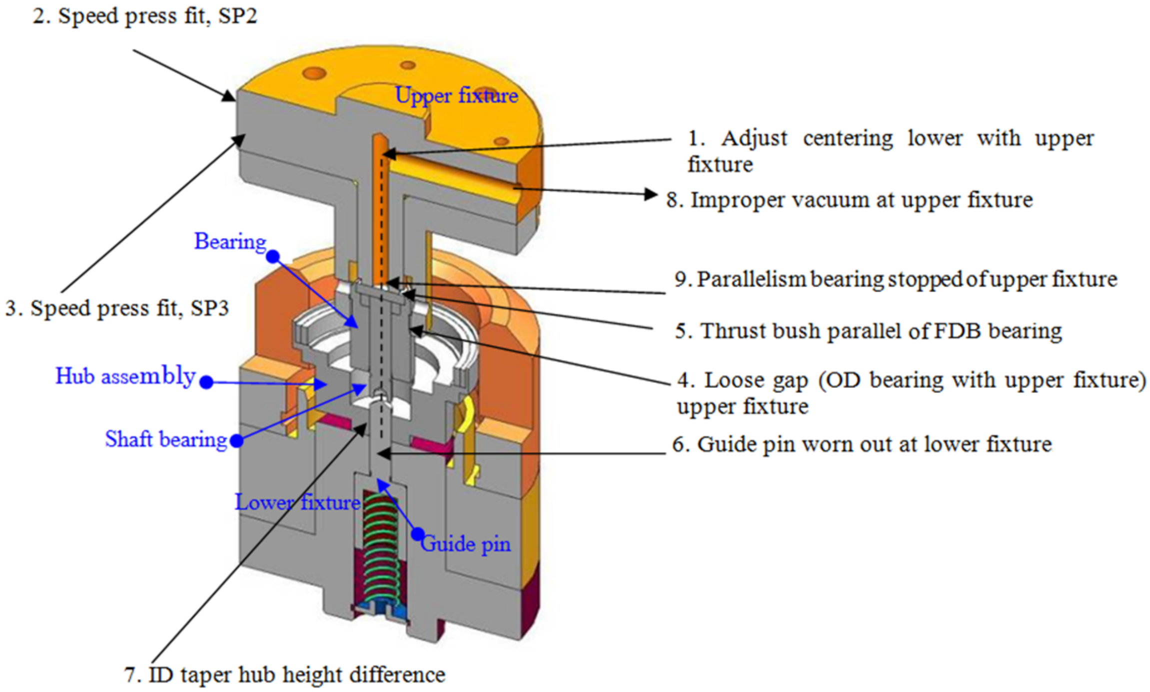

FIGURE 4. Nine potential KPIVs providing significant impacts for the defects

TABLE 2. Results of hypothesis testing for KPIVs with $\alpha = 0.05$

KPIV	P value	Result	Comment	Action
Adjust centering lower/upper fixture	0.383	Not Significant	Set SOP	Ahead action (Set SOP)
Improper pressing speed 2	0.014	Significant	Optimize	DoE
Improper pressing speed 3	0.123	Not Significant	Optimize	DoE
Loose gap of upper fixture	0.000	Significant	Current better	N/A
Thrust bush parallel of FBD bearing	0.6053	Not Significant	Action Control Plan	Ahead action (5 μm Max.)
Guide pin condition	0.0003	Significant	Current better	Ahead action (Taper pin)
ID taper hub height difference	0.001	Significant	Optimize	DoE
Improper vacuum pressure/upper fixture	0.087	Not Significant	Optimize	DoE
Parallelism of upper fixture failed	0.000	Significant	Set new spec.	Ahead action (0.002 mm Max.)

Table 3. Factors and levels of factors

Code of Factor	Description	High Level	Current Level	Low Level	Unit
Axial play	Axial gap height of bearing	0.014-0.015	N/A	0.018-0.020	mm
Speed 2	Speed press fit, SP2	1.5	2.75	4.0	mm/sec
Speed 3	Speed press fit, SP3	0.3	0.65	1.0	mm/sec
Vacuum	Improper vacuum at upper fixture	−50	−65	−80	kPa
Pre-heat	Pre-heat temp top surface hub	50	57	60	Deg C
Id Taper	ID taper hub height difference	−0.003	+0.002	+0.003	mm

Table 4. Current setting and DoE optimal values of six selected KPIVs

Code of Factor	Description	Current Value	DoE Optimal Value	Unit
Axial play	Axial gap height of bearing	0.014-0.018	0.0161	mm
Speed 2	Speed press fit, SP2	2.50	1.5	mm/sec
Speed 3	Speed press fit, SP3	0.70	1.0	mm/sec
Vacuum	Improper vacuum at upper fixture	−80	−80	kPa
Pre-heat	Pre-heat temp top surface hub	65	58	Deg C
ID Taper	ID taper hub height difference	+0.003	0.0003	mm

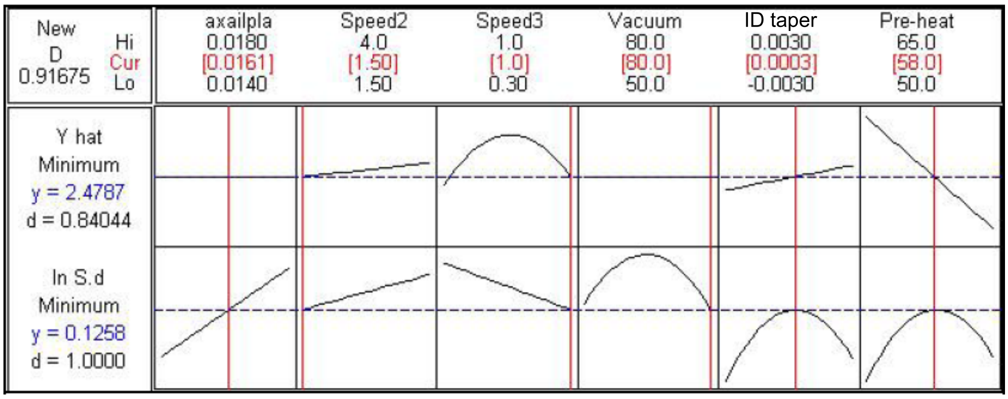

Figure 5. Optimal process parameters

3.4. **Improve phase.** In this phase, using the factors and levels as summarized in Table 3, the DoE using Taguchi L18 approach was chosen for testing the significance of the six KPIVs selected as well as for determining optimal levels of the significant factors. Table 4 displays the current setting and DoE optimal values of the six selected KPIVs (see Figure 5). The optimal parameters were used as the new setting values in the process of press fitting the spindle hub assembly unit for yield enhancement. In order to confirm that the optimal parameters can improve the production yield, the experiment was performed. From the hypothesis testing results with $\alpha = 0.05$ as shown in Figure 6, it is evident that the process yield is increased from 99.28% to 99.78%. Figure 7 shows the yield trends of the case study in the analysis phase, improvement phase, and control phase. It is seen that improvement of the yields can be obtained by using Six Sigma DMAIC approach.

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Test and CI for Two Proportions
Sample       X       N    Sample p
1(POR)    14039   14141  0.992787
2(DOE)     4033    4042   0.997773

Difference = p (1) - p (2)
Estimate for difference:  -0.00498645
95% CI for difference:  (-0.00700059, -0.00297231)
Test for difference = 0 (vs not = 0):  Z = -4.85  P-Value = 0.000
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FIGURE 6. Hypothesis two proportion testing results for yield enhancement

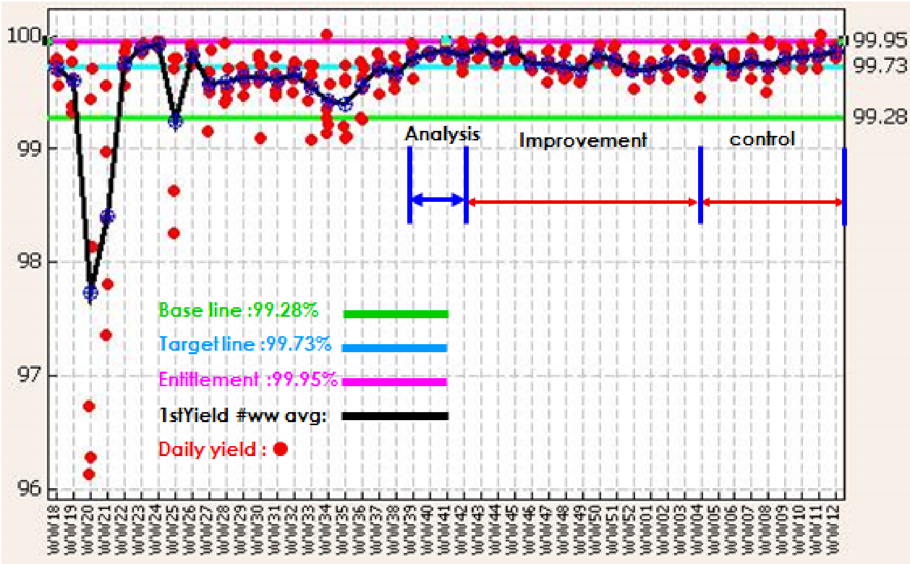

FIGURE 7. Yield trends of the case study

TABLE 5. Control plan

KPIVs and KPOV Control	Status
Machine: Setting process parameters by using DoE optimal values	**Machine**: Done
Material: Monitoring ID of Hub (IQA)	**Material**: Set optimal control of 0.0003 mm.
Method: Set standard alignment upper/lower fixture	**Method**: Establish standard of procedure for training
Measurement: Set up thrush bush parallel tester	**Measurement**: 100 % screening by tester (0.005 mm. Max.)
Monitoring: - KPOV: SPC control (X-bar and S-Chart) - KPIV: Pilot run beginning of shift build	**Monitoring**: - KPOV: Email notification to production personnel - KPIV: Pilot sample verification before running
FMEA: Hub assembly failed axial run-out testing	Reduce the risk priority number (RPN) by using optimal conditions The higher the RPN, the higher potential causes

3.5. **Control phase.** In the Control phase, the control plan was created to assist in tracking and correcting the performance of the KPIVs and KPOV as shown in Table 5.

4. **Conclusions.** Implementing step-by-step Six Sigma DMAIC procedures as the road-map to solve the underlying problem of defect elimination for process yield enhancement has been presented in this paper. A case study of improving the process yield of spindle motor hub assembly production has been discussed. Experimental results verify that the process yield can be increased by the proposed improvement. In the future, a new adjustment of the KPIV values can be made as a result of the completion of the first cycle for continuously improving the production process and decreasing the variances.

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