

A Strategy to Optimize the SPC Scheme for Mass Production of HDD Arm with Clustering Technique and Three-Way Control Chart

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Abstract—Consider a mass production of HDD arms where hundreds of CNC machines are used to manufacture the HDD arms. According to an overwhelming number of machines and models of arm, construction of separate control chart for monitoring each HDD arm model by each machine is not feasible. This research proposed a strategy to optimize the SPC management on shop floor. The procedure started from identifying the clusters of the machine with similar manufacturing performance using clustering technique. The three way control chart ($I-MR-R$) is then applied to each clustered group of machine. This proposed research has advantageous to the manufacturer in terms of not only better performance of the SPC but also the quality management paradigm.

Keywords—Three way control chart. $I-MR-R$, between/within variation, HDD arm.

I. INTRODUCTION

IN the hard disk drive (HDD) industry, $\bar{X}-R$ chart has been adapted to monitor the quality of product and process such as a critical quality characteristics: pivot diameter of HDD arm. HDD arms are produced from hundreds of computer numerical control machines. Consider a mass production of HDD arms where hundreds of CNC machines are used to manufacture the HDD arms. According to an overwhelming number of machines and models of arm, construction of separate control chart for monitoring each HDD arm model by each machine is not feasible. The manufacturer chose to adopt a single $\bar{X}-R$ chart for each arm model. The measured values were aggregated, charted on the $\bar{X}-R$ chart with control limits calculated from standard formulae. The measured characteristics were recorded and plotted into the control chart but the HDD arm manufacturer reported a high frequency of an out-of-control signal of the \bar{X} chart especially when run rules are used. This implementation of the single $\bar{X}-R$ chart for all machines has led to a large number plotted points falling beyond the control limits inducing significant time of investigation and cost. To alleviate the shop floor chaos, the control limits were subjectively drawn so that the over indication of the out-of-control is manageable. This procedure resulted in a great deviation of $\bar{X}-R$ performance from the standard since the notion of 3 sigma rule cannot be statistically justified. If there exists a significant degree of variability of the measurement of pivot diameter among different machines, a better strategy of applying SPC is required. There seems to be lacking of reports

on SPC strategy on how to optimize the SPC management for mass processes equipping with hundreds of production units inherited with variation among the units themselves. This research proposed a strategy to eliminate the misuse of the $\bar{X}-R$ and yet optimize the SPC management on shop floor. The procedure started from identifying the clusters of the machine with similar manufacturing performance using clustering technique. The three way control chart ($I-MR-R$) is then applied to each clustered group of machine. This proposed research has advantageous to the manufacturer in terms of not only better performance of the SPC but also the quality management paradigm. Section II provides the literature reviews, framework and assumption of the quality characteristics studied. Section III gives the methodology to design an SPC to achieve a desired performance and provides results of studied. The final section provides the discussion.

II. LITERATURE REVIEWS AND ASSUMPTIONS

It is widely known that the $\bar{X}-R$ chart can have inferior performance when applied to batch production processes exhibiting both between and within batch variation. [1] had considered the effect of batch-to-batch variation on the Shewhart control chart. See [2], [3], [4], and [5] for Shewhart control charts under batch processes. [6] and [7] presented a methodology to constructing Shewhart-type control charts with several components of variance are present. [8] gave excellent review and method on estimating the variance component. [9] provided study on likelihood ratio method for monitoring the parameter of nested design. [10] presented an SPC based on CUSUM scheme to monitor the variance component of the process when there exists batch-to-batch variation. Alternatively, [11] and [12] were the first to present the so-called "Three-Way" control chart to monitor the process inherited with two sources of variation: between and within. The Three-Way control chart consist of three subcharts: (i) a standard deviation or range chart (S or R Chart) for monitoring within subgroup variation, (ii) a moving range chart (MR Chart) constructed from two successive sample means to for monitoring the subgroup (between/short-term) variation, and (iii) a Shewhart Individuals Chart used for monitoring the process stability. [13] gave an excellent computation results on computing method of average run lengths (ARLs) for the Three-Way control chart.

Consider a structure of the measured characteristics $X_{ij} = \mu_0 + a_i + e_{ij}$ where $a_i \sim N(0, \sigma_a^2)$ represented the variation of the pivot diameter produced from different

machines (batch), $e_{ij} \sim N(0, \sigma_e^2)$ represented the natural variation of the pivot diameter within each machine. In the real manufacturing environment, different machines tend to have different operational performance. This might due to the variation in the machine part itself. If the variation between machines is significant comparing with the variation within machine, the process/quality variation can be under-estimated causing too-narrowed control limits. Assuming that the process parameter $\mu_0, \sigma_a^2, \sigma_e^2$ are known. The Three-Way chart monitors the process center, between-sample variation and within-sample variation. The average of pivot measurement from each machine, $\bar{X}_i = \sum_{j=1}^J X_{ij} / J$, is plotted (as individuals) onto the individual chart. The moving range chart of pivot average, $MR_i = \bar{X}_i - \bar{X}_{i-1}$, is plotted on the range chart to monitor the between machine variation. The range statistics, $R_i = \max(X_{ij}) - \min(X_{ij})$, is plotted on the range chart to monitor the within machine variation. The individual chart for statistics $\bar{X}_i \sim N(\mu_0, \sigma_a^2 + \sigma_e^2/n)$ signal the alarm if the plotted value fall above the limits $\mu_0 \pm k(\sigma_a^2 + \sigma_e^2/n)$. The moving range chart for statistics $MR_i = \bar{X}_i - \bar{X}_{i-1}$ signal the alarm if the plotted value fall above the limits $D\sqrt{\sigma_a^2 + \sigma_e^2/n}$. The range chart for statistics $R_i = \max(X_{ij}) - \min(X_{ij})$ signal the alarm if the plotted value fall above the limits $D^*\sigma^*$. Constants K, D, D^* are design parameters chosen on the basis of desired in-control ARL and out-of-control ARL performance. See [12] for more details on the average run length.

III. METHODOLOGY

The specification of the pivot diameter is set-up at 0.5395 ± 0.0004 . Fig. 1 shows an example of a construction of the single $\bar{X} - R$ chart for an arm model during a certain 2 weeks period. The measured values from different machines were aggregated and charted on the $\bar{X} - R$ chart with control limits calculated from standard formulae. Fig. 1 showed an overwhelming number of plotted points falling beyond the control limits. The distribution of the sample average of the pivot diameter are clearly dispersed wider than the natural limits of $\pm 3\sigma$ suggesting the over-dispersion among sample averages.

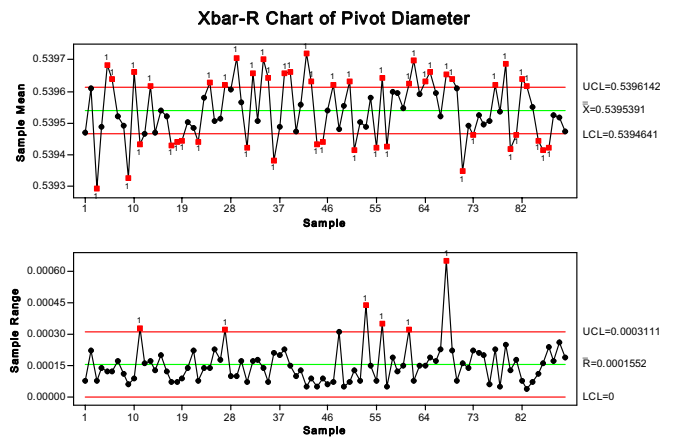


Fig. 1 The single SPC constructed to monitor the pivot diameter

The process capability analysis of the pivot diameter was shown in Fig. 2. The estimate of the standard deviation from within part is significantly smaller than the overall standard deviation. This suggested the validation of the assumption of two levels of variation. As mentioned, the applications of the single $\bar{X} - R$ chart for monitoring the pivot diameter can be misleading since only the variation within were estimated from the range method. The control limits were narrower than it should be since the variation between groups was not recognized. This illustration lead to a strategy for adopting the Three-Way control chart and yet minimize the number of chart used for the whole process.

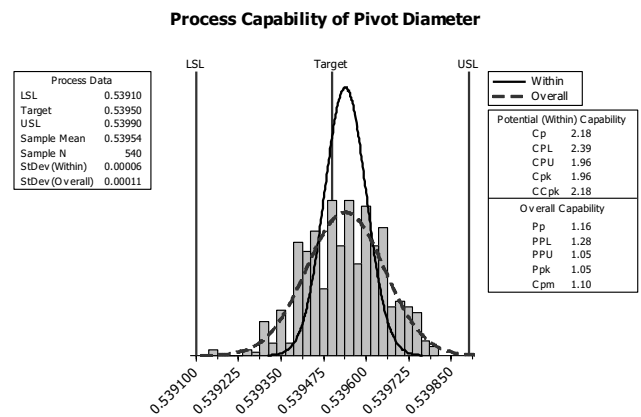


Fig. 2 The process capability analysis result of the pivot diameter

This research proposed the following algorithm:

- Step 1: Profiling the distribution function F of the sample measurements based on each machine (batch).
- Step 2: Determine the number of distinct group of distributions.
 - Step 2.1: Validate statistically if the groups are significantly justified using pair-wise Kolmogorov-Smirnov testing of hypothesis.
 - Step 2.2: Pair-wise Validation: If testing the hypothesis suggest that (i) F_a is

different from F_b and (ii) F_b is different from F_c and (iii) F_c is also different from F_a , then F_a , F_b , F_c are in different group. Otherwise, F_a , F_b , F_c are in the same group.

Step 2.3: Identify group the distribution: After complete step 2.2, the conditional/profiled distribution are grouped.

Step 3: Apply the “Three-Way” control chart of $I-MR-R$ to monitor each classified group of the machine (batch/production process).

Example

Step 1: Profiling the distribution function F of the sample measurements based on each machine (batch).

The distribution of the sample measurement were then estimated and plotted separately for each machine. Figs. 3, 4 show an example of the estimated density and distribution function respectively of the sample measurement from 5 different machines.

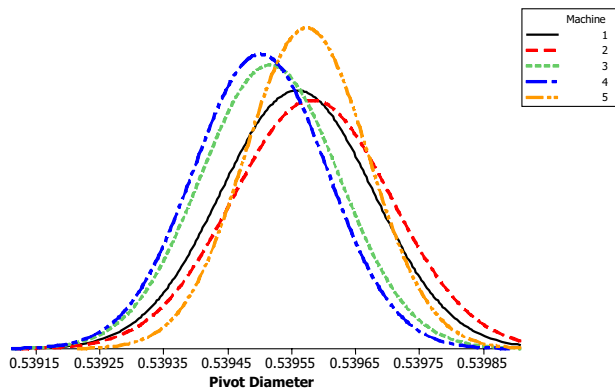


Fig. 3 The estimated density function of the pivot diameter

The word “alternatively” is preferred to the word “alte”

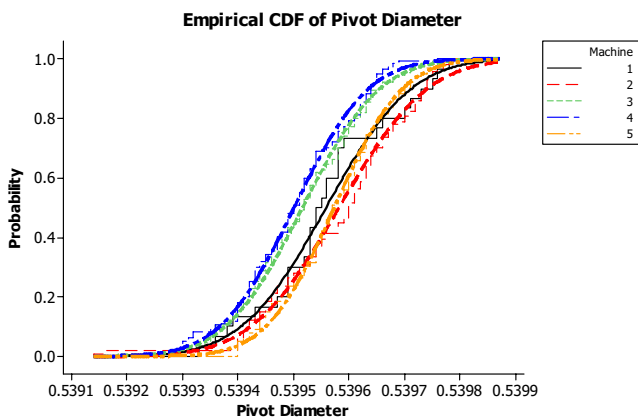


Fig. 4 The estimated distribution function of the pivot diameter

Step 2: Determine the number of distinct group of distributions.

Step 2.1: Validate statistically if the groups are significantly justified using pair-wise Kolmogorov-Smirnov testing of hypothesis.

From Figs. 3 and 4, there seems to be three distinct groups of distribution. The pair-wise Kolmogorov-Smirnov testing of hypothesis was shown in Table I reports the p-value of pair-wise Kolmogorov-Smirnov test for five distributions with the test statistics in the parenthesis.

TABLE I
THE P-VALUE OF PAIR-WISE KOLMOGOROV-SMIRNOV TEST FOR FIVE DISTRIBUTIONS

	2	3	4	5
1	0.0533 (0.2684)	0.2764 (0.1933)	0.0516 (0.2639)	0.4426 (0.1745)
2		0.00008 (0.2751)	0.000003 (0.3191)	0.5472 (0.1068)
3			0.8450 (0.0706)	0.0004 (0.2596)
4				0.0000 (0.3182)

Step 2.2: Pair-wise Validation:

The results of hypothesis testing indicated that (i) F_2 is different from F_3 , F_4 and (ii) F_3 , F_4 are different from F_5 but (iii) F_2 is not significantly different from F_5 . So there is only one distinct group of 5 distributions. Caution need to be taken that one might think that there should be a single distribution since the test results fails to reject any differences in pair-wise comparisons among 5 distributions. The results of analysis clearly showed that there exist both between and within variations in the pivot measurement. Conditional on this fact, there are differences among distributions of the measurement taken from different machine causing variation between sample averages.

Step 2.3: Identify group the distribution:

After complete step 2.2, the conditional/profiled distributions are grouped. There is only one group of five distributions.

Step 3: Apply the “Three-Way” control chart of $I-MR-R$ to monitor each classified group of the machine (batch/production process).

The three way control chart ($I-MR-R$) is then applied to the group of 5 distributions. The estimate of where σ_a^2 were obtained from the standard formulae based on the range statistics calculated based on within and between samples with values of 0.00011² and 0.00006² respectively. See [11] and [12] for more details. The result of construction was illustrated in Fig. 5. The problem of overwhelming points falling outside the control limits is now unrecognizable. This is because the control limits are now correctly estimated.

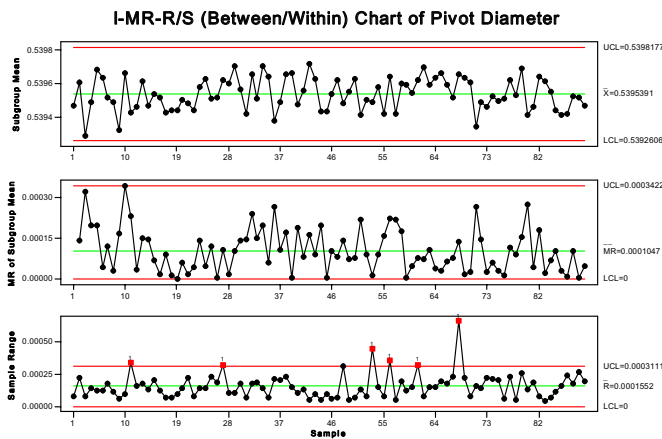


Fig. 5 The Three-Way control chart constructed to monitor the pivot diameter

IV. CONCLUSION AND DISCUSSION

The implementation of Three-Way control chart is suitable for the mass production environment especially for HDD arm manufacturing process that utilized hundreds of processing machine. The separate SPC for each HDD arm by each machine will definitely induced extra time and management cost. Optimization of the SPC scheme and resource leads to a single SPC scheme that can be used to monitor all the machines. Naturally, variations of the quality characteristics are not only stemmed from variation within each processing unit but also among the units. To monitor the process capability, the monitoring scheme needs to account for those two level variations. The Three-Way control chart is one of the SPC schemes that can be utilized for monitoring the process capability. This research emphasized on the strategy of applying the Three-Way control chart of standard type. In order to apply the three-Way control chart effectively and theoretically sensible, variation among machine (batch) units must be defined and verified. Based on the Three-way control chart principle, there must exist a single population of the machine units that induces the variation among the units. If this assumption is not true, it's arguably that the variation among the units could be nested within between different population leading to three levels of variation structure or greater than that. If this is the case the Three-Way control chart of standard type is no longer the right scheme of monitoring. The SPC scheme for higher order variance structure, e.g., based on Likelihood ratio, is required instead. Thus, this research paper show a strategy of applying the Three-Way control chart by identifying the clusters of populations of distribution. The standard procedure of distributional hypothesis testing based on Kolmogorov-Smirnov statistics was adopted. Within each population, the Three-Way control chart of $I - MR - R$ type was then applied. Further study on the comparisons between different types of Three-Way control chart procedure, i.e., $I - MR - S$, $I - MR - S^2$, $CUSUM - MR - R$ can lead to better performance of the monitoring scheme. Finally this research can shed the light on strategy of optimizing the resources for

quality monitoring of not only mass HDD arm production process but also the others.

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