PROCESS CAPABILITY IMPROVEMENT BY PUTTING 'STATISTICAL PROCESS CONTROL' INTO PRACTICE

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Abstract- Quality control helps industries in improvement of its product quality and productivity. Statistical Process Control (SPC) is one of the tools to control the quality of products that practice in bringing a manufacturing process under control. In this paper, the process control of a CNC Grinder manufactured at PMT Machines Ltd. Halol, (Gujarat) India is discussed. The varying measurements have been recorded for a number of samples of a Cam Roller Shoe obtained from a number of trials with the CNC Grinder. SPC technique has been adopted, by which the process is finally brought under control and process capability is improved.

Keywords- *Statistical Process Control, Range and Standard Deviation, Control Charts, Process Capability.*

I. INTRODUCTION

Statistical Process Control (SPC) refers to controlling a process (e.g., grinding) based on responding to process data with statistical techniques and tools. Statistical process control (SPC) describes a widely-used set of approaches used to detect shifts in processes in, for example, manufacturing. Among these are control charts" [1].

PMT Machines Ltd., Halol is one of the leading CNC Machine Tools manufacturers in India. The SPC methodology have been adopted for grinding of Cam Roller Shoes, a component of one of its customer companies, Delphi TVS, Chennai (India).

As the thickness of shoes in different samples after grinding was found to be out of tolerance limits asked by Delphi TVS, the process capability found to be less than the standard value. This required the idea of SPC implementation and the techniques been practiced.

II. LITERATURE REVIEW

The use of statistical concepts in the field of quality emerged in the United States in the beginning of the nineteenth century. But its democratic use began only in the 1930s. W. Edwards Deming, who applied SPC methods in the US during the Second World War, was the one responsible for introducing this concept in Japan after the war ended. These methods were not used in France until the 1970s. The 1980s saw the SPC methods being used frequently, due to the pressure from large clients like automobile manufacturers and aircraft manufacturers.

Companies who have been operating in the market for a while already have a quality control process in place. This process enables a company to meet four main objectives: higher quality, more effectiveness, optimum cost savings and greater rigor, and produces products of optimum quality [1].

SPC tools can be used by operators to monitor their part of production or service process for the purpose of making improvements [2].

A. Goals of SPC:

- understand the process
- eliminate special cause variation
- reduce common cause variation and maintain a process that is in "statistical control" and has high "process capability".

B. Errors and variation can arise from two kinds of causes:

- Special Causes: (assignable, bias, local variation), error/variation results in one direction (either + or -) and can be traced to an assignable, special cause, e.g., miscalibrated instrument. It can be detected by running known standards and recalibrating [3].
- Common Causes: (random, system variation) error/variation results randomly (without bias) in both directions (+ and -) and in varying magnitude – due to unknown causes. Random variation is chronic (continual), e.g., normal fluctuations in instruments, natural variation in raw materials.

Statistics is more applicable to measuring and controlling variation from common cause (random) than from special causes [3].

C. Variations can be reduced by:

- Fundamental Point: Special causes and random causes of variation are treated differently.
- Juran's 85% Rule: 85% of variation is random error in the system and can only be

remedied by management make changes to the system. 15% of variation is special cause and is fixable by the worker.

D. Usefulness of Control Charting:

Control charts are also known as Shewhart charts or process-behaviour charts. Variable control charts are used to study a process when characteristics is a measurement, for example, cycle time, processing time, waiting time, highest, area, temperature, cost or revenue [4].

Control charts detects special causes of variation, measures and monitors common causes of variation, helps to know when to look for problems and adjust or when to keep hands off and when to make a fundamental change [3].

E. Steps in an SPC Program:

- Identify the cause of variation in order to remedy it. This is not always obvious; often it is elusive because manufacturing operations are complex - many interrelated variables. Statistical Control Charts distinguish between Common causes and Special causes of variation.
- Remove special causes, e.g., recalibrate the instrument, store standards to minimize deterioration, etc. Once a process is free of special causes, it is said to be STABLE even though it still has variation due to random causes.
- Estimate the Process Capability.
- Establish and carry out a plan to monitor, improve and assure the quality of the process, e.g., charting, maintenance, training and record keeping, in order to constantly and forever reduce variation [3].
- Normally the values cluster about the 'average value'.
- Average = $\bar{x} = \dfrac{(x_1 + x_2 + \cdots x_n)}{n} = \dfrac{\sum x_i}{n}$ (1)

Where, n refers to number of data points (usually called the population), x_i refers to the measured dimension of a component of a sample, and $\bar{x}$ refers to the average (usually called the population or process mean).

When all parts are measured, the standard deviation calculation becomes,

$$\sigma_x = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n}} \quad (3)$$

Where, $(xi - \bar{x})$ is the difference between an individual datum and the sample average.

σ_x is the standard deviation of the sample. (pronounced sigma).

- The arithmetic average (mean) of ranges,

$$\left(\bar{R} = \frac{\sum R_i}{n}\right) \quad (4)$$

- Process (or population) Standard Deviation,
  $\sigma = \bar{R} / D_2$ (5)

Where, D_2 is the factor obtained from tables of constants used in constructing control charts.[5]

- Standard Deviation of the sample mean,
  $\sigma_x = \sigma / \sqrt{N}$ (6)
- Average x_i (Process mean), $\bar{x} = \sum x_i / n$ (7)
- Upper Control Limit, $UCL_x = \bar{x} + 3\sigma_x$ (8)
- Lower Control Limit, $LCL_x = \bar{x} - 3\sigma_x$ (9)
- Range charts are constructed immediately below the x_i or $\bar{x}$ chart. When more than 1 data point per day is analyzed and $\bar{x}$ values are plotted on a $\bar{x}$ chart, the range is the difference between the highest and lowest xi in that period (subgroup).
- Range, R = [Highest value – Lowest value] (10)
- Upper Control Limit, UCLR = D4$\cdot\bar{R}$ (11)
- Lower Control Limit, LCLR = D3$\cdot\bar{R}$ (12)

Where, D3 and D4 are the factors obtained from tables used in constructing control charts.[5]

- Process Capability (Capability Index): Process capability (Cp) is simply the ability of a process to meet a customer's product specification. A process must be in control before Cp is calculated. Capability Ratio (CR) is simply the inverse of Process Capability. The lower is the CR the more capable is the process.
- Process Capability Index (Cpk) is equal to the lower of CPU (upper process capability) and CPL (lower process capability). Cpk is a better measure of process capability than Cp or CR since Cpk takes into account the actual process center compared to the target [3].

III. METHODOLOGY

1) **Record:** Recorded component details. At first, component details were taken as furnished below:
   Component Name : Cam Roller Shoe
   Customer Name : Delphi TVS, Chennai, India.
   Specifications : 8.07 + 0.02 (as per the customer drg). Upper Specification Limit (USL) : 8.09 mm
   Lower Specification Limit (LSL) : 8.05 mm
   Several measurements of thickness ground by the CNC Grinder in different trials have been recorded for every component in the observation tables. One of the observation tables (trial no. 8) is given as under:

Table 1: Component Trial Report

COMPONENT DETAILS							
Part Name		**TC**		**Trial Date**		**15/09/2011**	
Trial Time		**09:00 am – 05:00 pm**		**Each Sample Size (N)**		**05**	
Per Cycle Time		**7 min 40 sec**		**Dressing Amount**		**0.5mm**	
S. No.	THICKNESS (IN MM)						
	Part 1 (x1)	**Part 2 (x2)**	**Part 3 (x3)**	**Part 4 (x4)**	**Part 5 (x5)**	**Mean (xi)**	**Range (Ri)**
1	8.078	8.069	8.079	8.080	8.084	8.078	0.015
2	8.070	8.067	8.080	8.076	8.077	8.074	0.013
3	8.079	8.072	8.070	8.064	8.070	8.071	0.015
4	8.078	8.066	8.078	8.073	8.080	8.075	0.014
5	8.068	8.079	8.086	8.084	8.083	8.080	0.018
6	8.067	8.067	8.078	8.065	8.063	8.068	0.015
7	8.053	8.058	8.065	8.072	8.062	8.062	0.019
8	8.078	8.072	8.073	8.063	8.059	8.069	0.019
9	8.064	8.058	8.061	8.076	8.066	8.065	0.018
10	8.054	8.070	8.059	8.050	8.062	8.059	0.020
11	8.057	8.064	8.048	8.045	8.046	8.052	0.019
12	8.040	8.046	8.043	8.049	8.062	8.048	0.022
13	8.039	8.034	8.045	8.056	8.046	8.044	0.022
14	8.055	8.064	8.049	8.052	8.045	8.053	0.019
15	8.053	8.053	8.058	8.070	8.061	8.059	0.017
16	8.064	8.057	8.049	8.050	8.055	8.055	0.015

Analysis: Here in the above observation record, we have a number of variable measurement outcomes for the number of components machined on a CNC Grinder. To analyze the process capability, the statistical quality control chart techniques can be implemented in the following way:

The arithmetic average (mean) of ranges, $\left(\bar{R} = \frac{\sum R_i}{n}\right)$

$= 0.28 / 16 = 0.0175$

Process (or population) Standard Deviation,

$\sigma = \bar{R} / D_2 = 0.0175 / 2.326 \quad = 0.0075$

where, $D_2 = 2.326$ (from table of constants, for N = 5)

Therefore, Standard Deviation of the sample mean,

$\sigma_x = \sigma / \sqrt{N} \quad = 0.0075 / \sqrt{5} \quad = 0.0034$

Average x_i (Process mean), $\bar{x} = \sum x_i / n \quad = 8.063$

The control limits are,

$UCL_x = \bar{x} + 3\sigma_x \quad = 8.073$

$LCL_x = \bar{x} - 3\sigma_x \quad = 8.053$

Range = [Highest value – Lowest value]

= 0.040 – 0.015 = 0.009

The control limits for Range chart are,

$UCLR = D4 \cdot \bar{R} \quad = 2.114 \text{ X } 0.0175 \quad = 0.037$

$LCLR = D3 \cdot \bar{R} \quad = 0 \text{ X } 0.0175 \quad =$

where, $D_4 = 2.114$ and, $D_3 = 0$ (from table of constants, for N = 5) [5]

2) *Control Charts:* Plotted control charts with the help of MS-Excel application software as shown below:

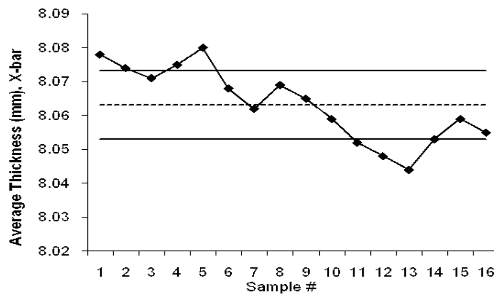

Fig. 1 : X – Chart for table 1.

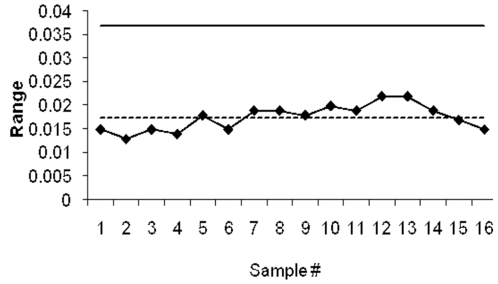

Fig. 2 : R - Chart for table 1

3) *Result:* As we can observe from the X - chart, the thickness of component numbers 1, 2, 4, 5, 11, 12, and 13 are out of the control limits, this means that process is not capable of producing the thicknesses within specification. It is concluded that the process is out of control and not capable to meet specific demand of tolerances. Now the root cause of this problem should be identified and solved. The CNC Grinder was checked by a team of Engineers from Design and Production Department and after a complete check up, it was found that the tool feed arrangement of CNC machine in Z direction was getting a shock of high tendency whenever feed command for varying depth of cut was given in the machine program. It happened all mainly because of an extreme backlash in drives of its special purpose jig. After a close discussion, the team decided to provide a calibrated scale with the drives in such a way that whenever machine starts to follow the command to move fast in a direction, the drives should take a lead exactly with the calibrated values of the scale. After the calibrated scale provided to the tool drives, all the first three sample trials gave the dimensional values within specification limits (i.e. 8.07 ± 0.2). It meant that the CNC Grinder was become capable of giving the dimensions of the components as per the given tolerances.

Table 2. Component Trial Report.

Component Details							
Part Name	**TC**			**Trial Date**		18/09/2011	
Trial Time	**09:00 am – 03:00 pm**			**Each Sample Size (N)**		5	
Per Cycle Time	**6 min 2 sec**			**Dressing Amount**		0.5mm	
S. No.	**Thickness (in mm)**						
	Part 1 (x1)	**Part 2 (x2)**	**Part 3 (x3)**	**Part 4 (x4)**	**Part 5 (x5)**	**Mean (xi)**	**Range (Ri)**
1	8.080	8.078	8.078	8.078	8.076	8.078	0.004
2	8.079	8.077	8.077	8.076	8.076	8.077	0.003
3	8.078	8.078	8.075	8.075	8.074	8.076	0.004
4	8.075	8.076	8.075	8.079	8.075	8.076	0.004
5	8.080	8.076	8.077	8.076	8.076	8.077	0.004
6	8.079	8.077	8.076	8.077	8.076	8.077	0.003
7	8.079	8.075	8.075	8.076	8.075	8.076	0.004
8	8.078	8.081	8.077	8.077	8.077	8.078	0.004
9	8.079	8.079	8.079	8.077	8.076	8.078	0.003
10	8.078	8.075	8.078	8.075	8.074	8.076	0.004
11	8.077	8.078	8.078	8.077	8.075	8.077	0.003
12	8.079	8.078	8.079	8.079	8.075	8.078	0.004
13	8.077	8.079	8.077	8.077	8.075	8.077	0.004
14	8.078	8.078	8.075	8.074	8.075	8.076	0.004
15	8.077	8.079	8.076	8.079	8.079	8.078	0.003
16	8.078	8.076	8.079	8.080	8.077	8.078	0.004
n = 16						∑ xi = 129.233	∑Ri = 0.059

4) *Record*: A process control is not merely obtaining the dimensions within specification limits but is said to be accomplished when the dimensions of all samples are obtained with the values nearest to the mean value in much lower ranges. The same procedure of SPC was repeated again to determine the process capability after the remedies were applied. One of the observation tables (trial no. 13) is given as under:

5) *Analysis:* To analyze the process capability, the statistical quality control chart techniques can be implemented in the following way:

The arithmetic average (mean) of ranges, $\left(\bar{R} = \frac{\sum R_i}{n}\right)$. $= 0.059 / 16 = 0.0037$

Process (or population) Standard Deviation, $\sigma = \bar{R} / D_2 = 0.0037 / 2.326 = 0.0016$

where, $D_2 = 2.326$ (from table of constants,for N = 5)[5]

Therefore, Standard Deviation of the sample mean, $\sigma_x = \sigma / \sqrt{N} = 0.0016 / \sqrt{5} = 0.00072$

Average $\bar{X}$ (Process mean), $\bar{X} = \sum x_i / n = 8.077$

The control limits are,

$UCLx = \bar{X} + 3\sigma_x = 8.079$

$LCL_x = \bar{X} - 3\sigma_x = 8.075$

Range = [Highest value – Lowest value]

= 0.004 – 0.003 = 0.001

The control limits for Range chart are,

$UCL_R = D_4 \cdot \bar{R} = 2.114 \text{ X } 0.0037 = 0.0078$

$LCL_R = D_3 \cdot \bar{R} = 0 \text{ X } 0.0037 = 0$

where, $D_4 = 2.114$ and $D_3 = 0$ (from table of constants, for N = 5)[5]

As we can observe from the X - chart, the thickness of all the components are out of the control limits, this means that process is capable of producing the thicknesses within specification limits.

It is concluded that the process is now under control and capable of meeting the specific demand of tolerances.

Process Capability, $C_p = \frac{USL - LSL}{6\sigma}$

= (8.09 – 8.05) =

4.167
6 X 0.0016

Capability Ratio, CR = 1 / C_p = 0.24

Let, CPU and CPL are Upper and Lower Process Capabilities, respectively.

CPU = $\frac{USL - \bar{x}}{3\sigma}$ = 2.71and, CPL = $\frac{\bar{x} - LSL}{3\sigma}$ = 5.625

C_{pk} = Minimum (CPU, CPL)

= Minimum (2.71, 5.625) = 2.71

6) *Control Charts:* Plotted control charts with the help of MS-Excel application software as shown below:

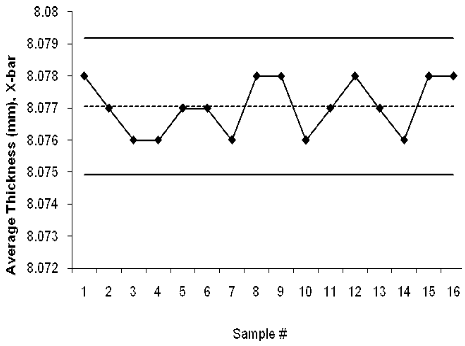

Fig. 3: X – Chart for table 2.

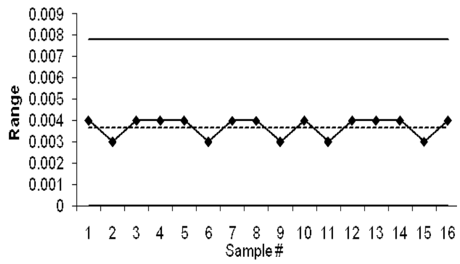

Fig. 4: R – Chart for table 2.

IV. RESULTS:

Upper Control Limit, UCL = 8.079 ;
Lower Control Limit, LCL = 8.075 ;

Range, R = 0.001 ;
Average Range, $\bar{R}$ = 0.0037 ;

Process Capability, C_p = 4.167 ;
Capability Ratio, CR = 0.24 ;

Upper Process Capability, CPU = 2.71 ;
Lower Process Capability, CPL = 5.625 ;

C_{pk} = Minimum (CPU, CPL) = 2.71.

7) *Discussion***:** Since, the value of Process Capability Index, as required by the customer, Delphi TVS, Chennai was greater than 2, and the process capability index we obtained after the implementation of SPC techniques is 2.71 which is greater enough than 2 therefore, we can say that the process is under control now and capable of producing all the components under the given specification limits with the very low normal distribution.

V. CONCLUSION

The control limits obtained after the remedial actions taken for the grinder are within specification limits and the thickness produced in all the components of every sample lie under the control limits. The thicknesses of all the components are located very close to the process mean. All these results are positive by which we conclude that the process is under control. The process capability (C_p) increased from 0.581 to 4.167 which show that implementation of SPC technique is proved to be successful in improving the performance of grinding process thereby making it more capable of producing the products with right dimensions. Capability Ratio (CR) is reduced from 1.721 to 0.24 which means that the process spread now occupies 24 % of the tolerance. The lower is the CR the more is capable the process. The provision of a calibrated scale with the mechanical drives of a CNC Grinder solved the backlash problems and increased its preciseness. C_{pk} is a better measure of process capability than C_p or CR since C_{pk} takes into account the actual process center compared to the target [3]. Here, we got C_{pk} as 2.125 which is greater than 2. C_{pk} of value greater than 2 was required by the customer company, Delphi TVS, Chennai and their demand has been met satisfactorily. These all become possible with the implementation of an SPC technique. Likewise, the SPC tools can be implemented to solve so many real life problems of different machines and processes in future that may come up with meeting the demand of higher quality and productivity of different manufacturing processes. The methods developed in the first half of this century by Shewhart and others are still very useful in many current applications.

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