**Journal of Manufacturing Engineering, September 2014, Vol. 9, Issue. 3, pp 157-162**

# EVALUATION OF PROCESS CAPABILITY OF ASSEMBLY PRODUCTION LINE USING STATISTICAL PROCESS CONTROL TECHNIQUES

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## ABSTRACT

This paper deals with application and use of statistical techniques to evaluate the process capability of assembly production lines. The process capability is a numerical measure of process parts variation in terms of capability indices. To understand the concept of process capability a case study is carried out for parallel assembly production line of two process parts. Quality charactertics of these two parts are the gap variation that causes the fitment (loose fit or interference fit) problem in parts during assembly. This fitment problem is analyzed with cause and effect diagram and a necessary corrective measure are recommended to remove the root cause. Control charts technique has been used to monitoring the gap variation during assembly of process parts and dimensions of individual process parts are also monitored. Process capability and defective rate for individual process parts as well as for assembled parts are determined. The results show that parts of process one is under control having capability value 1.33 with defective rate 0.006% but another process parts are out of control that producing defective parts with capability value 0.85 with defective rate 1.08. The overall process capability for assembly production line are 0.92 with defective rate 0.52. Therefore from the results analysis, it is concluded that rejected parts from process one can be assembled with rejected part of another process and creates one accepted assembled one.

***Keywords**: SPC, control charts, process capability and assembly production Line.*

## 1. Introduction

Success in the global market depends on consistent quality products. If companies do not produce good quality products consistently then it will hurt the company's future sales. So there is a need to produce consistently high quality products to improve productivity, drop rework cost. Poor quality is usually the results of variation in some stage of production. Therefore products quality depends upon ability to control the production process. This is where statistical process control (SPC) finds its application. SPC uses statistics to detect variations in the process so that they can be controlled [1]

### 1.1 Statistical Process Control

SPC is a simple, effective decision making tool to problem solving and process improvement through the reduction of process variation [2].

SPC techniques improved the quality in mass production by reducing the assignable causes. In case of mass production, process goes out of control due to variation in man, machine, methods, materials etc. which results poor centring and poor process capability. In order to satisfy the process capability measures it is necessary to improve the quality level by shifting the process mean to the target value and reducing the variations in the process [3]. In case of machining of component, variation in processes occurred mainly due to tool wear, and machine setting etc. Quality tools like control charts have been constructed on data obtained from the manufacturing process to discover and correct the assignable cause so that machine capability and process capability can be determined [4].

### 1.2 Process capability indices

When a process became statistically control then there is a need to find the capability of the process within specification limits. Various capabilities index such as $Cp$, $Cpk$, $Cpku$, $Cpkl$ are proposed to estimate the capability of manufacturing processes [5]. Capability indices are related to process parameters to measure the process performance and can be used with unilateral and bilateral tolerances with or without the target value [6]. Process capability indices (PCIs) are appropriate tools to measure the inherent capability of a process, but most of them do not consider the losses of a process, while in today's competitive business environment, it is becoming more and more important for companies to evaluate and minimise their losses.

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Therefore loss based PCI such as $Cpm, Cpmk, PCI\theta, Cpc$ are proposed [7]. A systematic procedure to measure process capability indices $Cp$ and $Cpk$ in an automobile transfer case through diagnostic study approach is carried out in the machining line that produces machine and spare parts. The root causes are found from the diagnostic study approach. Finally, by taking necessary remedial actions the total rejection rate was reduced to 4% from 28% [8]. Process capability indices are effective tools for the continuous improvement of quality, productivity and managerial decisions. In this study, a process-capability analysis is necessary to improve the quality level by shifting the process mean to the target value and reducing the variations in the process [9]**.**

A new concept is developed to determined overall process capability indexes to measure the capability of assembly line after defining relation between percentage yield and process capability [10]. Process capability indices have been used in the manufacturing industry to provide quantitative measures on process potential and performance. Process capability indices $(Cp, Cpk,)$ provide a common metric to evaluate and predict the performance of processes. In this study, at the first the process capability indices are presented then machine capability indices are discussed. Finally, process performance indices $Pp, Ppk$ and difference between $Cpk$ and Ppk are also presented [11].

## 2. Case Study

A real case from a XYZ automotive industry is studied. An assembly production line of Pleasure model body frame is selected as a process consideration.

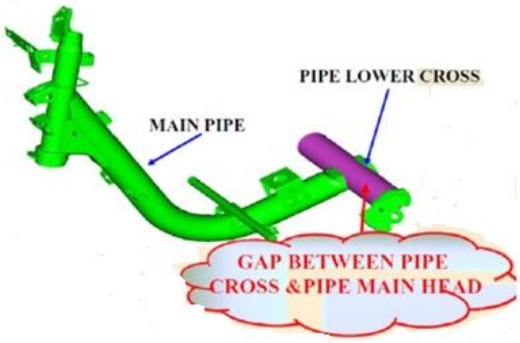

**Fig 1. Assembly of Main Pipe with Lower Cross Pipe**

This assembly production line (Pipe Main Head Assembly Line) consist of assembly of two pipes, Main Pipe and Lower Cross Pipe are shown in figure 1.

### 2.1 Problem definition

To eliminate the fitment problem during assembly of Main Pipe with Lower Cross Pipe in Pipe Main Head Assembly Production Line and To measure overall process capability of assembly line.

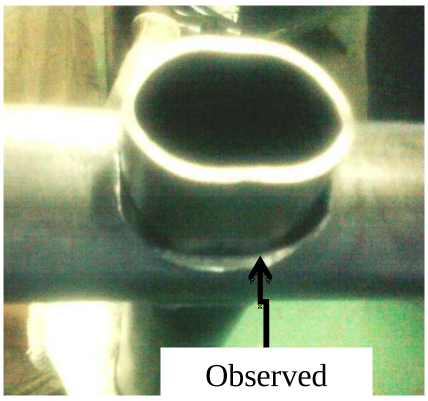

**Fig 2. Fitment problem in two pipes assembly**

### 2.2 Cause and Effect Diagram

All probable cause responsible for fitment problem is identified with cause and effect diagram. From the cause and effect diagram shown in figure 4 it is concluded that fitment problem is due to machine tool.

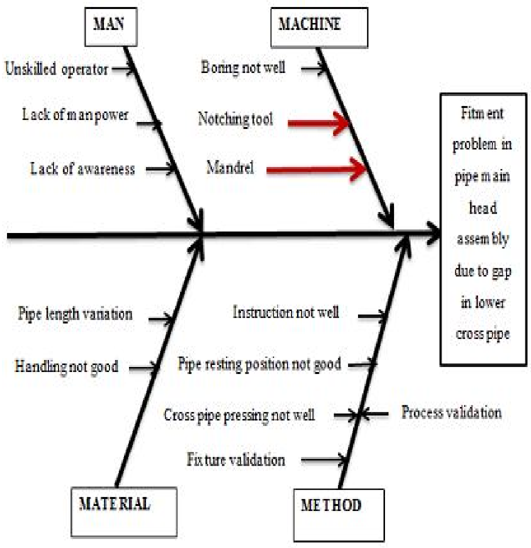

**Fig. 3 Cause and effect diagram**

### 2.3 Recommendation to remove the root causes

Following recommendations in machine tool are given to eliminate various root causes

- Tool punch re-sharpening.
- Tool maintenance schedule is made.
- Press tool designed changed from notching operation to centre piercing.

- Mandrel designed changed (two side mandrel are used).

## 2.4 Process capability of Pipe Main Head Assembly Production Line

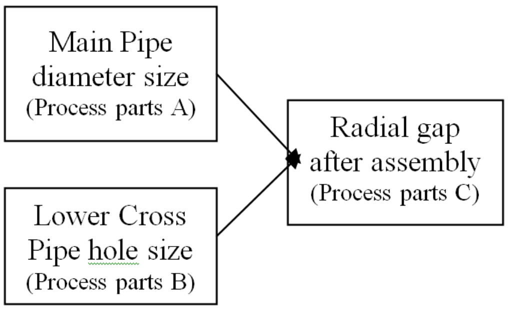

**Fig. 4 Parallel assembly line of Main pipe with Lower Cross pipe.**

Pipe Main Head Assembly Production Line is a parallel assembly of two process parts i.e. Main Pipe with Lower Cross Pipe is shown in figure 4. To measure capability of process parts twenty observations of Main Pipe diameter size and Cross Pipe hole size are taken randomly are shown in table 1. These observations are taken after removing the root causes as suggested in section 3.3.

The designed specifications for Main Pipe diameter size and Lower Cross Pipe hole size are:

Main Pipe diameter size $= 50\text{ mm} \pm 0.20\text{ mm}$,

Lower Cross Pipe hole size $= 52\text{ mm} \pm 0.15\text{ mm}$

Upper specification for Main Pipe diameter size($USL_A$)= 50.20 mm

Lower specification for Main Pipe diameter size($LSL_A$) = 49.80 mm

Upper specification for Lower Cross Pipe hole size ($USL_B$)=52.15 mm

Lower specification for Lower Cross Pipe hole size ($LSL_B$)= 51.85 mm

### 2.4.1 Assumptions

Two assumptions are made for calculation purpose:

1. There are not direct relation between process parts A and process parts B but outputs of these processes together will effect on process parts C.

2. Statistical distributions of process parts A and process parts B are normal

**Table 1. Sample observation table for Main Pipe diameter size process parts A and Lower Cross hole size process parts B**

| Sample No. | Main pipe diameter(A) mm | Lower Cross pipe hole size(B)mm | Radial gap(C)mm |
|---|---|---|---|
| **1** | 50.05 | 52.05 | 1.00 |
| **2** | 50.04 | 51.96 | 0.96 |
| **3** | 49.99 | 51.98 | 0.995 |
| **4** | 50.04 | 52.02 | 0.99 |
| **5** | 50.05 | 52.04 | 0.995 |
| **6** | 50.08 | 51.95 | 0.935 |
| **7** | 49.92 | 51.97 | 1.025 |
| **8** | 50 | 52.18 | 1.09 |
| **9** | 49.9 | 52.04 | 1.07 |
| **10** | 50.02 | 51.96 | 0.97 |
| **11** | 50.01 | 52.01 | 1.00 |
| **12** | 50.07 | 52.03 | 0.98 |
| **13** | 50.04 | 51.92 | 0.94 |
| **14** | 49.96 | 51.98 | 1.01 |
| **15** | 49.97 | 52.02 | 1.025 |
| **16** | 49.94 | 52.05 | 1.05 |
| **17** | 49.98 | 51.92 | 0.97 |
| **18** | 50.02 | 51.97 | 0.975 |
| **19** | 50.05 | 51.96 | 0.975 |
| **20** | 49.98 | 52.01 | 0.955 |

Nominal gap=1/2 (nominal hole size in Cross Pipe-nominal diameter size of Main Pipe)

$$\text{Nominal gap} = \frac{1}{2}(52 - 50) = 1\text{mm}$$

### 2.4.2 Mean & standard deviation

Mean or average of 20 samples for process parts A &process parts B are calculated as

Mean value of process parts A i.e $\bar{x}_A$

$$= \frac{(x_1 + \cdots\ldots + x_{20})}{20} = 50.005\text{ mm}$$

Mean value of process parts B i.e. $\bar{x}_B$

$$= \frac{(x_1 + \cdots\ldots + x_{20})}{20} = 52.01\text{ mm}$$

Standard deviation process parts A i.e

$$\sigma_A = \sqrt{\frac{\sum(\bar{x} - x_i)^2}{N}} = \sqrt{\frac{0.0496}{20}} = 0.0498$$

Standard deviation process parts B i.e

$$\sigma_B = \sqrt{\frac{\sum(\bar{x} - x_i)^2}{N}} = \sqrt{\frac{0.0684}{20}} = 0.0585$$

Standard deviation process parts C i.e

$$\sigma_C = \sigma_{gap} = \frac{1}{2}\sqrt{\sigma_A{}^2 + \sigma_B{}^2} = \frac{1}{2}\sqrt{0.0498^2 + 0.0585^2} = 0.0384$$

### 2.4.3 Control charts limits

Individual control charts (I-charts) are plotted on collected observation data for process parts A, process parts B and process parts C are shown in figure 5(a), 5(b), 5(c) respectively. The control limits for each process are calculated as:

Upper control limit for process parts A

$$U_A = \overline{X_A} + 3\sigma_A = 50 + 3 \times 0.0498 = 50.15 \text{ mm}$$

Lower control limit for process parts A

$$L_A = \overline{X_A} - 3\sigma_A = 50 - 3 \times .0498 = 49.85 \text{ mm}$$

Upper control limit for process parts B

$$U_B = \overline{X_B} + 3\sigma_B = 52 + 3 \times .0585 = 52.17 \text{ mm}$$

Lower control limit for process parts B

$$L_B = \overline{X_B} - 3\sigma_B = 52 - 3 \times .0585 = 51.82 \text{ mm}$$

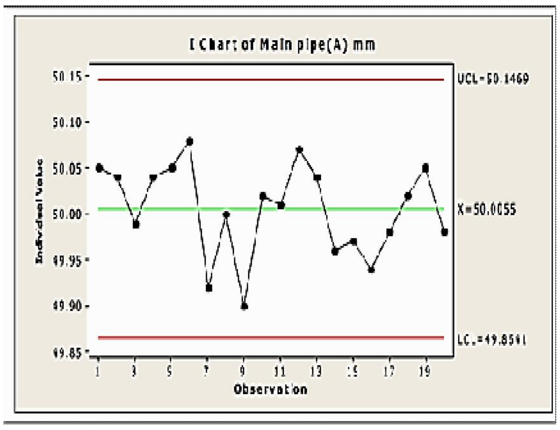

**Figure 5(a): I chart of process parts A (Main Pipe diameter size)**

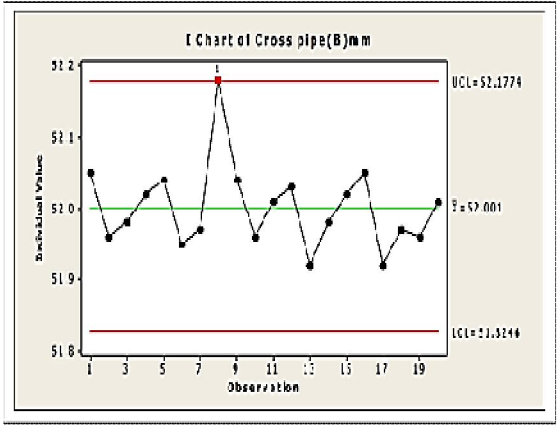

**Figure 5(b): I chart of process parts B (Cross Pipe hole size)**

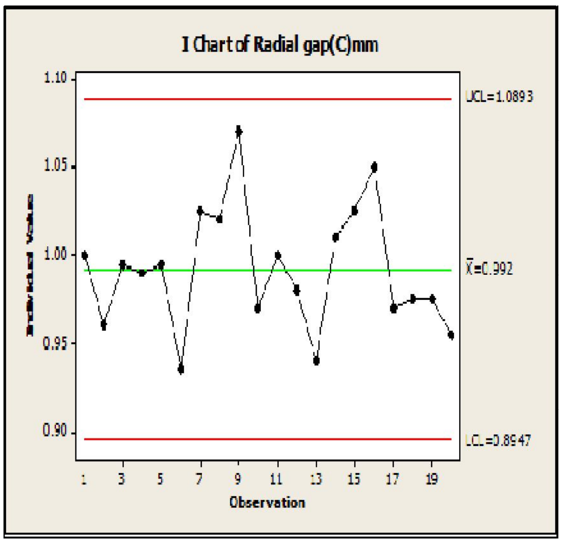

**Figure 5(c): I chart for radial gap after assembly of process parts A and process parts B**

### 2.5 Process capability ($C_p$)

Process capability plot for process parts A and process parts B are shown in figure 6(a) and 6(b)

Process capability of process parts A $C_{pA} = \frac{(USL_A - LSL_A)}{6\sigma_A} = \frac{(50.20-49.80)}{6 \times 0.0498} = 1.33$

Process capability of process parts B $C_{pB} = \frac{(USL_B - LSL_B)}{6\sigma_B} = \frac{(52.15-51.85)}{6 \times 0.0585} = 0.85$

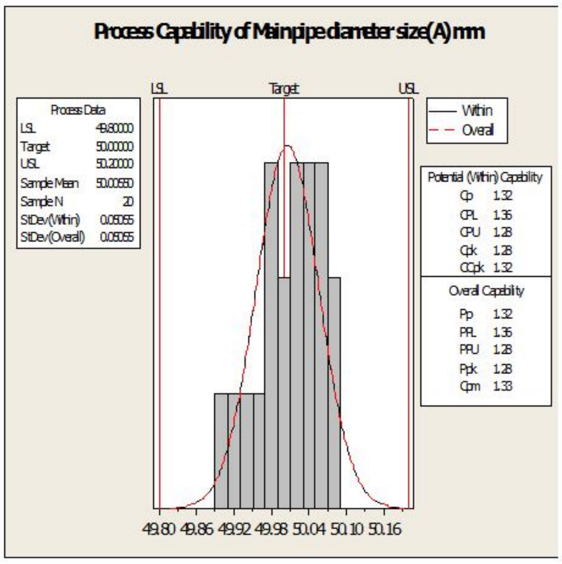

**Figure 6(a): process capability of process parts A.**

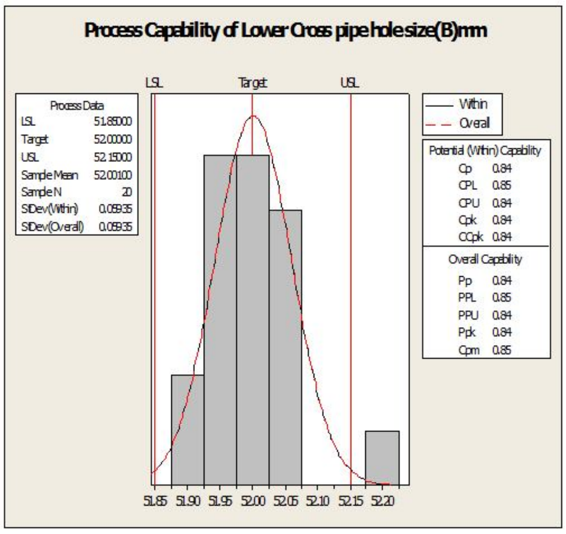

**Figure 6(b): process capability of process parts B.**

### 2.6 Rate of accepted parts

In parallel assembly lines, overall defective rate for assembly will be occurred, when there are cases which two parts cannot be assembled. Some of them are $X_A > U_A$, $L_A < X_A < LSL_A$, and $|X_A - X_B| >$ max $(|USL_A - LSL_B|$ and $|USL_B - LSL_A|)$ and so on. Therefore it is complicated to calculate the overall defective rate with considering all cases of occurrence of rejecting the parts and consider the rate of accepted part is better way [11].

Rate of accepted parts =

$$\emptyset\left(\frac{\max(|\mathrm{USL_A}-\mathrm{LSL_B}|\,\mathrm{and}\,|\mathrm{USL_B}-\mathrm{LSL_A}|)-|(\bar{\mathrm{X}}_\mathrm{A}-\bar{\mathrm{X}}_\mathrm{B})|}{\sqrt{\sigma_\mathrm{A}^2+\sigma_\mathrm{B}^2}}\right)-1+\emptyset\left(\frac{\mathrm{U_A}-\bar{\mathrm{X}}_\mathrm{A}}{\sigma_\mathrm{A}}\right)-\emptyset\left(\frac{\mathrm{L_A}-\bar{\mathrm{X}}_\mathrm{A}}{\sigma_\mathrm{A}}\right)-1+\emptyset\left(\frac{\mathrm{U_B}-\bar{\mathrm{X}}_\mathrm{B}}{\sigma_\mathrm{B}}\right)-\emptyset\left(\frac{\mathrm{L_B}-\bar{\mathrm{X}}_\mathrm{B}}{\sigma_\mathrm{B}}\right)$$

$$= \emptyset\left(\frac{\max(|50.20-51.85|\,and\,|52.15-49.80|)-|50-52)|}{\sqrt{0.0498^2+0.0585^2}}\right) - 1 + \emptyset\left(\frac{50.15-50}{0.0498}\right) - \emptyset\left(\frac{49.85-50}{0.0498}\right) - 1 + \emptyset\left(\frac{52.17-52}{0.0585}\right) - \emptyset\left(\frac{51.82-52}{0.0585}\right)$$

$$= \emptyset(4.55) - 1 + \emptyset(3.012) - \emptyset(-3.012) - 1 + \emptyset(2.90) - \emptyset(-3.07)$$

$$= 1 - 1 + 0.9987 - 0.0013 - 1 + 0.9981 - 0.0011$$

$= 0.9944$

Therefore rate of accepted parts = 0.9944

### 2.6.1 Overall defective rate (ODR) and % yield

ODR = 1-0.9944=0.0056

And % yield = 1-ODR = 0.9944

% yield = $2\emptyset(3C_p) - 1$

$$0.9944 = 2\emptyset(3C_p) - 1$$

$$\emptyset(3C_p) = \frac{1 + 0.9944}{2} = 0.9972$$

$$3C_p = \emptyset^{-1}(0.9972)$$

$$3C_p = 2.77$$

$$C_p = 0.92$$

Overall Process Capability (OPC) = $C_p = 0.92$

{$\emptyset$ is the Cumulative distribution function of standard normal distribution}

Rate of accepted parts (% yield), process capability, overall defective rate for different process parts are shown in table 2.

**Table 2: Overall defective rate for different process parts**

| Process parts | Standard deviation | Cp | % yield | ODR % |
|---|---|---|---|---|
| Process part A | 0.0498 | 1.33 | 99.994 | 0.006% |
| Process part B | 0.0585 | 0.85 | 98.92 | 1.08% |
| Process parts C assembly | 0.0345 | 0.92 | 99.44 | 0.56% |

## 3. Conclusions

From control chart techniques implemented on parts produced, it is concluded that process parts A are within control limits and process parts B are out of control limit but their assembled parts are within control.

Process capability value for process parts A and process parts B is 1.33 and 0.85 respectively but whole assembly has capability value 0.92.

% yield for process parts A is 99.994 while for process parts B are 98.92, but for process C i.e. after assembly of process parts A with process parts B are 99.44. The overall defective rate for Process A is 0.006% and for Process B is1.08% but for Process parts C i.e. after assembly of parts is 0.56%.

The result revealed that rejected parts from one process can be assembled with rejected parts of another process during assembly and make an accepted parts thus decrease the defective parts, saving a lot of rework cost and valuable time.

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