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Calculation of Process Capability of an Automotive Component after Implementation of SPC Technique

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Abstract

In this paper, an attempt has been made to calculate process capability (C_p) after implementation of SPC technique in the industry that is offering its customer the widest and latest range of sealing solutions for various applications in automotive industry. Further the numbers of rejections are controlled in the component assembly. The power of SPC lies in the ability to examine a process and sources of variation in that process, using tools that give weightage to objective analysis over subjective opinion and that allow the strength of each source to be determined numerically. The control chart for variables i.e; $\bar{X}$ Chart and R Chart is implemented in industry.

Keywords: *Control Charts, Process Capability, Process capability index, casting defects.*

1. Introduction

Process capability study (PCS) is a scientific and a systematic procedure that uses control charts to detect and eliminate the unnatural causes of variation until a state of statistical control is reached(1). When the study is completed, you will identify the natural variability of the process. Process-capability analysis is a technique applied in many stages of the product cycle, including process, product design, manufacturing and manufacturing planning, since it helps to determine the ability to manufacture parts within the tolerance limits and engineering values. There are several capability indices, including C_p, C_{pu}, C_{pl} and C_{pk}, that have been widely used in manufacturing industry to provide common quantitative measures of process potential and performance. Process-capability indices are powerful means of studying the process ability for manufacturing a product that meets specifications (2, 3). There is considerable theoretical and experimental research work on improving product quality and process efficiency using a process-capability analysis. Kane(4)described six areas of application for capability indices: the prevention of the production of nonconforming products, the continuous measure of improvement, communication, prioritization, the identification of directions for improvement, and the auditing of the quality system. Wright (5) discussed the cumulative distribution function of process capability indexes. The process-capability indices, including C_p, C_{pk} and C_{pm} , have been proposed in manufacturing industry to provide a quick indication of how a process has conformed to its specifications, which are preset by manufacturers and customers. Pearn(6)indicated the index of capability for monitoring the accuracy of the manufacturing process. Singhal(7) introduced the multi process performance analysis chart (MPPAC) based on process capability indices for controlling and monitoring multiple processes. The MPPAC provides an easy way to process improvement by comparing the locations on the chart of the processes before and after the improvement effort. Pearn and Chen(8)proposed a modification to the MPPAC, combining the more advanced process capability indexes C_{pm} and Cpm to identify the problems causing the process failing to centre on the target. Pearn (9)introduced the MPPAC based on the capability index, which is a simple transformation of C_{pmk} . They developed the multi-process performance-analysis chart based on process capability indices to analyze the manufacturing performance for multiple processes.

2. Literature Review

Process capability is the long-term performance level of the process after it has been brought under statistical control. The use of process capability was adopted as far back as 1920s. It was used to measures the variability of the output of a process and to compare that variability with a proposed specification or product tolerance[2,3,5]. According to 1S0 (15504) defined process capability as a process to its purpose as managed by an organization management. For information technology, 1S0 (15504) also specifies a process capability measurement framework for assessing process capability. The measurement framework has been generalized so that it can be applied to non IT processes[1,6]. Another article explained that in order to achieved continuous improvement one must always attempt to redefined the voice of the process" to match and then to surpass the expectations of the customer[3]. Process capability indices are used effectively to summarize process capability information in a convenient unit less system. These indices are C_p, C_{pl}, C_{pu} and C_{pk}[2,3]in his article discussed that the indices for process capability are based on the assumption that the underlying process distribution is approximately normal. Furthermore, [5, 6] in their journal of quality technology (2003) explained that the data chosen for process capability study should attempt to encompass all natural variables. Also, the number of sample used has a significant influence on the accuracy of the C_{pk} estimates. Therefore smaller samples will result in even larger variations of the C_{pk} statistics. Process capability is often thought as being purely on industrial discipline because it is in industry that it has had its widest adoption. Thus, this review will not be completed if mention is not made of some of the researchers who have made similar research. Among them is Shewart after studying way of statistical quality control, also originated the control charts. This is a very effective mode of quality control and process capability. This Research, the process capability analysis as a means of decision making in manufacturing company was aimed, to investigate whether the production process is in control, to investigate whether the specification limit of the company is properly centered, to examine the process capability of the company and to state if the process is capable or not.. The method use in the control chart are $\bar{X}$ and R chart. Also the analysis of process capability was used. It was discovered that the specification limit of the company is not properly centered i.e. off centered. It is recommended that in order to achieve continuous improvement of the process, the company should always attempt to redefined the voice of the process to watch and them to surpass the expectation of the customers. Also, the company specification limit should be redefined to be properly centered and to meet customer requirement.

3. Research Methodology

Key Steps for implementation of SPC tool:

a. Calculating the value for $\bar{X}$.

$$\bar{X} = \frac{X_1 + X_2 + X_3 + X_4}{n}$$

Where, n is the number of samples.

b. Calculating the value for $\bar{\bar{X}}$.

$$\bar{\bar{X}} = \frac{\sum(\bar{X}_1 \dots\dots . \bar{X}_k)}{k}$$

Where, k is the number of subgroups

c. Calculating the value for $\bar{R}$.

$$\bar{R} = \frac{\sum(R_1 \dots\dots R_k)}{k}$$

Where, k is number of subgroups.

d. Upper and lower control limit for $\bar{X}$ Chart

Upper Control Limit, $\boldsymbol{UCL_{\bar{X}} = \bar{\bar{X}} + A_2 R}$

Lower Control Limit, $\boldsymbol{LCL_{\bar{X}} = \bar{\bar{X}} - A_1 R}$

Where, A_2 and A_1 are constants.

e. Upper and Lower Control Limit for R Chart

Upper Control Limit, $\boldsymbol{UCL_R = D_4 \bar{R}}$

Lower Control Limit, $LCL_R = D_3\bar{R}$

Where, D_4 and D_3 are constants.

4. Case Study

The emphasis is given on the production of shocker seals because rejection level before implementing SPC tools for this product is 9.1% the following main root causes are found in higher rejection of shocker seals of this industry.

Moulding: Moulding is the first process of manufacturing of shocker seals. It is found that various Moulding defects are responsible for the rejection. Following defects are observed in this process, causing for rejection.

- Air trap
- Tear
- Knitting
- Foreign matter
- Curing
- Excess material
- Less material
- Dirty cavity

Probable causes of each defect are listed below:

Air trap
- Insufficient Vacuum
- Improper Environmental temperature

Tear
- Higher temperature
- Improper manual loading

Material (excess/less)
- Improper setting of grub screw volume

Cold bit
- Improper cleaning of nozzle hole
- Dirty Top portion of mould

Trimming
- Offset trimming problem
- Spiral Lining problem
- Step Trimming problem

Recommendations to Remove the Moulding Defects:

- In-process inspection is must for each manufacturing operation.
- Adequate Vacuum must be created.
- Proper Environmental temperature should be maintained
- Maintain temperature of the casting between 1900^0C to 2100^0C.
- Manual loading should be replaced by mechanized loading.
- Grubbed screw volume should be maintained at the required level.
- Clean the nozzle hole properly.
- Clean top portion of mould properly.
- Trimming should be done very carefully.

5. Implementation of $\bar{X}$ and R Charts to the Diameter of Shocker seals.

The sample size (n) of 4 is considered and 200 observations of outer diameter of shocker seals for are taken in random manner. These observations are taken after removing the root causes. The observations before the case study are not included because of the limitation of length of the paper. The concept of sub-grouping is followed when observations are taken.

Target outer diameter of shocker seals = 62 mm ± 0.10 mm (tolerance)

So, upper and lower specification limits can be calculated as:

Upper specification Limit (USL) = 62.10 mm and
Lower specification Limit (USL) = 61.90 mm

(i) Mean ($\bar{X}$) Chart

Mean or Average of one sample can be calculated as:

$$\bar{X} = \frac{X_1 + X_2 + X_3 + X_4}{n}$$

The Mean or Average of one sample can be calculated as:

Where, n is the sample size = 4 (for this case)

Similarly, Mean or Average of 200 samples can be calculated as:

$$\bar{\bar{X}} = \frac{\sum(\bar{X}_1 \dots \dots . \bar{X}_k)}{k}$$

Where, k is the number of subgroups = 200 (for this case)

$\bar{\bar{X}}$= 12400.40/200 = 62.002 mm and
Average range can be calculated as:

$$\bar{R} = \frac{\sum(R_1 \dots \dots \dots R_k)}{k}$$

$\bar{R} =$ 15.02/200 = 0.075

Upper Control Limit,$UCL_{\bar{\bar{X}}} = \bar{\bar{X}} + A_2 R$

= 62.002+0.738×0.075

= 62.06 mm

Lower Control Limit,$LCL_{\bar{\bar{X}}} = \bar{\bar{X}} - A_1 R$

= 62.002 - 0.738×0.075

= 61.94 mm

A2 = 0.738, D4 = 2.28, D3= 0 (values of these factor, corresponding to sample size, are available in all the books of Quality control)

(ii) Range (R) Chart

$$Range = R_{max} - R_{min}$$

$$\bar{R} = \frac{\sum(R_1 \dots \dots \dots R_k)}{k}$$

$$\bar{R} = 15.02/200 = 0.075$$

Where, k is the number of subgroups = 200

Upper Control Limit,$UCL_R = D_4 \bar{R}$

= 2.28*0.075

= 0.171

Lower Control Limit,$LCL_R = D_3 \bar{R}$

= 0*0.075

= 0

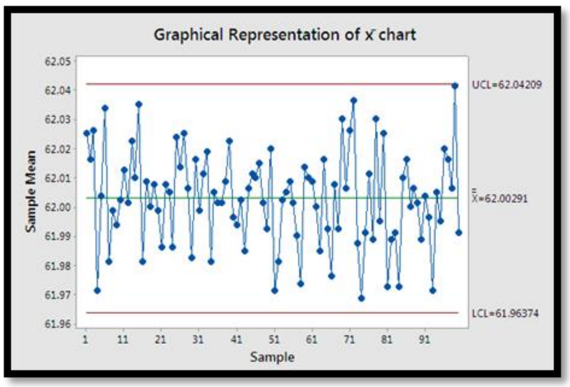

Figure 1. Graphical Representation of $\bar{\bar{X}}$ Chart

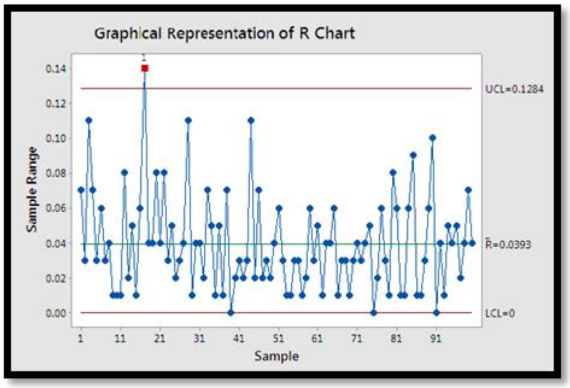

Figure 2. Graphical representation of R Char

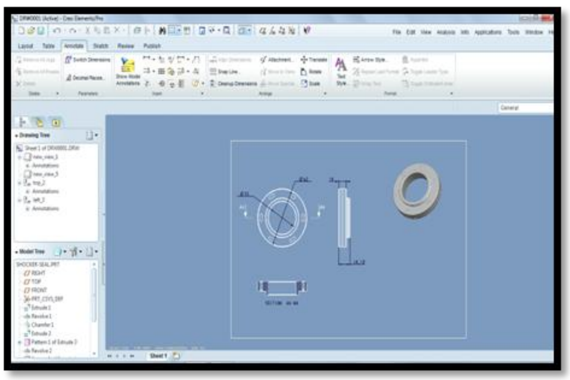

Figure 2a. Component Drawing (Shocker seal)

6. Process Capability (C_p):

Process capability compares the output of an *in-control* process to the specification limits by using *capability indices*. The comparison is made by forming the ratio of spread between the process specifications (the specification "width") to the spread of process values, as measured by 6 process standard deviation units (the process "width").

The Process Capability: Indices

It is also a widely-accepted practice to express process capability using the following indices:

- C_p is the simple process capability index. It is the process width divided by 6 times sigma, its estimated within-subgroup standard deviation, where the process width = Upper Spec Limit minus Lower Spec Limit. If $C_p < 1$, the process is wider than the spec limits, and is not capable of producing all in-specification products. C_p could be greater than one, but bad parts could still be being produced if the process is not centered. Thus, there is a need for a capability index which takes process centering into account: $C_{pk.}$

- C_{pk} is the difference between x double bar and the nearer spec limit divided by 3 times sigma. If C_{pk} >=1, then 99.7% of the products of the process will be within specification limits. If C_{pk} <1, then more non-conforming products are being made.

Bear in mind that specification limits are not statistically determined, but rather are set by customer requirements and process economics.

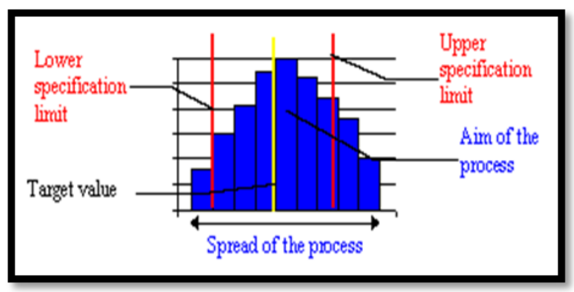

Figure 2b. Spread of the Process

In the PathMaker software, the following process capability indices are calculated if specification limits are applied to histograms:

Cp: The distance between the upper specification limit and the lower specification limit, divided by (6 times the standard deviation). If $C_p < 1$, the process is wider than the spec limits, and is not capable of producing all —in-specification products. $C_p$could be greater than one, but bad parts could still be being produced if the process is not centered. Thus, there is a need for a capability index which takes process centering into account: $C_{pk.}$

Cu: The difference between the process mean and the upper spec limit, divided by 3 sigma, or 3 times the standard deviation.

Index Symbol	Meaning	Estimate Equation
C_p	Process Capability	$\frac{USL - LSL}{6\sigma'}$
C_{pu}	Upper Capability Index	$\frac{(USL - \bar{X})}{3\sigma'}$
C_{pl}	Lower Capability Index	$\frac{(\bar{X} - LSL)}{3\sigma'}$
C_{pk}	Process Capability Index	Min of (C_{pu}, C_{pl})

Cl: The difference between the process mean and the lower spec limit, divided by 3 sigma, or 3 times the standard deviation.

Cpk: C_{pk} is the difference between the process mean and the nearer spec limit divided by 3 times sigma. (C_{pk} is the lesser of $C_u$and $C_{l.}$). If C_{pk}>=1, then at least 99.7% of all products of the process will be within specification limits. If C_{pk}<1, then some non-conforming products are being made, and you may need to study your process to see how it can be improved.

The Process Capability Ratio (C_p)in all four cases i.e; I, II, III, IV :

Population standard deviation (σ') = $\bar{R}$/d2

Where, d2 = 2.059 (for sample size of 4)

σ' = 0.075/2.059 = 0.036

So, Process capability (C_p) = $6\sigma'$= 6×0.036 = 0.21

To be process under control,

$(USL - LSL) \geq 6\sigma'$

(62.10-61.90) ≥ 6×0.036 = 0.21

0.20 ≥ 0.21

So, process is almost under the control and rejection level has been reduced after removing the root causes of rejection.
Process Capability Ratio,

$$C_p = \frac{USL - LSL}{6\sigma'}$$

$$C_p = \frac{62.1 - 61.9}{6 * 0.036} = 0.93$$

Process Capability Index,

$$C_{pk} = Minimum(C_{pu}, C_{pl})$$

$$C_{pu} = \frac{(USL - \bar{X})}{3\sigma'}$$

$$= \frac{(62.06 - 62.002)}{3 * 0.036}$$

$$= 0.54$$

$$C_{pl} = \frac{(\bar{X} - LSL)}{3\sigma'}$$

$$= \frac{(62.002 - 61.94)}{3 * 0.036}$$
$$= 0.58$$

Process Capability Index,
$Cpk = Minimum(Cpu, Cpl)$

Process Capability Index,
$Cpk = Minimum(0.58, 0.54)$

$= 0.54$

So, Process Capability Index (C_{pk}) of the process is 0.54

Although 200 observations of shocker seals are taken, only plots of 50 observations each are shown in Figure 3,4,5,6 respectively. These observations are taken after removing the root causes of rejection.

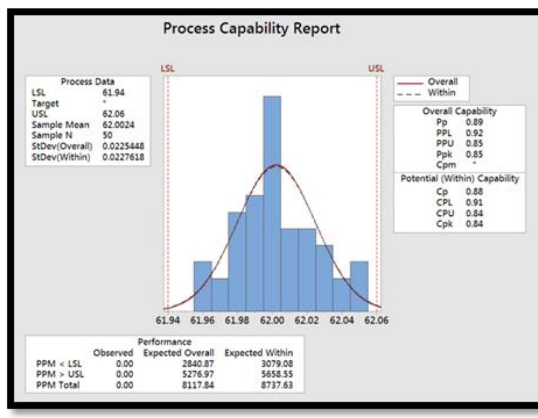

Figure 3. Process Capability Report (1-50).

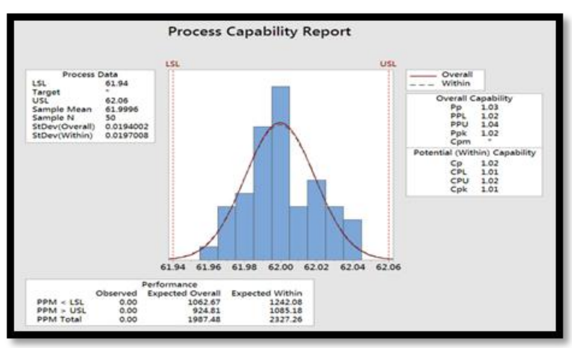

Figure 4. Process Capability report (51 – 100).

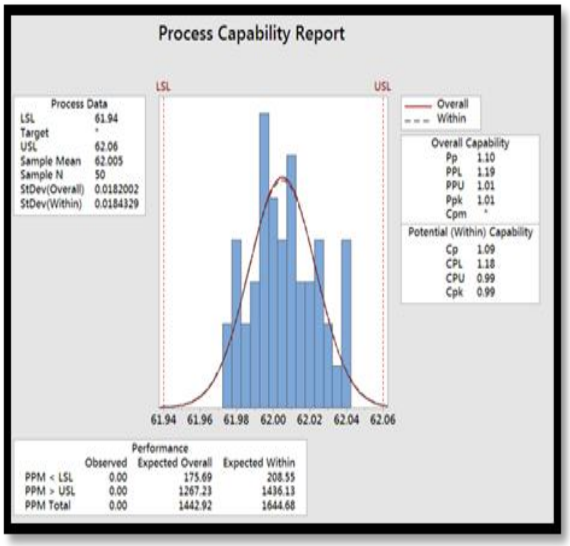

Figure 5: Process Capability Report (101-150).

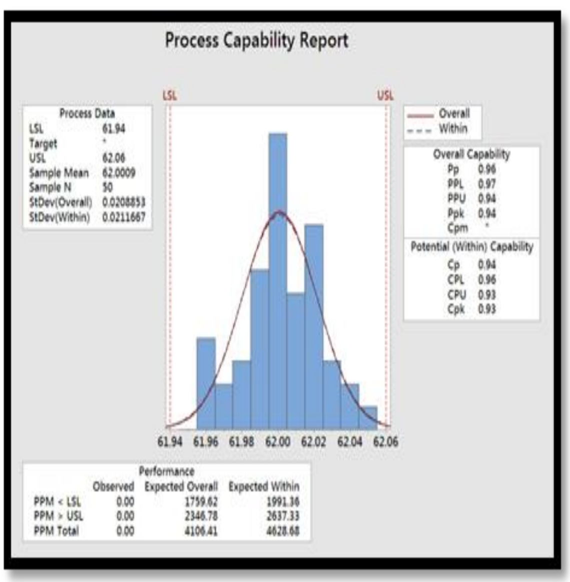

Figure 6: Process Capability Report (151-200).

7. Conclusion

The present work deals with the study of shocker seals. After implementing the required suggestions/recommendations for shocker seals, it is found that process capability has been improved and it is greater than required. The process capability attained in all the four cases i.e; I,II,III,IV is equal. Out of 200 observations of outer diameter of shocker seals, no any observation is falling outside the control limits on $\bar{X}$ Chart, but only one observation is falling outside upper control limit in case of R Chart. So, $6\sigma'$ is not achieved in case of R Chart, but the process is under control and process capability is achieved upto the desired level.

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