INVESTIGATION OF THE PROCESS CAPABILITY OF WATER PUMP PLASTIC COVER MANUFACTURING

Sohaib Khlil
Middle Technical University, Iraq
Technical College-Baghdad, Department of Applied Mechanics

Huthaifa Alkhazraji
University of Technology, Iraq
Control and System Engineering Department

Zina Alabacy
University of Technology, Iraq
Control and System Engineering Department

ABSTRACT

In this study, a statistical analysis was conducted based on process capability indices to investigate the ability of manufacturing process of a water pump plastic cover, which is a product that is manufactured by the State Company for Electrical Industries in Iraq, to meet the desired specifications. The $\bar{X}$ – $R$ control charts, normal probability plot and histogram were constructed based on the data gathered from the production line. Matlab software was used to perform the statistical calculations and plot the graphs. It was found that the process capability during manufacture was inadequate and incapable of achieving the specified requirements for a significant number of manufactured products. Adjusting the process capability index by decreasing the process mean to the target value and reducing the variations of the process to meet the allowable product tolerance are two recommendations suggested for improving the quality level of the production.

Keywords: Quality Control, Process Capability Index, Control Charts, Water Pump Plastic Cover


http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=9&IType=11
1. INTRODUCTION
The challenge in today’s competitive markets is to produce products at high quality while keeping the cost at a minimum (Motorcu and Güllü, 2006). A product is considered to be at a high-quality level if it satisfies its specification or customer requirement (Judi et al., 2011). To achieve a high-quality, various quality control techniques are implemented at every stage of the manufacturing process (Kane, 1986). Among them, Process Capability Indices (PCIs) are common method that utilises the concept of statistical process control to measure the ability of a process to manufacture products that meet certain level of specifications (Yeh and Bhattacharya, 1998; Ebadi and Shahriari, 2013). Over time, researchers shifted their focus from evaluating the capability of a product to evaluating the capability of the overall production process (Deleryd, 1998). One of the most common problems facing industry is the variability that exists in the production process (Mohammadi et al., 2015). These variabilities can be categorised into two types: random and assignable (Al-saady et al., 2012). Control charts, for example, are a well-known tool used to recognise the causes of the assignable variability, whether it results from common causes or special causes. However, control charts are not considered a suitable stand-alone tool to determine if the customer's requirements are achieved. It is important to relate what the customer expect (Voice of the Customer), which is determined by the specification limits, to what it known about the production process (Voice of the Process), which is determined by the control limits. Therefore, to ensure that product quality is continuously monitored and improved, the control chart is recommended for use with PCIs (Adeoti and Olaomi, 2017).

Within the area of quality control, researchers have made many contributions evolving process capability index. Juran (1974) presented the first process capability index $C_p$ as a ratio between the desired specification limit and the actual process variation. The index $C_p$ has been criticised of being unable to identify the scenario where the process is not centred in the middle of the specifications limits (Chan et al., 1988). To overcome the drawback of the index $C_p$, Kane (1986) proposed the index $C_{pk}$ by including the process mean. However, the two indices $C_p$ and $C_{pk}$ are calculated independently of the target value of the process. For this reason, an alternative process capability index $C_{pm}$ was developed by Chan et al. (1988) that take into account the actual process variation with respect to the target value in the assessment of process performance. By combining the indices $C_{pk}$ and $C_{pm}$, Pearn et al. (1992) proposed a new index called $C_{p_{mk}}$.

Most PCIs consider the collected process data is normally distributed and if this is not the case, then the use of these indices might be misleading (Kotz et al., 1993). Thereafter, it was recognised that the properties of many processes do not satisfy this assumption (Johnson et al., 1992). In addition, Munechika (1992) provided a number of machining process examples that were generated with a non-normal distribution. Therefore, research attention was given to alternative methods to compute PCIs under non-normal conditions (Borrini et al., 2010). For example, Wright (1995) proposed a new index $C_z$, which integrates a penalty for skewness. Pearn and Kotz (1994) proposed a new generalisation of PCI, based on the assumption that population has a Pearsonian distribution. Recently, Kovářík and Sarga (2014) reviewed the performance of nine approaches that deal with non-normality. Further research on various methods to evaluate the capability of non-normality processes have been proposed, including: Chen and Pearn (1997), Tang and Than (1999), Deleryd (1999), Pal (2004), Abbasi and Niaki (2010) and Kovářík and Sarga (2014).

Additionally, there is a large body of research on the applications of PCIs in various processes of manufacturing products. For example, for the speaker driver (Chen and Pearn, 1997), Liquid Crystal Display (LCD) (Pearn and Wu, 2005), spheroidal cast iron parts (Motorcu and Güllü, 2006), polyjet printing for plastic components (Singh, 2011), blow moulded for cleaning liquid (Al-saady et al., 2012), connecting rod manufacturing process (Sharma and Rao, 2013),
pharmaceutical production (Chowdhury, 2013), boring operation (Rajvanshi and Belokar, 2012), crankshaft manufacturing (Sharma and Rao, 2014), carburettor manufacturing (Yadav et al., 2018), aluminium alloy wheel machining (Sharma et al., 2018) and soft drinks processing unit (Yogi, 2018).

The objective of this study is to assess of the quality control of a water pump plastic cover based on PCIs. The State Company for Electrical Industries in Iraq manufactures this product. For this purpose, the $\bar{X} - R$ control charts, normal probability plot and histogram were constructed based on the data gathered from the production line. Matlab software was used to perform the statistical calculations and plot the graphs.

2. PROCESS CAPABILITY INDICES

Many quality control practitioners use PCIs as a tool to assess the performance of the manufacturing process. These indices provide valuable information to evaluate the quality of the production process (Genta and Galetto, 2018). The design of first-generation capability indices was based on a classical philosophy of statistical process control. Based on that philosophy, all measurement results within the determined tolerance interval are considered as good. Measurements outside the tolerance interval are considered bad (Kureková, 2001). Among many indices that are developed in literature, the most widely used is the capability index $C_p$ that was introduced by Juran (1974) and is given by (Tsui, 1997):

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

where

- $USL$ The upper specification limit,
- $LSL$ The lower specification limit,
- $\sigma$ The process standard deviation.

Potential Capability ($C_p$) index is defined as the ratio of specification width to the process spread; it indicates how the process conform to the specification limits (Kane, 1986). In general, if the value of the potential process capability index is smaller than one ($C_p < 1$), this means that the standard specified limit is less than the control limit (poor process). On the other hand, if the value of the potential process capability index is greater than one ($C_p > 1$), this means that the production might produces products that meet the customers’ requirements and the process is potentially capable (Chowdhury, 2013). However, a $C_p > 1$, does not imply that a manufacturing process is not producing defect products. The value of control limits might be less than one for the standard specified limits, but the process mean is not located in the centre of the specification limit. For this reason, the process capability index $C_{pk}$ as given in Eq. (2) was developed by Kane (1986) in addition to the index $k$ as given in Eq. (3), are combined to determine the process capability to achieve the customers’ requirements (Palmer and Tsui, 1999).

$$C_{pk} = \min(C_{pu}, C_{pl})$$

$$C_{pu} = \frac{USL - \mu}{3\sigma}$$

$$C_{pl} = \frac{\mu - LSL}{3\sigma}$$

$$k = \frac{\mu - m}{d}$$

where

- $\mu$ The process mean.
- $m$ The midpoint of the specification interval, i.e. $m = (USL + LSL)/2$. 
The half-length of the specification interval, i.e. \( d = (USL - LSL)/2 \).

The index \( C_{pk} \) indicates if there is any reduction in process capability resulting from a lack of centring, whereas the index \( k \) refers to the distance that the process lies off-centre (Palmer and Tsui, 1999). Some authors added to the index \( k \) an absolute value for the case where \( LSL \leq \mu \leq m \) (Kane, 1986). However, Palmer and Tsui (1999) believed that it is useful to keep the sign of \( k \) in order to know whether the process mean needed to decrease or increase to meet the process target, which will be explained in Section 4. Both indices \( C_p \) and \( C_{pk} \) are suitable for situations where the reduction in the variability is the main contributor to improve the process capability performance (Wu et al., 2009). Chan et al. (1988) developed the so-called Taguchi capability index \( C_{pm} \) by including the process departure \((\mu - T)^2 \) as given in Eq. (4) to reflect the degree of process targeting.

\[
C_{pm} = \frac{USL-LSL}{6\sqrt{\sigma^2 + (\mu-T)^2}}
\]

where

\( T \) The target of the product characteristic.

In calculating process capability indices, it is often assumed that the manufacturing process is under statistical control and the collected process data is normally distributed (Pearn and Wu, 2005). This study adopted the following approach to conduct an analysis on the quality of a process based on PCIs:

**Step1.** Select the critical component from the manufactured product (Deleryd, 1998; Rajvanshi and Belokar, 2012).

**Step2.** Collect data from the manufacturing process regarding the selected component (Pearn and Chen, 1999; Deleryd, 1998; Rajvanshi and Belokar, 2012).

**Step3.** Ensure the process data is collected as individual subgroup measurements at the time sequence of the manufacturing process (Chan et al., 1988).

**Step4.** Estimate of the manufacturing process average \((\bar{X})\), the range \((\bar{R})\) and standard deviation \((s)\) from the collected process data as given below (Kotz et al., 1993):

\[
\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n}
\]

\[
s = \sqrt{\frac{\sum_{i=1}^{n} (x_i-\bar{X})^2}{n-1}}
\]

\[
\bar{R} = \frac{\sum_{i=1}^{n} R_i}{n}
\]

**Step5.** Construct \( \bar{X}, \bar{R} \) and \( s \) control charts to ensure that the manufacturing process data is under statistical process control (Pearn and Wu, 2005).

**Step6.** Check the normality distribution of the collected process data (i.e. normal probability plots, histograms and the Anderson-Darling test) (Chan et al., 1988; Deleryd, 1998; Rajvanshi and Belokar, 2012).

**Step7.** Estimate the process capability indices from the estimated process average mean \((\bar{X})\) and standard deviation \((s)\) as given by (Chan et al., 1988):

\[
\hat{C}_p = \frac{USL-LSL}{6s}
\]

\[
\hat{C}_{pu} = \frac{USL-\bar{X}}{3s}
\]
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\[ \hat{c}_{pl} = \frac{\bar{x} - LSL}{3s} \]

\[ \hat{c}_{pk} = \min(\hat{c}_{pu}, \hat{c}_{pl}) \]

\[ \hat{k} = \frac{(\bar{x} - m)}{d} \]

\[ \hat{c}_{pm} = \frac{USL - LSL}{6\sqrt{s^2 + (\bar{x} - T)^2}} \]

3. CASE STUDY: WATER PUMP PLASTIC COVER

In this section, the approach of utilising PCIs to evaluate the quality of a manufacturing process is provided through a practical application in an industrial case study. The State Company for Electrical Industries (SCFEI) is an Iraqi manufacturing company that focuses on the development and production of a variety of electrical appliances, including parts of water pumps. The water pump plastic cover was selected for a case study in this research to analyse the capability of the machining line to manufacture this type of product, as shown in Figure (1.a). The critical character for this product is the distance between the two screwed studs on the plastic cover as shown in Figure (1.b). For that particular model of the plastic cover of water pumps, the target value for the distance between the two screwed studs is set to 66.0 mm with a tolerance of 0.4 mm. Given this, the lower and upper specification limits are LSL = 65.8 mm and USL = 66.2 mm. Table (1) summaries the specification characteristic of the water pump plastic cover.

To assess the production process, (21) samples (n) were taken for seven weeks, three days per week. Each sample consisted of four observations (k). Samples were selected randomly during the manufacturing process. The distance between the two screwed studs were measured by using a micrometre with accuracy (0.001 mm) and scale range (0-150 mm). Table (2) presents the collected process data. In addition, the last three columns of Table (2) summarises the calculated sample mean (\( \bar{X} \)), the sample range (R) and the sample standard deviation (\( \sigma \)) for the samples. The software package MATLAB was used to check if the manufacturing process was operates within statistical process control and the distribution is normal. Figure (2) plots \( \bar{X} \), R and \( \sigma \) charts for the manufacturing process data. It can be seen from Figure (2) that no points are outside of the control limits and all points are within the upper and lower control limits.
result, it can be claimed that the process of producing the water pump plastic cover is under control and stable.

**Table 1** The specification characteristic of the water pump plastic cover (Author)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>USL</td>
<td>66.2</td>
</tr>
<tr>
<td>LSL</td>
<td>65.8</td>
</tr>
<tr>
<td>T = m</td>
<td>66</td>
</tr>
</tbody>
</table>

**Table 2** The 21 samples of 4 observations with calculated sample statistics (Author)

<table>
<thead>
<tr>
<th>Samples (n)</th>
<th>Observations (k)</th>
<th>( \bar{X} )</th>
<th>R</th>
<th>s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( X_1 )</td>
<td>( X_2 )</td>
<td>( X_3 )</td>
<td>( X_4 )</td>
</tr>
<tr>
<td>1</td>
<td>66.34</td>
<td>66.40</td>
<td>66.33</td>
<td>66.25</td>
</tr>
<tr>
<td>2</td>
<td>66.32</td>
<td>66.77</td>
<td>65.57</td>
<td>65.94</td>
</tr>
<tr>
<td>3</td>
<td>65.96</td>
<td>66.45</td>
<td>66.14</td>
<td>66.13</td>
</tr>
<tr>
<td>4</td>
<td>65.89</td>
<td>65.89</td>
<td>66.13</td>
<td>66.55</td>
</tr>
<tr>
<td>5</td>
<td>66.42</td>
<td>66.28</td>
<td>66.21</td>
<td>65.96</td>
</tr>
<tr>
<td>6</td>
<td>66.19</td>
<td>66.61</td>
<td>65.95</td>
<td>66.03</td>
</tr>
<tr>
<td>7</td>
<td>66.03</td>
<td>66.38</td>
<td>65.71</td>
<td>66.47</td>
</tr>
<tr>
<td>8</td>
<td>66.32</td>
<td>66.65</td>
<td>66.66</td>
<td>66.15</td>
</tr>
<tr>
<td>9</td>
<td>65.89</td>
<td>66.42</td>
<td>66.65</td>
<td>66.13</td>
</tr>
<tr>
<td>10</td>
<td>66.61</td>
<td>66.21</td>
<td>65.86</td>
<td>66.32</td>
</tr>
<tr>
<td>11</td>
<td>66.28</td>
<td>65.62</td>
<td>66.20</td>
<td>66.15</td>
</tr>
<tr>
<td>12</td>
<td>66.15</td>
<td>65.89</td>
<td>66.42</td>
<td>65.96</td>
</tr>
<tr>
<td>13</td>
<td>66.65</td>
<td>65.99</td>
<td>66.13</td>
<td>66.21</td>
</tr>
<tr>
<td>14</td>
<td>66.51</td>
<td>65.76</td>
<td>65.89</td>
<td>65.92</td>
</tr>
<tr>
<td>15</td>
<td>65.61</td>
<td>65.96</td>
<td>66.28</td>
<td>66.15</td>
</tr>
<tr>
<td>16</td>
<td>66.15</td>
<td>66.02</td>
<td>66.51</td>
<td>65.81</td>
</tr>
<tr>
<td>17</td>
<td>65.83</td>
<td>66.32</td>
<td>66.04</td>
<td>66.15</td>
</tr>
<tr>
<td>18</td>
<td>66.51</td>
<td>65.89</td>
<td>66.56</td>
<td>66.12</td>
</tr>
<tr>
<td>19</td>
<td>66.05</td>
<td>66.15</td>
<td>66.74</td>
<td>66.21</td>
</tr>
<tr>
<td>20</td>
<td>66.13</td>
<td>66.61</td>
<td>65.88</td>
<td>65.89</td>
</tr>
<tr>
<td>21</td>
<td>66.51</td>
<td>66.02</td>
<td>66.32</td>
<td>66.56</td>
</tr>
</tbody>
</table>

**Table 3** Summary of Results for Calculations \( \bar{X}, \bar{R}, s \) and \( P-value \) (Author)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \bar{X} )</td>
<td>66.189</td>
</tr>
<tr>
<td>( \bar{R} )</td>
<td>0.4450</td>
</tr>
<tr>
<td>( s )</td>
<td>0.0849</td>
</tr>
<tr>
<td>( P-value )</td>
<td>0.218</td>
</tr>
</tbody>
</table>
Normal probability plots, histograms and the Anderson-Darling verified the normal distribution. Figure (3) plots the normal probability and the histogram of the collected data. It can be seen from Figure (3) that the sample data appears to be normal. Furthermore, $P$ – value that is resulted from the Anderson-Darling test is 0.218 which is greater than the critical value (0.05). Therefore, PCIs can be applied.

4. RESULTS ANALYSIS AND DISCUSSION

Based on the Eqs. (10, 11, 12, 13, 14 and 15), the indices $C_p, C_{pk}, C_{pu}, C_{pl}, k$ and $C_{pm}$ are calculated as 0.785, 0.043, 1.527, 0.043, 0.954 and 0.322 respectively. Table (4) summarises the calculation results for the indices $C_p, C_{pk}, C_{pu}, C_{pl}, k$ and $C_{pm}$. Usually, the value of the indices
calculated from the sample data is used to make a conclusion on whether the given process meets the specification requirement or not (Pearn and Chen, 1999).

Table 4 Summary of results for calculations $C_p$, $C_{pk}$, $k$ and $C_{pm}$ (Author)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_p$</td>
<td>0.785</td>
</tr>
<tr>
<td>$C_{pu}$</td>
<td>0.043</td>
</tr>
<tr>
<td>$C_{pl}$</td>
<td>1.527</td>
</tr>
<tr>
<td>$C_{pk}$</td>
<td>0.043</td>
</tr>
<tr>
<td>$k$</td>
<td>0.945</td>
</tr>
<tr>
<td>$C_{pm}$</td>
<td>0.322</td>
</tr>
</tbody>
</table>

Many researchers have made different explanations and interpretations of these indices (Tsui, 1997). Chao and Lin (2006) claimed that the interpretation of PCIs is still ambiguous. However, in general two pieces of important information can be determined from PCI values: process mean regarding the target value and the process variation regarding the specification limits (Wu et al., 2009). In this paper, a similar procedure to the common understanding and interpretations from Tsui (1997), Palmer and Tsui, 1999, Pearn and Chen (1999), Pearn and Wu (2005) are used to determine whether a given process meets the capability requirement or not. Chen et al. (1988) developed the $C_{pm}$ index for those cases where the target ($T$) is not in the midpoint of the specification limits ($m$). The $C_{pm}$ index gives similar information as the $C_{pk}$ when the target value is the midpoint of the specification limits. In this particular case that is undertaken in this study, the target ($T$) is in the midpoint of the specification limits (i.e. $T = m$). Therefore, the analysis is based on the value of the $C_p$, $C_{pm}$ and $k$ indices.

Figure 5 Decision making for testing $C_p$ & $C_{pm}$ (Author)
By comparing Eq. (1) and Eq. (6), it can be notice that the only difference between the two equations is the term \((\mu - T)^2\). This term becomes zero if the mean of the process \((\mu)\) locates at the targe value \((T)\). As a result, if the mean of the process \((\mu)\) locates at the targe value \((T)\), the indices \(C_p\) and \(C_{pm}\) are equal \((C_p = C_{pm})\). Based on that, Figure (5) shows how the decision is made based on the value of \(C_p\) and \(C_{pm}\). If \(C_p = C_{pm}\) and \(C_p \& C_{pm} \geq 1\) then the process is centred and capable; If \(C_p = C_{pm}\) and \(C_p \& C_{pm} < 1\) then the process is centred but not capable; If \(C_p \neq C_{pm}\) and \(C_p \& C_{pm} \geq 1\) then the process is not centred but capable; If \(C_p \neq C_{pm}\) and \(C_p \& C_{pm} < 1\) then the process is not centred and not capable; If \(C_p \neq C_{pm}\) and \(C_p \geq 1\) and \(C_{pm} < 1\) then the process is not centred and not capable. As mention in Section 2, the index \(k\) is used to measure the distance that the process lies off-centre. Figure (6) shows how the decision is made based on the value of \(k\). If \(k > 0\), then the process location needs to be adjusted by decreasing the process mean until \(C_p = C_{pm}\). On another hand, if \(k < 0\), then the process location needs to be adjusted by increasing the process mean until \(C_p = C_{pm}\). Therefore, from the value obtained of \(C_p\), \(C_{pm}\) and \(k\) from the collected data, it can be said that the process of producing the water pump plastic cover is not centred and not capable. Further, minimizing process variation and adjusting the process location by decreasing the process mean until \(C_p = C_{pm}\) are two actions need to be done in order to improve the process capability of the production process.

5. CONCLUSION

Process capability indices are a systematic approach based on statistical analysis have been widely used in manufacturing industries to provide an indication of how a process has conformed to its specifications. Process capability analysis has been proved over variety of industrial application to be a very valuable engineering tool in make decision regarding quality control problems.

In this paper, a process capability analysis was used to demonstrate the capability of a machining line, of the State Company for Electrical Industries in Iraq, to meet the desired specifications for a water pump plastic cover. The X-R control charts, normal probability plots and histograms of the collected data were plotted and the process capability indices applied. The results from the control charts clarified that the process of producing the water pump plastic cover is under control and stable. However, it was revealed from the value of PCIs that the process capability for the production process was inadequate and the process mean was not centred on the target. Reducing the variations in the process and decreasing the process mean to the target are two recommendations for improving the quality level of the production.
REFERENCES


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