Analyzing Universal Testing Systems Performance Using Process Capability Analysis

Author: Rajiv Iyer

Introduction:

Today, in the age of a global economy, competitive pressure is dramatically increasing due to cheaper overseas manufacturing. However the need for producing products with zero defects remains a top priority. Manufacturers cannot afford to produce bad products or shut down production lines for quality adjustments. To address these growing challenges, companies have adopted strategies such as total quality management (TQM) and Six Sigma Methodologies. Many companies also have certifications such as ISO 9001:2015 that represent the entire organizations approach towards defect free processes and traceable quality management.

The fundamental core of these strategies is to monitor the performance of individual process and benchmark themselves against the performance of industry leaders. One metric that is used for benchmarking is the process capability index (PCI).

The basic concept of the PCI is to understand the variation of data from an individual process to pre-defined specification limits. Statistics also refers to PCI as a guideline to understand the capability of the process[1].

Specification limits are typically defined by the manufacturers interested in a particular process or application. They can also be derived from empirical data from the process itself. For example, a company might define a process with 10% tolerance limits as acceptable or define a process with an acceptable minimum and maximum range from the target or mean of the process.

Estimating PCIs

PCIs can also be known as process capability ratios (PCR), which are quantitative estimates used to understand the capabilities of an individual process or product. Statistical experts recognize the behavior of a process in the form of data distribution[1]. In order to assess its adequacy, the distribution is compared to the specifications' limits. Two of the commonly used PCIs or PCRs are C_p and C_{pk}. The mathematical formula for C_p and C_{pk} are as follows[1]:

$$C_p = \frac{USL - LSL}{6\sigma} \qquad C_{pk} = min\left\{\frac{ULS - \bar{X}}{3\sigma}, \frac{\bar{X} - LSL}{3\sigma}\right\}$$

Where; USL = upper specifications limit, LSL = lower specifications limit and σ = standard deviation of the data.

The index C_p only considers the spread of the data and compares the spread with the specification limits, whereas C_{pk} considers the actual location of the data in terms of mean calculations and therefore is sensitive to shifts in the data. Many industrial applications prefer C_{pk} as it is a more accurate estimate of process capability compared to Cp[1].

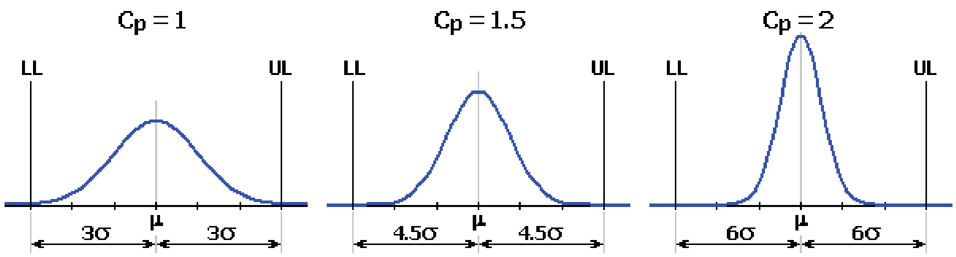

Figure 1: Process capabilities at various C_p values[2]

Figure 1 presents an overview of different C_p estimates and their correlation to the spread of the data within specification limits. Observations that can be seen in Figure 1:

- C_p = 1 the process might just meet the specification limits indicating the process may not be capable[1]
- C_p = 1.5 indicates the performance of the process is well within specification limits and therefore capable[1]
- C_p = 2 indicates the process is well within specification limits and extremely consistent indicating the process is highly capable[1]

Ideally, in most cases we consider C_{pk} and C_p equal as it is assumed that the data from the process is centered with the mean being the central line. Therefore, in PCI studies it is common to estimate C_{pk} and ignore the C_p. If a desirable target for an application is defined, the PCIs should consider the target as the reference central line and not the average of the data.

To interpret the PCI estimates, in addition to the charts shown in Figure 1, statistics define the relationship between PCI values to overall process yield that can be achieved from a system or product. In other words, C_p or C_{pk} estimates represent the number of defects in parts per million that will yield from a process or system.

Table 1: Process yield and PPM defects for various PCI estimates[1]

Specification Limits	Process Yield	Parts Per Million Defects (PPM)	Process Capability Index (C_p or C_{pk})
+/-1sigma	68.70%	317300	0.33
+/-2sigma	95.45%	485500	0.67
+/-3sigma	99.73%	2700	1.00
+/-4sigma	99.9937%	63	1.33
+/-5sigma	99.999943%	0.57	1.67
+/-6sigma	99.9999998%	0.002	2.00

Table 1 presents the relationship of PCI estimates to process yields at the specification limits. In many cases, a six-sigma quality product or process is desired which indicates capabilities of achieving a C_p or C_{pk} value of 2.00 and higher.

How do PCIs Apply to Instron® Systems?

Materials testing applications include destructive and non-destructive testing of components manufactured from raw materials such as metals, plastics, rubber, etc. and therefore, when using an Instron testing system, companies are interested in understanding the consistency of measurements over multiple samples, over multiple batches, and over multiple systems installed at different locations.

For example, if company A has multiple sites manufacturing the same plastic component, it is essential to evaluate the quality of the component produced from the various sites. Therefore when a materials testing system such as an Instron, is used at multiple sites, it is highly critical to validate the performance of the testing system and investigate the quality of the finished parts. This is where PCIs play a significant role in estimating C_{pk} over defined acceptable tolerance limits.

On the other hand, companies using a materials testing systems in an R&D environment need to validate the system's capability, PCIs play a key role. This type of information could help manufacturers verify if the components produced have zero defects as well as financially justify the capital investment of the testing system. Further, the data analysis presented is critical towards qualifying the system before installation.

Case Study

An Instron 5944 electromechanical system is used to conduct ASTM D790, a standard test method to measure flexural properties of unreinforced and reinforced plastics and electrical insulating materials. Using parameters defined in the D790 test methodology, a sample set of 30 plastic specimens were used from the same batch to measure the flexural strength during three point bending. Data on the flexural strength was recorded from the test and process capability analysis were implemented to estimate C_p/C_{pk} values.

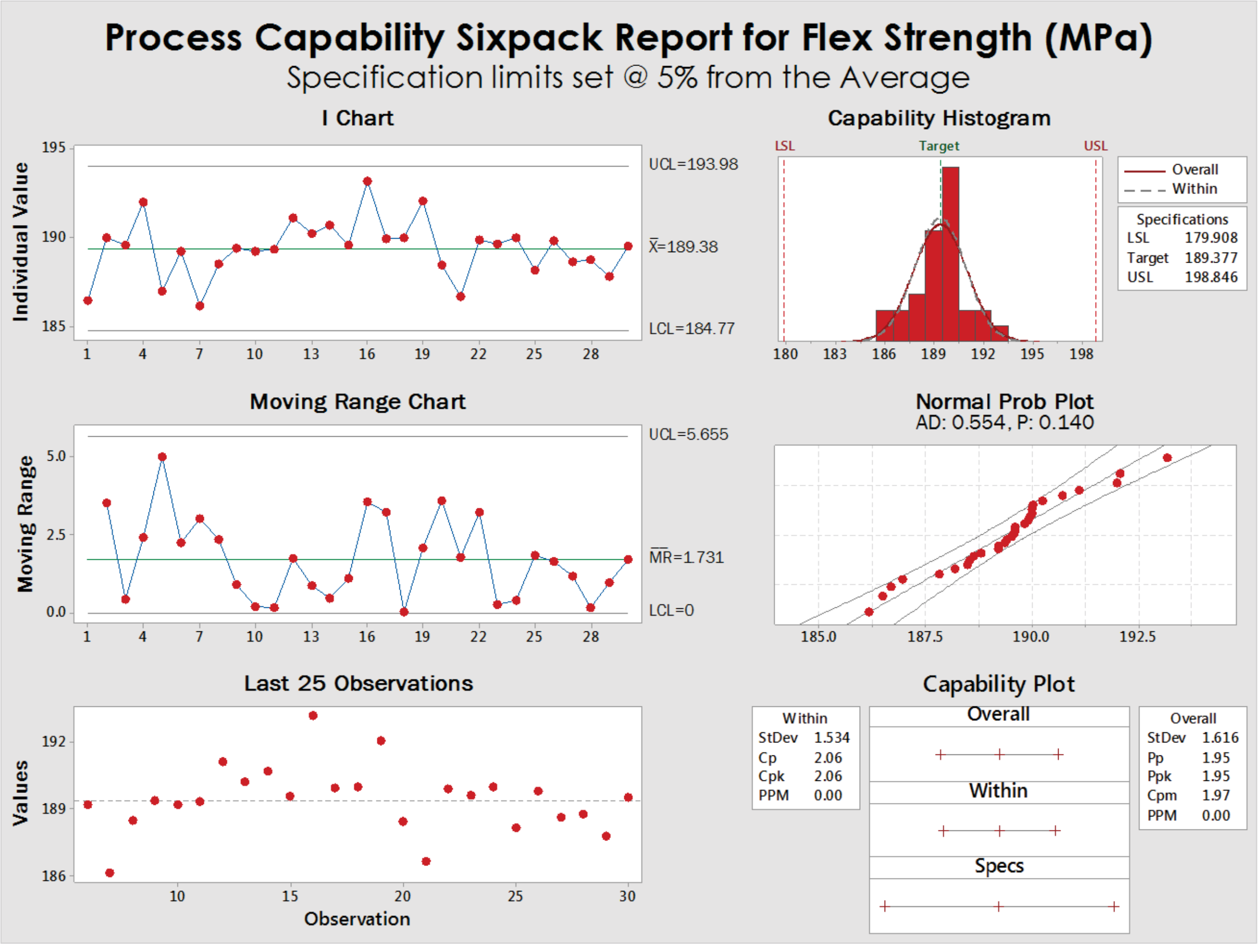

Figure 2: Process Capabilities Analysis – Sixpack Report on Flexural Strength (MPa)

Results from Figure 2 show that a C_{pk} of 2.06 at ±5% tolerance is achieved, proving that the system is highly capable (six-sigma capable) of running the ASTM D790 test method. Further, it can also be validated that the plastic specimens manufactured from a batch comply to the standard with defects as small as 0.002 parts per million within 5% tolerance limits as C_{pk} is greater than 2.00. The sixpack capability report shown on Figure 2 is a snapshot of the process capability analysis and shows consistency of measurements among the 30 samples tested.

In the scenario where no specification limits are defined for PCI computations, estimates are calculated for various specification limits. Figure 3 presents a correlation of C_{pk} estimates at various specification limits.

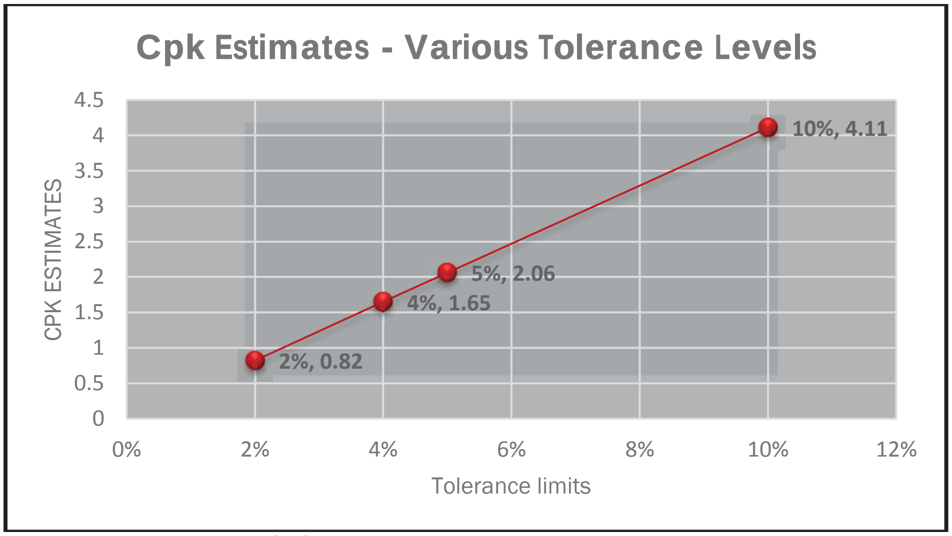

Figure 3: C_{pk} Estimates at Various Tolerance Levels

From Figure 3, one can conclude that at 2% tolerance limits the C_{pk} is 0.82 thereby indicating the process as not capable. At 4%, C_{pk} is 1.65 which indicates the process is capable but not six-sigma capable. Many industrial applications consider C_{pk} of 1.33 and higher as acceptable. At 5%, the process can achieve six-sigma capability with C_{pk} greater than 2.00 yielding defect rates as small as 0.002 ppm. Further, at 10% the performance of the product is well beyond expectations. This conclusion is extremely valuable to manufacturers to understand the quality of their product. Manufacturers can rely on their Instron systems for measurements and PCI estimates to understand the defect rates or process yields.

This article outlines the capabilities of using a 5944 electromechanical system to conduct flexural testing of plastics and the tolerance band to achieve a high quality process. Similar tests can be conducted for other materials and applications to evaluate preliminary capabilities of the system and the product under test.

For more information and discussions related to PCIs and their analysis, please contact us at www.Instron.com

References

1. Montgomery, C. D., 2009, Introduction to Statistical Quality Control (6th ed.), John Wiley & Sons, USA.
2. Solis, L., "Determining between a PPK and CCK Business Process", http://i-mie.com/determining-between-a-ppk-and-cck-business-process-by-laurence-solis/, October 2013, Accessed February 2017.
3. MINITAB 17, Statistical Software Package.