6σ

Assessing Initial Process Capability

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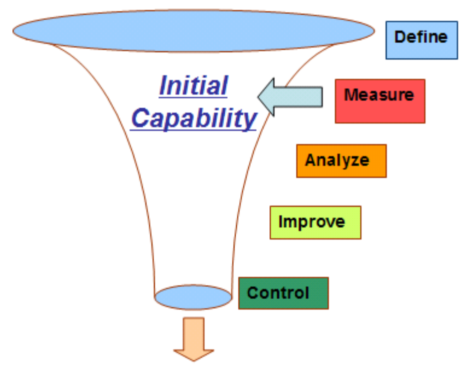
By Hemant Urdhwareshe,
Director, Institute of Quality and Reliability,
ASQ Certified Six Sigma Black Belt, CQE, CRE, CQMgr

In the last article, we discussed about Measurement Systems Analysis (MSA). This was necessary before we attempt to evaluate how capable our process is in meeting customer's requirements. In process capability evaluation, we compare and find ratio of two values:



1. Process Tolerance
2. Process Variation

Process tolerance is derived from customer's requirements. Thus it is sometimes called *"Voice of Customer"*. Process Variation on the other hand is our ability to manage and control the process. It is sometimes called "*Voice of Process*". Tolerance for the process is usually specified by the designer. This obviously must relate to the customer's requirements. In complex products, there are large number of components and subassemblies. Customer does not specify tolerance of each component but is interested in performance and reliability of the end product. For example, a customer for a car would expect good appearance, comfortable and safe ride, fuel economy, low maintenance etc. He or she will never specify tolerance for pistons or steering or starter motor! Thus it is designers' responsibility to understand customers' requirements and convert these in to internal specifications. When these specifications are met, product should meet customer's requirements.

To quantify *Process Variation*, a statistical value called "Standard Deviation" (SD) is used. This is represented with a symbol σ. However, σ can be exactly calculated only if we measure all the parts produced by the process! This is never possible in real life. Thus, statisticians have introduced another symbol "S" for estimate of the standard deviation. Value of S for sample sizes of 32 or more are used as approximation to the value of population standard deviation σ. S is calculated using formula:

$$s = \sqrt{\frac{\sum (x - \bar{x})^2}{(n-1)}}$$

We can use any scientific calculator or spreadsheet (such as Microsoft Excel) to compute the SD. As we can see, we calculate sum of the squares of differences between each value in the data and the average in the numerator.

To evaluate process capability,

- Measurement System used for process output must be capable and
- Process must be stable and predictable.

We have already discussed in the last month how to evaluate measurement system capability.

While assessing stability in initial capability study, it is expected that all the preliminary work of setting up process parameters is completed and we are ready to run the process. We also need to ensure that process is not changed or disturbed during capability study. To assess stability, one of the popular techniques is statistical control charts. We will discuss about these later. In absence of control charts, we can verify whether process output is “Normally Distributed”. However, this is not statistically as robust as using control charts. “Normal Distribution” is a well-known mathematical distribution. Output data from many processes tend to “fit” in this distribution. Once we have verified that the data fits reasonably well in Normal Distribution, we can use the mathematical formulate to interpret process variation and process capability. An important property of Normal Distribution is 99.73% of data points lie within +/- 3 Standard Deviations. See figure 1 for this. Thus the spread of +/-3σ or total 6σ is a measure of process variation. **A ratio of tolerance to this 6σ is called Process Capability Index Cp**. Thus:

$$\text{Capability Index Cp} = \frac{\text{Tolerance}}{6\sigma}$$

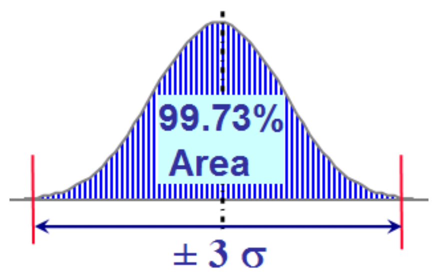
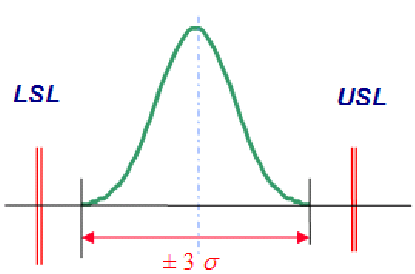


Figure 1

To summarize the above paragraph,

- 99.73% values lie within ±3σ for Normal Distribution
- ±3σ i.e. total 6σ is sometimes called the natural tolerance of the process or Voice of Process
- Tolerance is difference between upper specification limit (USL) and lower specification limit (LSL)
- (Tolerance / 6σ) is called capability index Cp (see Figure 2)



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

Figure 2

We consider three cases of Cp values:

1. If value of Cp is less that 1, process variation is more than the tolerance. Process is therefore not capable of meeting specifications. Such process will always produce some parts that do not meet specifications.
2. If Cp equals 1, tolerance equals process variation. Such process is barely capable of meeting specifications and
3. If Cp is sufficiently greater than 1, process variation is smaller than the tolerance. Such process is capable of meeting specifications. In this case, chance of producing nonconforming parts is very low. This is the most desirable situation.

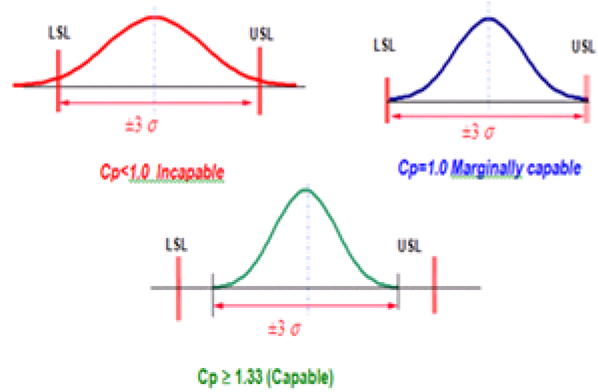


Figure 3

Figure 3 shows these 3 cases for Cp<1, Cp=1 and Cp=1.33.

How many pieces should we measure?

Process Capability measurement can be done in the short term as well as in the long term. When we measure relatively less number of components, we are evaluating "Short Term Capability". Sometimes this is also called "Process Potential Study". In such short term study, we are interested in evaluating inherent process variation. Many factors such as tools, operators, environment etc. do not change appreciably during study. Minimum number of pieces that statisticians recommend is 32 for short term capability. For sample sizes less than this, the calculated standard deviation S may be quite different than the population standard deviation σ. Long term process capability is usually assessed using control charts and allows effects of many events in the process such as operators, raw material, tool changes etc. We will discuss only short term capability in this article.

Let us now consider an example of short term process capability.

Example of Short Term Capability

Design specification of a spring requires force to be controlled between 145 and 155 Newton. Data of 50 pieces was collected and standard deviation was found to be 1.286.

We first need to check whether the data is normal. If yes, we can calculate process capability. A simple check is shape of histogram. This should be "Bell Shaped". This can be done better using a technique of "probability plotting". Most of the statistical software is capable of performing Normal Probability Plotting. A perfect straight line corresponds to a perfect normal distribution. Thus points close to the straight line indicate that data a "reasonably normal". Figure 4A and 4B show Histogram and Normal Probability Plot of spring force data from Minitab Software. We can see that points the histogram is bell shaped and points are close to straight line in the Probability Plot. We can therefore consider the data as normal.

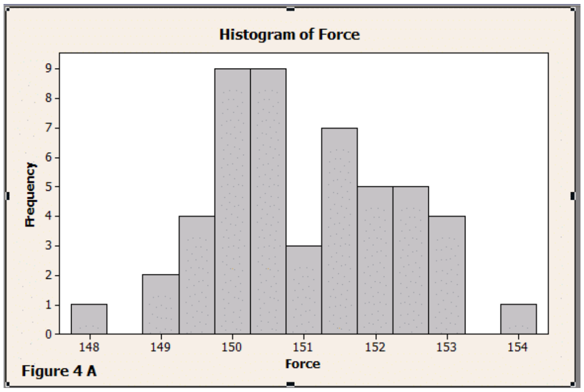


Figure 4 A

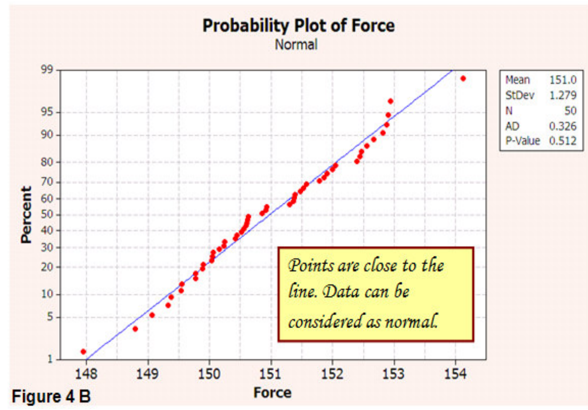


Figure 4 B

We can now estimate the capability index Cp. We calculate ratio of tolerance i.e.10 Newton and 6 times standard deviation S=1.286. This value is 1.3.

$$\text{Capability Index } Cp = \frac{\text{Tolerance}}{6\sigma} = \frac{10}{6 \times 1.286} = 1.30.$$

The Cp that we calculated represents "inherent capability" to meet specifications. Thus we are only interested in knowing whether the process of manufacturing springs is capable of meeting the speciation without considering some of the factors that may change in the long term. Thus long term capability is likely to be lower than this value as long term variation will be more due to many other causes.

So far, we have not given any importance to *centering of the process*. However, in reality, the proportion of parts that are outside specifications will change depending on where the process average lies with reference to the upper and lower specifications. For the spring example, these values are seen in Minitab output in Figure 5. Please note that although there is no nonconforming piece in the sample, expected overall performance shows that 0.09% parts are likely to be

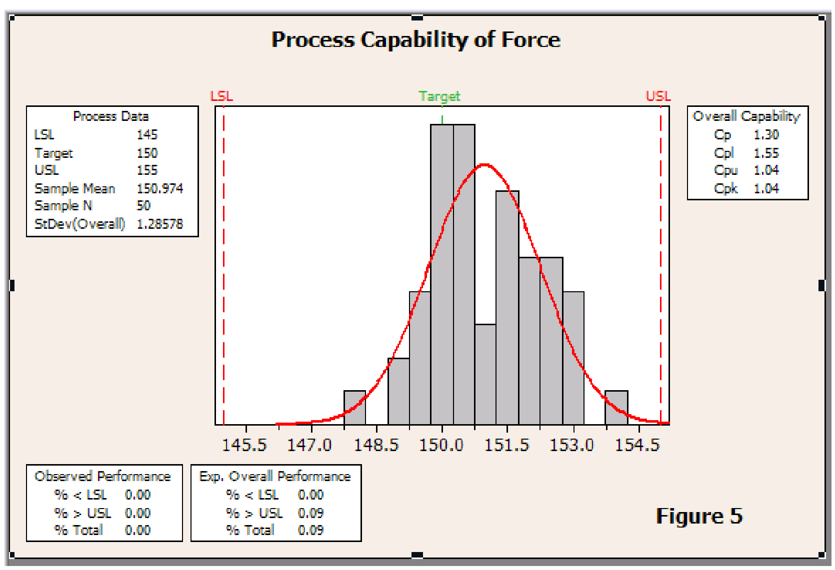


Figure 5

above specification. This is because the process is shifted slightly towards upper specification. Cpu and Cpl represent capability to meet upper and lower specifications respectively. These values are 1.04 and 1.55. Lower of these two values is called Cpk. Cpk can either be equal to or less than Cp. Thus in this example, Cp is 1.3 but Cpk is 1.04.

Figure 6 shows a case where process average is shifted towards lower specification. Even if the Cp is 1, the Cpl and Cpk value will be less than 1 resulting in nonconforming parts below the lower specification limit. Thus C_{pk} considers effect of centering.

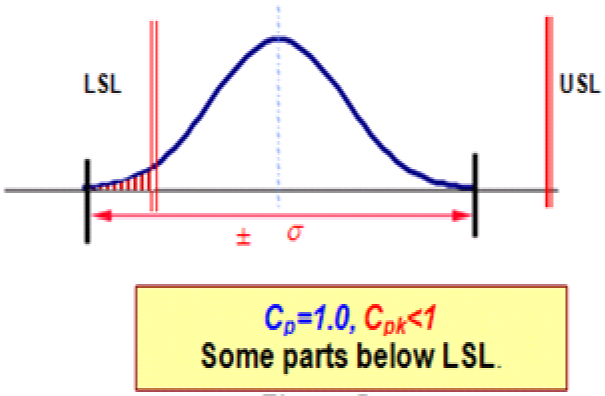


Figure 6

- CPU =(USL - Mean) /(3 x σ)
- CPL =(Mean - LSL) /(3 x σ)

C_{pk} = Cpu or Cpl whichever is lower

Minimum Capability requirement is a management policy and relates to the customer expectations. Few years back, most engineering and automotive manufacturers consider 1.33 as acceptable. The currently, automotive industry requires their suppliers to demonstrate a capability index of 1.67. Capability index of value lower than this requires corrective action and appropriate sampling plans to protect customer.

About Author:

Hemant Urdhwareshe is Director, Institute of Quality and Reliability, Pune. He is

- *Qimpro Foundation Silver Standard 2003 Award Winner*
- *First ASQ Certified Six Sigma Black Belt in India*
- *ASQ Certified Quality Engineer, Quality Manager and Reliability Engineer.*
- *The only person in India with 4 or more certifications from ASQ (as on Mar 2005)*
- *Senior Member ASQ*

Email: hemant@world-class-quality.com *Phone: 020-25367952*

Visit: www.world-class-quality.com