PROCESS CAPABILITY FOR UNILATERAL TOLERANCES INCLUDING TRUE POSITION

Tools & Tips Webinar sponsored by the AESQ Process Control Methods SMIG
8th February 2023
CAPABILITY FOR UNILATERAL

Agenda – 60 minutes

Overview – P. Teti

Who is the PCM Subject Matter Interest Group – P. Teti

Why this webinar? Where can we find help?

PCM Community of Practice – Linked In

Process Capability – A. Stout

Non-normal – A. Stout

Capability for Unilateral Tolerances – A. Stout

Capability for True Position – A. Stout

Q&A – PCM SMIG Team

Summary and Close – P. Teti
WEBINAR OVERVIEW

We are recording today’s webinar and will distribute the video link following the close of the webinar. It will also be posted on the AESQ website for free viewing.

We will take questions during today’s webinar using the Chat feature.

Please remain on Mute during the presentation to prevent background noise. We will also be muting all lines at the start of the session.
CAPABILITY FOR UNILATERAL

Why this webinar?

Communicate how to conduct a robust Process Capability study that meets RM13006 guidelines.

Show how to use statistical tools in conducting and analyzing a Process Capability Analysis.

Promote the available free documents and tools that can be used by any AESQ supplier.

Answer questions suppliers may have about process capability methods.
RM13006 provides the user with an array of practical approaches to process control used to ensure consistent product quality.

The purpose of this reference manual is to raise the overall capability of the aerospace engine supply chain, standardize the process control requirements across AESQ suppliers, and build on the requirements for PFMEA and Control Plans (ref. RM13004).

RM13006 supports AS9145 - Requirements for Advanced Product Quality Planning and Production Part Approval Process, and AS9103 - Variation Management of Key Characteristics, supported by detailed guidance and case studies.

This reference manual was developed by a dedicated team from AESQ member companies with expert knowledge and experience in the areas of process control, process improvement, quality systems, and supplier engagement.
The purpose of the PCM Subject Matter Interest Group is to promote the effective deployment of the process control methods across the AESQ Supply Chain.

The Group is made up of Subject Matter Experts from the AESQ Member Companies.

The Group is accountable for the AS13100 related Requirements and associated Reference Manual content, ensuring that it is up to date and reflects current knowledge and best practice.

It shall promote the effective deployment of the Reference Manual using Communities of Practice (CoP). The CoP is open to any subject matter expert or individual experienced or trained in process control from the aero engine community.

Activities may include webinars, best practice sharing, development of shared training materials, conferences and published papers.

https://aesq.sae-itc.com/interest-groups
Who is the Process Control Methods SMIG Team?

Curators for RM13006

Experts to answer process control related questions

Provider of process control related guidance
PROCESS CONTROL METHODS CoP

Where to get help

AESQ Supplementary Materials webpage for a copy of RM13000 and supporting templates

https://aesq.sae-itc.com/supplemental-material

Subject Matter Interest Group – meets monthly – supports continuous improvement of RM13006 and supporting templates & tools

AESQ Process Control Methods Community of Practice (CoP) on Linked-In

Current membership is 200 – let’s get some more!!

https://www.linkedin.com/groups/12647920/
PROCESS CAPABILITY IN RM13006

SECTIONS INVOLVING PROCESS CAPABILITIES IN RM13006

- 2.1.1 IMPORTANCE OF PRODUCT CAPABILITY
- 3.3 CHOICE OF CAPABILITY METRIC
- 5.3 PROCESS CAPABILITY FOR PROCESSES WITH INTENTIONAL SHIFTS
- **6.0 PROCESS CAPABILITY INDICES**
  - 6.1 FUNDAMENTALS OF VARIABLE DATA
  - 6.2 PROCESS STABILITY IN PRACTICE
  - 6.3 PROCESS CAPABILITY FOR ATTRIBUTE DATA
- **7.0 GUIDANCE FOR NON-NORMAL DATA**
  - 7.2 CAPABILITY ANALYSIS FOR NON-NORMAL DATA
- 9.1.2 PROCESS CAPABILITY FOR MULTIPLE IDENTICAL FEATURES
- 11 DATA ANALYSIS ENABLERS
- 13 STATISTICAL FORMULAE FOR PROCESS CAPABILITY

+ New material for future update
THE IMPORTANCE OF PROCESS CAPABILITY

Why does Process Capability matter?

- It gives a voice to your process from the viewpoint of the customer
- It gives you a number to evaluate your process
- It lets you know your potential (compare Ppk to Cpk to Cp)
- It lets you know where to spend your resources and be proactive
KEY PRINCIPLES OF PROCESS CAPABILITY

Before looking at capability

• Can you trust your measurements? (MSA)
• Can you trust your data? (visualize)
• Do you have enough data to capture full process variation?
KEY PRINCIPLES OF PROCESS CAPABILITY

- Is the data in time order?
- Is the process in statistical control?

I-MR

Looks good

May be a trend at the start. Investigate prior to starting capability analysis.

To get an estimate of capability it may be acceptable to allow up to 2 “out of control” points, per 25. Every effort should be made to identify the root cause and correct it. The real world is not so pretty.
KEY PRINCIPLES OF PROCESS CAPABILITY

Distributions can differ in:

LOCATION  SPREAD  SHAPE

This one is not normal!
Normal Distribution

- The shape of a histogram can provide important information about the presence of assignable causes and variation
- The Normal distribution (bell-curve) frequently occurs when the process is subjected only to random variation (common causes)
KEY PRINCIPLES OF PROCESS CAPABILITY

Bimodal Distribution

- The histogram exhibits two “humps” (NOT a normal distribution)
- Normal probability plot shows a poor fit to the confidence interval
KEY PRINCIPLES OF PROCESS CAPABILITY

Skewed Distribution
• Not symmetrical, NOT a normal distribution
• One tail is longer than the other
• Skewing is said to be in the direction of the longer tail
• Could be due to unilateral tolerance
KEY PRINCIPLES OF PROCESS CAPABILITY

Truncated Distributions

- A distribution in which one or both tails are missing (NOT a normal distribution)
- The histogram either begins or ends abruptly
GUIDANCE FOR NON-NORMAL DATA

- Distribution fit
  - Using Normal for Non-Normal data will provide incorrect and misleading capability values

Cpk = 1.4
Really good?
Ppk = 0.53
Is that right?

Cpk = 0.9, Ppk = .83
Is that correct?
GUIDANCE FOR NON-NORMAL DATA

• Assessing Normality
  • A large amount of data can make goodness of fit too sensitive
  • Visually review of histogram
  • Probability plot shows a good fit, especially in area of risk (near spec limit)
  • p-value > 0.05 for Normal
  • Anderson Darling Number (AD or A** or A square) preferably < 0.75
  • Or other statistic (RJ, K-S, S-W, AIC,...)

- Probability Plot of Data
  - Normal - 95% CI
  - p = 0.228
  - AD = 0.481

- Histogram
  - Frequency
  - Measurement

- Probability Plot of Flatness
  - Normal - 95% CI
  - p < 0.005
  - AD = 4.311

- Histogram of Flatness
  - Frequency
  - Flatness
GUIDANCE FOR NON-NORMAL DATA

RM13006 Section 7 – Guidance for Non-Normal Data

Causes of Non-Normal include

- Natural skew due to a boundary condition
- Data from two or more components of variation (e.g., true position of a hole from x and y coordinates)
  - A cyclic process behaviour
  - A process with a natural tendency to drift
  - Selective or biased measurements
  - Process instability - lack of control
  - Lack of resolution in measurement systems or rounding
  - Reworking non-conformances prior to measurement
  - Human factors (e.g., stopping at a maximum limit when machining down to a size)
  - Two distributions being present within the data (i.e., bi-modal).
GUIDANCE FOR NON-NORMAL DATA

Actions

• Check your process
• Check your data (at least 30)
• Find a non-normal distribution with better fit
  – Weibull is often used
    • Zero values will need McAdam shift (see RM13006 section 7.2.2)
• Capability
  • Z-score method that uses proportions
  • ISO method uses 0.135 or 99.865 percentiles
  • Special cases
• Last resort: Transform with Box Cox or Johnson

For more
  – See RM13006 section 7
  – Attend our Webinar #8 - Dealing with Non-Normal Data

Note: Standard Deviation (SD or $\sigma$) is not applicable for non-normal distributions.
RM13006 Section 6. Process Capability Indices

“NOTE: It will not be possible to calculate Cp or Pp indices for processes with unilateral (single sided) tolerances as the tolerance width cannot be defined. However, Cpk and Ppk can be calculated from the Cpl/Ppl or Cpu/Ppu (whichever can be calculated).”
ONE SIDED TOLERANCES

Unilateral – Case 1: A natural or physical limit on lower side

- Don’t analyze as 2 sided
- Example: Shaft runout would have a maximum spec, not to be exceeded.
  
  But runout cannot be less than zero
- When calculating capability leave LSL blank or identify it as a boundary

\[
P_{PU} = \frac{USL - \bar{X}}{3\hat{\sigma}_{n-1}}
\]

\[
Ppk = P_{PU}
\]
ONE SIDED TOLERANCES

Unilateral – Case 2: Lower spec only

Examples
- Min wall
- MTBF
- MTTF
- Horsepower

P_{PL} answers: Is the process likely to yield products with characteristics below the minimum allowable?

\[ P_{PL} = \frac{\bar{X} - LSL}{3\hat{\sigma}_{n-1}} \]

\[ P_{pk} = P_{PL} \]
MAXIMUM MATERIAL CONDITION

(M) MMC - Maximum Material Condition
• Condition where the most material exists
• Greatest mass on feature
• Min ID
• Max OD
• If (M) on drawing, as the feature deviates from its Maximum Material Condition, that amount may be added to the positional tolerance

Min ID is the MMC condition
2.000 - .040 = 1.960”

If Actual ID is 2.010”
**MMC Bonus** = 2.010 − 1.960 = .050” dia
Or .025” radial

TP tolerance with bonus = .060 + .050 = .110” Dia or .055” radial

Dimensions in inches
TRUE POSITION CAPABILITY

Special Case

How to analyse?
• TP Rad
• Adjusted TP
• Residual Tolerance
• Percent of Tolerance
• Effective Size to Virtual
• Area Method
TRUE POSITION CAPABILITY

TP Rad

Using conventional radius/diameter analysis method

Good Weibull fit only occurs **only** when X & Y are on target.

Both X and Y axis are usually Normally distributed.

TP Rad is Non-Normally Distributed

\[ TP \text{ Rad} = \sqrt{x^2 + y^2} \]

\[ TP \text{ Dia} = 2 \times TP \text{ Rad} \]
TRUE POSITION CAPABILITY

Using TP Rad method

Capability Case 1 = Capability Case 2

Not good as variability is different
Not the only way, but a new way to start to understand. Discussion, development and incorporation into RM13006 is pending.

Advantages of Area Method
- Good way to visualize and represent the true situation.
- “Most methods combine the individual variable bonus tolerance with the individual position deviation and then compare the resulting surrogate variable to a constant limit…found to be untrustworthy” isixsigma.com
- “…the natural variability must also be expressed in terms of a circular region.” infinityqs.com
**TRUE POSITION AREA METHOD**

**Process Performance**

\[ P_p = \frac{Tolerance}{Process\ spread} = \frac{green\ circle}{red\ circle} \]

\[ Area = \pi r^2 \]

\[ AreaP_p = \frac{\pi R^2}{\pi r^2} \]

\[ AreaPp = \frac{R^2}{(3s_{max(x,y)})^2} \]

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

**R = Radial Tolerance**

**r = Process Radius**

\[ (3s_{max(x,y)}) \]

To be conservative the larger variability is used, either x or y.

**Used with Pp and Ppk**
TRUE POSITION AREA METHOD

TP nominal center line

Actual TP average center

TP tolerance radial zone R

Actual TP 3s radial zone r

\[ P_p = \frac{\text{Tolerance}}{\text{Process spread}} = \frac{\text{green circle}}{\text{red circle}} \]

\[ \text{Area} = \pi r^2 \]

\[ \text{Area}_{P_p} = \frac{R^2}{r^2} \quad \text{Area}_{pp} = \frac{R^2}{(3s_{max(x,y)})^2} \]
TRUE POSITION AREA METHOD

$k = \text{radius to process center}$

$\sqrt{X_{\text{ave}}^2 + Y_{\text{ave}}^2}$

Actual TP average center

Actual TP 3s radial zone $r$

TP nominal center line

TP tolerance radial zone $R$
TRUE POSITION AREA METHOD

$k = \text{radius to process center}$

$$k = \sqrt{X_{Ave}^2 + Y_{Ave}^2}$$

Actual TP average center

Actual TP 3s radial zone $r$

Consumed Process Variation diameter zone (for Ppk calc.)

$$\text{Area Ppk} = \frac{R^2}{(k+r)^2}$$

TP nominal center line

TP tolerance radial zone $R$

$P_{pu} = \frac{USL - \bar{X}}{3s}$

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

$Area_{Ppk} = \frac{R^2}{(\sqrt{X_{Ave}^2 + Y_{Ave}^2} + 3s \max(x,y))^2}$
TRUE POSITION AREA METHOD

$k = \sqrt{X_{\text{Ave}}^2 + Y_{\text{Ave}}^2}$

- TP nominal center line
- TP tolerance radial zone $R$
- Actual TP average center
- Actual TP 3s radial zone $r$
- Actual TP variability + feature MMC bonus variability (Pooled 6s diameter zone)
- Consumed Process Variation diameter zone (for Ppk calc.)

$k =$ radius to process center
TRUE POSITION AREA METHOD

\[ k = \sqrt{X_{Ave}^2 + Y_{Ave}^2} \]

\[ AreaPp_{Bonus} = \frac{(R + 0.5 \times Bonus_{Ave})^2}{(3 \sqrt{s_{max(x,y)}^2 + s_{Bonus}^2})^2} \]

\[ AreaPpk_{Bonus} = \frac{(R + 0.5 \times Bonus_{Ave})^2}{(\sqrt{X_{Ave}^2 + Y_{Ave}^2} + 3 \sqrt{s_{max(x,y)}^2 + s_{Bonus}^2})^2} \]
**TRUE POSITION AREA METHOD**

**Area Pp without MMC Bonus**

\[ AreaPp = \frac{R^2}{(3s_{\text{max}(x,y)})^2} \]

**Area Pp with MMC Bonus**

\[ AreaPp_{\text{Bonus}} = \frac{(R + 0.5 \times Bonus_{\text{Ave}})^2}{(3s_{\text{max}(x,y)} + s_{\text{Bonus}})^2} \]

**Area Ppk without MMC bonus**

\[ AreaPpk = \frac{R^2}{(\sqrt{X_{\text{Ave}}^2 + Y_{\text{Ave}}^2 + 3s_{\text{max}(x,y)})^2}} \]

**Area Ppk with MMC Bonus**

\[ AreaPpk_{\text{Bonus}} = \frac{(R + 0.5 \times Bonus_{\text{Ave}})^2}{(\sqrt{X_{\text{Ave}}^2 + Y_{\text{Ave}}^2 + 3s_{\text{max}(x,y)} + s_{\text{Bonus}})^2}} \]
TRUE POSITION AREA METHOD

PreControl type chart to monitor
1. Diameter
2. X-axis
3. Y-axis
4. TP Dia
5. X-Y Plot
TRUE POSITION AREA METHOD

Example without Bonus
Example with Bonus

Special recognition goes to Paul McAdam, retired P&WC Quality Fellow, who did most of the development of these methods.
SUMMARY

Have quality data you can trust (MSA)
Have enough data to capture full process variability
Make sure your process is stable (Control Charts)
Choose the correct distribution
Choose the appropriate capability Indices to evaluate your process (Ppk preferred, Area Method for TP)
Track and improve!
## FUTURE WEBINARS

*From the Process Control Methods SMIG Group*

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<tr>
<th>NO.</th>
<th>WEBINAR TOPICS</th>
<th>TARGET DATE/TIME</th>
<th>WEBINAR LEAD</th>
<th>SUPPORTING SUB-TEAM</th>
<th>BRIEF DESCRIPTION</th>
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<td>2</td>
<td>What makes a good Process Capability Study?</td>
<td>1/26/2023 (11 AM U.S. Eastern)</td>
<td>Steve Hampton</td>
<td>Marnie Ham/Karen Scavotto</td>
<td>Cpk values are only as good as what goes into the data used to calculate Cpk, such as the adequacy of the measurement system and achieving statistical control.</td>
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<td>3</td>
<td>Process Capability for Unilateral Tolerances including True Position</td>
<td>2/8/2023 (11 AM U.S. Eastern)</td>
<td>Andrew Stout</td>
<td>Grant Braun/Karen Scavotto Shailesh Shinde</td>
<td>How do we handle process capability for one-sided or unilateral tolerances including true position where Maximum Material Condition modifiers may play a role.</td>
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<td>4</td>
<td>The use of non-statistically based process control methods</td>
<td>3/8/2023 (11 AM U.S. Eastern)</td>
<td>Paul Gorg</td>
<td>Pete Teti/Earl Capozzi/Rudi Braunieder/Nicklas Godebu</td>
<td>Process controls need not only be statistically based. Here we explore non-statistical methods such as error-proofing devices, the PreControl method, and the use of run charts with non-statistical limits.</td>
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<td>5</td>
<td>The Power of Precontrol</td>
<td>4/11/2023 (11 AM U.S. Eastern)</td>
<td>Andrew Stout</td>
<td>Steve Hampton/Geoffrey Carpentier</td>
<td>PreControl is a powerful non-statistical tool that is easy to get up and running with that can be used to qualify the set-up of a lot as well as a control for the production run.</td>
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<td>6</td>
<td>The One-Hour Process Control Assessment</td>
<td>5/16/2023 (11 AM U.S. Eastern)</td>
<td>Pete Teti</td>
<td>Geoffrey Carpentier</td>
<td>If you were visiting a supplier and only had time to carve out one hour for a process control assessment, what questions would you ask and where whom would you ask those questions to?</td>
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<td>7</td>
<td>Why is statistical control a prerequisite for process capability?</td>
<td>Target 2nd Qtr (June)</td>
<td>Marnie Ham</td>
<td>Andrew Stout/Geoffrey Carpentier/Douglas Dush</td>
<td>Process Capability indexes without the use of SPC Control Charts are invalid. Control Charts are the method to monitor and control a process and are a key prerequisite prior to calculating Cpk.</td>
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<td>8</td>
<td>Dealing with Non-Normal Data</td>
<td>Target 3rd Qtr. (September)</td>
<td>Karen Scavotto</td>
<td>Marnie Ham/Shailesh Shinde/Andrew Stout</td>
<td>What happens when the data coming from a process is non-normal? What can be done to accurately assess process capability? We will show you!</td>
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<td>9</td>
<td>Conducting capability studies for one-sided geometric tolerances</td>
<td>Target 4th Qtr. (October)</td>
<td>Karen Scavotto</td>
<td>Marnie Ham/Shailesh Shinde/Andrew Stout</td>
<td>Aerospace component manufacturers the world over deal with geometric/one-sided features such as runout, flatness, etc. What rules have to change when assessing process capability?</td>
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Look for these future topics in the “Upcoming Events” page on the AESQ website:

https://aesq.sae-itc.com/interest-groups
Q & A SESSION

USE THE “CHAT” FUNCTION TO ASK A QUESTION...
SUMMARY

All resources will be available on the AESQ website within a few days.

An email will be sent to all registrants with a link.
THANK YOU FOR PARTICIPATING