

Concept of using General Process Capability Data

Andreas Bruun Okholm, s082562

Mathias Rask Møller, s082536¹

Technical University of Denmark

(Dated: 6 November 2013)

A approach to generate Generalised Process Capability Data in order to populate and add functionality to a Process Capability Database. A description of the concept of generalisation, uses and implementation.

A Process Capability DataBase (PCDB) is a tool for mechanical designers to get information of what is possible to achieve in the companies production. This is done by storing and displaying statistical information about features on produced components. By applying Process Capability (PC) information in the design process it is possible to reduce: rework, cost, failure rate, assembly problems and increases product performance (Tata and Thornton, 1999).

As mentioned in (Tata and Thornton, 1999; Tata, 1999; Rask Møller and Okholm, 2013) and a number for key challenges has to be addressed to expand the use of PCDB.

- **Data Communication:** The databases are typically not easily searchable which makes it very difficult to find the correct data and in many cases the data sought after data does not exist. Further more the data is not presented in a way which is easily understandable by mechanical designers.
- **Fragmented Organization:** Development department are dependent on data from production.
- **Information Technology:** Make a database which is fast, live, global, self populating, up to date and live up to the industry criteria of security and anonymity.

There has been a couple of attempts in academia to solve some of these difficulties (Thornton and Tata, 2000; Kern, 2003; Thornton, 2004), but there hasn't much attention on the subject since indicating there is still issues to resolve before it can be efficiently used in the industry.

In this article we present a concept of data indexing, processing and presentation which tries to make it faster and easier for the mechanical designer to efficiently use process capability data in new designs. The general principle is to provide a interface where the data is presented in a much more generalised than typically done in PCDB interfaces. The core indexing scheme is simplified, but details are retained or improved using a flexible tagging system. Instead of presenting the designer with statistical information, actual recommended specifications limits is shown directly. The specification limits is normalised in regards to the specified dimension making more use out of each dataset, minimising the risk of database queries not returning any results.

Combined with advances in Information Technology we hope this will help make PCDBs a viable tool in the mechanical design process.

I. INDEXING

PCDB data needs to be indexed to efficiently retrieve data of relevance to the current design. The data stores in a PCDBs are typically measurements sets; the statistical result of number of measurements of a given part dimension combined with the design characteristics design. Feature, geometry, material and process is suggested by Kern (2003) to be the primary Design Characteristics (DC). For each primary DC there exists a tree structure of possibilities. An example of an index using Kerns proposed design index could be "Plane", "Position", "Aluminium", "Turning".

In some of the most used processes for mass produced parts like casting and injection moulding, it seems feature and geometry is not necessarily important DCs. The CAM machine milling the moulds does not recognise different features and does not adjust it's precision automatically (SOURCE?).

For our index, *material* and *process* should be only required DCs. This is combined with a tagging systems, where tags also lives in tree structures. Using tags gives more flexibility since more than one tag can be applied to one measurement set and it's possible to index for design characteristics that's specific to a single production method or material. As an example for injection moulding it would be interesting to index the material type of the mould - aluminium, steel, hardened, ... Indexing the mould iterations (T0, T1, T2) could also give valuable insights about, which specification limits requires mould rework or process adjustment. A last example could to tag if the dimension measured across a parting line in the mould potentially showing a general increase in desired specification limits.

Most product specifications are just plain tolerances (SOURCE?)- these are all just variations of point to point measurements and can as such just be combines into one pool - diameters, positions, thickness, radii... ?

What is measured and since indexed limits the possible conclusions, which can be made when extracting the data. If the goal is to understand the long term process capability impact of an injection mould process it's either necessary to have measurement sets from many products at different stages of their lifespan or multiple measurements through the lifespan of a couple of products.

II. PROCESSING CAPABILITY DATA

Processing the capability data consists of three steps:

1. Compute Process Capability Specification Limit (PCSL).
2. Normalize PCSL.
3. Interpret normalised PCSL data.

A. Process Capability Specification Limit

The process capability indices (C_p and C_{pk}) described by Kane (1986) has been widely adopted in statistical process control, been extended and further researched for better understanding (Wu, Pearn, and Kotz, 2009). Instead of looking at process mean μ , standard deviation σ and specification upper and lower limits USL , LSL using Process Capabilities Indices (PCIs) transforms these values into unit less numbers, which provides a quick overview of how a process is performing.

The PCIs ability to transform process variables of any object into unit less capability index can be reversed to calculate desirable specification limits. For en example the commonly used CPI C_{pk}

$$C_{pk} = \frac{d - |\mu - m|}{3\sigma} \quad (1)$$

can be reversed

$$d = 3C_{pk}\sigma + |\mu - m| \quad (2)$$

where $d = (USL - LSL)/2$ is half the specification limit and $m = (USL + LSL)/2$ is the midpoint between the specification limits. The half specification limit (symmetric tolerance value) is the required tolerance to achieve the desired process capability index value.

There are several commonly used PCIs each serving their purpose (Wu, Pearn, and Kotz, 2009; Taguchi, 1986)

- C_a : Closeness of process mean to target
- C_p : Relative size of variation
- C_{pk} : Amount of nonconforming (%NC)
- C_{pm} : Value loss (Taguchi loss function)
- C_{pmk} : Version of C_{pm} , sensitive to mean shift.

Visualising the $CPIs = 1$ shows how a process on target $C_a = 1$ allows the same variation for all PCIs 1. The line for C_{pm} is in below that of C_{pk} except for values of C_a close to 1. Using C_{pm} will in general be more conservative resulting in larger specification limits than C_{pk} . The plot shown is for a capability equal to one for higher values this effect is even more pronounced.

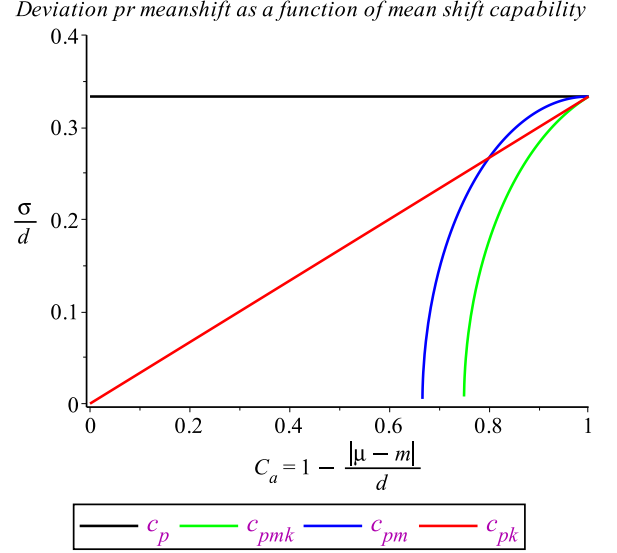


FIG. 1. C_p referens only to the variance of the process. C_{pk} is related to the yield of the product. C_{pm} takes a loss function in to account relates to a target dimension. C_{pmk} takes both the yield of the product and a loss function.

TABLE I. C_{pk} Non-conformities

| C_{pk} | σ level | NC _{max} (ppm) | NC _{min} (ppm) |
|----------|----------------|-------------------------|-------------------------|
| 1.00 | 3 | 2699.8 | 1349.9 |
| 1.33 | 4 | 63.3 | 31.7 |
| 1.50 | 4.5 | 6.7 | 3.4 |
| 1.66 | 5 | 0.6 | 0.3 |
| 2.00 | 6 | 0.002 | 0.001 |

For the purpose of our database we have chosen to use C_{pk} , since it provides the most easily understandable result - directly related to the yield of the process. The yield of a process is within $2\Phi(3C_{pk}) - 1 \leq \text{yield} < \Phi(3C_{pk})$ where $\Phi(\cdot)$ is the cumulative distribution function of the standard normal distribution $N(0,1)$ (Boyles, 1991). For typical capability levels the resulting non-conforming products in parts per million (ppm) is listed in table I

The desired specification limit will result in a maximum percentage of NC products.

Using C_{pm} would be sensible sense if the desired tolerances directly influence product performance - for instance in optics construction.

B. Normalization

Comparison of different standard tolerance dimension relations.

ISO 286? describes a non-linear function for comparing tolerances on objects of different dimension. This

function used to normalize tolerances and display PC independent of size (with in the limits of the function.)

Tysk og fransk standarder plast støbe standarder finde kilder

ANSI ?!

Choice of ISO based continious function and custom-ary user in industry

C. Analyze normalized data

fit normal distribution of sub groups. find subgroups

extracting data

robustness

visible confidence intervals of interperatation

III. USER INTERFACE

Readability of accumulated normal distribution compared to a bell curve.

Two figures showing the actual interface

General Interactivity in plots Special courses comment of measurement sets.

Group sorting Reference to Thornton graphical display article.

Visible confidence intervals

User can set tolerance (from IT to specific dimentions)

Two views General charts inspired by ANSI Process view inspired by Thornton Graphical display

IV. STATISTICAL VALIDITY

measurement sets are assumed to fit a normal distribution.

What you measure is what you get. Each product in the sample set, produces a measurement. From the sample set is a measurement set created.

Confidence intervals - sample size of each measurement set.

Number of measurement sets to predict process capability.

show current production capability in terms of it-grade

V. USING THE GENERAL PROCESS CAPABILITY DATA

apply tolerance, By looking at normalized data of the variance of products of the same material and process, it is possible to find a suitable tolerance improvement per rework material selection

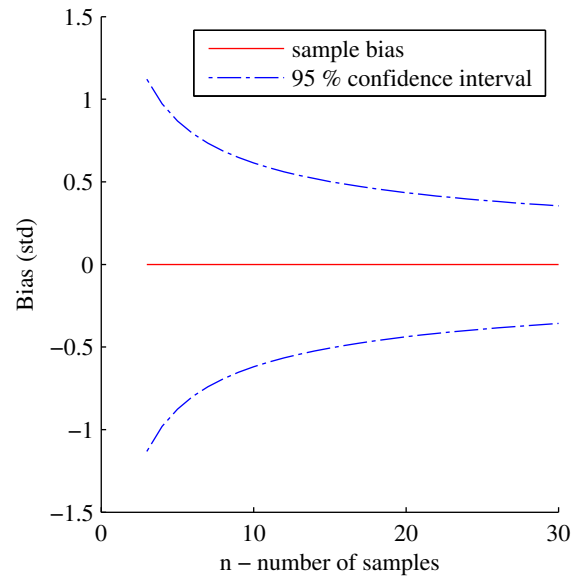


FIG. 2. The uncertainty of the standard deviation estimate is reduced as the number of samples is increased. The increase in accuracy gained per additional decreases with more samples. From the graph we have chosen 12 to be the optimal point for general process capability use.

VI. DISCUSSION

Using todays techonolgy, generalization of PC data upon request from the user i feasible. A proposed technical setup is described in ?.

Initiating PCG is a tough process. The reward for doing robust design engineering is long reach The reward for using PCDB or robust design in general to make changes in early design is a long term and might only benefit the company and not feedback to the designers compared the reward for the hero in production solving the expensive errors in design.

Implementing GPC requires a change economical barrier big company incement from quality department gain: knowlegde of own PC high precision data Extensive knowlegde on causes and problem loss: cross companies diverse data gain: Alot of data knowlegde of processes and matrial outside your field knowlegde of possible to achive in industry Index storing of own data and partially analysed loss: Indusry espionage concerns loss of information due to anonymity

proto running at a university, unbiast.

REFERENCES

- Boyles, R. A., "The taguchi capability index," Journal of Quality Technology **23**, 17-26 (1991).
- Kane, V. E., "Process capability indices," Journal of Quality Technology **18**, 41-52 (1986).

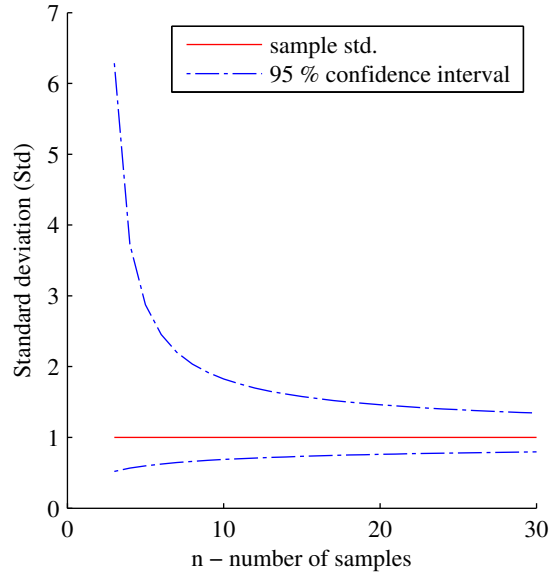


FIG. 3. The uncertainty of the standard deviation estimate is reduced as the number of samples is increased. The increase in accuracy gained per additional decreases with more samples. From the graph we have chosen 12 to be the optimal point for general process capability use.

- Kern, D. C., *Forecasting manufacturing variation using historical process capability data: applications for random assembly, selective assembly, and serial processing*, Ph.D. thesis, Citeseer (2003).
- Rask Møller, M. and Okholm, A., “Literature review of process capability databases,” (2013).
- Taguchi, G., *Introduction to quality engineering: designing quality into products and processes* (Quality Resources, 1986).
- Tata, M. and Thornton, A., “Process capability database usage in industry: myth vs. reality,” in *ASME Design Engineering Technical Conferences* (1999).
- Tata, M. M., *The effective use of process capability databases for design*, Ph.D. thesis, Massachusetts Institute of Technology (1999).
- Thornton, A. C., *Variation risk management: focusing quality improvements in product development and production* (Wiley Hoboken, 2004).
- Thornton, A. C. and Tata, M., “Use of graphic displays of process capability data to facilitate producibility analyses,” *AI EDAM* **14**, 181–192 (2000).
- Wu, C.-W., Pearn, W., and Kotz, S., “An overview of theory and practice on process capability indices for quality assurance,” *International Journal of Production Economics* **117**, 338 – 359 (2009).