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Tool risk setting in statistical tolerancing and its management in verification, in order to optimize customer's and supplier's risks

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Abstract

The statistical tolerancing aims to enlarge tolerances while limiting the customer risk. The rules are largely shared when the factors vary according to a normal law. But a lot of manufacturing processes cannot deliver a mean exactly centered or stable, and some are multi-generator. This paper will clarify the different options of calculation; define what is "tool risk" and how to set it. In the second part we will define the criteria of verification according to the hypothesis and the settings made during design, and the way to detect appearance of a tool risk and fix it. In appropriate contexts, this coupling tolerancing-verification allows high benefit by enlarging tolerances while mastering the risks, that is the target of statistical tolerancing.

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1. Introduction

The management of the mean is a well known issue for statistical tolerancing. Usual ways to master the deviation of the mean, like probabilist[1] and semi quadratic[1] methods, conduct to small tolerances. Pillet with inertial tolerancing[2] demonstrated we could accept a mean variation at the condition that the dispersion decreases, but this stays constraining. Anselmetti[1] and Judic[3] promoted a full statistical approach of semi quadratic. We will go deeper in this direction, see that there are several ways to manage the deviations according to their nature, during tolerance allocation, and then during verification.

2. Reminders

2.1. Vocabulary used in this paper

- Functional parameter (*FP*, or "*X*"): elementary characteristic specified by the designer on a component, factor of a function. We can extend this definition to include manufacturing and process parameters.
- Functional condition (*FC*): condition on a characteristic *Y* of a product or sub assembly required to ensure a function (internal or external)
- Functional design: activity consisting in:
  - Defining an equation $Y=f(X_i, i=1 \text{ to } n)$ issued from a physical model (kinematic, thermal..) using *n* FP
  - Defining the requirements on *Y* , in other words the *FC* (condition on an upper or lower specification limit : USL, LSL, also called U,L)[4]
  - Assigning the nominal values of X_i and their limits (tolerances)
- Tolerancing: last activity of functional design consisting to define the tolerance range (*TR*) of a functional parameter.
- Mean: arithmetical average of a population (μ)
- "Tool risk": risk of non conformity of the mean of *Y* when tools are toleranced by statistics (see more in 6.9)

2.2. Functional design methods

Unfortunately the designer does not usually have independent equations to solve, but an equation system (that

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we can summarize as a cross table). As the parameters are involved in several *FC*, they usually become constrained on upper and lower side. It is why in geometric tolerancing, sizes and positions have bilateral tolerance ranges, with different effects in case of non conformity (*NC*).

The *Y* are initially one sided on LSL or USL. In reality the internal function consist of a system in order to satisfy the external functions, and their limits are not always independent. This high level model is sometime difficult to build. But "de facto" the *Y* become both sided. When it is not the case, the solving may give inconvenient solutions, the most probable root cause being that requirements or models are missing.

In the next we will consider that the *Y* are both sided: this allow to make top- down design.

The alternative (bottom up design) consists in assigning the X_i, calculating the 2 limits of *Y*, and testing the non specified one on prototypes. Obviously this is not the best way to achieve robust design, because all combinations of *FC* limits cannot be built.

3. Tolerancing activity

3.1. Economical constraints

Thanks to simulations, the designer has found a solution for the system, meaning that he has *Y* convenient and X_i convenient. He has to ensure the robustness by assigning tolerances.

On mathematical point of view, one solution for tolerancing, is to set Tolerances for X_i=+/-0.

Obviously we need to introduce another requirement: tolerances must be largest as possible in order to minimize the cost of the components. To get a consistent answer from solvers, a cost function may be defined.

3.2. Pre requisite

This activity necessitates to have defined the technology, because feasible tolerances depend on the option chosen to manufacture the component. Often a hypothesis is taken and changed if not convenient, leading to iteration.

3.3. Consequence

As soon a technology or manufacturing process is selected, we should know (from experience) the theoretical distribution function of the functional parameters (probability density).

3.4. Transfer function of distributions from FP to FC

The model of *Y* allows defining the resulting distribution by combination of parameters distributions.
Iteration allows specifying the X_i that satisfy the requirements.

4. Statistical hypothesis on parameters distribution

Following describes from 4.2 to 4.5 the most frequent statistical hypothesis and proposes a universal model in 4.6.

4.1. Time consideration

Tolerancing defines *FP* specifications that must be valid on the long term (*LT*), ie for the whole production period. Short term (*ST*) studies, ie when most of process parameters are hold constant, will help to understand how long term distributions are built.[5]

Notice that the *ST* distribution of *Y* is obtained from *ST* distributions of X_i, in "just in time"processes. On the opposite we cannot affirm that *LT* distribution of *Y* can be calculated from *LT* distributions of X_i. Time is a factor that must be studied because it can introduce correlation between X_i.

4.2. Worst case (WC) hypothesis

In this option, the designer considers the worst cases, ie in most of cases, minimum and maximum limits.

This is the hypothesis to take:

- When no assumption can be made, for example when we have no experience or the manufacturer cannot give additional information.
- At the condition however that the manufacturer guarantees these limits.

4.3. Gaussian hypothesis

This hypothesis will consider a Gaussian (or "normal") distribution centered on the midrange.

It must be centered on the long term[6]. The only option to get a long term Gaussian with a short term Gaussian not centered is to have the mean varying according to Gaussian. Other hypotheses cannot give a strict Gaussian.

This distribution is typical of process under control in SPC wording. The variation of the mean can be due to sampling rather than process variation.

As the Gaussian are infinite, we have to define the number of sigma contained in the Tolerance Range (*TR*), and if the Gaussian is truncated (no *NC* outside)

So :

- If the Gaussian is not truncated at *TR*, the *WC* hypothesis is not compatible with Gaussian hypothesis because no limit exists, i.e. no real *TR*.[7]
- If the Gaussian is truncated, the distribution is not strictly Gaussian, which affects the calculation of *Y*.

4.4. Equiprobable hypothesis (also called "probabilist")

The distribution is constant inside the *TR*, and null outside.

This distribution can be obtained by 2 typical ways:

- Continuous drift of the mean inside the tolerance range, and instantaneous Gaussian with small standard deviation. Once limit of *TR* is approached, the process is adjusted to other limit and a new cycle begins.
- Sort after production. This is rarely chosen in a new design because of the waste.

The resulting long term distribution is then centered in the *TR*. In first case, the short term distribution can be anywhere, but will move certainly.

This hypothesis is compatible with worst case.