SIX SIGMA

SIX SIGMA MECHANICAL DESIGN TOLERANCING

by

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ABSTRACT

This booklet presents the rationale and methodology for establishing, analyzing, optimizing, and allocating mechanical assembly tolerances. The presentation progresses step by step from the underlying statistical methods to "real world" mechanical design applications. Both the discussion and examples of design analysis and optimization are constructed around the philosophy of Motorola's Six Sigma Program – the creation of product designs that are robust to natural sources of manufacturing and material variation.

The booklet opens with a brief historical account of how human need has motivated the evolution of mechanical tolerances. Certain key events that played a major role in this evolution are highlighted. This discussion closes with an explanation of why it is absolutely essential for the technical community of Motorola Inc. to continue its efforts with respect to "designing for manufacturability."

Following the background information, the statistical principles underlying design analysis are presented and thoroughly discussed from a theoretical as well as a pragmatic frame of reference. Particularly strong emphasis is given to the arithmetic mean (μ), standard deviation (σ), standard transform (Z), and normal distribution. The discussion then turns to how basic statistical tools are used to form various indices of manufacturing process capability (C_p and C_{pk}). In each instance where an analytical tool is presented, it is shown how the supporting statistical principles and equations are shaped and subsequently applied to a generic product referred to as a "widget." This particular product example is interwoven throughout the entire booklet to create a common denominator. In addition, two case studies are presented. The first case involves design optimization of a fairly simple assembly chassis. The second study presents the outcomes of a design optimization related to a sophisticated hand-held military radio.

Directly following the discussion on basic statistics, worst-case analysis is introduced. Although worst-case analysis is not considered a statistical procedure, it has been included for convenience; that is, a means for benchmarking the relative efficacity of comparable statistical procedures. The first statistical tolerance analysis procedure discussed is the "Root-Sum-of-Squares" method, or simply RSS. Focus is on the major reason for using RSS analysis: taking advantage of the probabilities related to tolerance stacking. Also discussed are the limitations of RSS analysis. As an alternative to RSS analysis, a method called "Dynamic Root-Sum-of-Squares," or DRSS, is introduced. In addition, a second method called "Static Root-Sum-of-Squares" (SRSS) also is presented. Both methods take into account shifts and drifts in the process mean which normally result from such factors as tool wear and machine set-up. With DRSS, as well as SRSS, the design engineer structures a baseline design and then computes the probability of assembly. If the outcome is not relatively close to Motorola's Six Sigma criteria (99.99966 percent likelihood of assembly, in either direction of the nominal assembly gap) the engineer conducts an optimization and allocation study using the statistically-based equations presented in this booklet. The end result is a mechanical assembly that exhibits 6σ performance at the assembly level of analysis.

The booklet closes with a discussion of a statistical procedure that compensates for short-run production. Implications and limitations of this particular practice are discussed from a pragmatic point of view. In addition, other areas of application within the field of mechanical engineering are discussed. As a final point, the role of computer hardware and software for use in mechanical design analysis and optimization is highlighted.

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Publication Number **6σ-2-10/88**

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