The Implications of Tolerance System Interpretation on Past and Present Dimensional Variability Studies

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ABSTRACT

Dimensional variability studies and published dimensional variability standards have been used by the foundry industry for years as an indicator of the casting process' ability to produce uniform parts. These studies are an extremely useful tool in the continuous "dimensional dialogue" between foundries and customers. The nature of these studies, and of the current tolerancing systems used by casting designers, leaves room for some misinterpretation and misuse of these study results. This paper contains two important discussions. The first part explains exactly what these studies represent. Following this is a brief explanation on dimensional and geometric tolerances and how they communicate dimensional requirements.
I. INTRODUCTION

Since the advent of mass-produced interchangeable parts, dimensional tolerances have been used to control the form, location, orientation and size of part features. Regardless of the type of cast feature, tolerances enable casting designers to communicate the needed dimensional control to the foundry producing that feature.

Over the years, the foundry industry has attempted to characterize their ability to produce parts within prescribed dimensions. Examples of these comprehensive dimensional capability studies include the SFSA (1977), SCRATA (now CTI) and IBF TS-71 dimensional studies.\textsuperscript{1,2,3,4} From these and other studies, the SFSA (U.S), DIN (German) and ISO (international) standards for cast steel feature variability have been developed.\textsuperscript{5,6,7}

The current SFSA/Penn State dimensional capability study is similar to previous dimensional studies in that it also seeks to define the present ability of the steel casting process (and casting producers) to produce uniformly-sized features. The results of all of these studies and related standards are of an empirical nature. That is, production castings were used to calculate part feature variability. It must be understood that these studies, including the ongoing research, describe dimensional variability as it relates to one component of the dimensional tolerance system.

Without a thorough understanding of the existing tolerance systems, the results of these studies can easily be
misinterpreted and incorrectly applied. In the following pages, these results will be discussed. To prevent any misunderstanding on the true nature of these studies, both dimensional and geometric tolerances will be outlined in some detail.

II. PREVIOUS STUDY ANALYSIS

As stated earlier, the 1977 SFSA dimensional capability study addressed the stochastic variability of selected cast part features. This variability is represented by the equation:

\[ \pm T = A \times W^{1/3} + 0.022 L^{1/3} \]

where:
\( T \) = half tolerance (in.)
\( W \) = casting weight (lbs.)
\( L \) = feature length (in.)
\( A \) = constant (tolerance grade-dependent)

This equation suggests that for a dimension \( L \) inches long, on a casting weighing \( W \) pounds, a foundry can expect a total variation of \( \pm T \) inches. This variability is not the total variability of the feature, but rather, it is the variability of one selected cross section of that feature, represented by a two point measurement. A two point measurement is a linear interpretation of one of an infinite number of feature cross sections. Figure 1 illustrates how a two point measurement relates to a part feature. The dimension labeled \( d \) is a single cross sectional dimension found along the entire length of the feature.

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Figure 1: Diagram of two point measurement
All of the features included in past studies, regardless of size or shape, were represented by two point measurements.

Similarly, the result of the current SFSA/Penn State study will be a model that represents the variability of selected feature cross sections. The primary objective of the ongoing capability study is to provide the steel casting industry with an updated picture of the point to point variability of the steel casting process. The major difference between this study and the 1977 study is that measurement system analysis was used to insure that the final results do not include a large measurement variability.

The main point of this discussion is the fact that dimensional studies do not define the ability of a foundry to cast a feature within tolerance. What they do state is that a foundry can expect the individual cross sections composing that feature to vary by the given amount. The models listed in these studies do not account for the form deviations of cast features. These form deviations can only compound overall feature variation when combined with the cross sectional variability.

To understand why these studies do not represent feature variability, a clearer picture of both the dimensional and geometric tolerance systems is required.

**III. DIMENSIONAL TOLERANCES**

All material discussed below is documented in ANSI standard Y14.5M. This document contains standards for symbology and interpretation of both dimensional and geometric tolerances.
Dimensional tolerances function as limits for the deviation permitted on feature dimensions. These dimensions may be linear, angular or a taper. Dimensional tolerances can be expressed as bilateral, unilateral or single limits on these types of dimensions. The manner in which these tolerances are interpreted depends largely upon how they are applied. If dimensional tolerances are used on features defined as "features of size", they control the form of that feature in addition to its cross sectional size. A feature of size is defined as a cylinder, sphere, or two opposing parallel planes. Radii with greater than 180 degrees of curvature are also considered features of size. ANSI Y14.5M formally states that, for features of size; "Where only a tolerance of size is specified, the limits of size of an individual feature prescribe the extent to which variations in its geometric form as well as size are allowed." In order for a particular feature of size to meet this definition it must fulfill two criteria. First, the actual size of any cross section of that feature must lie within the specified size limits. Second, the surface or surfaces of that feature must lie within a boundary of perfect form of that feature at its maximum material condition (MMC). Wherever the size of that feature departs from MMC, the form of the feature may deviate from the perfect form by an amount equal to that departure. To illustrate this, a feature of size consisting of two parallel planar surfaces is shown in Figure 2. To conform to the specified tolerance, each cross sectional measurement of this feature must
lie within the prescribed size bracket. The form of the two parallel planar surfaces may deviate from perfect as long as the feature still fits within the perfect form envelope.

![Diagram of tolerated feature size and tolerances](image)

**MEANS:**

\[1.98 < d < 2.02, \text{ and,}\]

![Diagram of tolerated feature with cross sections](image)

**Figure 2: Toleranced feature of size**

In this example, every cross section \( (d) \) of the feature must be between 1.98 and 2.02 inches wide. The feature may be distorted as long as it can still fit within a boundary of perfect form consisting of two parallel planes that are 2.02
inches apart. The feature may be orientated in any way as long as every point on the surfaces lies within this boundary of perfect form.

To control the form, orientation and location of a non-
"feature of size", designers can use a size or position tolerance on a surface with the same effect. For example, consider the top planar surface illustrated in Figure 3.

![Figure 3](image)

Figure 3: Toleranced non-feature of size

Since this feature is dimensioned relative to a datum, both its form and location are controlled. As with geometric tolerances, the datum is associated with an actual physical feature on the
part. In this example, the datum feature is the lower planar surface. The datum is a plane that contains at least three extreme points on the datum feature. The tolerance zone consists of two planes, at a distance of 1.98 and 2.02 inches, respectively. To satisfy this tolerance, every point on the top surface must lie within this tolerance zone.

III. GEOMETRIC TOLERANCES

Casting designers also have geometric techniques at their disposal for specifying part tolerances. ANSI Y14.5M defines a "geometric tolerance" as a general term for a category of tolerances used to control form, profile, orientation, location and runout. Geometric tolerances are presented using a feature control frame symbology prescribed in the Y14.5M document. The geometric tolerance system is characterized by very specific tolerance designations. For example, designers can control flatness or circularity with individual tolerances. Often, the application of one of these more specific tolerances can control a feature in the same manner that a combination of dimensional tolerances would. Regardless of the specific geometric tolerance used, the associated tolerance zone is always a two- or three-dimensional zone that may or may not be defined with respect to a datum system. The use of a datums is dictated primarily by the type of geometric tolerance used.

To highlight some of the differences between specific geometric tolerances and how they are used, three tolerances will be discussed. Figure 4 shows the first; a flatness tolerance.
This tolerance callout dictates that the top planar surface of the feature must lie within a 0.02 inch wide tolerance zone. This tolerance zone consists of two parallel planes. Note that this tolerance controls the form of the surface only. The location and orientation of the tolerance zone is not specified.

The second example of a geometric tolerance is a parallelism tolerance. Figure 5 illustrates the associated tolerance zone.
Figure 5: Parallelism tolerance

This tolerance states that the top planar surface of the part must lie within a tolerance zone when the part is rested on datum A. Datum A is represented by a plane defined by at least three extreme points on the bottom surface of the part. The tolerance zone consists of two planes parallel to datum A, and 0.02 inches apart. Note that this tolerance controls the flatness as well as the orientation of the top surface.

The last example is a profile tolerance. This tolerance is depicted in Figure 6. It specifies that the top surface of the
feature must rest within a tolerance zone 0.02 inches wide, centered 2.00 inches above datum A. Note that this tolerance controls location as well as parallelism.

Figure 6: Profile tolerance

Ultimately, the type of geometric tolerance applied by the casting designer must be dictated by the function of the feature or surface in question.
IV. SUMMARY

In the previous pages, both the geometric and dimensional tolerance systems have been briefly described. This overview was included to aid the foundry industry in the interpretation and use of results from past and ongoing dimensional variability studies and standards. The important concept that should be drawn from this paper is the fact that the results of variability studies are based on cross sectional measurements. Hence, these studies and standards do not determine to what tolerance a feature can be cast, but rather, how much variability the casting process imparts to individual cross sections of that feature. Although this conclusion seems to say that these studies are flawed, this is not the case. These results are a valuable tool, if used properly, in the "dimensional dialogue" between the casting supplier and final user.

The true nature of these results does, however, point to other important areas for future work. Preliminary work in the realm of geometric tolerance variability has already commenced as part of the SFSA/Penn State dimensional capability study. This research on geometric tolerance variability will certainly lead to future studies on feature variability.
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