AN EXAMINATION OF THE EFFECT OF VARIATION IN DATUM TARGETS' LOCATIONS ON PART ACCEPTANCE

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Any method of dimensioning and tolerancing is designed to assure that parts manufactured to the stated dimensions and within the stated tolerances will assemble to mating parts and result in a final assembly that satisfies some desired requirement. To accomplish this, dimensions must be described in a way that reflects the functionality of the part and eliminates any confusion as to what and where to measure. Proper tolerance analysis should then guarantee with a reasonable certainty that a measurement for a given dimension that is within the stated tolerance should result in a suitable assembly. Only when this is accomplished can a measurement be useful as an assessment of the suitability of a part. If this is not the goal of dimensioning and tolerancing, then any measurements taken will be a waste of effort.

The use of datum targets to establish datums is commonplace in industry today. Datum targets are used primarily for manufacturing and inspection setups where it is impractical to use the entire part feature and corresponding datum feature simulator. More complex parts can now be dimensioned and toleranced using GD&T since the advent of the CMM. Using the CMM, datums can now be established mathematically using point measurement data rather than requiring the physical mating of the part datum feature and the simulated datum feature. Parts with irregular surfaces and parts that are flexible are primary candidates for use of datum targets. The use of datum targets in these cases is designed to reduce dimensional variation of the part due to locating the part in manufacturing and inspection processes. Care must be taken to assure that the datum target points preserve the functionality of the part.

Establishing a simulated datum from datum target points may be done physically or mathematically, as is the case when using a datum feature on a part. The process is the same but the datum feature points used are now limited in number and have a defined position on the part surface. Establishing a datum feature using datum target points becomes a fairly simple task of calculating a datum plane that passes through the datum target points.

In the process of establishing a simulated datum, there are several possible sources of variation. This variation in establishing a datum will have an effect on any feature that references that datum. Any variation or error in establishing the datum will manifest itself as variation or error in the measurement of the distance between the feature and the datum.

Datum variation can occur from actual variation in the part datum feature itself, from the process of locating the part datum feature to the datum feature simulator, from the measurement error in measuring the part datum feature or datum target points, or from the algorithm used to calculate the mathematical definition of the simulated datum. These types of variation may be referred to *as datum feature error* or *datum target point error*.

When using datum targets, the decision must be made as to where on the part datum feature the datum targets should be located. This type of variation may be referred to as *datum target point location*. Datum target point location will be a significant factor only if the datum target points are located in such a manner that small variations in datum target measurements cause large variation in the simulated datum. An example of this would be to place secondary datum targets very close to each other and at a distance from the feature that references the datum.

Other than the analysis of measurement error, common practice ignores these sources of variation and includes them in the resulting variation of the feature measured. As long as the feature in question meets engineering requirements, this may not be viewed as a problem. However, having the ability to calculate the amount of variation due to datum target point location and error may be valuable in assessing how to improve the process. In addition, understanding the effects and sources of variation will give the manufacturing and measurement process owners the knowledge required to assess tolerance requirements for manufacture and use of part datum features.

The objective of this paper is to understand and quantify the variation of a measured feature e.g., hole true position, that is due to the variation of the datum target points. This information will be used to develop a predictive model that may be used when there is a priori knowledge of datum target point variation. These objectives may be stated as follows:

1. Develop a mathematical model for the evaluation of hole true position GD&T callout in terms of datum target point coordinates.
2. Evaluate and quantify the amount of feature variation due to datum target point variation.
3. Develop a methodology to predict true position variation given a priori knowledge of datum target point variation.
4. Evaluate the methodology and its implications.

First, a two-dimensional model is developed to analyze the effects of datum target point location and datum target point error on a hole true-position tolerance. For this analysis there are several assumptions that are being made. In the case where parts are not flexible and tooling is used to locate the part for processing and measurement, the location and error of datum target points probably aren't of much concern. Since these types of parts may be located with good repeatability, the variation discussed here is minimal. This is certainly true if the datum targets truly reflect the functionality of the part and tooling is manufactured with sufficiently close tolerances. However, there are two cases where variation in datum targets may cause problems.

Case 1 – Flexible Parts

Flexible parts cause special problems when trying to assess compliance to engineering specifications and fitness for use. Since it is not practical to have tooling that contacts an entire surface, datum targets are frequently used for both processing and inspection. In the case of large contoured sheet metal parts, there can sometimes be dichotomy between the functionality of the part and the use of datum targets to aid in the manufacturing and inspection process. When parts require multiple processes, the variation induced by this relocation and the subsequent location for inspection may influence part acceptance decisions.

Case 2 – Datums and Features Produced in the Same Process

Today's machines may take a sheet of material or an extrusion and manufacture a part complete. In cases such as these, both the datums and features produced are relative to machine datums, and as such, cannot be recreated for inspection purposes. Datum targets or even datum simulators used for measurement purposes may show that parts do not meet engineering requirements even though the features may be acceptable. Since a machine may be capable of several different processes - drilling, milling, etc. – the machine process used to manufacture datum features and part features may have different capabilities relative to the machine datums. Axis specific movement may even have quite different capabilities, so the possibilities of different process specific capabilities are quite numerous.

As the first step in the analysis process, the mathematical model of hole position in terms of the coordinates of the datum target points is developed. In this model the primary datum is considered to have no variation. This assumption was relaxed later, and a three-dimensional model was developed. An exact mathematical model is developed to give the deviation from nominal in terms of the datum target point error. From this exact model, an approximate model is developed which is used to give the variation of hole position error in terms of the variation of the datum target point errors. Analysis of these models gives an explanation of the hole position error location and variation in terms of the datum target point error location and variation.

The mathematical model is then used to quantify the amount of variation that can be attributed to datum target point error. The results show how the datum target point errors affect the hole position errors. The effect is not constant for a given hole pattern and increases as the hole position moves away from the center of the pattern. The conclusion may be drawn that the secondary datum target points should be placed as far apart as possible with their midpoint located at the average of the X-coordinates of the hole pattern. Likewise, the tertiary datum target point should be placed at the average of the Y-coordinates of the hole pattern. The datum target point error of the tertiary datum target point affects only the X-direction of hole position error. It affects all hole positions equally, and therefore may be thought of as the largest single contributor to variation. The datum target point error of the secondary datum target points affects both the X- and Y-direction of hole position error. As the hole location deviates further from the center of the hole pattern, the greater the effect of secondary datum point target error will be on the hole position error.

These results may be used to aid in location of datum target points on engineering drawings. The conclusions support the accepted practice of datum target location as shown in many textbooks. If the case arises where datum feature variation is at such a magnitude that hole positions tolerances cannot be met, it is recommended that the engineering drawing be changed to establish a more stable datum system. In the cases discussed here, the most likely candidate for datums would be the holes themselves. Of course, the functionality of the part must be examined and preserved with any changes in datums.

In addition, the knowledge of sources of variation can be used to determine part orientation when machining a part. If there is a priori knowledge of differing machine axis capabilities, the part may be oriented in such a way that it minimizes the effect on hole position errors. The knowledge can also be used to allocate tolerances for fixtures that locate parts during manufacturing since it can be calculated just how much variation between fixtures locating the same part to the same datum target points will affect the hole position error.

An estimation technique was also presented that uses summary statistics of datum target point error to predict the number of holes that can be expected to meet a given tolerance requirement. This estimation technique may also be used to estimate the amount of tolerance consumed by datum target point error. That information is valuable in tolerance allocation and analysis exercises.

The previous discussion assumed no variation in the primary datum. In some cases, this may not be a valid assumption. In addition, it may be necessary to evaluate the effect of datum target variation on holes that are not perpendicular to the primary datum. Based on the analysis for the secondary and tertiary datums, the mathematical model for three datums was calculated using fixed datum target points.

This model may be used to quantify the amount of variation in hole position that may be attributed to datum target point error. It is shown that the variation in hole position due to the datum target point error of the primary datum target points is very minimal. Therefore, unless the variation in the primary datum target points is of some particular concern, the estimates from using only the secondary and tertiary datum target point variation are satisfactory. Both the two-dimensional and the three-dimensional models developed in this research are valuable tools in understanding how datum target point error can influence hole position error when referencing those datums.