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Density Effect of Inspection Data Points in As-Built Modeling of Parts

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ABSTRACT

At Los Alamos National Laboratory, the use of inspection data generated at various stages of the life cycle of a product is being investigated in a feedback process to the design engineers and physicists. This data will be used to determine through analysis how to optimize assembly, mitigate nominal deviations, and confront aging issues. This "as-built" engineering philosophy characterizes a system through the topographical data generated through inspection. Through intricate modeling techniques, the topographical definition gives rise to a solid model in a Computer Aided Engineering (CAE) software package such as Parametric Technologies Pro/ENGINEER™. Once a solid model has been built, the definition can be used for a variety of analytical purposes including mass property calculations, finite element model generation, and virtual environment generation.

A strictly analytical approach was used to exercise the "as-built" engineering method in characterizing components. A hypothetical component was used and mass properties were calculated analytically to provide nominal definition. This was then compared to mass properties calculated as a result of modeling theoretical inspection data in two formats; manual-collected data such as that obtained from a Coordinate Measuring Machine (specifically the Brown and Sharp) inspection process and automated-collected data such as obtained from a Sheffield inspection process. Mass properties calculated from a solid model generated using the Pro/ENGINEER™ modeling operations were also compared with the nominal definition. The inspection data was generated from a software package that allows a user to specify geometrical constraints, point density desired, and output data format. The software outputs topographical point sets describing the geometry. These topographical point sets were used as input to the Pro/ENGINEER™ CAE system Scan Tools module for generation of a solid model. Point sets were connected by splines to define curves, the curves were blended to create surfaces and the surfaces were manipulated to create a solid model. The mass properties were then calculated and compared with nominal. The Blended Surface option in Pro/ENGINEER™ was used in the modeling of all the inspection data format types.

As would be expected, the higher density of points, the more accurate the model in the mass property calculation. The Sheffield format of data produces a smoother surface and the effect of this can be seen in the resulting mass property calculations. Los Alamos uses a standard of inspection to an accuracy of 2.54×10^{-3} inches. The model must be an order of magnitude more accurate than this standard. For this application, we anticipate an accuracy of .00024%. We considered three densities of CMM data ($5^\circ \times 2^\circ$, $10^\circ \times 2^\circ$, and $20^\circ \times 2^\circ$ wedges) and three densities of Sheffield data ($.5^\circ \times .5^\circ$, $1^\circ \times 1^\circ$, and $2^\circ \times 2^\circ$ slices). Further study will define the exact density of inspection data needed to augment our manufacturing process using "as-built" engineering modeling.

KEYWORDS

Product characterization: As-built engineering: CAE modeling

1. Introduction

As-Built Engineering modeling is a methodology that allows customized product realization at mass manufacturing speeds, prices, and ductility. In the manufacturing process, once a piece part has been machined, deviations to the nominal definition are inevitable. The modern day approach to dealing with these deviations and determining if a component is acceptable includes the use of setting tolerances during the nominal design process. Nominal design represents what we hope to manufacture but does not capture what is actually manufactured and assembled. The deviations to the nominal definition are characterized during the inspection process and deviations that are out of tolerance identify parts to be reworked or scraped.

The use of inspection data generated at various stages of the life cycle of a product is being investigated at Los Alamos National Laboratory in a feedback process to the design engineers and physicists. This data will be used to determine through analysis how to optimize assembly, mitigate nominal deviations, and confront aging issues. This "as-built" engineering philosophy characterizes a system through the topographical data generated through inspection. Through intricate modeling techniques, the topographical definition gives rise to a solid model in a Computer Aided Design (CAD) software package such as Parametric Technologies Pro/ENGINEER™ or Structural Dynamics Research Corporation I-DEAS™. Once a solid model has been built, the solid definition can be used for a variety of analytical purposes including mass property calculations, finite element model generation, and virtual environment generation.

The "as-built" model contains the state of the system being surveyed at the time it was last inspected. Using this information, measurements can be made of any changes that have occurred. By tracking changes in the form of an evolving set of "as-built" models, engineers can begin to understand what effect different environments have on various components of an assembly as they age. This models-based log of each system's maturation can fully characterize the life cycle of the system by including maintenance work history and all repairs, replacements, and modifications.

Two factors contributing to variations in the accuracy of the "as-built" model will be considered in this paper - 1) the density of inspection points and 2) the type of inspection process used. The density of inspection data points required to distinguish a component's current state must be identified in the use of "as-built" modeling without becoming burdensome in the respect of having to collect an excessive amount of data points and making the process inordinately expensive. Additionally, the type of inspection process used has bearing on the modeling techniques used and, therefore, the quality of the resulting solid model. The intricacies of tracing a system's history through "as-built" characterization and models based engineering is also dependent on the capabilities of the CAE system used to accurately build the model.

2.0 Process

A strictly analytical approach was used to exercise the "as-built" engineering method in characterizing components. A hypothetical component consisting of a hemispherical shell of arbitrary thickness with a cylindrical section extruded from the open end was used as the model in this exercise. Mass properties were calculated analytically and used as the nominal definition. The nominal definition was then compared to mass properties calculated as a result of modeling topgraphical inspection data in two formats. These two formats included a manual data collecting format such as that obtained from a Coordinate Measuring Machine (CMM) (specifically the Brown and Sharp) inspection process and an automated data collecting format such as obtained from a Sheffield inspection process. Mass properties calculated from a solid model generated using the Pro/ENGINEER™ modeling operations were also compared with the nominal definition. The inspection data was generated from a software package authored by Dr. Ronald Dolin of the Los Alamos National Laboratory that allows a user to specify geometrical constraints, point density desired, and output data format. The software outputs topographical point sets describing the geometry. These topographical point sets were used as input to the Pro/ENGINEER™ CAE system Scan Tools module for generation of a solid model. Point sets were connected by splines to define curves, the curves were blended to create surfaces and the surfaces were manipulated to create a solid model. The mass properties were then calculated and compared with nominal. The Blended Surface option in Pro/ENGINEER™ was used in the modeling of all the inspection data format types.

The two types of inspection data format used in this exercise are typical of those used at the Los Alamos National Laboratory and are significantly different in surface definition. The Brown and Sharp CMM format is gathered using a manual process and is operator-effort intensive. This method is generally used for delicate parts that might be damaged if an automated process were used. Due to the operator-effort intensive nature of this format, the density of inspection data points is generally less than that gathered using an automated process. The format of the data gathered is in a wedge definition. The inspection technician must "eyeball" the appropriate path for the inspection probe and the curve definition often varies markedly for this method. For the purpose of this exercise, we have assumed a technician with a very steady hand and remarkable eyeball capability. The density outputs considered were 5° x 2°, 10° x 2°, and 20° x 2° wedges (see Fig.1 for a sample configuration). This is typical output from a highly characterized component.

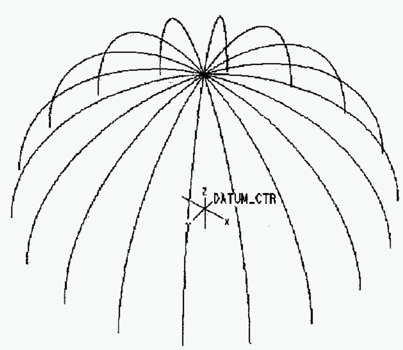

Figure 1 - Coordinate Measuring Machine Type Inspection Data

The Sheffield is an automated process for inspection data gathering and produces "slices" for the data output. The Blended Surface option that was used in the generation of the solid models used in this exercise adapts to this data format much more readily then the "wedge" format. The automated nature of this process allows a higher density output of inspection data points. The density outputs considered for this format of data were .5° x .5°, 1° x 1°, and 2° x 2° slices (see Fig. 2 for sample configuration). The cylindrical portion of the geometry was modeled using "slice" format in all cases.

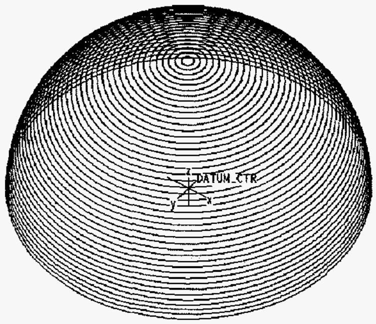

Figure 2 - Sheffield Type Inspection Data

3.0 Results and Conclusions

Table 1 indicates the results generated in this exercise. As would be expected in the case of the "wedge" format, the higher density of points the more accurate the model in the mass property calculation. However, this trend was not followed in the case of the "slice" format. The Sheffield format of data produces a smoother surface and the effect of this can be seen in the resulting mass property calculations. Los Alamos uses a standard of inspection to an accuracy of 2.54×10^{-3} inches. The model must be an order of magnitude more accurate than this standard. For this application, we anticipate an accuracy of

$$\delta / r$$

where δ = difference in calculated from nominal
r = outside radius of cylinder

or, numerically, .00024%.

Table 1 - Results of Parametric Inspection Data Study

Configuration	Volume	Number of Points in Model	% Difference from Nominal
Solid Pro/E Model	156116.21	N/A	0.00000
.5° x .5° slice	156104.92	276166	0.00723
1° x 1° slice	156115.68	81586	0.00034
2° x 2° slice	156115.45	20634	0.00049
5° x 2° wedge	156067.35	23230	0.03130
10° x 2° wedge	156002.02	19882	0.07314
20° x 2° wedge	155665.29	5986	0.28883

The Pro/ENGINEER™ models range in size from 4.9 Megabytes to 151.7 megabytes. The wedge data is less accurate at modeling the data but more economical. Modeling techniques are being examined to determine why the .5° x .5° slice results are less accurate than the 1° x 1° slice data. The effect of using an alternative CAE software package is also being examined.