

A study of CMM measurement variation in precise, thin-wall iron castings

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Abstract

The role of coordinate measuring machines in foundries has historically been somewhat different than in other industries. In the foundry layout room, the CMM is often used simply to see if there is enough material at specific gage points – measurement techniques such as establishing complex datum reference frames^[1,2] and considering the number and spacing of sample points are usually not an issue. However, as modern foundries develop better production techniques to make competitive thin wall and precision castings^[3], the measuring methods must keep pace. This paper analyses measurement techniques used by various metrology shops with the goal of determining best measurement practice for reducing the variations in measurements. A set of 10 artifacts (castings) were sent to different metrology shops and the measurement techniques and thickness results were recorded for each shop. The thickness of the castings reported by each metrology shop is compared to other shops in a method similar to a Gage Repeatability and Reproducibility (GR&R) study^[4,5]. We extend this analysis to consider the effects of different measurement techniques, and then propose a procedure to reduce the variation caused due to different measurement techniques.

Keywords: CMM measurement techniques, Datum reference frames, iron castings, GR&R

Introduction:

The metrology round-robin study was conducted by shipping a set of ten castings to different metrology shops in turn. The measurements were performed at a CMM manufacturer's demonstration laboratory, two foundry layout rooms, and at a pattern shop and also two different measurements at UNC charlotte. The most common questions that arose when the artifacts arrived at the round-robin participants were how to establish the co-ordinate system and how many points should be taken on each web. To address these questions, the number of points to be taken and a suggested co-ordinate system were documented, and these instructions accompanied the artifacts to the participants. The co-ordinate system suggested is shown in Figure 1. The +Z axis is along the central cylindrical feature of the star casting and the +Y axis is along the thickest undrafted web. The undrafted webs occur at the parting line of the mold (see figure) where draft is not required for the pattern to be removed from the mold. The +X axis is perpendicular to the other two axes.

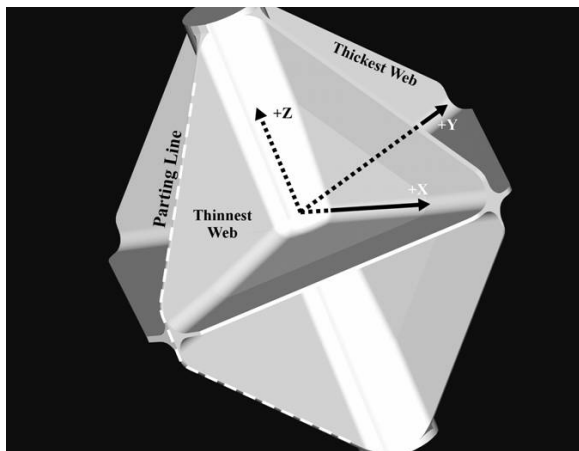


Figure 1: Initial co-ordinate system suggestion

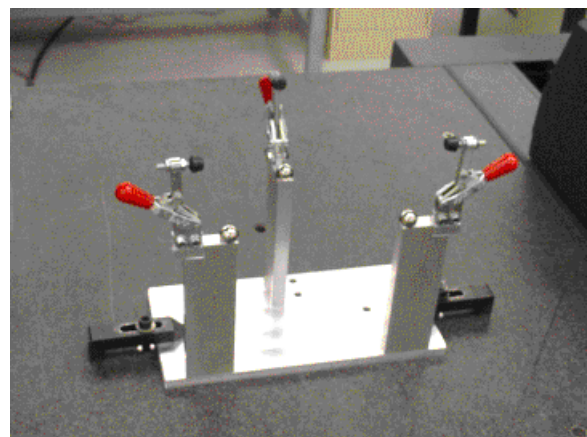


Figure 2: Locating Fixture

Experimental Approach:

At UNC Charlotte, a Brown and Sharpe XCel 765 Coordinate Measuring Machine (CMM) was used to measure the castings, and direct computer control (DCC, or automatic) programs were written to conduct the measurements using both QUINDOS and PC-DMIS software. The fixture shown in Figure 2 was used to kinematically restrain the casting in all six degrees of freedom on the CMM. The fixture consisted of three precision balls mounted on pillars, each ball contacting the casting on two orthogonal sides to constrain part motion. The CMM probe was oriented for each sampling such that it avoided interference with the fixturing. The measuring program establishes a coordinate system by sampling a subset of the webs (or fins) on the casting. The planes of the coordinate system nominally pass through the middle of the fins (e.g., the x-y plane passes through the middle of the four horizontal fins). Each fin was then sampled with either ten or eleven points depending on the location of the fins. Measurement points were collected from each side of the fin, and a midpoint and thickness were calculated for each location. The sampling patterns used for QUINDOS program are shown in Figure 3. The pattern shown in Figure 3(b) allows for the fixture on some of the webs.

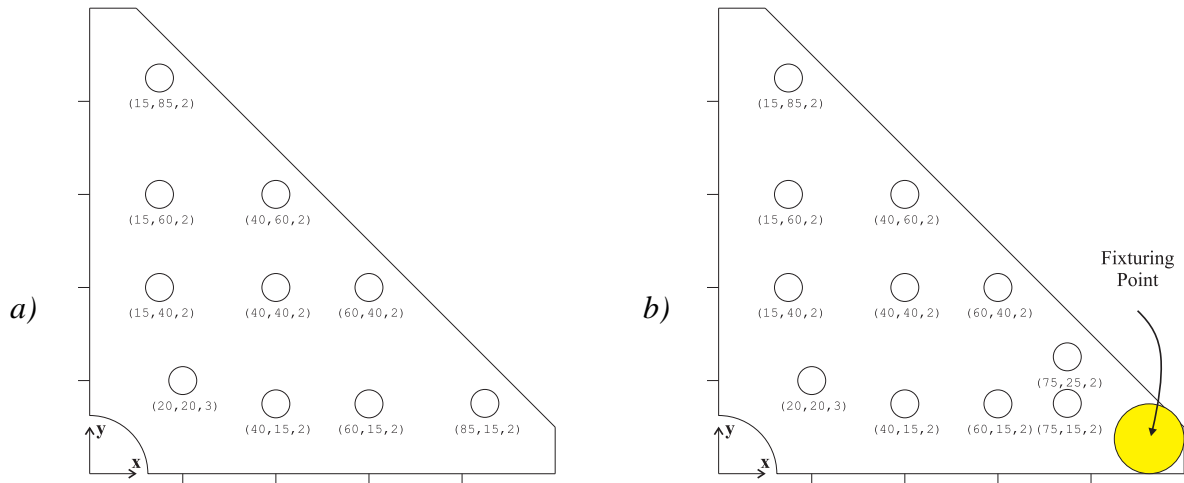


Figure 3: Sampling Patterns

The setup used at UNC Charlotte to measure the artifacts is shown in Figure 4. The cylindrical section is vertical and the parting plane webs are from front to back. The horizontal webs were used to establish the primary datum (*xy-plane*) and the parting line webs were used to establish the secondary datum (*y-axis*) and the other vertical webs perpendicular to these datum's were used to establish the tertiary datum (*z-height of the origin*). The setup used for measurement of the artifact by one of the participants is shown in Figure 5. In this setup the cylindrical section is in horizontal orientation. Although it shouldn't matter, we suspect that the difference in setup increases the uncertainty in the measurement results. The primary difference in coordinate systems is due to difference choices in the reference surfaces for the datums.

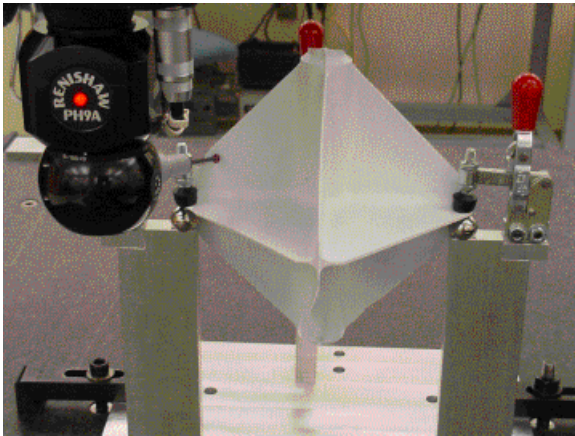


Figure 4: UNC Charlotte setup

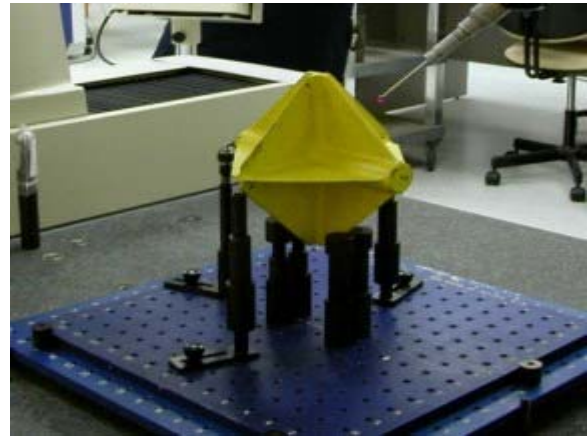


Figure 5: One of the participant's setups

Data Analysis and Results:

The thickness measurements reported by each participant were averaged by web for all ten castings. The overall average for each web was also calculated. Each participant's deviation in thickness from the average was calculated for each web. This deviation was plotted against web number and sorted in descending order by the range of the thickness over the five participants, as shown in Figure 6. Each bar in the figure represents a participant in the study. The graph illustrates the range of values obtained by different metrology shops. Each shop fairly consistent, in that most reported values on the same side of the average for most webs. For example, the shop indicated by the white bar is consistently high for all but the parting line webs. Note that the range of values for many of the webs exceeds 1mm – this indicates a need for improvement and standardization in the inspection process.

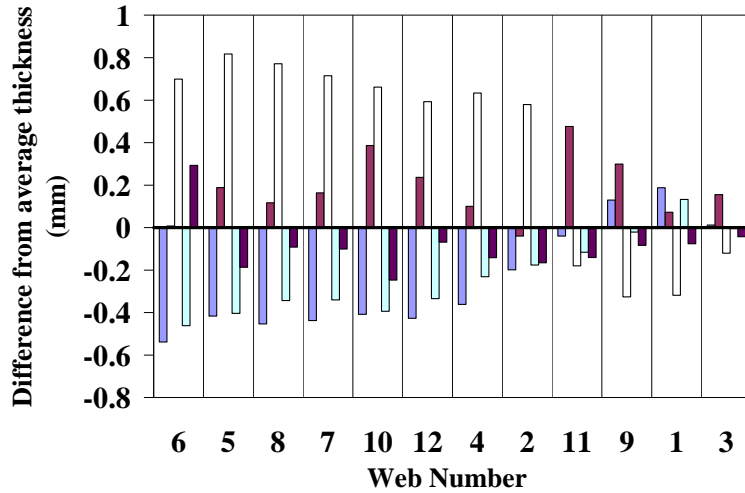


Figure 6: Deviation in thickness from the average vs. Web number

In Figure 6 it can be seen that the deviation is less for the four webs along the parting line (web numbers 11, 9, 1, 3) for most of the participants, regardless of how they set the part up for measurements. It is interesting to note that the part-to-part variation of these webs is not necessarily low. In Figure 7 the standard deviation of the 10 parts' thicknesses is plotted on a per-web basis, and the parting line webs have some of the highest variability.

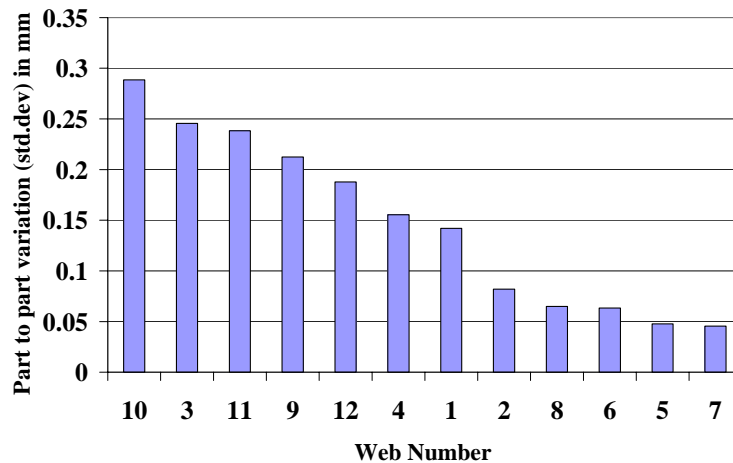


Figure 7: Standard Deviation in Thickness among the 10 sample parts vs. Web Number

Conclusions and future work:

The variation in the measurements obtained from the different metrology shops is evident from Figure 6. We believe that these variations could be greatly reduced if proper datum targets were shown in the drawing instead of a picture showing the desired axes. This would allow the measurement points for thickness values to be specified with basic dimensions from the datum reference frame, rather than stating "measure points 15mm from the edge of the web." The desired datums from the part model are shown in Figure 8. The appropriate specification of datum targets is needed, as shown in Figure 9. By using datum targets on the drawings the uncertainty due to different measurement techniques can be reduced. Future work includes sending the artifacts to the various participants with drawings with proper datum targets on them. The CMM measurement variation will (we hope) be reduced using this datum target scheme.

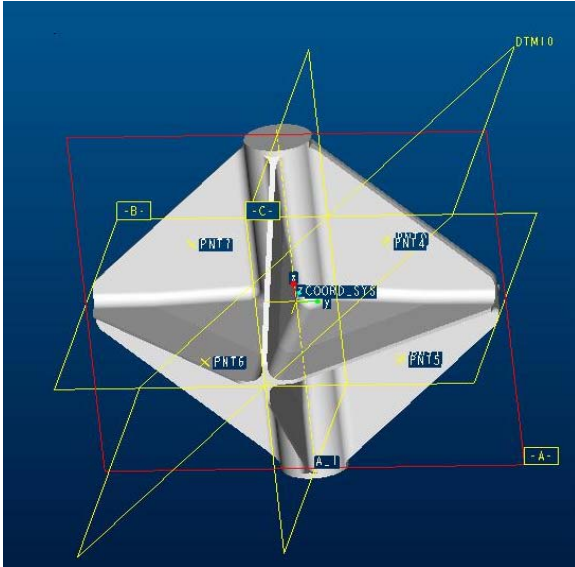


Figure 8: Part model showing Datums and points used to create Datum Targets

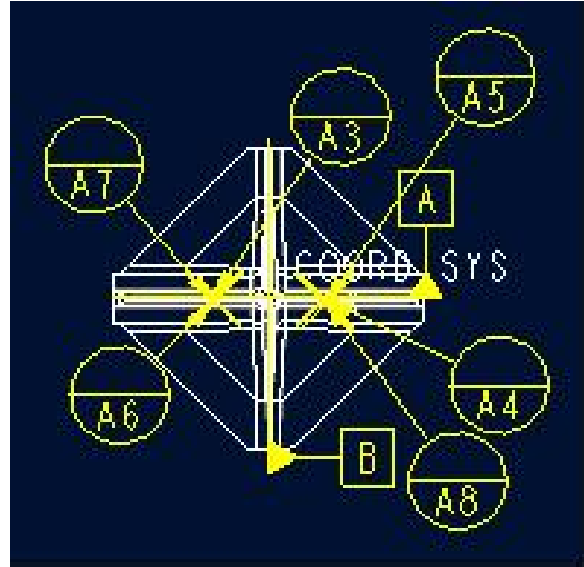


Figure 9: Part drawing showing example of Datum Targets Symbols and Datums

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