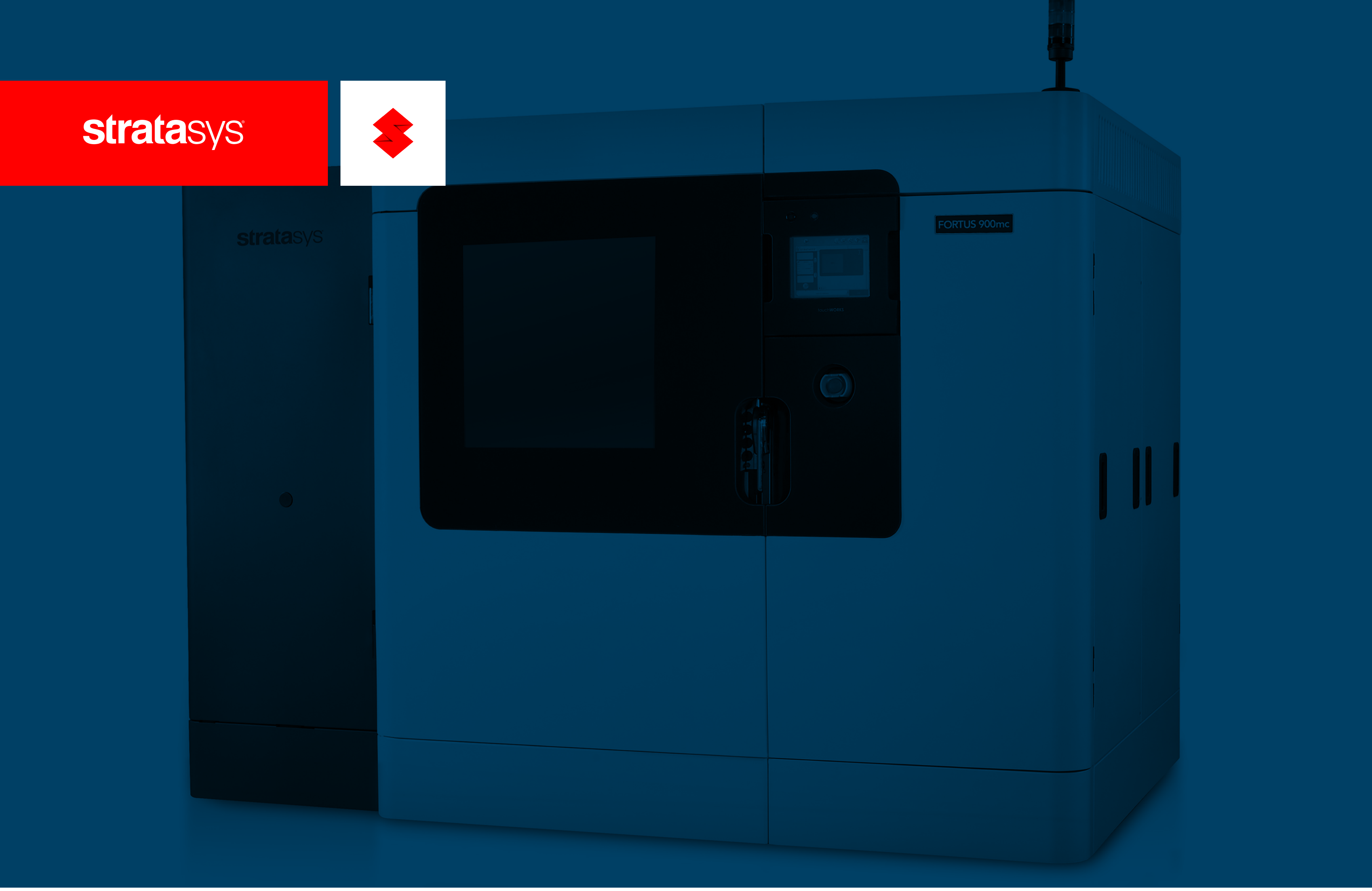

Fortus 900mc Accuracy Study

By Jesse Hanssen, Stratasys

Applications beyond concept modeling and general prototyping have stringent demands for qualifying a process' capabilities. For advanced prototyping, analysis and the growing number of direct digital manufacturing (DDM) projects, accuracy assessments must be comprehensive studies based on sound quality control practices. To quantify the capabilities of the Fortus 900mc™, Stratasys performed an in-depth analysis of accuracy, precision, and repeatability.

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Figure 1: To document accuracy, precision and repeatability, the Fortus 900mc was subjected to an in-depth assessment of its part quality.

Following the procedures set forth in the accuracy assessment of the Fortus 400mc™, the Fortus 900mc (Figure 1) was evaluated through the same comprehensive dimensional inspection. The study of the Fortus 900mc's process capabilities confirms that the system satisfies published tolerance specifications and shows that it outperforms all other Fortus machines. The study also reveals that the Fortus 900mc offers consistent part quality with a high degree of repeatability across machines, builds, and platform locations.

REAL-WORLD TESTING

Applications beyond concept modeling and general prototyping have stringent demands for qualifying a process' capabilities. For advanced prototyping, analysis and the growing number of direct digital manufacturing (DDM) projects, accuracy assessments must be comprehensive studies based on sound quality control practices. To quantify the capabilities of the Fortus 900mc, Stratasys performed an in-depth analysis of accuracy, precision, and repeatability.

RESULTS

The results of the accuracy study confirm that the Fortus 900mc produces parts within the published tolerance specification: the greater of ±0.0035 inch (0.09 mm) or ±0.0015 inch/inch (±0.0015 mm/mm). This conclusion is based on a 95 percent certainty level (two sigma).

Material:	ABS-M30
Tip:	T16 [0.016 in. (0.41 mm) dia.]
Slice:	0.010 in. (0.25 mm)
Style:	Solid
Supports:	Soluble supports
Build Parameters:	Default—0.020 in. (0.51 mm) road width; 90° delta angle

Figure 2: Test part construction parameters

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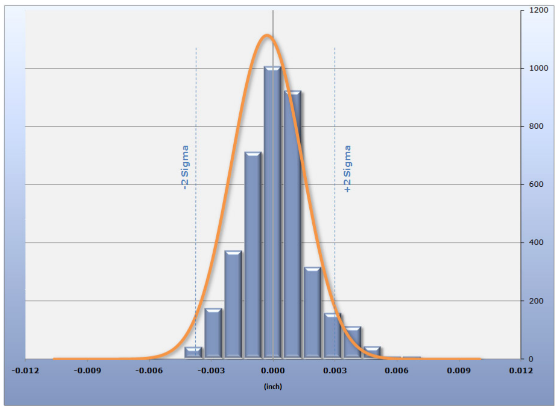

Figure 3: Histogram with normal distribution curve for dimensional deviation of all measurements shows a standard deviation of 0.0017 inch (0.043 mm) centered on a mean of -0.0003 inch (-0.008 mm).

Of the 3,888 measurements, 99.5 percent are within ±0.005 inch (0.13 mm), and 49.9% are within a narrow tolerance band of ±0.001 inch (0.03 mm). Throughout the extensive analysis, only 197 measurements (5.1 percent) exceed the tolerance specification.

The histogram (Figure 3) reports the deviation from nominal dimensions for all parts on the three Fortus 900mc machines used for the analysis. It shows both the number of occurrences by deviation range and the resulting normal distribution curve. This normal distribution has a very small standard deviation of 0.0017 inch (0.043 mm). Additionally, the deviation spread is nicely centered on a mean of -0.0003 inch (0.008 mm).

The normal distribution shows a two-sigma capability, which gives a 95.4 percent certainty, of -0.0038 to +0.0031 inch (-0.10 to +0.08 mm). Included in the two-sigma calculation are 720 measurements (18.5 percent) with allowable tolerance of up to +/- 0.0075 inch (0.191 mm).

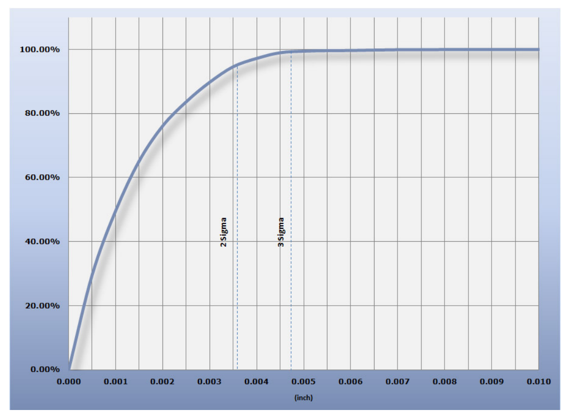

Figure 4: Probability curve, which plots the absolute dimensional deviation, shows that 94.6 percent of all measurements were within ±0.0035 inch (0.09 mm).

Figure 4 is an alternative representation of the tolerance expectations for the Fortus 900mc. This probability curve reports the percentage of measurements by their absolute deviations. It shows that nearly 94.6 percent of the measurements are within ±0.0035 inch (0.09 mm) and 99.5 percent are within ±0.005 inch (0.13 mm).

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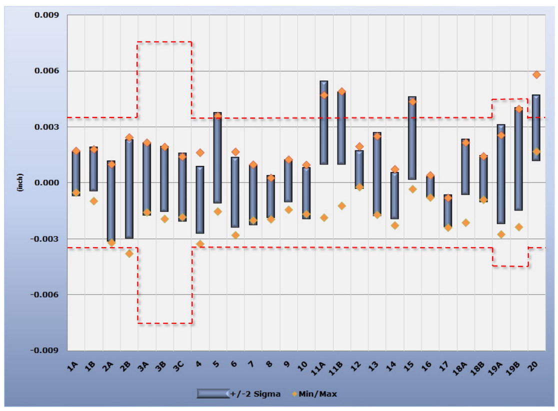

Figure 5: Dimensional deviation plot for all parts from one Fortus 900mc. Plot shows acceptable tolerance band (red lines), two sigma value (blue bars) and min/max deviations (orange diamonds).

Figure 5 plots the dimensional deviations, by location on the test part, for a single Fortus 900mc. The red, dashed lines indicate the acceptable tolerance band per the published specification. As shown, all locations have a two-sigma value between 0.0006 and 0.0027 inch (0.015 to 0.069 mm), which is well within the tolerance range. Although a few locations have a bias to the upper limit, the small standard deviation suggests that minor machine and software adjustments, following a sampling run, could be used to further improve the dimensional quality of manufactured parts.

A common objection to direct digital manufacturing (DDM) is that additive fabrication technologies have unacceptable variances from part-to-part, build-to-build and machine-to-machine. While true of earlier technologies, a goal of the Fortus 900mc is to improve output consistency. To confirm that the goal has been achieved, the machine number, build number, and platform location were documented for each test part. The dimensional analysis indicates that the Fortus 900mc is a stable platform with repeatable dimensional accuracy.

Figure 6 reveals consistent performance among the three Fortus 900mc machines. The slight variation between them is due mostly to the offset from zero. These mean values for machines #1, #2 and #3 are 0.0004 inch (0.01 mm), -0.0005 inch

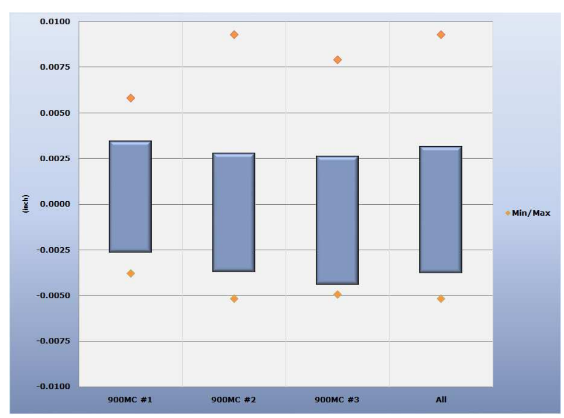

Figure 6: Plot of two-sigma values of dimensional deviations by machine shows consistent results with small variation in mean values.

(0.01 mm) and 0.0009 inch (0.02 mm), respectively. If manufacturing parts, the machines would be adjusted to normalize the average deviations. This would further improve the repeatability of the output quality from machine-to-machine.

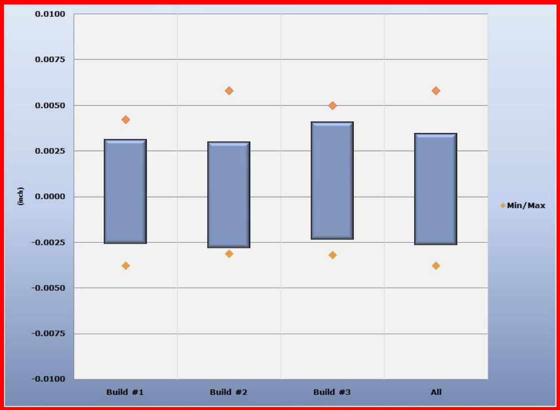

Figure 7: Comparison of dimensional deviation across builds on a single 400mc shows consistent two sigma and mean values.

The dimensional deviations for three runs on one Fortus 900mc are presented in Figure 7. To mimic a production environment, the test parts were built over multiple days and each machine required material replenishment. Even with these variables, the two-sigma capability is extremely consistent. The mean values have a variance of just 0.0008 inch (0.018 mm), and the standard deviations differ by only 0.00018 inch (0.005 mm). Essentially, there is negligible variance between production runs.

Figures 8 and 9 present more evidence of consistency in dimensional accuracy. The results shown in Figure 8 highlight that the part's accuracy does not vary in accordance with its position on the build platform. From edge-to-edge,

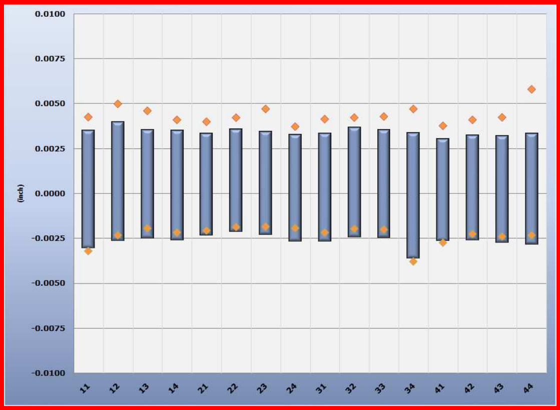

Figure 8: Two sigma values of dimensional deviations across 12 locations of sample parts in one build show that part placement has little effect on dimensional accuracy.

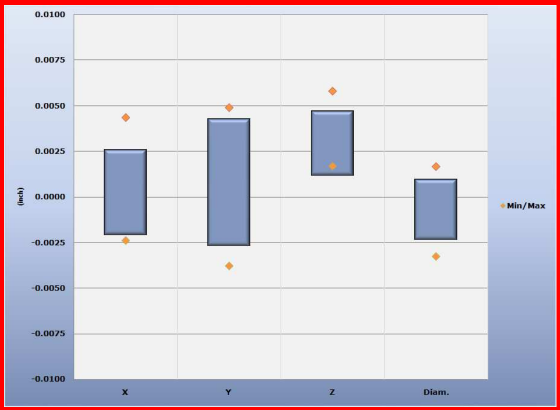

Figure 9: Plot of dimensional deviations (two sigma) by measurement axis. Results for cylindrical measurements in the XY plane are also listed.

the standard deviation fluctuates by only 0.0008 inch (0.02 mm). Finally, Figure 9 presents the two-sigma performance by axis. In all cases, there is a high level of certainty that the dimensional quality of a feature will be within a ±0.0035 inch (0.09 mm) tolerance band. For improved quality, adjustments could be performed to correct the skewing to the high side of the tolerance range for the Y and Z-axes.

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REAL SOLUTION

From its conception, a design goal for the Fortus® product line was to improve on the accuracy of Stratasys systems to address the requirements of manufacturing. The assessment, which was conducted on all Fortus systems, shows considerable improvement in dimensional accuracy and repeatability. In both areas, the Fortus 400mc and Fortus 900mc prove to be superior to the systems that preceded them. It is believed that these Fortus systems would also demonstrate this superiority over other additive fabrication technologies if tested under the same conditions.

This accuracy assessment confirms that the Fortus 900mc manufactures parts to its published tolerance specifications and that it is a suitable tool for direct digital manufacturing. Across three machines, 144 parts and 3,888 dimensions, it delivers predictable and repeatable results. While having a 286 percent bigger build footprint, the Fortus 900mc outperforms the smaller Fortus 400mc in every measure of dimensional accuracy. Across the 3 x 2 foot (0.9 x 0.6 meter) build area, the Fortus 900mc manufactures more features and more parts within allowable tolerances, and this translates to the lowest standard deviation of any Fortus system.

Considering the output quality, throughput potential, and material characteristics, the Fortus 900mc has process capabilities that are ideally suited for manufacturing to stringent specifications. Its consistent and repeatable accuracy — from machine-to-machine and build-to-build — provides the confidence that the Fortus 900mc can be relied upon to manufacture a consistent quality product on an ongoing basis.

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