Reference engineering of satellite dishes

Glass/vinyl ester, glass/epoxy or carbon/epoxy laminates

By Karen Fisher, Senior Editor

Ability to take precise measurements throughout fabrication process makes complex contours possible.

- *Direct in-process reference to CAD data*
- *Accuracy to ±0.003 inch*
- *1/4 tooling costs of NC-machined steel*

Starting with a parabolic equation, how does one design and produce a satellite dish whose surface accurately mimics that equation? In the conventional approach, the CAD design informs the fabrication process—but no mechanism exists for comparing the template, mold or component to ideal design values. Quality is confirmed only through a performance evaluation of the finished dish. Accuracy of tooling and fabrication is assured through relatively expensive procedures, such as numerically controlled (NC) machining of high-cost materials.

L-TEC (Owings Mills, Md.) wanted a less expensive, more accurate approach, and found it by working with Direct Dimensions (Baltimore). Direct Dimensions is providing accurate measurements of each step in the fabrication process. Reference engineering—computerized referencing of these measurements back to the CAD design—allows L-TEC to make intermediate adjustments throughout fabrication. The final component is compared directly with the design, providing information about part quality prior to performance evaluation.

Reference engineering is made possible by a unique coordinate measuring machine (CMM) that borrows technology developed for medical applications. The FaroArm from Faro Technologies (Lake Mary, Fla.) is the product of a technology transfer prompted by the former Martin Marietta Corp. (Baltimore). Martin Marietta's Aero and Naval Systems Division was looking for a way to accurately measure large, complex-contoured components being fabricated for commercial jet engine applications. The measurements are needed to ensure compliance with the engine manufacturer's specifications and to identify process improvements to minimize assembly variation.

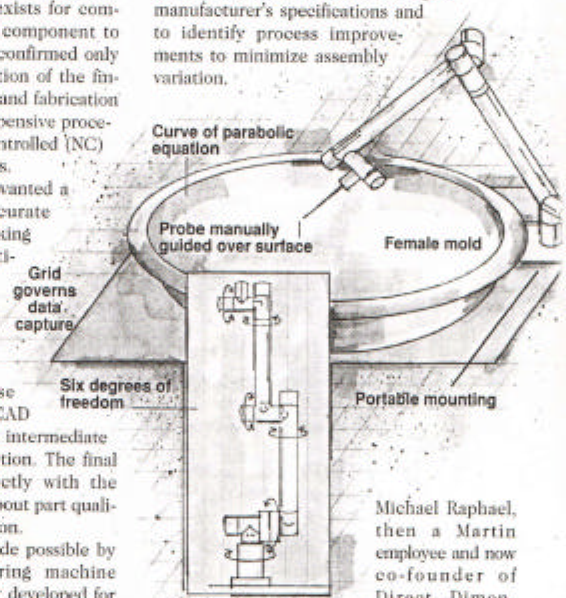

Figure 1. Parabolic shape of satellite dish is inspected with the FaroArm portable coordinate measuring machine.

Michael Raphael, then a Martin employee and now co-founder of Direct Dimensions, worked with Faro to adapt the FaroArm to industrial applications. The device was used in neurosurgery and other applications to precisely measure skeletal dimensions prior to surgical procedures. To work successfully in an industrial environment, the technology required a more rugged design and new mounting capabilities, as well as more advanced software.

Raphael recognized this technology as a promising alternative for measurement of the large complex components, conventionally performed through comparison with physical templates or by triangulation (similar to surveying techniques) with electronic theodolites. Although CMMs have been used to measure composite components for many years (particularly in automotive applications), these devices typically are immobile benchtop units with limited measurement envelopes (up to 8 ft) and few degrees of freedom for the measurement probe. Parts must be moved from the fabrication floor to the CMM for measurement, an unlikely scenario with 8-ft by 12-ft nacelles, for example.

The FaroArm, on the other hand, can be mounted to the component on the shop floor. It is a portable CMM that uses articulating links and rotating joints to provide six degrees of freedom, allowing accurate digitization of points and surfaces on complex-contoured parts. The FaroArm can provide up to a 12-ft measurement envelope, and "leapfrogging" capability allows the unit to be remounted and the two data sets correlated from a common reference point. Accuracy is ± 0.003-inch.

Through direct computer interface, the data is immediately available for analysis of the surface contour. Data captured by the FaroArm can be imported into a number of CAD programs, including CATIA, CADKEY, MASTERCAM, FastSurf and SmartCAM. Conversely, CAD data can be downloaded to Surfacer software from Imageware, which provides real-time reverse engineering of collected data into CAD models within a Windows environment. Faro has also developed AnthroCAM, a program that runs as an extension to AutoCAD to inspect and create three-dimensional geometry from collected data on the fly. The FaroArm can thus work directly within the coordinate system established in the CAD design file.

At Martin Marietta (now Lockheed Martin), the FaroArm has been used to check composite bondments for distortion from the cure cycle, reducing the need for rework during final assembly of thrust reversers. The arm has also been used to measure large parts trimmed by a large robotic router machine, verifying the machine's NC programming. Positioning of clips and brackets has also been performed with the FaroArm.

Figure 2. FaroArm inspects surface precision on gel-coated mold prior to dish fabrication.

L-TEC faced some of the same challenges as Martin Marietta: the company designs complex-contoured satellite dishes from 1 to 8 meters (about 3 to 26 ft) in diameter. A high degree of accuracy is required; any deviation from the designed contour results in power loss in the electrical signals being captured by the dish. "Surface tolerance becomes even more critical as satellite communications rely on higher frequencies," points out Jay LeVan, president of L-TEC. Dish surfaces must not deviate more than a few thousandths of an inch from design values.

Unlike Martin, L-TEC was also searching for an alternative to high-cost tooling materials and expensive NC machining of tooling for its dishes. The company wanted to build its tools with inexpensive fabricating techniques and rely on hand work to ensure precision. LeVan explains that a 6-ft diameter steel, NC-machined mold, for example, might cost $60,000 to $80,000. Under the process adopted by L-TEC, however, a like-sized mold made of glass/polyester might cost $10,000 to $15,000. (These molds also may have ceramic powder additive in the resin for improved toughness.) The challenge, LeVan points out, is that "we must continually improve the mold as we go through the production process." This improvement, through hand rework, requires regular inspection and comparison of the surface with the design standard.

Figure 3. Guided by information on high and low points derived from the FaroArm inspection, technicians hand work the mold surface to improve its accuracy.

An additional challenge stems from the fragility of plaster templates and size of tools built for the dish fabrication process. Because the larger tools in particular require significant backup structure and, in some cases, are bolted to the floor, the measurement device has to be brought to them. The portability, accuracy and data analysis capabilities offered by the FaroArm are all critical to L-TEC's application.

The process of building a satellite dish begins with a desired performance level (the "F/D" value, or focal length divided by diameter) and a parabolic equation. In some cases, L-TEC's customer starts with a parabolic equation and modifies the resulting shape to improve the electrical design (by reducing signal sidelobes, for example). The parabolic equation or modified data set is entered into AutoCAD, and the program develops a surface contour for the dish.

From the CAD data, L-TEC creates a sweep arm cut to the exact profile of the dish surface (from center to edge). The FaroArm checks this profile, and any glitches are remachined. Next, a positive plaster template with wood backup structure is created. The sweep arm scrapes and shaves the plaster to the desired shape. After a coating of epoxy and hand sanding, the template's shape is checked against the design contour with the FaroArm.

FaroArm software is set up so that data points are automatically captured each time the arm intersects a preestablished grid. For example, a data point may be captured every two inches in the X direction and every half-inch in the Y direction. A computer monitors progress in data capture and shows the technician the areas on the surface still requiring scanning. The dishes usually require 700 to 1,000 data points for thorough analysis; these can be captured in 15 to 20 minutes.

Once a complete data set has been captured, the computer performs a "best fit" (with Qualstar 3-D best fit software from ICAMP, Bolton, Conn.) in which the data points are floated into the design surface to find the best match with this surface. Because of this capability, the arm can capture data in a "relative" coordinate system—perfect alignment to the design coordinate system prior to data capture is not required.

A computer image shows deviations from design values. Error vectors are color-coded on the computer screen to highlight where the template is high or low. "The system is very quick to analyze and compare the data to the design curve," LeVan reports. Additionally, the data can be used to verify concentricity of cross-sections along parallel planes within the template, a task that would otherwise be nearly impossible without NC machining and the costly use of CMM to verify concentricity. The system also provides histograms and other statistical reports showing deviations from design values. The information available from the data set and analysis is a valuable feature as L-TEC reports to customers.

Using a pen tip on the probe, the FaroArm again is employed to mark the places on the template that deviate too severely from design values. These areas are reworked (built up or sanded down), and the FaroArm captures a new data set. A number of iterations can be completed in one work day (Raphael reports that 13 iterations on an 8-ft template and mold were completed in one day). Typically, between three and six iterations bring the template well within desired tolerances.

A similar procedure ensures surface quality of the glass/polyester molds made from the templates and, finally, of the finished dishes. To achieve the desired tolerance in the finished product, L-TEC holds the template and mold to even tighter tolerances. For example, a dish requiring tolerance of 0.0075 inch might be produced with a template meeting a 0.006-inch tolerance.

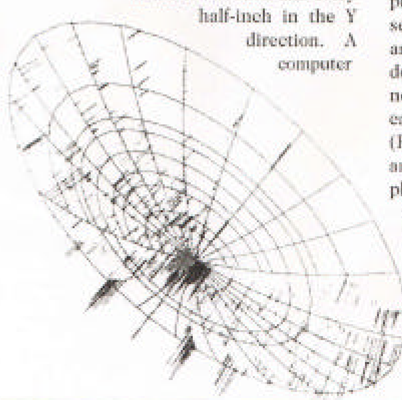

Figure 4. FaroArm software supplies graphic as well as numerical reports of surface accuracy. Here, color-coded vectors highlight areas of deviation from the designed surface.

Reference engineering allows L-TEC to use low-cost fabrication techniques, including the hand-surfaced tooling and vacuum-assisted resin transfer molding (VARTM) of the dish. Most of the dishes are made from glass reinforcement (weaves, continuous strand and chopped strand) in a vinyl ester or epoxy resin. Some larger tracking dishes, which travel up to 15°/sec and accelerate at up to 15°/sec^2, are made from carbon/epoxy to handle the large moment that the action of tracking places on the dish. Reference engineering with the FaroArm can be applied to the fabrication process of any kind of composite; at Martin Marietta, the arm measured carbon/bismaleimide components.

The FaroArm is also used on the finished dishes to determine the exact location of the surface's focal point. Instead of relying on the nominal design value, L-TEC's customers can locate the feedhorn in accordance with actual focal point, ensuring that they get optimal performance out of the dish.

The documentation provided by Direct Dimensions also is a valuable piece of the dish's engineering package. "It allows the customer to tolerate a little more deviation in other components within the dish system," Raphael says.

"The ability to measure all the way through the process is tremendously beneficial," Raphael points out. LeVan concurs: "Holding less than 10 thousandths tolerance in composites without the quick response you get from the FaroArm literally would not be cost effective, and definitely not cost competitive." **HPC**

*For more information on the FaroArm, circle **343** on the reader service card.*