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CAD Speeds Up Dinnerware Designs

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In 1811, immigrants from Germany named Pfaltzgraff established a company in York, Pennsylvania, to produce salt-glazed stoneware. Five generations of family ownership and management later, the Pfaltzgraff Company has become America's leading manufacturer and marketer of casual dinnerware and accessories for the home. Now the oldest pottery maker in the US, Pfaltzgraff has also introduced its brand to other countries.

The US dinnerware market, which totaled around $1.4 billion in 2001, dominates 76 percent of the import market segment according to Market Studies. To compete in this environment, Pfaltzgraff has adopted aggressive product introduction goals that include the design and development of dozens of new shapes every year. The job of designing and fabricating the tooling to mass produce these shapes falls to the Computer-Aided Design (CAD) Group of the Engineering Department. Most of the CAD staff have a mechanical engineering background and received their computer training on the job. The entire CAD staff works closely with the Process Engineering Group—whose responsible for production efficiency—to achieve optimum tool performance.

Using computers to model ceramic products and design the molds and dies to make them began 15 years ago during a surge in new product demand. Pfaltzgraff has used Catia software from Dassault Systemes since 1986 and currently uses versions 4 (Unix based) and 5 (Windows based.) In addition, Pfaltzgraff uses thinkdesign software from the think3 company on Windows platforms. The hardware required to run Catia version 4 is about three times more expensive than that required for version 5. Although thinkdesign runs best on hardware similar to the Catia version 5 systems, it can run on inexpensive ($1,100) machines.

From paper to computer

The original designs for Pfaltzgraff were drawn using pencil and paper. Moving from a regional dinnerware supplier to the global marketplace, however, meant that Pfaltzgraff could no longer do things the old-fashioned way. So in 1986, Pfaltzgraff became one of the first dinnerware manufacturers to install CAD. The company had been looking at CAD systems since 1984 and finally installed a Catia system two years later. At that time, the tooling required to produce the molds and dies for production was developed using a manual process. Skilled workers were also in short supply and demand for them was increasing. Using software capable of defining the complex surfaces of ceramic dinnerware was seen as a means of reducing the need for employees with hard-to-find skills as well as decreasing development lead times and increasing the accuracy of production tooling.

When CAD was first integrated into the product development process, a technician would sit with a designer as the designer described a desired sculptural effect. The operator translated the concept, in real time, into Catia terminology. In this way, the operator was the interface to the computer for the designer. The technicians also received new design projects in the form of a sketch, technical drawing, plaster model, or an existing product that had been designed before the modeling process was computerized. Each CAD operator performed all the activities for a project through each stage, from drafting (documentation) to product modeling (surfacing) to tool design (more surfacing) to numerical control programming. Each operator worked with designers, manufacturing engineers, and the company machine shop.

In an effort to reduce system, training, and tooling development costs, Pfaltzgraff has migrated much of their operation to the less-expensive Catia version 5 and thinkdesign. Thinkdesign has several advanced surfacing features that prove especially useful for designing sculpted and embossed products. Its familiar Windows interface and compatibility with commonplace hardware configurations also makes it a practical tool for modeling many of the manufacturing processes.

No matter which software Pfaltzgraff uses, computer imaging is a considerable time saver and a tremendous enhancement to communication, especially since dinnerware manufacturing involves evaluating many processes by a visual inspection of tooling configurations (see Figure 1). Engineers judge molds, for example, not so much for simple dimensional accuracy but for their consistency of cross section and dimension relative to overall size. In other words, an experienced process engineer can look at an image of a mold or die and evaluate all the pertinent characteristics to determine whether it and the product it's making can be easily manufactured.

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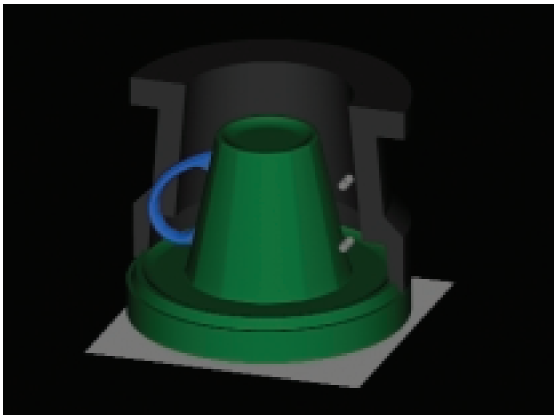
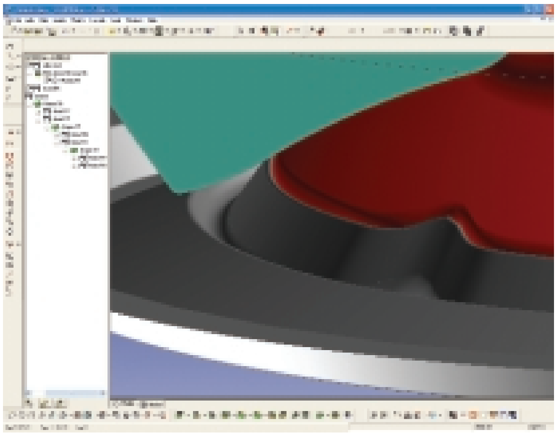
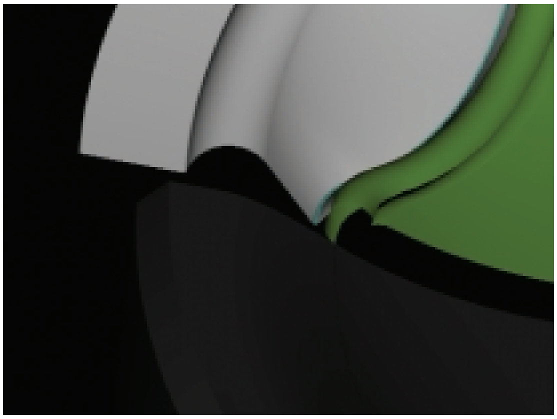


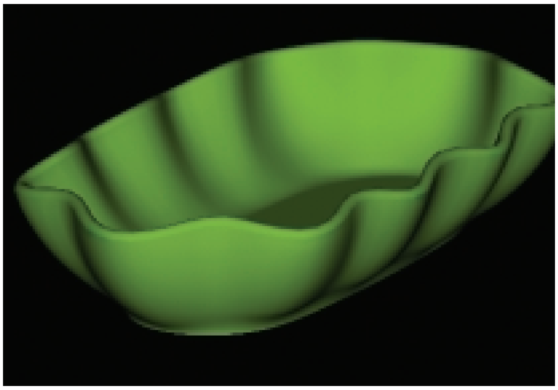
1 The dimensions of a cup and its tooling can easily be viewed on the computer for accuracy.



2 The green roller tool pushes clay against the gray mold to form the shape of the red plate. Excess clay is trapped in the pocket outside the plate and separated by the narrow gap between the tool and mold, which cracks away from the plate.



3 The mold forms a pinch point with the roller tool that lets the clay dry and crack off, defining the plate rim's shape.



4 When the rim or outside edge of a product isn't flat, it requires special consideration in the tool design stage. The seamline between the dies necessary to form a clean edge must be carefully constructed.

The role of tooling

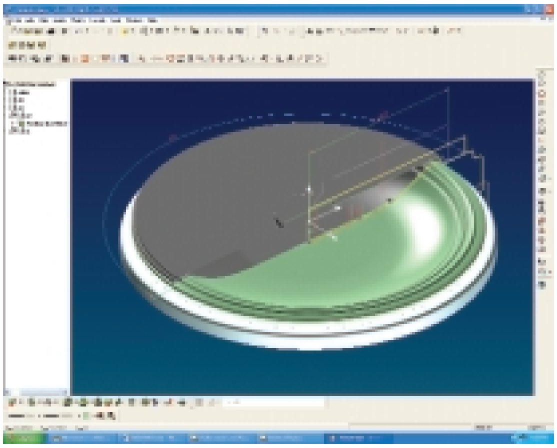
The manufacturing process can be categorized into two major types of forming methods—those that use wet clay and those that use dry clay. All processes require some type of tooling or dies, ranging from plaster molds to polyurethane coated dies. Wet forming includes *casting*, *jiggering*, and *ram pressing*.

In casting, a slurry of clay, water, and other additives is poured into plaster molds. Because these molds are porous, they absorb the moisture from the clay, forming a firm skin next to the mold surfaces. After a set period of time designed to produce a desired wall thickness or fill a solid cavity, the excess liquid is drained from the mold, leaving a hollow clay shape. This process produces the complex shapes precluded by the more automated methods.

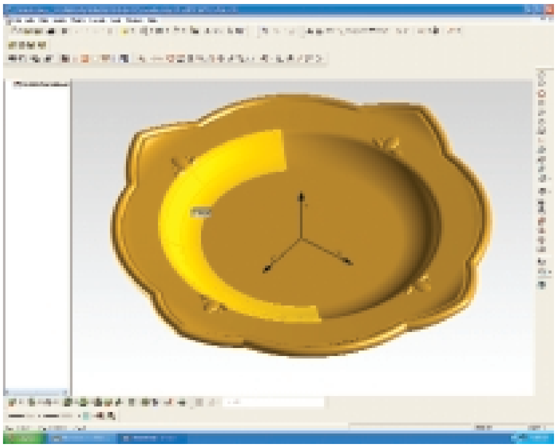
In jiggering, a rotating (or "roller") tool (see Figure 2) forms a shape by pressing a slug of soft clay into a rotating plaster mold. The roller tool forms the contour of the side opposite to the plaster mold. The process is limited to round and oval shapes such as plates and bowls. Sometimes the molds can contain self-scrapping pockets of clay that, when sufficiently dried, fall from the main body of the piece leaving a scalloped or otherwise shaped rim. The relationship between the roller tool and the mold requires exacting geometry to achieve a clean delineation between the scrap and the rim. Figure 3 illustrates this process.

Ram pressing involves pressing a slug of soft clay between two halves of a hard plaster mold. As the mold halves close, the clay fills the mold cavity and the excess extrudes out the sides. The mold must be configured in such a way as to trap the clay as it's squeezed out to build sufficient pressure within the mold cavity. Parts made with this process include platters, trays, and other irregular shapes. Aligning the mold's edges is critical, especially for those shapes that require a parting line (where the two mold halves meet) that varies in three dimensions (see Figure 4). Such alignment can be difficult to maintain without sophisticated graphical representation.

Pfaltzgraff also uses a *dry pressing* process (see Figure 5, next page). A cavity between horizontally oriented dies is filled with dried clay particles and then compressed under high pressure to form plates or shallow bowls. Products formed using this method frequently contain embossed patterns or scalloped rims. Computer



5 The relationship between the various parts of the tooling that create the critical “fill space” unique to the isostatic process.



6 With this salad plate, the grid just hints at the underlying structure of the surface and the opportunities for quality problems that might not be seen in the image.

graphics plays a huge role in the design of isostatic dry press tools. The isostatic process requires that the volume of the die cavity during the fill cycle is precisely greater than the pressed volume by whatever the compression ratio of the material properties is. Defining the size and shape of this volume based on a free-form target isn’t possible without some sort of 3D modeling tools.

After the dinnerware shapes are fabricated, several other processes take place. The ware is dried and sometimes coated with a glaze before firing inside a kiln at a high temperature. This firing process densifies the soft clay into a hard material. Because clay shrinks upon heating (the organic additives burn off), this behavior must also be taken into account when designing the tooling.

The tooling design process

Obviously, tooling is an integral part of dinnerware manufacture and must be designed properly. Tool sets for the various forming processes may consist of as few as two or as many as six components. In addition to the process of forming clay into a particular shape, it’s sometimes necessary to perform further work on the clay in a secondary process, such as drilling holes in a salt shaker or trimming the underside of a knob. Tools for secondary processes can mean two or three additional components that must precisely share geometric features. Thus, each forming process will have its own set of standards.

The first step in tooling design is to model the product shape. Sometimes, as in the case of a basic, round saucer, this can be a simple task. At other times, modeling can require demanding sculptural techniques, as with cup handles or teapot spouts. Modeling free-form shapes requires a collaborative effort between the modeler and the designer that can push computer graphics to the limits of shape visualization as Figure 6 illustrates.

With the introduction of CAD, the tooling design process has been reduced from months to weeks. Engineers model a concept sketch in CAD and render an image so designers can look at it from all sides. Once designer approves or modifies this image, the mold or die is designed using CAD. From this design, the engineer programs a numerical control tool path to make the molds and dies.

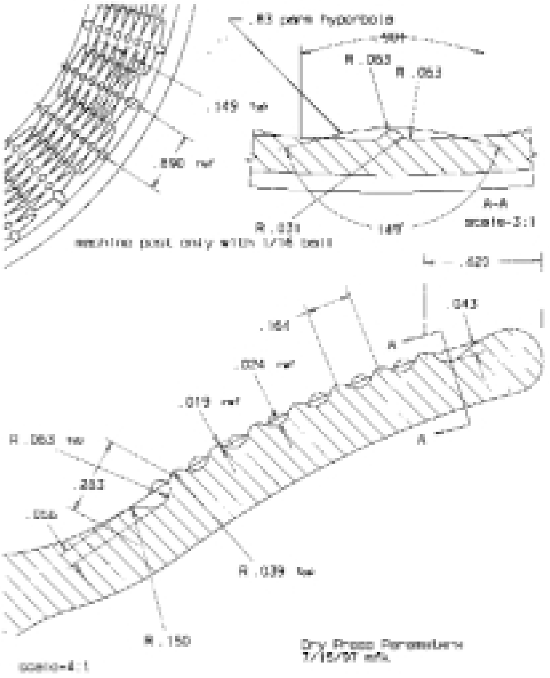
Prior to the availability of these easily rendered computer images, approval of the modeled shape could only take place after machining one or more of the tooling components. Now, thanks to rendering software that demands nothing more than a moderately priced video card, approval can usually take place immediately after modeling.

Standardization process

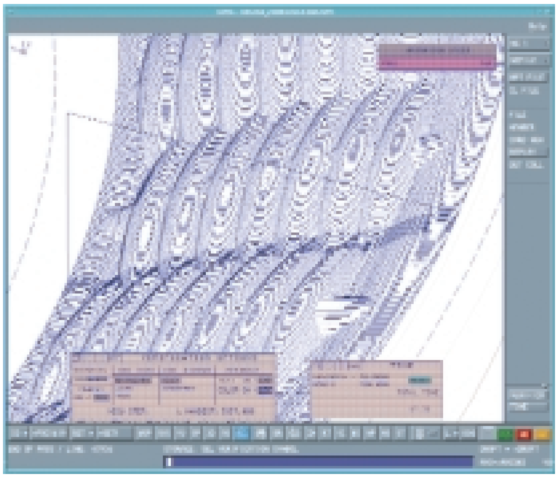
One of the corollary benefits of using a CAD system to design tooling is capturing the graphical information for establishing tooling standards. These are the gaps, distances, and various specifications that the Process Engineering Group has identified over the years as contributing to the most efficient configuration for molds and dies. While feature descriptions and numerical parameters can define a standard, only graphical information can do it unambiguously. Often, the complexity of parametric information can make sculptural details a challenge to describe and nearly impossible to understand. As Figure 7 shows, relationships between the various parts of a wicker embossment—and the parts themselves—can be specified in measurable terms that allow for a reasonable amount of consistency. The distance, for example, between the rows of reeds on the dinner plate can be made the same as those on the platter, if designers determine it to be important to the overall product concept. Providing this specification in a graphical format is ultimately more concise and easier to implement than creating lengthy element definitions and then establishing descriptions of the physical relationships of those elements.

After documenting the specification, the tool design engineer models the shape parametrically. By using the graphically recorded details of an approved feature, these details become reusable information that reduces modeling labor and ensures any desired aesthetic continuity from shape to shape.

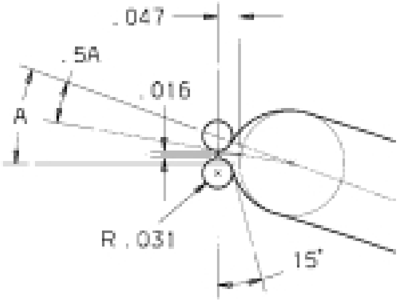
Finally, the tool design engineer programs the numerical control tool paths and reviews them on the com-



7 This document specifies the measurable features of a wicker-like embossment. The features specified are constant for each product type.



8 The path followed by the cutter forms blue contours as it moves back and forth through the raw material following the shape of the part, illustrating how the wicker-like embossment specified in Figure 7 is fleshed out in 3D by the numerical control toolpaths.



9 Specifications for locating the parting line on a ram press tool. The dimensions called out in the document indicate how to derive the exact point adjacent to the shape's rim.

puter screen for accuracy (see Figure 8). Instead of previously testing a numerical control program on the shop floor using a $100,000 machining center, you could watch it on the screen in virtual reality (VR). This is where the real value of computer graphics emerges.

Constructing the geometric representation of common mold and die configurations helps to shed light on those areas that require more precise specification, such as radial elements. Building a surface on the rim of a bowl that allows a mold to be pulled from the shape might have traditionally required the trained eye of an experienced craftsman. But building that same surface using a computer requires mathematical specifications. Determining such parameters enables consistency and has the added advantage of documenting the expertise of the most experienced craftsmen while defining process controls for what previously had been little-understood operations.

The paradox of technology

Despite these advantages, sometimes CAD can create its own problems. For instance, having infinite control can lead to infinite examination and thus difficulty in obtaining agreement between engineering and production on what's the proper standard for forming clay. As Figure 9 shows, when the question of the parting line location and its positioning relative to the cavity wall angle came up, discussions went on for months between the engineer and production groups before they agreed on a generalized parameter was agreed upon.

Graphic simulations also can only be evaluated in the context of understood data. Conditions that fall outside the boundaries of the current knowledge base can't be accurately examined even with graphical tools. For instance, the behavior of clay during firing still isn't completely understood. This lack of understanding can result in defective parts, no matter how well the tooling is designed or standardized.

As another example, the position of the foot on the bottom of a plate must be carefully calculated so that it provides a balance between the mass of clay in the center and the mass of the plate rim. If the foot position isn't calculated correctly, nonuniform shrinkage can occur during firing and warpage results. Because Pfaltzgraff uses a once-fire process (the product is heated to firing temperature only once), all product shapes must be structurally balanced to maintain their shape through the kiln.

The road to standardization

Although focusing on all processes, most standardization has been established for dry pressing because it requires the greatest precision. Standardized tooling features have been completed for about 30 of the 60 or so common components. It now takes an experienced modeler about 12 hours to model a typical, nonround

10 Shapes that require complex surfacing or parting planes that aren't flat often present unusual forming problems. This handled soup bowl requires surfaces flowing to deeply sculpted die edges at steep angles and is a challenge to maintain neat and minimal seams.

product shape and about 8 hours to design the tooling to mass produce it. Programming tool paths may take as much as 16 hours and actual machining time for a normal tool set may take as little as 14 hours with setup. The programmers use custom postprocessors for the numerical control programs and a few step-saving scripts for greater efficiency, but the majority of the applications run off the shelf.

New patterns also require the development of product standards. Each new shape family requires the documentation of those features that make it unique. These features must be consistently applied to all products in the line as was previously described for the wicker embossment.

Initial work has been completed to standardize the tooling and most tooling components fill about 8 Gbytes of storage. The next step is to streamline the storage and retrieval of all standardized configuration data and establish procedures to keep the data constantly up to date. Because so much of what Pfaltzgraff does is graphical in nature, an efficient means of storage and retrieval is difficult to achieve. Currently, images and text are stored in a database with access provided through Web pages on the company intranet. While this makes the data easily accessible, there are two drawbacks: the queries are limited to whatever is designed into the HTML form and data entry is tedious. The company is currently considering commercially available product data management solutions.

Toward optimized tooling

Standardization will become more important—and thus the use of computer graphics will increase—as the demand for complicated designs like embossed shapes continues. Pfaltzgraff aims to develop standardized tooling through routine automated procedures that will be optimized for each forming process. This will allow more time for improving tooling performance for complex designs such as the handle in Figure 10. A better understanding of typical tooling parameters provides a benchmark for comparison of unusual forming challenges and an opportunity to focus on particular problem areas. For example, if round trivets can be produced with standardized tooling at a predictable yield and square trivets fall consistently short of that measure, engineering efforts can focus on the differences between the die cavity shapes, knowing that all other parameters are optimized.

CAD software continues to add new functions, such as true parting line commands and automated methods of using parameterized objects. These new tools offer many new opportunities for future improvements in efficiency. However, computer graphics could do better at showing small subtle changes in curvature since a rendered image conveys only so much information. VR technology, such as tactile feedback systems, may eventually provide the solution to this problem by letting more senses interact with the computer-generated image.

Besides tooling design and standardization, an excellent candidate for the future use of computer graphics is clay behavior analysis. One area where this might be applied is in obtaining a better understanding of structural failures during firing. The ability to predict shape changes during the firing process more accurately would greatly enhance the value of computer-aided ceramic tool design.

As Pfaltzgraff continues on its path to computerized design and tooling standardization, the company will use this technology to survive in a market that gets tougher to compete in every day. ■

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