FAST, PRECISE, SAFE PROTOTYPES WITH FDM

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ABSTRACT

Time compression, the ability to quickly reduce the time it takes to get new products to market, has increased the pressure on all phases of the manufacturing process. Manufacturers must find and implement time saving systems without sacrificing quality.

Fused Deposition Modeling (FDM) provides a synergistic solution for design and manufacturing engineering: visualization models and part concept designs become accurate physical models leading to final working parts automatically and right within the normal engineering office environment.

This clean running, single step operation uses non-toxic, biodegradable thermoplastic wire-like filaments eliminating liquid photopolymers, powders or lasers from the process.

FDM safely generates three dimensional prototypes from 3D CAD software data reducing the new product development cycle and allowing validation of part design and production tooling.

INTRODUCTION

This paper outlines the use of FDM to speed product design and to streamline the manufacturing process.

Building prototypes in toolrooms and model shops is a common step in the manufacturing process, fitting between part design and actual part manufacturing. With the advent of CAD/CAM systems and the speed and accuracy these computer-based capabilities bring to the design and manufacturing steps, it was expected that engineers would look at prototyping as a logical next area in which to apply advanced technology.

The current technological quest has been to create a true desktop system suitable for use in an office environment. The FDM process has moved the state of the art beyond lasers, beyond systems that require messy materials and beyond large, cumbersome units to allow for true 3D desktop prototyping.

FDM quickly and safely produces non-toxic physical prototypes from 3D CAD data reducing the time to market, reducing product development costs and allowing verification of production tooling.

BACKGROUND

The Stratasys 3D MODELER is suitable for an office environment, measuring 30" x 36" x 68" and weighing 250 lbs.

In 1988 Scott Crump invented the FDM process (patent pending), an automatic, non-laser based technology using non-toxic materials for rapid part creation. The process builds on early professional experiences with thermofusion control mechanisms and low temperature thermoplastics.

FDM is a unique technology to empower design and manufacturing engineers to be able to quickly produce precise, multi-material models in an engineering environment, right at the CAD workstation.

Stratasys is a privately held company with partial funding provided by Battery Ventures in Boston. Stratasys began shipping 3D MODELERS in the second quarter of 1991.

THE NEED FOR RAPID PROTOTYPING

In today's business environment, manufacturers need every competitive advantage to get a quality product to market as quickly as possible. The ability to rapidly produce 3D models of the images created on CAD workstations has become an additional tool to positively impact both quality and speed (Marks, 1990).

By allowing design and manufacturing engineers to quickly, accurately and efficiently create prototypes, the design process will improve. When an accurate physical model is generated in less than an hour, the designer can economically create multiple iterations prior to final design.

Rapid prototyping gives shape, form and feel to the image on the computer screen by producing 3D models of complex, sculptured-surfaced parts within minutes or a few hours. Rapid prototyping will increase experimentation and allow improvements to be quickly incorporated (Wohlers, 1990).

3D MODELER

The FDM process uses the Stratasys 3D MODELER in conjunction with a CAD workstation. Stratasys' 3D MODELER is a single step, self-contained modeling system that offers the user several advantages. Speed is an important benefit of this technology; typical models can be produced in minutes rather than hours or days. The lightweight FDM head operates up to 900 inches per minute (15 inches per second). As no post curing is required, the FDM technique enables the designer to create multiple versions of a part design within a short time frame.

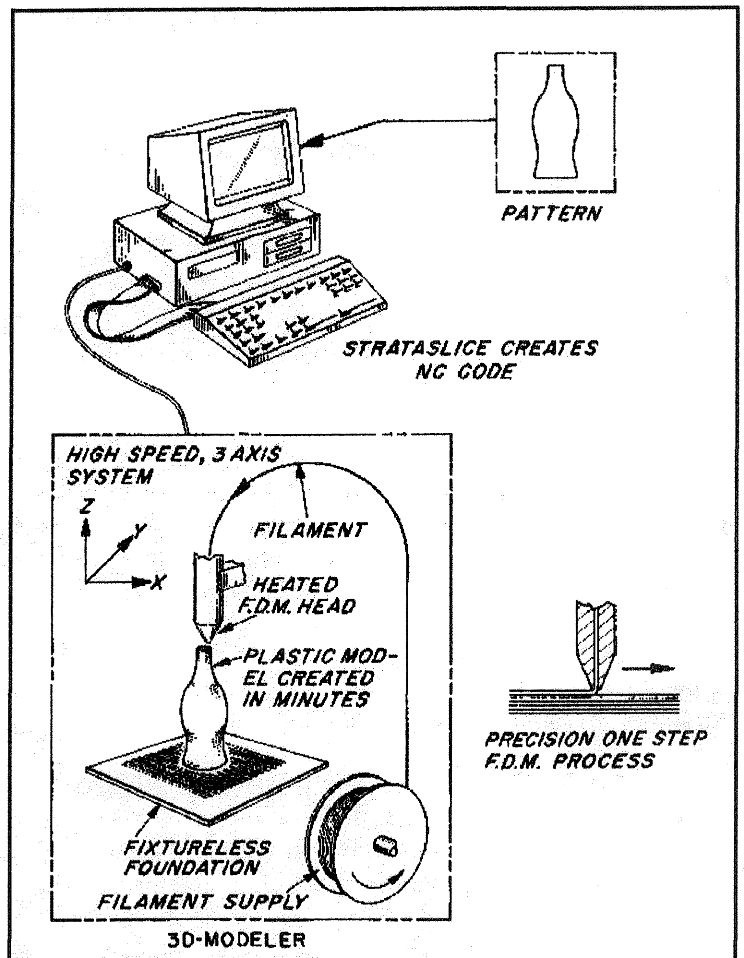
ELEMENTS OF THE FDM PROCESS

In this process a conceptual geometric model is created on the CAD workstation. It is then imported into the SGI workstation where it is sliced into horizontal layers that are down-loaded to the 3D MODELER.

Liquid thermoplastic material is extruded and then deposited into ultra thin layers from the lightweight FDM head one layer at a time. This builds the model upward off a fixtureless base. The plastic or wax material then solidifies in 1/10 of a second as it is directed into place with an X-Y controlled extrusion head orifice that creates a precision laminate.

A spool of .050 inch diameter modeling filament feeds the FDM head and can be changed to a different material in 1 minute.

Maintaining the liquid modeling material just above the solidification point is fundamental to the FDM process. The thermoplastic melt temperature is controlled to 1 degree Fahrenheit above solidification.



The Fused Deposition Modeling (FDM) process produces safe, accurate 3D models in minutes.

The 3D MODELER tightly controls the thermoplastic melt temperature just above solidification then employs precision volumetric pumping through the extrusion orifice.

The model is immediately sheared, quickly solidified, and each layer is bonded to the previous layer through thermal heating. The completed model is ready to be removed from the 3D MODELER.

Successive laminations, within the 0.001 to 0.050 inch thickness range and a wall thickness of .010 to .250 inch range, adhere to one another through thermal fusion to form the model. Our overall tolerance is +or- .005 inches in the X,Y,Z axis over a 12 inch cubed working envelope.

SAFETY BENEFITS

The Stratasys 3D MODELER is a stand-alone modeling system that is located next to the CAD workstation. It stands 6 feet tall with a 3' by 3' footprint. The system requires no exhaust hood or special facilities, providing a natural extension to the engineering workstation and easily fitting into an office environment.

The process operates at a temperature of 180 degrees, about the temperature of a cup of coffee, making it safe for office use. There is no worry of possible exposure to toxic chemicals, lasers, or liquid polymer baths. The Stratasys process uses no powders and there is no messy cleanup. Concern over disposal of hazardous materials is eliminated.

MATERIALS

The Stratasys technology allows a variety of modeling materials and colors. All are inert, non-toxic thermoplastics which closely resemble actual production materials. The system uses a wax-filled plastic adhesive material, a tough nylon-like material or investment casting wax. These thermoplastics soften and liquefy when heat is applied.

The investment casting wax material is excellent for lost wax investment casting with its low ash content and low viscosity, which will quickly produce a residue-free cavity for a quality cast. The Stratasys investment casting material melts out at a low temperature without cracking the shell mold.

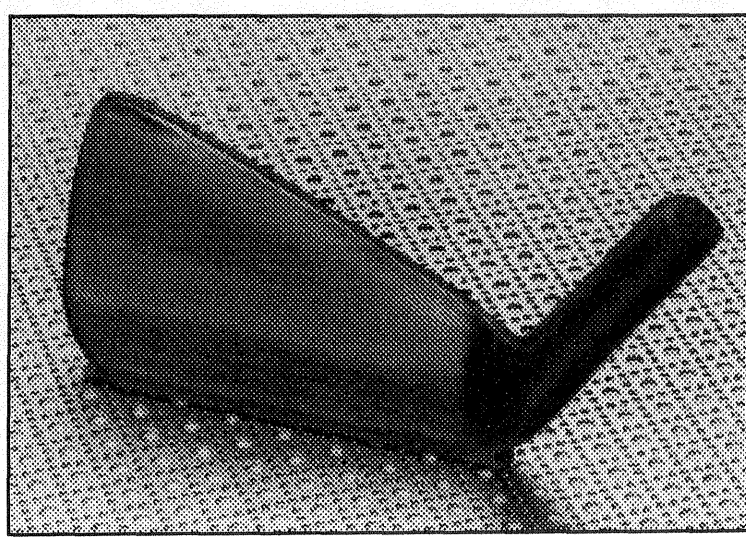
The machinable wax is primarily used for conceptual modeling and spray metal molding. For instance, the accuracy of the model allows its use in the spray metal process for injection molding. Both the investment casting wax and the machinable wax can streamline the manufacturing process by allowing the user to go directly to manufacturing using the model as the manufacturing pattern.

The nylon like filament is a tough material producing sturdy models suitable for concept models or form, fit and function applications.

In the three years the FDM technology was in development several obstacles were overcome. A major breakthrough was the decision to settle on a filament system of material media as opposed to a "hopper" system. The spool based filament system has proven to be a significant strength of the 3D MODELER.

The spools give the user the ability to change material in about

Golf club iron produced by the Stratasys 3D MODELER. Model creation time: 30 minutes.



one minute by threading the desired material into the prototyping unit. There is virtually no waste and no vat to clean out.

The materials to produce a part are cost effective, usually under ten dollars. Materials used with laser based fabrication systems can cost $20 or more. For example the material for one golf club head costs approximately $9.00 and one spool of material can produce roughly 40 club heads.

The FDM process is not limited by the UV polymers required by many other rapid prototyping systems and new materials are continuously under development.

SUPPORTS

The FDM process does not need elaborate supports to produce a part as do some other systems. The 3D MODELER has the ability to create a support in mid-air rather than building the support up from the base. The system is also capable of extruding plastic into free space depending on the part geometry. When supports are not used, the FDM head forms a precision horizontal support in mid-air as it solidifies.

OPEN SYSTEMS

The 3D MODELER imports geometry through standard RS232 serial ports. Either wireframe, surface or solid CAD data from all standard CAD software packages can be imported through IGES running on UNIX workstations.

There are three methods of driving the modeler:

1. Through IGES

   A file is brought into the CAD software program in an IGES format (Stratasys supports the IGES entities listed below). This file can be edited, scaled, oriented and even surfaced if required. Supports, if needed, can be added graphically.

TABLE OF SUPPORTED IGES ENTITIES

Geometric

100	Circular Arc
102	Composite Curve
104	Conic Arc
106	Copious Data
108	Plane
110	Line
112	Parametric Spline Curve
114	Parametric Spline Surface
116	Point
118	Ruled Surface
120	Surface of Revolution
122	Tabulated Cylinder
124	Transformation Matrix
126	Rational B-Spline Curve
128	Rational B-Spline Surface
140	Offset Surface (limited support)
141	Boundary Surface
142	Curve on a Parametric Surface (limited support)
143	Bounded Surface
144	Trimmed Surface

Annotation Entities

106	Crosshatching (limited support)
202	Angular Dimension
206	Diameter Dimension
210	General Label
212	General Note (limited support)
214	Leader Arrow
216	Linear Dimension
218	Ordinate Dimension
220	Point Dimension
222	Radius Dimension
228	General Symbol

Structure Entities

308	Subfigure Definition
314	Color Definition (limited support)
402	Associate Instance
404	Drawing (limited support)
406	Property
408	Singular Subfigure Instance
410	View (limited support)
412	Rectangular Array Subfigure Instance
414	Circular Array Subfigure Instance

2. Direct through NC code

   NC code taken directly from other CAM programs can drive the Stratasys 3D MODELER. All CAM systems that can compute multiple continuous surfaces with an ever increasing positive Z Axis are supported.

3. Through .STL format

   It is possible to import an .STL file and post out NC code to drive the modeler.

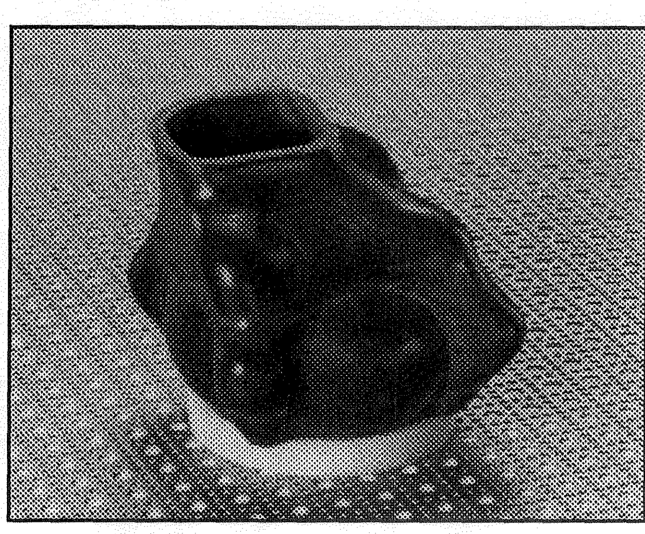
APPLICATIONS

Applications cross a wide spectrum of industries. Any industry that manufactures a tangible product and can benefit from reducing design and manufacturing errors, increasing manufacturing speed or compressing the time to manufacturing has a potential for this technology.

Fit, Form and Function Applications

A common frustration in assembled products occurs when interior components are built that will not fit together or do not fit the housing. The ability to rapidly produce prototypes reduces this source of manufacturing error or decreases the time it takes to hand produce prototypes of all components.

The aerospace industry is just one example where fit, form and function are a concern.



Eagle claw for furniture manufacturer produced by the Stratasys 3D MODELER. Model creation time: 40 minutes.

Investment Castings

Manufacturing complex metal components requires a multi-step investment casting process. As the name implies, the Stratasys investment casting wax is excellent for lost wax investment castings.

FDM can streamline the investment casting process by allowing the designer to go directly from the CAD geometry to investment casting, using the Stratasys model as the wax pattern. The time consuming step of hand making the master can be eliminated.

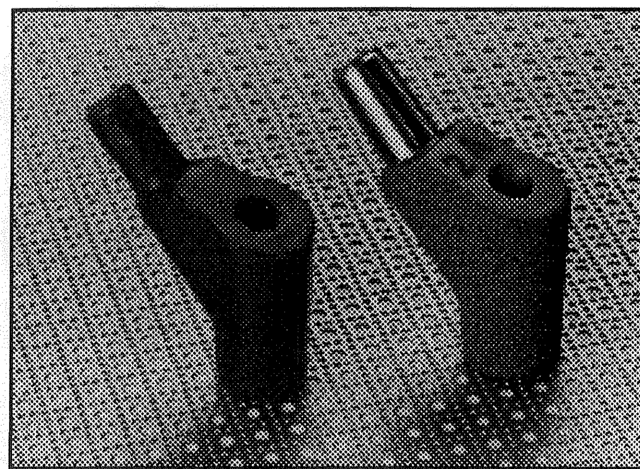
In addition, the shell mold can be rapidly dewaxed using normal investment casting procedures (Kennerknecht and Sifford, 1991). The Stratasys investment casting wax does not have to be specially burnt out.

This investment casting wax is also machinable. The part can be milled, drilled, carved, sawed and tapped making the model uniquely workable.

Investment Casting Examples

The investment casting process is used by a manufacturer of products for the orthopedic surgeon. These products include reconstructive parts such as hip and knee replacement implants as well as shoulder, ankle and other less frequently replaced joints.

Typically the parts are machined from solid blocks of titanium. The need for high quality is apparent when considering the part will be a component of someone's leg or knee for life. From a financial aspect the need for quality is apparent when considering the expense of the titanium. Precision, quality parts with complex surfaces are an ideal match for the FDM process.



Biomet hip replacement joint produced by the Stratasys 3D MODELER. Left part was made in the Stratasys investment casting wax. Right part was investment cast directly from the wax. Model creation time: 58 minutes.

The ability to rapidly produce models allows evaluation by the consulting orthopedic physicians, along with the team members from marketing, design, engineering and manufacturing.

Once a design has been analyzed and consensus is reached the company benefits from the advantages of Stratasys' investment casting wax. By saving steps in the manufacturing process, the company can speed its products into this competitive market.

The jewelry industry is another example where investment casting is used extensively. Although it lacks the emotional impact of a life-changing knee implant, other parallels exist. Certainly the high cost of raw material makes the use of a prototype in a less expensive material desirable.

Injection Molding

This moldmaking technique, combined with spray metal processes, are used by many manufacturers to produce prototype injection molds, thus producing multiple accurate shapes from a model.

The accuracy of the Stratasys model allows the use of the model in the spray metal process for injection molding. The filament materials used by Stratasys have high durability and stability required for a master for spray metal molding.

The FDM process, by again streamlining the model making process and increasing accuracy over alternative hand-production methods, can positively impact the entire manufacturing process.

Consumer products, like perfume bottles and disposable pens, are two examples of products using this process.

Conceptual Modeling

The prototype or model itself can be a marketing tool for the manufacturer. To be able to hand a client a prototype of the proposed part at the final presentation or to include a prototype with the proposal package has strong emotional appeal in the sales process. Conceptual modeling also enables engineers to quickly produce multiple iterations of a sample part to streamline the design process.

Concept models are important in the shoe industry. One major shoe manufacturer creates hundreds of new shoe heel designs each year. Each heel style is normally produced in one size based on the designer's drawing. After this initial prototype design is verified, models are created for sizes 3 through 12, with the heel dimensions graded for the size.

The ability to quickly and accurately produce the concept model allows this manufacturer to improve quality and productivity in the manufacturing process.

SUMMARY

FDM provides a combination of attractive features to provide true desktop 3D modeling. It is a non-laser based system providing a cost effective, accurate and environmentally safe way to produce 3D models and prototypes.

Reducing time to market by accommodating engineering changes quickly and improving product quality demands state-of-the-art prototyping tools.

REFERENCES

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