2006-2317: APPLICATION OF RAPID PROTOTYPING FOR ENGINEERING DESIGN PROJECTS

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Utilization of rapid prototyping equipment in senior design projects

Abstract: The use and application of Rapid Prototyping methods has been considered as an useful, but not necessary, step in the design process of new and improved products. Rapid Prototyping (RP) is an optional technology that has changed greatly from the early RP equipment and technology to the currently available option on materials, technology and machines. In certain cases in industry the utilization of RP technologies and equipment is of great benefit. Rapid Prototyping not only allows the people involved to visualize the concepts and/or alternatives being presented, but in some cases it gives them a better and more complete set of parameters that can be utilized to transfer ideas from the conceptual stage to the analysis/improvement stage in the design process. Nowadays the latest RP technologies can be used during the development of engineering projects. From the academic point of view, these projects are with the participation of students and, typically, with local industry. Thus resulting in a situation that benefits all the parties involved. The paper presents a couple of projects where the use of RP was beneficial for design visualization and verification. Initial and final designs for each case are presented, with explanation on the modifications performed and the value added by the use of RP.

1. INTRODUCTION

The techniques of Rapid Prototyping (RP) began few decades ago when fragile, dimensionally inexact "touch and feel" models were produced to aid in the 3-D representation of drawings. Today, the science of RP has advanced to the point where exceptionally accurate, durable and functional parts can be fabricated with a variety of materials using a number of prototyping methods (Beaudin, R., et. al, 2000). Those RP models, produced mainly from non-metals, have been useful in validating a component for form and fit; and lately there has been a generation of techniques that is producing functional and metallic parts.

Rapid Prototyping refers to “several processes that create physical models directly from a CAD database” (Sriram, et.al. 2002). Components produced by RP machines are usually composed of different materials than the final product versions, and hence do not share many of the desired properties. They are, however, able to provide the designer with an idea of physical, ergonomic, and other properties of a particular component before it is send for production. There currently exist four accepted methods of Rapid Prototyping:

a) Stereolithography (SLA)
b) Selective Laser Sintering (SLS)
c) Fused Deposition Modeling (FDM)
d) 3D Printing.

The Stereolithography (SLA) process begins with a vat of photopolymer resin. The resin, liquid in raw form, becomes a solid when exposed to a localized ultra-violet (UV) light emitted from a laser. After the resin hardens, a platform within the vat submerges the solid layer below the surface of the liquid resin, again exposing it to the UV light and creating another hardened layer. As the process goes on, each hardened layer bond with the one below it, building the part up layer by layer. Once the model is fully formed, excess support material must then be broken, filed, and sanded away to yield the finished prototype. Selective Laser Sintering (SLS) is an offshoot of stereolithography that employs powdered metal and a binder melted together by a laser in layers. Once complete, the SLS part is heated to melt out the wax support material, and is then infiltrated with molten brass to add strength (Baes, 2003).

Fused Deposition Modeling (FDM) constructs a part by extruding liquid resin through an injection head in very small layers. As the resin is laid down on the platform, it hardens, and adheres to the layers surrounding it. Much like the SLA machines, support material must then be removed to produce the finished part. And 3-D Printing employs the use of a normal inkjet head. The ink is removed from the head by the machine, and liquid binding material is then injected in. The machine behaves much like a traditional printer in that it prints (i.e., binds the powder being utilized) a two-dimensional profile onto a platform. When one profile is completed, the platform is lowered one layer and the printing head process another profile. When the part has been completed, it is removed from the machine and the excess material is removed or/and blown off with compressed air. Different forms of 3D printing currently exist that employ different materials and support systems, but the common characteristic, which gives them; their name is the inkjet platform from which they operate (Kemper and McGrath, 2003).

Figure 1. SLA and SLS machines by 3D Systems, Inc.

Figure 2. FDM (Stratasys) and 3D Printing (Zcorp) RP machines

2. OBJECTIVE

One of the most pressing problems in industry is to reduce the time and cost of the product development cycle. As industry evolves to shorter development cycles so must its existing technologies including RP methods. The key to the reduction in this cycle time lies in solving the "Tooling Bottleneck" of part production. It is here that RP can evolve by integrating its capabilities with existing methods, and it promises to be able to become part of the solution of this fundamental problem. By working with the industry the RP world can move forward from its current stage of producing expensive, but still sometimes inadequate, prototypes for the "high-end" design market to the routine working stage of being a keystone in the day to day design and manufacturing cycle (Frey, G., 2002).

Although currently RP can be used to produce excellent 3-D models of a new or replacement part, it is still not considered an essential step in the design process, but in some cases, thanks to RP there have been better designs and products realized, which further validates the techniques. Until very recently, the ability to take a design from concept to creation within just a few days was a myth. Rapid Prototyping facilitates this speedy realization of a concept and leads to substantial savings of both, time and money. In the academic world, the option of utilizing RP technology in design projects is not typical. Not every engineering or technology unit would own, or have access to, rapid prototyping equipment that students can use in their projects. This is unfortunate because it is undeniable the pedagogical value of utilizing RP models for visualization, concept presentation and product improvement. In this paper we present couple of senior design projects where students utilized RP technologies, which helped in delivering a better product with a faster design cycle.

3. METHODS AND RESULTS

3.1 Engine Valve.

One of the design projects that has been conducted with the help of Rapid Prototyping techniques is the redesign of the valve for a rotary engine. In this case, given the fact that we were talking about a special type of small engine, for low- power high-torque situations, space constraints were an issue. As known, due to dynamic and kinematics factors, the valve has to have a cam activating it, with such cam having a very specific profile in order to obtain proper operation of the mechanism. During the design process it was not feasible, due to cost involved, to manufacture a cam and other components in order to check on its adequacy for this redesigned engine. Instead, RP techniques were applied and after having the model created in a CAD system (Figure 3), a prototype was created.

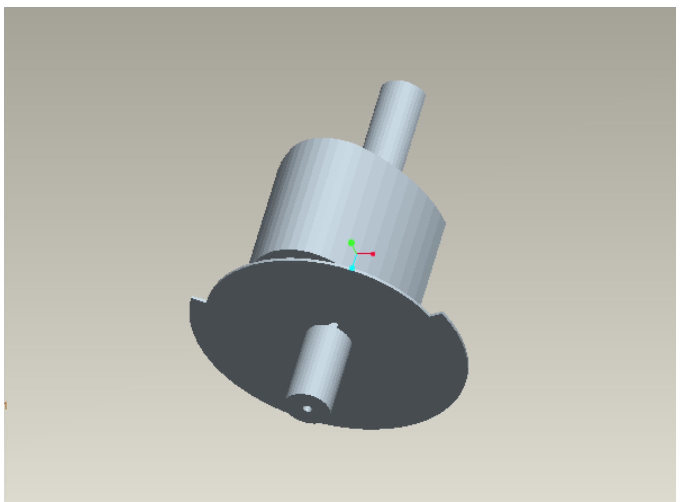

Figure 3. Engine Valve

In this particular situation, because the students had the opportunity to create a prototype for the entire engine (Figure 4), it was possible to check the operation of the new valve design. After such inspection it was required to make few adjustments in order to have a better assembly process and operation. There is no doubt that RP resulted in a more robust design, where some design and fabrication issues were addressed before documenting and releasing the product for production.

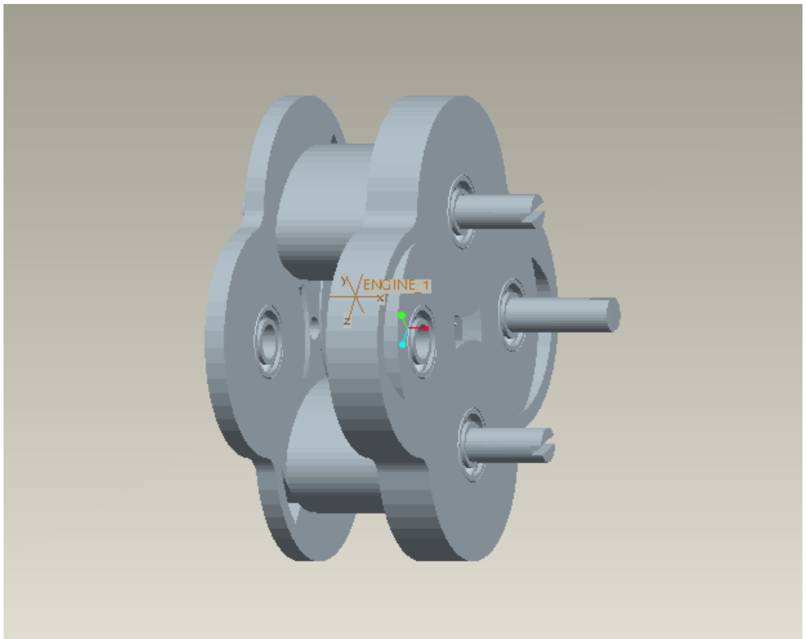

Figure 4. Model of engine

3.2 Plastic Cover.
Another design project where RP techniques were used was the design of the plastic cover for a communication device (Figure 5). In this project, even after the CAD models have been presented to the sponsors of the project, there was a need to create a prototype in order to further assure the sponsors that it was an appropriate design, but more important, it was necessary to have a prototype in order to get feedback from the actual end-users. The end-users are non-technical people that were having difficult time visualizing and picturing the model in the CAD workstations and pictures, reason why it was decided to create the prototype. Once a full-scale prototype was created for the entire device, it was a wonderful tool because the designers were able to get very good feedback from the people involved in the use of the device.
Some modifications were required to address the issues brought up by the end-users. Interesting aspect given the fact that the sponsors had approved the design before RP was utilized. The modifications were in terms of size and location for the features to be used for interacting with the device. Because it is a plastic component, good savings were realized by not fabricating molds and injection molding engineering on the previously approved design.

3.3 Human Spine.
A biomechanical application of RP technology is represented in a study carried out to identify the validity of a parametric model to identify curvature defects affecting the behavior of intervertebral discs in the human spine. In this project, a feature-based parametric CAD model of the entire human spine was created (Figure 6) with the objective of having a versatile modeling

tool. With the use of a parametric model it is possible to generate CAD model of spine for humans with different anthropometric characteristics. It was of particular interest to have the proper size (based on the expected total length) as a function of the age and gender of the person. Additionally, since it is a project to identify problematic areas in the spine, the curvature of the spine in the saggital and frontal planes was included as a parameter.

The RP model served as a visual aid in identifying and understanding why particular spine regions (i.e., lumbar) become more problematic than other ones. The prototype was adequate enough to identify the intervertebral discs that are under higher levels of strain, either tensile or compressive, for various subjects under different postures. The RP model was essential in this project because it would have been basically impossible to realize the same level of experimentation in vitro. Once the trouble spots have been identified then the project proceeded with a more focused analysis of the intervetrebal discs in order to predict possible rupture or bulging.

Figure 5. Cover for Communication Device

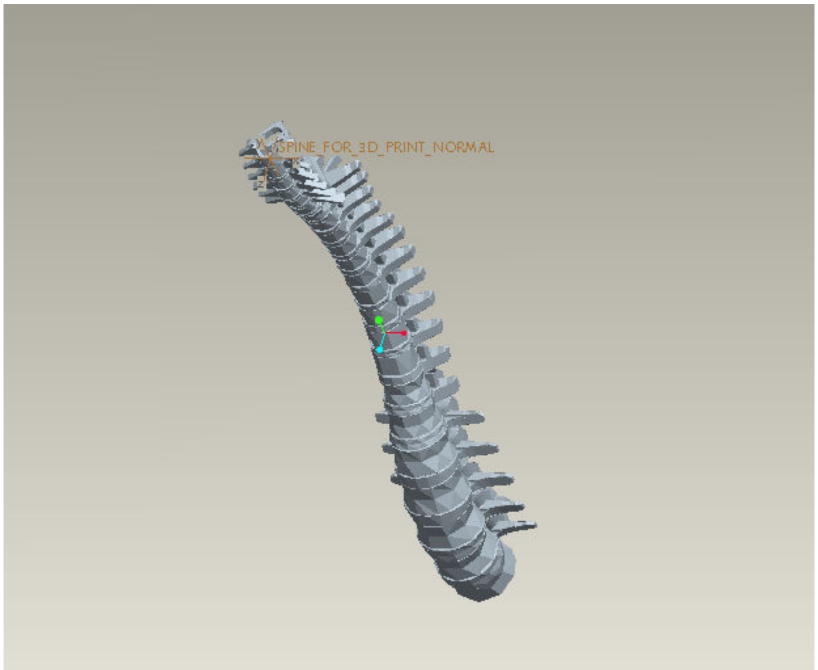

Figure 6. Model of Human Spine

4. USE OF RP TECHNOLOGY

For these senior design projects, and for any project in the College of Engineering and Applied Science (CEAS) here at Western Michigan University (WMU) for that matter, the RP equipment utilized is based on 3-D Printing technology (Z-Corp). The College acquired this equipment two years ago while establishing the Center for Integrated Design (CID) where some aspects of Virtual Engineering are implemented. There is Rapid Prototyping equipment as well as Reverse Engineering and Virtual Reality equipment. The decision on the particular RP technology selected for the CID lab was based, at the end, on cost of parts. With the objective of making this equipment available to students, it was important to have low prototyping cost. Our policy is to charge students only for the cost of the material utilized when they are working in their own projects; in projects where industry/sponsor is involved, we charge the actual cost of running the machine in the production of the prototype (e.g., maintenance cost, cleaning and other supplies are added). In the cases presented here, the full engine prototype was created twice with a total cost of $800, the plastic covers where prototyped four times for a total cost of $350, and the spine was created three times for a material cost of $150.

At this point the use of any of the equipment in the CID lab is not required in any design course. The use of RP equipment is required in the Computer-Aided Manufacturing course (lab). The proposal to use RP equipment in regular junior-level design/lab course has been approved (Bowe, M., 2002). The use of Reverse Engineering equipment has been proposed for the Metrology lab. One major issue with these pieces of equipment, just like with any other lab equipment, is the need for supervising their utilization. So far it has not been a problem because the faculty member is present when they are being utilized, but it is expected that some lab assistant or teaching assistant will need to be assigned to this lab once the use of the equipment is a course requirement.

5. SUMMARY

Virtual engineering technology, along with several other design techniques, has been accepted and adapted in many industries. In response to this technology gaining approval, options like Rapid Prototyping are now becoming an important, if not essential, step in the design process. It is clear that industry and academic institutions are benefiting and will benefit, from the use of these technologies. We have presented couple of cases were the use of RP technologies were beneficial on design projects where industry and university were collaborating. Exposing participant students to a more complete design cycle experience and allowing them the utilization of RP equipment realize the benefits in the academic side. In the industrial side, they realize the benefits of collaboration with academics by means of senior design projects, because they have access to some resources (i.e., equipment, students, faculty) that otherwise would be almost impossible to have in-house. Without a doubt this is a beneficial situation for all parties involved.

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