IMPELLER PUMP DEVELOPMENT USING RAPID PROTOTYPING METHODS

Włodzimierz Przybylski, Stefan Dzionk

S u m m a r y

Integrated product development based on Rapid Prototyping methods, aided with computer 3D design and computer engineering enables fast and full new product verification and validation, both from technological and customer requirements point of view. A case study derived from industrial practice, using pomp rotor construction is also included.

Keywords: rapid prototyping, impeller pump developing, stereolithography

Metody szybkiego prototypowania w rozwoju pomp wirowych

S t r e s z c z e n i e

Metody szybkiego prototypowania, przy wspomaganiu komputerowym projektowania 3D wraz z systemami wspomagania inżynierskiego, pozwalają uzyskać wyrób o prognozowanych właściwościach technologicznych i użytkowych. W artykule przedstawiono studium przypadku zastosowania metod szybkiego prototypowania w rozwoju elementów pomp wirowych.

Słowa kluczowe: metody szybkiego prototypowania, projektowanie pomp wirowych, stereolitografia

1. Introduction

In the development of a new product it is invariably necessary to produce a single prototype of a designed product or system before the allocation of large amounts of money to new production facilities or assembly lines. The cost is very high and production tooling takes considerable time to prepare. Consequently, a working prototype is needed to design evaluation and to suggest problem solutions before a complex product and system are introduced [1-3].

The technology which considerably speeds the iterative product development process is the concept and practice of Rapid Prototyping (RP) also called Solid Freeform Fabrication (SFF). Developments in Rapid Prototyping began in the mid-1980s. The advantages of this technology include the following elements:

Address: Prof. Włodzimierz PRZYBYLSKI, Stefan DZIONK, Ph.D. Eng., Department of Manufacturing Technology and Automation, Gdańsk University of Technology, 80-233 Gdańsk, Narutowicza11/12, Poland, e-mail: wprzybyl@pg.gda.pl, sdzionk@pg.gda.pl

- Physical models of parts produced from CAD data files can be manufactured in a very short time and allow the rapid evaluation of manufacturability and design effectiveness. In this way, Rapid Prototyping serves as an important tool for visualization and for concept verification.
- With suitable materials, the prototype can be used in subsequent manufacturing operations to produce the final parts. In this way Rapid Prototyping serves as an important manufacturing technology.
- Rapid Prototyping operations can be used in some applications to produce real tooling for manufacturing operations (Rapid Tooling). In this way, it is possible to obtain tooling in few days.

2. Rapid Prototyping – an overview

Rapid Prototyping process can be classified into three major groups: subtractive, additive and virtual processes. Subtractive processes involve material removal from a workpiece that is larger than the final part. Additive processes build up a part by adding incrementally to produce a part. Virtual processes use advanced-based visualization technologies [4-7].

However, because their properties are more suitable for these operations, polymers are the workpiece material most commonly used today, followed by ceramics and metals. New processes are being introduced continually and thus existing processes and material are improved.

Manufacturing a prototype traditionally has involved a series of machining processes using a variety of tooling and it usually takes from weeks to a few months, depending on part complexity and size. This approach requires skilled operators applying material removal by various types of machining and finishing operations. To speed up this process, subtractive processes more often take advantage of computer aided technologies (CAx), such as:

- Computer aided design (CAD), which can produce three–dimensional representations of parts.
- Interpretation software, which translates the CAD file into a format usable by manufacturing software.
- Manufacturing software which is capable of planning the operations required to produce the desired shape (CAM/CAPP software).
- Numerically controlled machinery (CNC) with the capabilities necessary to produce the parts.

When a prototype is required only for the purpose of shape verification, a soft material (usually a polymer or a wax) is used as the workpiece in order to reduce or avoid any machining difficulties. The material intended for use in the traditional application also can be machined, but this operation may be more time consuming, depending on the machinability of the material. Depending on part complexity and machining capabilities prototypes can be produced from few days to few weeks.

Additive Rapid Prototyping operations all build parts in layers, which consist of stereolithography, fused-deposition modelling, ballistic-particle manufacturing, three-dimensional printing, selective laser sintering and laminated object manufacturing, etc [8]. The main difference between the various additive processes depends on the method of producing the individual slices which are typically 0,1 to 0,6 mm thick and can be thicker for some systems. All additive operations require elaborate software. The first step is to obtain a CAD file description of the part. The computer then constructs slices of the three-dimensional part. Each slice is analyzed separately, and a set of instructions is compiled in order to provide the Rapid-Prototyping machine with detailed information regarding the manufacture of the part.

This approach requires operator input in the setup of the proper computer files and in the initiation of the production process. Following this stage, the machines generally operate unattended and provide a rough part after a few hours. The part then is subjected to a series of manual finishing operations (such as sanding, polishing and painting) in order to complete the Rapid Prototyping process. It should be recognized that the setup and finishing operations are very labour intensive and that the rapid process consumes only a small portion of a total production time required to obtain a physical prototype.

3. Principle of Stereolithography

A very common Rapid Prototyping method is Stereolithography (SLA) [3, 9, 10]. This process (Fig. 1) is based on the principle of curing (hardening, solidification) a liquid photopolymer into a specific shape. A vat and a platform includes a mechanism, which can be lowered and raised. A vat is filled with a photosolidificated liquid – acrylate polymer. The liquid is a mixture of acrylic monomers, oligomers (polymer intermediates), and a photoinitiator (a compound which undergoes a reaction upon the absorption of light).

At its start position, a layer of liquid exists above the platform. A laser generating an ultraviolet beam is focused upon a selected surface area of the photopolymer and then moved around in x-y plane. The beam cures that portion of the photopolymer and produces a solid body. The platform then is lowered sufficiently to cover the cured polymer with another layer of liquid polymer, and the sequence of the solidification is repeated. The platform is lowered by a vertical distance which equals dimension of models. Note that the surrounding liquid polymer is still fluid (because it has not been exposed to the ultraviolet beam) and that the part has been produced from the bottom up in individual "slices".

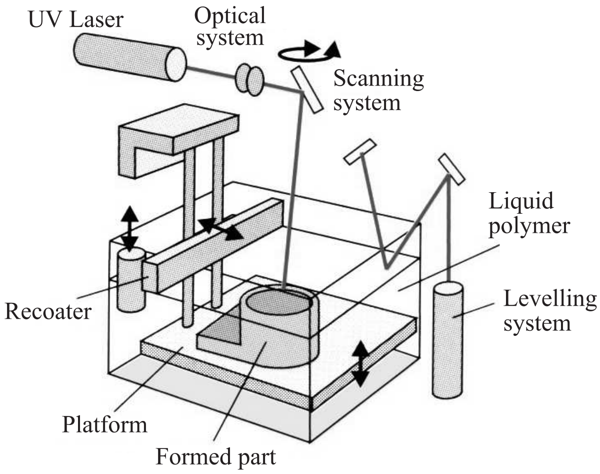

Fig. 1. Schematic illustration of the stereolithography process [9]

The unused portion of the liquid polymer can be used again to make another part or another prototype. Stereolithography can utilize a weaker support material. In stereolithography this support takes the form of perforated structures. After its completion, the part is removed from the platform, drained, and cleaned ultrasonically (or mechanically) and with an isopropanol (acetone) bath (Fig. 2).

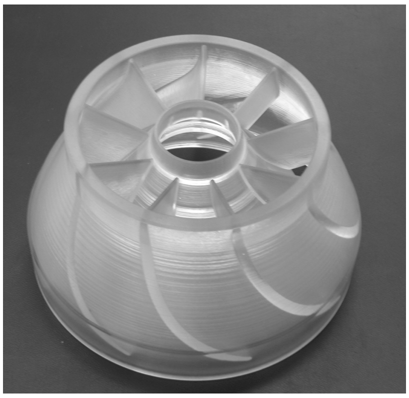

Fig. 2. Exemplary product (pump diffuser) developed with the use of Rapid Prototyping Technology

Then the support structure is removed, and the part subjected to a final curing cycle in a ultraviolet chamber (PCA). The smallest tolerance that can be achieved in stereolithography depends on the sharpness of the focus of the laser (approximately 0.02 mm). Oblique surfaces also can be of very high quality.

Solid parts can be produced by applying special laser – scanning patterns to speed up the process. For example, by spacing scan lines in stereolithography. Volumes or pockets of uncured polymer can be formed within cured shells. When the part is placed in a post-processing chamber, the pockets cure and a solid part is formed. Similar parts, for example investment-cast will have a drainable honeycomb structure which permits a significant fraction of the part to remain uncured.

The total cycle time in stereolithography range from a few hours to a day (without post-processing such as sanding, polishing and painting. Stereo-lithography has been used with highly focused laser to produce parts with micrometer sized features. The use of optics, required to produce such features, needs thinner layers and lower volumetric cure rates. However, this process has been used for the fabrication of micromechanical system and in such cases it is called microstereolithography.

4. Industrial Case Study

In order to present the product development and practical usefulness of the Rapid Prototyping technique it was applied and tested for a new pomp rotor

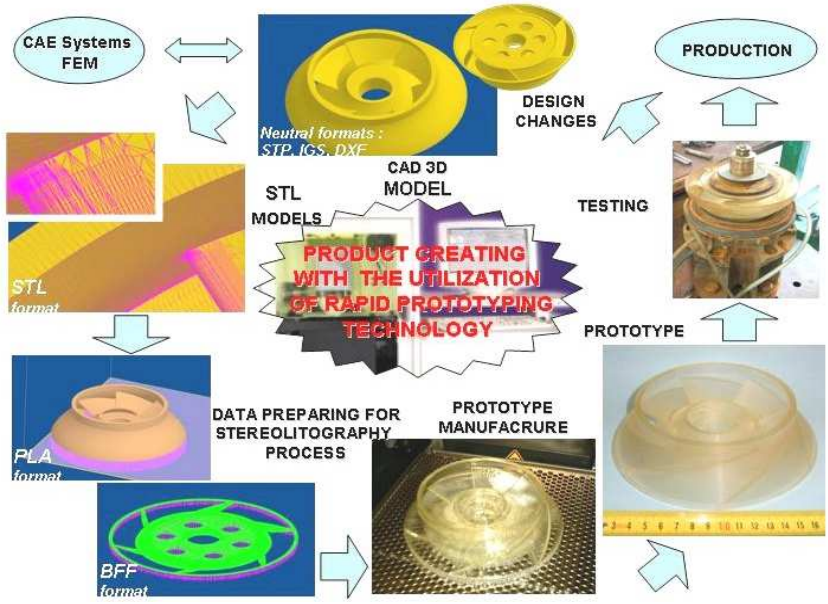

Fig. 3. Cycle of the integrated product development of the pomp rotor with the utilization of Stereolithography Technology (SLA)

construction. The industrial case illustrated in this project is based on the order and data from a medium sized industrial company in north Poland. An iterative process of product development in this company occurs when errors are discovered or more efficient or better design solutions are looked for the study of an earlier generation prototype of pomp rotors. The main problem with this approach, however, is that the design (or redesign) and production of a prototype of pomp rotor can be extremely time consuming. Manufacturing can take several months to prepare, and the production of a single complicated part, as a pomp rotor, by conventional machining operations can be very difficult. Furthermore, while waiting for a prototype to be prepared, facilities and staff still generate large costs.

Those factors were the main reasons to utilize the stereolithography technology for pomp rotor manufacturing at Gdańsk University of Technology. A product development was outlined in Fig. 3.

The physical property of cured resin presents Tab. 1.

Table 1. Properties of cured resin [9]

Accura SI 10 post-cured material*		
Measurment	**Condition**	**Nd Laser**
Tensile strength 90-minute UV post-cure	ASTM D 638	64-65 MPa (9240-9450 PSI)
Elongation at break	ASTM D 638	4.6-5 %
Tensile Modulus	ASTM D 638	3100-3307 MPa (450-480 KSI)
Flexural strength	ASTM D 790	91-94 MPa (13200-13700 PSI)
Flexural modulus	ASTM D 790	2618-2756 MPa (380-400 KSI)
Impact strength Notched Izod	ASTM D 256	16-18.2 J/m (0.3-0.34 ft - lbs/in)
Heat deflection temperature 90-minute UV post-cure	ASTM D 648 @ 66 PSI @ 264 PSI	59 53
Glass transition, Tg	DMA, E”	61°C (141.8°F)
Coefficient of thermal expansion 90-minute UV post-cure	ASTM E 831-93 TMA (T<Tg) TMA (T>Tg)	67.9 x 10^{-6} m/m °C 186 x 10^{-6} m/m °C
Hardness, Shore D	ASTM D 2240	86
* Mechanical properties reported are determined after conditioning of the parts at 50% RH and 23°C for a period greater than 72 hours as specified by ASTM standards. Mechanical properties of parts without this conditioning may be different from values reported.		

The exemplary results concerning the main characteristics are presented in Fig. 5. As it can be generally observed, the technical parameters of the pomp rotor prototype are convergent to those obtained in real pomp exploitation. On the other side, testing and validation during investigation enabled the redesign of geometry and rotor blades, in order to optimize the whole pomp construction in continuous product development. The pomp rotor prototype was exploited in the pomp at nominal load and rotational speed of 3000 rpm.

What is interesting, after finishing tests on the research stand the wear and damage of the prototyped rotor was not significant (Fig. 4).

Fig. 4. The pomp rotor prototype after testing [10]

5. Conclusions

In order to present benefits for industry and practical usability of the product development the case study for pomp rotor prototype has been above described. For industrial enterprises a very important factor is the speed with which a new or improved product can flow to a market. In a competitive market, it is well known that products that are introduced before those of their competitors generally are more profitable and take a larger share of the market. At the same time, a very important aspect for the enterprise is the production of high-quality pumps.

Stereolitography as a means of rapid manufacturing of pomp rotors prototypes has proved its usefulness in product development cycle. Manufacturing a pomp rotor prototype, with many complicated shapes, traditionally involves a series of advanced machining processes utilising a variety of expensive tooling. In consequence it is time and cost consuming.

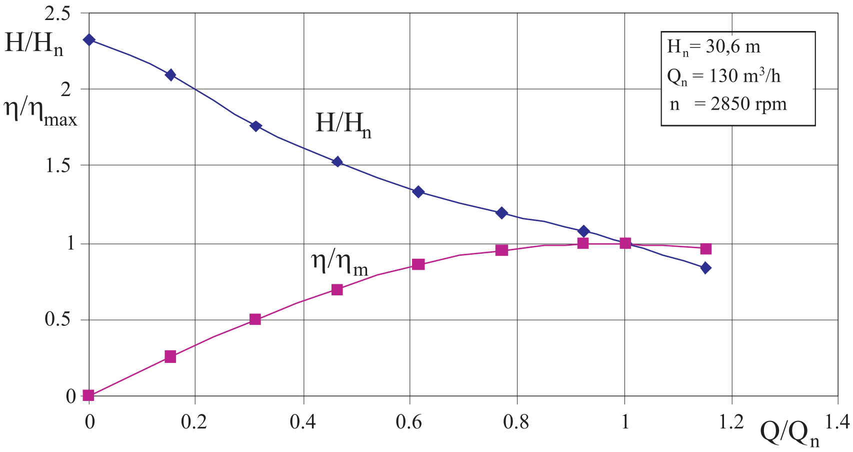

Fig. 5. Dimensionless characteristic of the two stage deep-well pomp. The rotor and the diffuser were made using Rapid Prototyping Technology/Stereolithography Process [10]

Testing and investigation in the research stand, using the pomp rotor prototype, confirms that technical characteristics of pomp rotor made in SLA technology do not significantly differ from those obtained with a normally used material for such elements.

References

[1] T. BORATYŃSKI, M. FRANKIEWICZ, P. KARCZMAREK: Kompleksowy rozwój produktu metodami RP/RT. Prace Naukowe Instytutu Technologii Maszyn i Automatyzacji Politechniki Wrocławskiej, Konferencje nr 41, Wrocław 2003, 217-224.

[2] E. CHLEBUS, K. OCZOŚ, E. DYBAŁA, T. BORATYŃSKI: Nowoczesne technologie w rozwoju wyrobu. Prace Naukowe Instytutu Technologii Maszyn i Automatyzacji Politechniki Wrocławskiej, Konferencje nr 36, Wrocław 2000, 79-106.

[3] S. KALPAKJIAN, S.R. SCHMI: Manufacturing Engineering and Technology. Pearson Prentice Hall, Upper Saddle River 2006.

[4] H.-J. BULLINGER, J. WARSCHAT, D. FISCHER: Rapid product development – an overview. *Computers in Industry*, **42**(2000), 99-108.

[5] R. PUZYREWSKI, K. ŻOCHOWSKI, P. FLASZYŃSKI: Agregat pompowy głębinowy. Praca niepublikowana. Politechnika Gdańska, Wydział Mechaniczny, Gdańsk 2005.

[6] B. WIEDEMANN, H.-A. JANTZEN: Strategies and applications for rapid product and process development in Daimler-Benz AG. *Computers in Industry*, **39**(1999), 11-25.

[7] U. SANCIN, M. DOBRAWC, B. DOLŠAK: Human cognition as an intelligent decision support system for plastic. *Expert System with Applications*, **37**(2010), 7227-7233.
[8] E. CHLEBUS: Innowacyjne technologie rapid prototyping – rapid tooling w rozwoju produktu. Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2003.
[9] 3D Systems Inc., News & Events, Valencia, USA, Darmstadt, Germany.
[10] M.J. GORDON: Industrial design of plastic products. John Wiley & Sons, New York 2003.

Received in November 2010