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APPLICATION OF RAPID PROTOTYPING METHOD FOR DEVELOPMENT OF MECHATRONIC SYSTEMS

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Summary: *This paper deals with rapid prototyping method of fast production of real parts, which are used for development of some mechatronics systems. The rapid prototyping is the process of creating physical objects from computer models generated using CAD program that a prototype machine can build a 3D prototype out of metal, plastic or resin. The rapid prototyping is used to quick and easy produce prototype parts. This fact is very interesting and useful for development of several mechatronics systems. The complicated geometry of models and prototype parts can be tested or the behavior of whole system is verified during development cycle of mechatronics system. This methodology was used during development cycle of the vibration power generator. The generator is complex mechatronics system, which harvests electrical energy from mechanical vibration for feeding of wireless sensor. This device was designed with application of rapid prototyping for production of several generator parts.*

1. Introduction

This paper deals with rapid prototyping method of fast production of real parts, which can be very useful for development of some mechatronic systems, robotics and other applications. The rapid prototyping technology is based on the automatic construction of physical objects using solid free form fabrication. The first techniques of rapid prototyping were available in the late 1980s and were used to produce models. Nowadays the rapid prototyping parts are produced across several industrial for fabrication of test products, prototypes or parts in relatively small numbers.

The rapid prototyping is the process of creating physical objects from virtual computer models generated using CAD program. This technology transforms CAD model to virtual thin cross-sections and than a prototype machine can build each cross-section in physical model. This technology is base on additive fabrication and the prototype machine lays down layers of liquid, powder or sheet materials. Consecutively the final prototype is built up from series of cross sections from virtual CAD model, which are fused or joined together. The main advantage of this method is fabrication of any shape and geometry.

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2. Rapid Prototyping Technologies

The rapid prototyping technology substitutes for classic production cycle of components and using of these prototype parts can be very useful during development of several mechatronic systems and other applications.

The basic principle of these technologies is gradual forming of a layer with constant thickness from an additive material. The prototype component can be, according to the applied technology, manufactured from thermoplastic material, photopolymer, wax, powder (e.g. metal), paper, foil or another material sheet etc. Additive manufacturing is extremely versatile because of its ability to create almost any geometry even parts that could not be commercially created with processes such as machine cutting or injection molding.

The marking rapid prototyping is relative because construction of a model with presented methods can from several hours or days. It depends on the used technology and the size of the model. Additive technologies for rapid prototyping can typically produce models in a few hours, depending on the type of machine and the size and number of models.

Several number of different rapid prototyping technologies are available in the marketplace. The principle of these technologies are summarized in textbook (Drápela, M., 2006) or the detailed information about several rapid prototyping principles are published in web site (http://en.wikipedia.org/wiki/Rapid_prototyping) with links to rapid prototyping machines producers. The review of rapid prototyping technologies with used materials and model building is shown in Tab. 1.

Rapid Prototyping Technology	Label	Base Materials	Building of Model
Fused Deposition Modeling	FDM	Thermoplastics, Eutectic metals	Layers of material
Selective laser sintering	SLS	Thermoplastics, Metals powders	Sintering by laser
Stereolithography	SL	Photopolymer	Hardening by laser
3D Printing	3DP	Various materials (powder, metal, ceramics)	Selective bonding
Laminated Object Manufacturing	LOM	Paper, Foil	Laminating and cutting by laser
Electron Beam Melting	EBM	Titanium alloys	Sintering by electron beam

Tab. 1: Review of Rapid Prototyping Technologies

Some technologies use two materials during prototyping parts. The first material is the part base material and the second is the support material (to support overhanging features during construction). The support material is removed from final prototype by cutting, heat or dissolved with some solvent.

3. Fused Deposition Modelling at BUT Faculty of Mechanical Engineering

Dimension BST 3D printer, which works at the FDM (Fused Deposition Modelling) principle of rapid prototyping, is located at Faculty of Mechanical Engineering. The FDM produces

ABS plastic prototype models, which have high strength and durability. The input material is wire at the cartridge which is entered to the printing head where ABS is melted and it is pressed through the nozzle to the basic pad. The nozzle moves to produce a profile of the part then pad moves down and the next layer is built on top until the entire prototype model is fully built. A support construction from easy breakable ABS is used for the overhanging places.

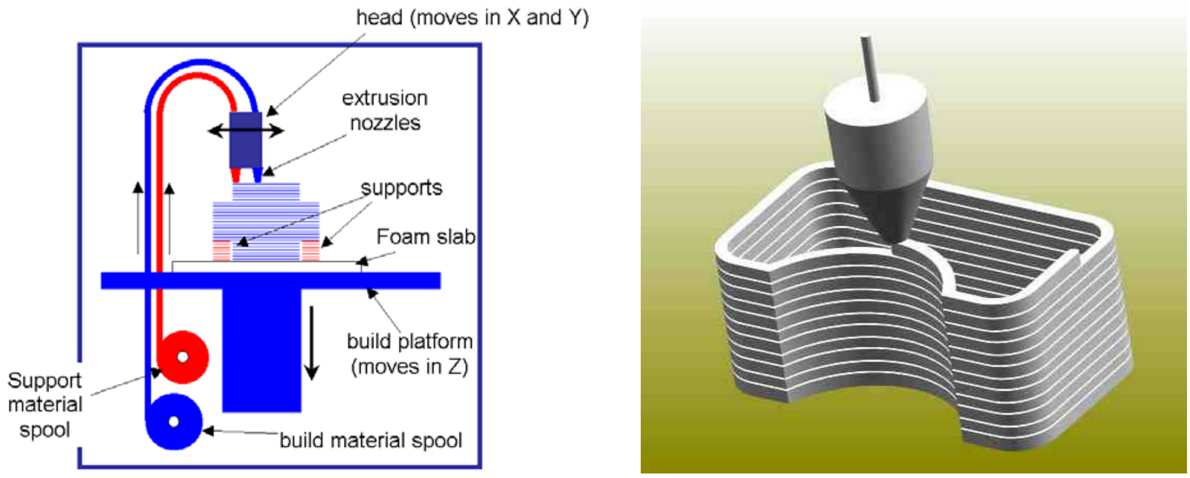


Fig. 1: Principle of Fused Deposition Modelling

	**Size and Power Requirements:** Size: 686 x 914 x 1041 mm Weight: 136 kg **Network Connectivity:** TCP/IP 100/10 base T **Compatibility:** Windows XP **Build Size:** Maximum size 203 x 203 x 305 mm **Materials:** ABS plastic in standard white, blue, yellow, black, red, green or steel gray colors. Custom colors available. **Material Cartridges:** Autoload cartridge with 922 ccm ABS material. Autoload cartridge with 922 ccm support material. **Layer Thickness:** 0.245 mm or 0.33 mm of ABS and support material.

Tab. 2: Machine Dimension BST 768 (www.dimensionprinting.com)

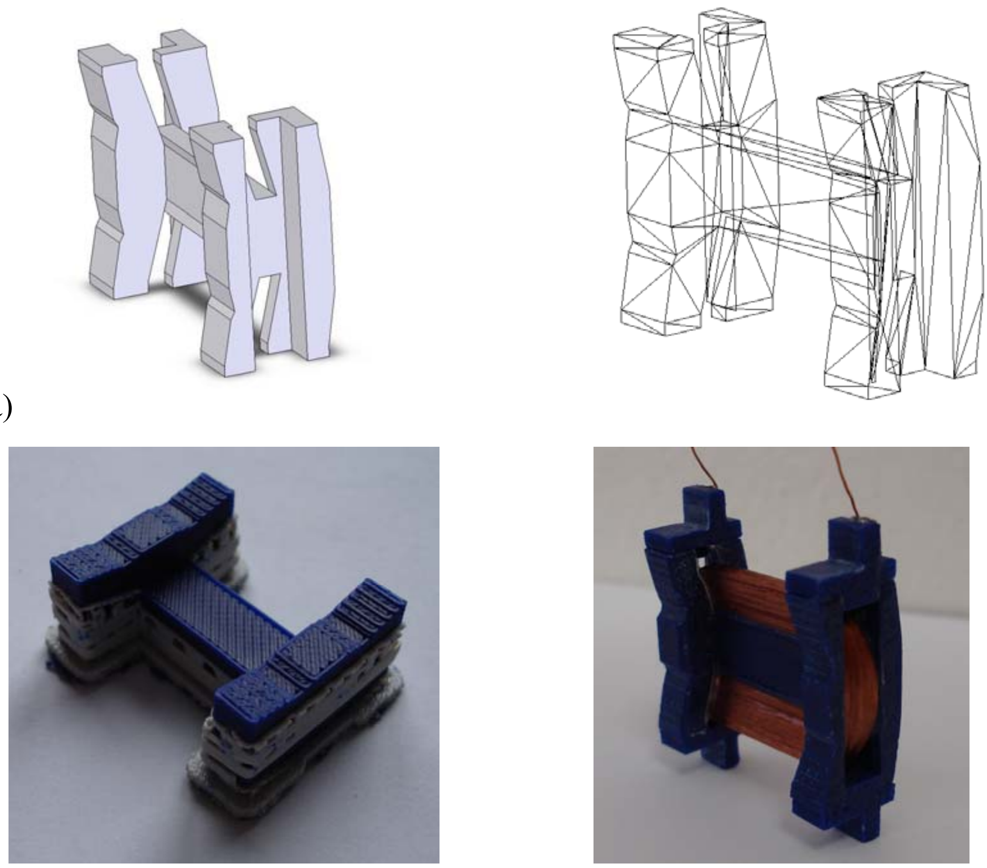
ABS (acrylonitril butadien styrene – $(C_8H_8{\cdot}C_4H_6{\cdot}C_3H_3N)_n$) is a strong, durable production grade thermoplastic used across many industries. ABS is an ideal material for conceptual prototyping through design verification through direct digital manufacturing. Some typical material properties of ABS part are shown in Tab. 3. ABS rapid prototype parts can be sanded, milled, drilled, tapped, painted and even plated with nickel, chrome or copper.

Properties	**Value**
Tensile Strength	22 MPa
Flexural Strength	41 MPa
Heat Deflection Temperature @ 66 psi	90°C
Dielectric Strength	32 kV/mm
Dielectric Constant @60Mhz	2.4
Rockwell hardness	R105
Specific gravity	1.05

Tab. 3: Properties of ABS (www.stratasys.com)

4. CAD model and Stereolitography format

The STL format (stereolitography) was development for simple transport of 3D CAD models to manufacturing by rapid prototyping methods. This format presents CAD model as solid which is consisted of polygonal shape mesh in binary or ASCII format. All employed CAD systems allow export of CAD models to STL format with required accuracy, mesh density and angle limitation.



a) b) c) d)

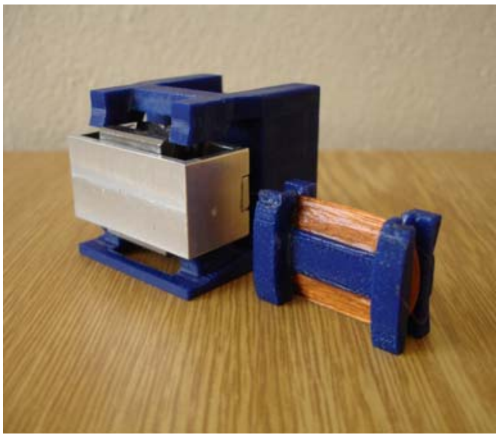
Fig. 3: CAD and STL model and plastic prototype of air coil frame

The stages of plastic prototype fabrication are shown in Fig. 3. The first stage is CAD model part with required geometry. The model is transported to SLT format with polygonal mesh in Fig. 3 b). This SLT mesh is virtual input model to rapid prototyping machine, which products real plastic model from ABS plastic with support structure, Fig. 3 c). The support structure is removed and the plastic part is finally treated (filing out of layers edge, grinding, etc.) and subsequently the final prototype parts can be used for next assembly. The Fig. 3 d) shows self-bonded air coil which is wound around plastic prototype frame. The difficult shape of frame, which corresponds to operating of device, was fabricated using FDM technology and the frame was used for further assembly.

5. Application in Mechatronic Systems

The vibration power generator is mechatronic system which consists of mechanical resonance system and electromechanical transducer. The generator harvests energy from an ambient mechanical vibration and generates useful electrical power for feeding of several wireless sensors which operates in environment excited by sufficient vibration. The generator was developed in several cycles, described in paper (Hadaš, et al., 2007), and the development cycles include testing and verification of a test product. The generator design of the test product was solved using of rapid prototyping parts (FDM technology). Easy assembly of plastic parts using epoxy glue creates suitable system for testing and measurements during development of this mechatronic system. On the base of testing of plastic generator the final function product of generator was designed on the based of FDM parts.

The final vibration power generator, shown in Fig. 4, operates as independent source of energy for wireless sensors. The FDM technology offers very shape difficult plastic frame of generator, where geometry correspond to functional features designed optimally to operating of the whole generator. The housing of generator and used electronics was designed and fabricated from ABS prototype too.

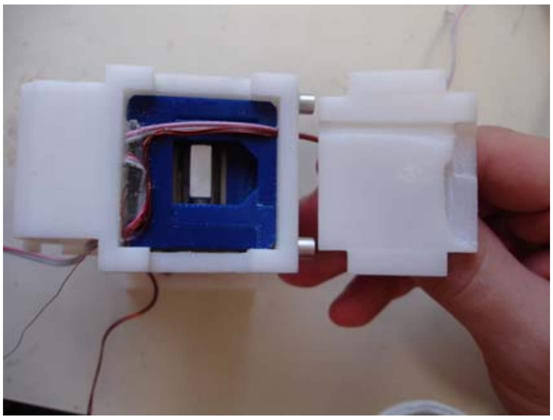


a) Non-assembled generator with coil

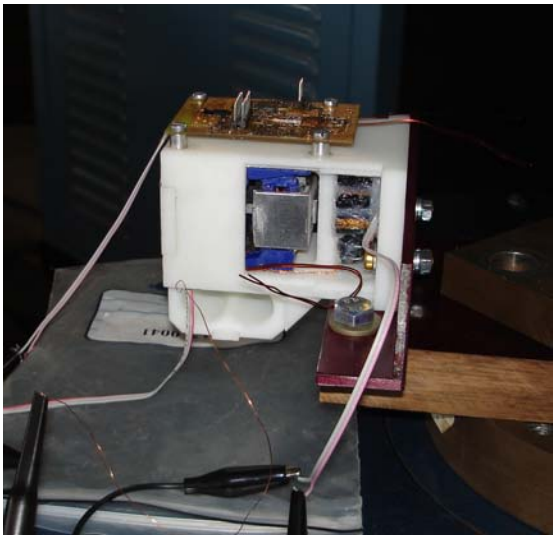
b) Plastic housing of generator and electronics

Fig. 4: Vibration power generator – plastic prototype

The Fig. 5 shows another application of generator with ABS housing. The shown housing includes generator, generator, electronics, wires, back up battery and wireless temperature sensor. This whole device operates as independent embedded sensor with own energy source in aeronautic applications developed in project WISE.



a) Assembly of Generator with electronics



b) Test of generator with electronics

Fig. 5: Vibration power generator with housing for wireless sensor in aeronautic applications

6. Application in Robotics and other Applications

The rapid prototyping methods are useful for fabrication of prototypes in other application. The FDM prototypes are mostly used for functional testing or as a final product in application as robotics. The paper (Driessen, et al., 1999) shows mobile rehabilitation robot with frame base on rapid prototyping mechanical parts. This research deals with rapid prototyping of all complex problems by using fast realization methods for different components in robotics (i.e. mechanical prototypes of parts and e.g. rapid prototyping of controllers etc.).

The publication (Ebert-Uphoff, et al., 2005) describes using of rapid prototyping for robotics applications. The kinematics pairs and bodies of robots can be fabricated with very difficult geometry by rapid prototyping methods from virtual CAD model of a robot. This plastic part provides fast, simple and inexpensive methods for the design and fabrication of prototypes of robotic mechanisms. Furthermore, physical prototypes can be used to validate geometric and kinematic properties such as mechanical interferences, transmission characteristics, singularities and workspace. Actuated prototypes have also been successfully built and controlled. Actuated mechanisms can be used in lightweight applications or for demonstration purposes. The main limitation in such cases is the compliance and limited strength of the plastic parts, which limits the forces and torques that can be produced.

Other very interesting applications of these methods are presented by (Růžička & Donát 2006) in biomechanics. These technologies contribute to the design process of implants, prostheses, splints or fixtures and medical equipment. Several technologies can be used for producing functional prototypes. These technologies can also be employed in surgery planning. At the present time medical imaging appliances are available to analyze the situation inside the patient's body non-invasively. Image data can be acquired by computer tomography, magnetic resonance imaging and ultrasound.

7. Conclusions

Rapid prototyping parts are suitable for fabrication of test or functional products and demonstrators used not only in mechatronic applications. These prototype parts can be used to development of robots, manipulators, actuators, control systems, etc. This technology is suitable and helpful for easier development of mechatronics systems with verification of system behavior.

Owing to this modern method of parts fabrication was developed vibration power generator very quick and cheap and plastic parts create whole immovable generator construction and housing of all additional components.

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