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FUSED DEPOSITION MODELING TECHNOLOGY FOR THE PRODUCTION COMPONENTS OF THE SUPER-EFFICIENT SHELL ECOMARATHON CAR

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Abstract - Fused Deposition Modeling rapid prototyping technology consists in applying a melt of thermoplastic material with the print head layer by layer until the complete physical object is created. With the decrease of the 3D printers' price, FDM was also used in the production of final products or spare parts. Thanks to the low price of 3D printers and print materials for this technology, it is currently the most widespread 3D printing technology in the world. This paper presents the application of FDM technology for part production of the super-efficient car Eco Arrow 3.0 which took part in the Shell Eco Marathon competition in the prototype class. The use of 3D printing technology to produce many elements of the car designed especially for its construction allowed to significantly reduce the cost and time of their implementation at the stage of prototypes and final models.

Keywords - 3D Printing, 3D Printing Costs, Fused Deposition Modeling, Additive Manufacturing, Shell Eco Marathon

I. INTRODUCTION

Fused Deposition Modeling (FDM) is one of the oldest 3D printing technologies, it was invented in 1988 by Scott Cramp who founded one of the most known companies in the 3D printing industry – Stratasys [1]. This rapid prototyping technology consists in applying a melt of thermoplastic material with the print head layer by layer until the complete physical object is created. Originally, due to the high prices of 3D printers, it was mainly used to manufacture prototypes in large industrial companies. At the beginning of the 21st century, with the expiration of key patents protection, much cheaper FDM printers began to appear on the market. With the decrease of the 3D printers' price, FDM was also used in the production of final products or spare parts. Thanks to the low price of 3D printers and print materials for this technology, it is currently the most widespread 3D printing technology in the world.

This paper presents the application of FDM technology for part production of the super-efficient car Eco Arrow 3.0 which took part in the Shell EcoMarathon competition in the prototype class. This car was built by Iron Warriors – a team of students from the Technical University of Lodz. A characteristic feature of this type of projects is necessity to fabricate single copies of many different parts. It often happens that after testing it is essential to introduce some modifications in the component and remake it. The time needed to complete the production of parts is also important. Printing real models yourself, self-owned 3D printer is much faster than ordering the parts at an external company. It can take several weeks to send the documentation of the designed part to receive the finished product. This is much too long, especially for prototypes that may need iterative improvements. Service at external companies also generates high costs. Self-made parts on 3D printer are much cheaper solution. Using your own printer in the case of FDM technology, the only cost is electricity and print material as thermoplastic-material wire wound on a roll [1, 2].

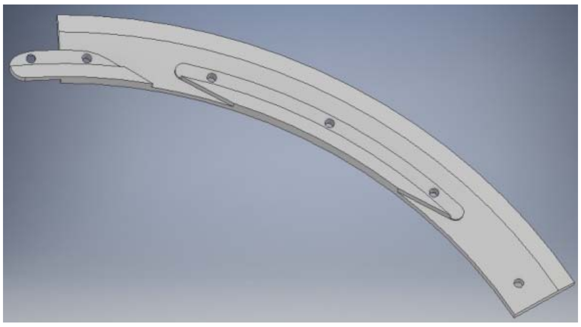
II. PRINTED MODELS

Designing models for fabricating on a 3D printer gives a lot of freedom in their shape. The 3D printer makes it also possible to cheaply produce parts that cannot be produced using traditional methods or very expensive in single copies. An additional advantage of FDM technology is the ability to choose the internal structure of the model. In cases where high mechanical strength is required, a high filling density can be used, and when it is not necessary, can be low and a much lighter element is obtained, what further reduces the cost and time of its production. The use of low density of the model fill gives the greatest savings in the case of large volume components. For very slim models, the weight reduction when printing the hollow part will be small, due to the fact that in such a model, the surface to volume ratio is large, and the external parts of the model are printed with full filling to a depth of 1-2 mm. The space in which the low-density fill is applied will be small.

Below we present examples of model parts with different characteristics and desirable properties that have been printed from one of the most popular materials used in FDM technology - ABS

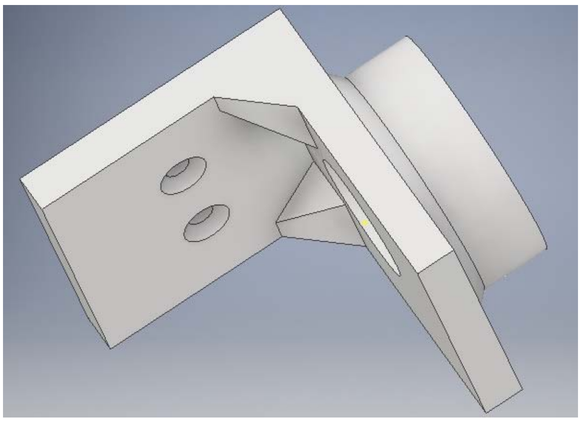
(Acrylonitrile butadiene styrene)[3]with the 3D Ultimaker 2 Extended 3D printer. They were used during the construction of a car competing in Shell EcoMarathon race. The winning aim is to achieve the least fuel consumption by a constructed vehicle.

2.1. Drive belt guard
The model shown in the Picture 1 is a part of the transmission system in the car. Six pairs of such elements connected with bolts protect against falling of the toothed drive belt from the receiving gearwheel. The modular design of the gearwheel with the use of printed parts enables cutting out a central part of the 40 cm in diameter sprocket with a flat sheet metal in 2D, which significantly reduces the cost of manufacturing such a large gearwheel. This model is characterized by very low thickness, so reducing the density of the filling does not significantly reduce the weight of the finished part. Due to the appearance of a large flat surface, this model has a large contact surface with the printer's work platform. The amount of necessary supports during printing was very small.



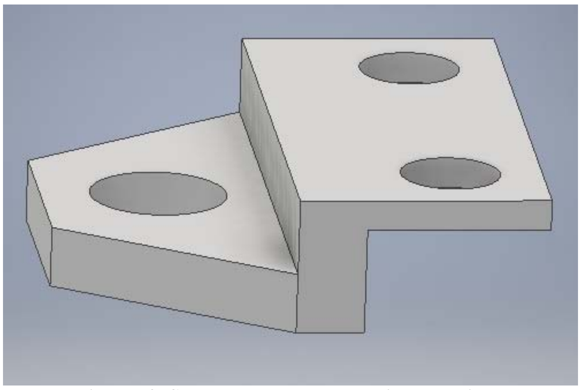
Picture 1. Drive belt guard design drawing.

2.2. Safety switch holder
In each car that competes in the Shell EcoMarathon competition, a safety switch must be placed to enable cut off power from the outside. Picture 2. present such a safety switch holder. This element has to have high mechanical strength due to its additional function: the top of the car’s body is partly based on it. Therefore, it has thick walls and struts, as well as it has been printed with a very high filling density.



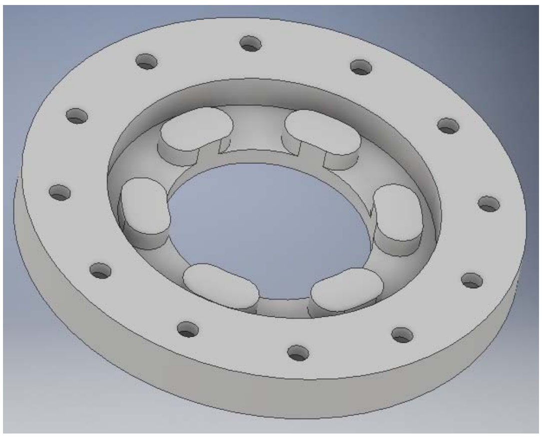
Picture 2. Safety switch holder design drawing.

2.3. Speed sensor holder
Model presented in the Picture 3 does not have to have high mechanical strength, but it has to maintain high rigidity, so that the sensor placed in it does not get vibrations which could disrupt its operation. It has been designed with relatively thick walls. However, it can be printed with a fairly low filling density that reduces its mass while not significantly reducing the rigidity of the part. This model has a simple geometry so it could be easily made using traditional methods, however, the use of 3D printing thanks to the low density of the model fill ensures lower mass of the finished part. The car has two such components with rotational speed sensors installed there to control the clutch that disconnects the rear wheel of the car when the engine in the vehicle is turned off and the car is rolling due to inertia.



Picture 3. Speed sensor holder design drawing.

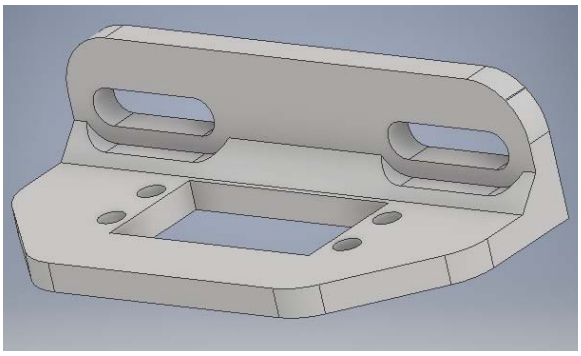
2.4. Magnet holder for speed sensor
The model shown in the Figure 4, similarly to the speed sensor holder, doesn’t have to have high mechanical strength, so it was printed with low filling density. Magnetic fields of the magnets mounted in it are received by the sensor placed in the speed sensor holder.



Picture 4. Magnet holder for speed sensor design drawing.

2.5. Servomotor holder
Servomotor holder presented in the picture 5 as the name suggests is used to mount servo in it, which is responsible for automatically disconnecting the drive

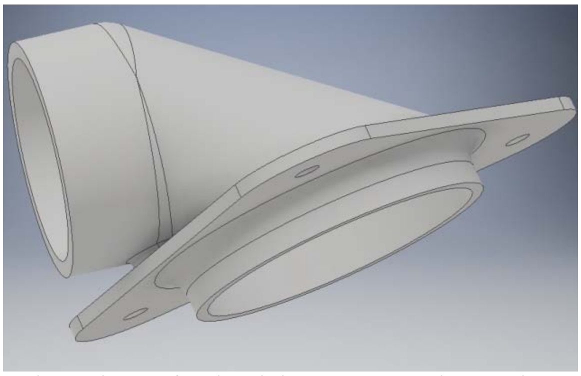
while the vehicle's engine is not turned on. This aims to reduce the rolling resistance of the car. This part must have high mechanical strength, so they have been printed with a high filling density.



Picture 5. Servomotor holder design drawing.

2.6. Part of engine air intake system

Model presented in the Picture 6 is a part of engine air intake system. An air filter is mounted in this part to protect the engine from dirt. A characteristic feature of this element are thin walls, similarly to the drive belt guard reducing the density of the model filling, does not achieve a significant mass reduction. Another important feature of this part is a complicated geometry. For this model to be printed correctly it is necessary to use a large amount of supports. It is important to keep the flow resistance in this part as small as possible. To achieve that it is necessary to use low layer height, which gives a better surface quality, but unfortunately significantly extends the printing time. Due to the complicated shape of the model, manufacturing it with traditional methods is much more expensive than using additive technology.



Picture 6. Part of engine air intake system design drawing.

2.6. Phone holder

The phone holder presented in the Picture 7 make possible to install the phone on the steering wheel as a speedometer and a counter helping the driver to control the travel time using a special mobile application. The grip with the phone is mounted on the steering wheel using magnets placed in the bottom part of the grip. It allows easily remove it from the car if necessary. This model was printed with a low filling density which allowed to significantly reduce mass of this part.

Picture 7. Phone holder design drawing.

III. COSTS, PRINTING TIME AND WEIGHT OF THE MODELS

Table 1 presents basic printing parameters for individual models. These values were selected to achieve optimal results depending on the desired characteristics of the part. The density value of the filling was set from 20% for mechanically unloaded parts up to 90% for parts that need to be durable. In case of printed parts with a low filling density, it was possible to achieve even more than 50% reduction in the weight of the printed part. Total weight reduction for all printed parts reached over 20% in comparison to parts made of solid ABS, and70% compared to parts made of aluminum. The height of the printed layer for the model with the desired surface quality was set at 0.1 mm, in the other models a 0.3 mm layer was used to achieve greater mechanical strength[4]. The use of a lower layer height of applied material results in a practically linear increase in printing time relative to the weight of the material used to print the model. The total printing time of all parts used for building a car sums up to almost 44 hours. The printing time of a single part depends on its size and set parameters. The shortest printing time of single part was about an hour, the maximum printing time was 12 hours. This is a time short enough that in the case of damage to any of the printed elements, the spare part is ready even on the same day. Using traditional methods this is in most cases impossible. Apart from the purchase price of a 3D printer and assuming self-service of the printer the total cost consists of the price of the material and electricity. The total cost of producing all of the presented parts was less than 15 USD. This price is many times lower than using traditional methods.

	Drive belt guard x12	Air intake part	Safety switch grip	Speed sensor holder x2	Magnet holder for speed sensor x2	Servomotor holder	Phone holder	Sum
Volume of the model [cm^3]	211	50	35	52	60	22	104	534
Infill density [%]	90	60	90	40	30	90	20	-
Layer height [mm]	0,2	0,1	0,3	0,3	0,3	0,3	0,3	-
Print time [min]	1212	716	134	139	160	77	185	2623
Model mass [g]	228	44	37	34	39	24	49	455
Used material [g]	230	76	42	43	40	25	50	506
Material cost [USD]	5,98	1,98	1,09	1,12	1,04	0,65	1,30	13,16
Electricity cost [USD]	0,61	0,36	0,07	0,07	0,08	0,04	0,09	1,31
Total cost [USD]	6,59	2,33	1,16	1,19	1,12	0,69	1,39	14,47

Table 1. Print parameters, parts features and costs

IV. CONCLUSIONS

All printed parts were mounted in the vehicle and successfully fulfilled their tasks while participating in the Shell EcoMarathon competition. ABS is a sufficiently durable material for many parts mounted in the Shell EcoMarathon vehicle. The use of 3D printing technology to produce many elements of the car designed especially for its construction allowed to significantly reduce the cost and time of their implementation at the stage of prototypes and final models. An additional advantage of using printed in 3D parts is their lower mass than parts made using traditional methods, thanks to which it was possible to reduce the weight of the car. An additional aspect that supports the use of additive technologies is the small amount of generated waste, which is beneficial for the natural environment.

REFERENCES

[1] Chee Kai Chua, Kah Fai Leong, Chu Sing Lim, Rapid Prototyping: Principles and Applications, ISBN: 978-981-277-897-0
[2] Ben Redwood, Filemon Schöffer, Brian Garret, The 3D Printing Handbook: Technologies, design and applications, ISBN:978-908-274-850-5
[3] www.sculpteo.com/en/glossary/abs-definition
[4] www.my3dmatter.com/influence-infill-layer-height-pattern/#more-95

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