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ASSESSMENT OF QUALITY AND COST OF MANUFACTURING AGRICULTURAL MACHINERY MADE BY FDM METHOD

Summary

The use of 3D printing technology allows to make simple machine parts including agricultural machinery in home conditions using FDM printers. Printing technology can be used to produce machine components that are subject to accelerated wear or variable strains that damage them. It is an alternative to parts made of plastics whose cost is significant and the availability is limited. The article presents an analysis of the quality of printed elements and the cost of their production from one of the most commonly used printing material which is ABS. The FENDT 412 Vario tractor engine cover latch assembly was analyzed. The results of the research indicate the possibility of using 3D printers for the production of agricultural machine parts in the home conditions. Elements with the required shape and strength were obtained at much lower production costs.

Key words*: agricultural machinery, 3D printing, quality, cost of manufacturing*

OCENA JAKOŚCI I KOSZTÓW WYTWORZENIA ELEMENTÓW MASZYN ROLNICZYCH WYKONANYCH METODĄ FDM

Streszczenie

Zastosowanie technologii druku 3D pozwala na wykonywanie prostych elementów maszyn, w tym również maszyn rolniczych w domowych warunkach, z wykorzystaniem drukarek FDM. Technologia drukowania może zostać wykorzystana do wytwarzania elementów maszyn, które ulegają przyspieszonemu zużyciu lub są narażone na zmienne naprężenia, powodujące ich uszkodzenie. Jest to alternatywa dla części wykonanych z tworzyw sztucznych, których koszt zakupu jest znaczny, a dostępność ograniczona. W artykule poddano analizie jakość wydrukowanych elementów oraz koszt ich wytworzenia z jednego z najczęściej wykorzystywanych podczas drukowania tworzyw, jakim jest ABS. Analizie poddano zespół zatrzasku pokrywy silnika ciągnika rolniczego FENDT 412 Vario. Wyniki badań wskazują na możliwość wykorzystania drukarek 3D do produkcji elementów maszyn rolniczych w warunkach gospodarstwa domowego. Uzyskano elementy o wymaganych kształtach i wytrzymałości, przy znacznie mniejszych kosztach produkcji.

Słowa kluczowe*: maszyny rolnicze, wydruk 3D, jakość, koszty produkcji*

1. Introduction

Agricultural working machines and their components are currently largely made of plastics. This is conditioned by the cost of production of such elements and the amount of agricultural vehicles or machines that are produced. Development of agricultural machinery results in the search for increasingly efficient and cheaper materials that can be used on an industrial scale. Complicated shapes of products and machine components are difficult to produce using traditional methods and very often the cost of production is high. Therefore the FDM method is used to model the prototype element, then perform it and examine according to specific procedures and assumptions. Due to the rapid wear of certain elements their availability is limited. Using 3D printers there is no need for a specific injection molds and a CAD program is enough to design and improve the current product. Current technology development allows easy and cheap access to the FDM method. During the harvest or growing season the workload particularly late into the night causes no time to wait for buy or deliver damaged machine parts. Each downtime of the machine causes economic losses. Therefore thanks to the Rapid Prototyping method a user of a given machine with knowledge of basic functions in CAD programs is able to perform a new element that will replace the damaged one. With standard table dimensions printers most components can be printed for quick machine repairs. The most popular method of 3D printing, the FDM method consists in melting the material from which the structure of the element is built [1]. There are also design solutions for printers with two heads. This is especially useful in case of complicated elements where it is necessary to make supports [2]. In such cases the material dissolved in water is used. Completed elements in 3D printing technology are subject to tests that are aimed at determining and comparing their properties in relation to elements produced by injection [6-8].

2. Preparation of elements for testing

The engine hood cover latch FENDT 412 Vario tractor was chosen as the test piece. It has a structure consisting of several elements made of plastic and metal elements such as:

- spring,
- pin,
- cotter pin.

The above mentioned metal elements, due to the lack of possibilities were not made of plastic on a 3D printer. The cover latch construction also consists of elements made of plastic:

- catch pawl lever
- catch pawl,

- catch pawl housing.

During the design of the catch pawl elements due to the complex shapes part of the geometry has been simplified. In the catch pawl the finger rounding has been removed so there will be no support during the manufacturing process - the printed element was of inferior quality. The empty spaces of the printout are also filled what increases the cost of the material. However, it shortens the printing time and in addition this operation prevents shape errors during printing.

3. Damage to the tested elements

The elements were dismantled from an agricultural tractor and after a thorough analysis significant wear of components cooperating with each other was found. In the element being the body of the construction damage from the catch is visible. The damage has the character of abrasion. The catch pawl also has numerous abrasions from the side of the catch pawl housing and from the side of the catch pawl lever. The engine cover catch pawl has the largest losses of material. The wear is caused by large vibrations transmitted by the engine to the elements of the tractor's body. The manufacturer probably did not predict these vibrations and their impact on plastic elements. The vibrations caused mutual friction of the surface of cooperating elements resulting in losses of the material. The formation of large losses often results in the need to replace components. Below in Fig. 1, Fig. 2 and Fig. 3 signs of wear have been presented which have individual elements of the engine cover catch pawl.

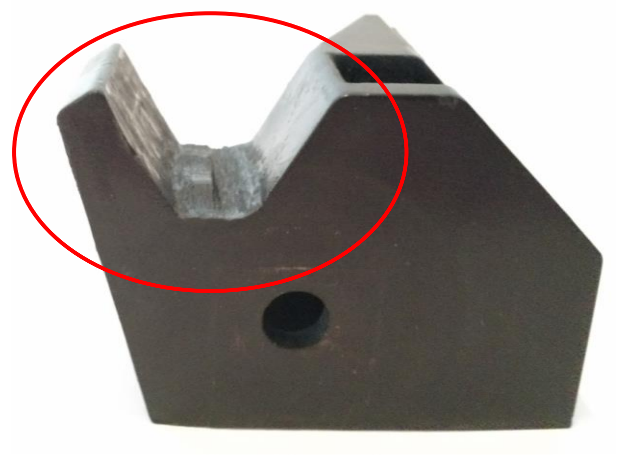

Fig. 1. Traces of wear of the engine cover latch - catch pawl housing [6]
Rys. 1. Ślady zużycia obudowy zatrzasku pokrywy silnika [6]

Fig. 2. Traces of wear of the engine cover latch - catch pawl lever [6]
Rys. 2. Ślady zużycia haczyka zatrzasku pokrywy silnika [6]

Fig. 3. Traces of wear of the engine cover latch - catch pawl [6]
Rys. 3. Ślady zużycia zatrzasku pokrywy silnika [6]

The catch pawl was made using the 3D printing method of ABS plastic from Makerbot while the body was printed from black ABS by DevilDesign. Below in Tab. 1 parameters of printing process were shown.

Table 1. Print parameters of engine cover latch elements
Tab. 1. Parametry wydruku elementów zatrzasku pokrywy silnika

	Catch pawl	Catch pawl housing	Catch pawl lever
Type of material	ABS	ABS	ABS
Manufacturer	Makerbot	DevilDesign	Rico3D
The temperature of the extruder [ºC]	240	245	240
The temperaturę of working table [ºC]	100	125	120
Fulfillment	90%	90%	100%
Layer thickness [mm]	0.25	0.25	0.2
Number of coatings	4	4	4

Source: own work / Źródło: praca własna

Analyzing the printed results it was found that the surface of the printed element converted to the STL file does not always reflect the model well. Printing elements have shape errors and visually diverge to a certain extent from those made by the manufacturer using the traditional method. The part is modeling focus on technological and not constructional reasons. It is caused by the complicated construction. Shape errors and manufacturing errors are shown in Fig. 4 and Fig. 5. The element should be designed in terms of use not visual. The visual condition of the received elements will always be different from the original parts.

Fig. 4. Shape error of the engine cover latch - catch pawl lever [7]
Rys. 4. Błąd kształtu otworu zapadki zatrzasku pokrywy silnika [7]

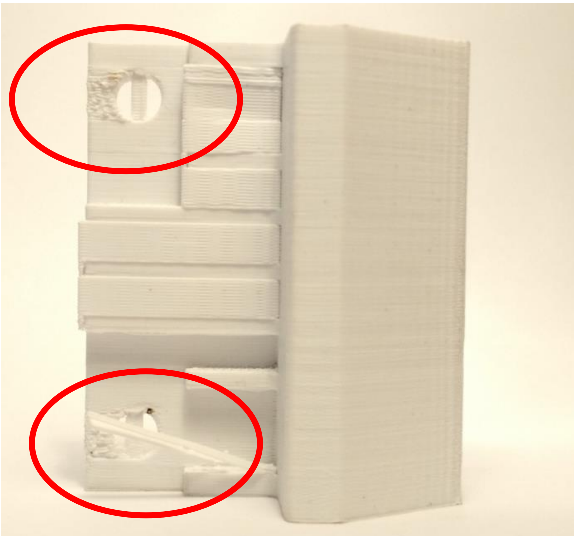

Fig. 5. Shape errors created during printing process [7]
Rys. 5. Błędy kształtu powstałe podczas wydruku [7]

After mounting the necessary elements that were not printed (spring, pin, cotter pin) a finished product resembling the original working element was obtained. It was necessary to remove the material oversupply and supports. The printed element was made only with DevilDesign black ABS. During printing process an unexpected errors occurred that did not take place in the case of previous printing of the remaining parts. These errors include:
- drawing the surface at a certain height,
- unplanned head stop due to poor g-code processing during printing.

Drawing errors were probably caused by material thickness errors that were not included in the computer program. This indicates that this technology is not adapted to the home conditions. It should be also stated that in order to properly use a 3D printer operator needs a basic knowledge of rapid-prototyping. Fig. 6 shows the comparison of the element made with the 3D printing method and the original element.

a)

b)

Fig. 6. FENDT 412 Vario tractor engine cover latch element: a) made by 3D printing, b) element originally made by the manufacturer [7]
Rys. 6. Element zatrzasku pokrywy komory silnika ciągnika rolniczego FENDT 412 Vario: a) wydruk 3D, b) element oryginalnie wykonany przez producenta [7]

4. Economic analysis

Execution of machine parts at home by the FDM printing method allows for quick and independent printing of a part regardless of its availability at points of sale. However it is necessary to analyze the cost of producing such an element and compare it to the price of the print service and to the purchase price of the finished product. Therefore the following assumptions were made during the cost analysis:
- cost of ABS filament from DevilDesing for 79.90 PLN for 1 kg [3],
- the cost of energy is 0.60 PLN for 1 kWh in the G11 tariff [4],
- the time and amount of used filament was taken from the MakerBot Deskop program,
- CAD software has been downloaded for testing purposes from the Internet,
- MakerBot Replicator 2X has been downloaded from the manufacturer's website.

During the analysis the cost of purchase of the printer was omitted (the price of the used printer is about 15.000 PLN [5]).

Based on the carried out analysis in accordance with the above assumptions it was found that the cost of self-printing at home is 5 times less in relation to the purchase of parts in the warehouse. In addition the cost is from 4 to 16 times lower than the order of the element to the company dealing in 3D printing services. Below in Tab. 2 a set of costs of manufacturing the engine compartment cover latch elements for the three variants described has been presented.

5. Conclusion

Analyzing the available technological solutions of 3D printing it can be stated that it is a useful method in the production of simple agricultural elements and elements for other heavy machinery. The increasing availability and decreasing prices of 3D printers using the FDM method allow for their purchase and independent production of simple machine elements. Free programs are enough to support such devices. However the operator must have a basic knowledge of printing technology and CAD programs to design and print the parts well. When analyzing the costs of printing and purchasing a new element it should be stated that the cost of printing compared to the purchase of new parts is several times lower. 3D geometry and structure errors can be overcome by using higher quality printers or by controlling the printing process. Nevertheless in the next stage of research, 3D printing elements of machine and device as well as strength and durability of such elements in operating conditions should be tested.

Table 2. Analysis of manufacturing costs of engine cover latch elements [7]
Tab. 2. Analiza kosztów wytworzenia elementów zatrzasku pokrywy silnika [7]

Element of cover latch	Method of implementation	The cost of the material [PLN]	The cost of energy [PLN]	Total cost [PLN]
Catch pawl lever	Purchase in the warehouse	-	-	29.00
	Print service	-	-	14.00-26.00
	Self-printing	1.92	0.47	2.54
Catch pawl	Purchase in the warehouse	-	-	30.00
	Print service	-	-	14.00-30.00
	Self-printing	3.60	0.94	4.68
Catch pawl housing	Purchase in the warehouse	-	-	35.00
	Print service	-	-	23.00-50.00
	Self-printing	3.36	0.89	4.39

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