EVALUATION OF ACCURACY AND USEFULLNES OF OPTICAL ENCODER MADE WITH 3D PRINTER

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Abstract

Rapid Prototyping Techniques allow to put an idea into reality in very short time. 3D printers are one of Rapid Prototyping Techniques, which have gained large popularity. Devices differ among themselves in construction and in the materials used for printing, so errors can be caused in each case by different elements and systems. Therefore question arises: it is possible to manufacture precision elements such as encoders scales etc. using 3d printers? This paper presents an attempt to apply methods of rapid prototyping in the field of precise metrology, on the example of the optical encoder made using 3d printer.

Keywords

3D printer, FDM, encoder, metrology, stepper motor, Rapid Prototyping

1. Introduction

Rapid Prototyping Techniques allow to put an idea into reality in very short time. They are successfully used in many areas of life, from museology to medicine [1,2,3]. They are also slowly gaining importance in the industries where they can be utilize in preparation of assembly elements or free-formed machine's bodies. The undeniable advantages of rapid prototyping techniques include: reduction of object development time and manufacturing costs. 3D printers are one of Rapid Prototyping Techniques, which have gained large popularity. It is probably due to fact that such a printers can be successfully constructed even in a home by amateurs. Elements used in 3d printers assembly are simply and cheap. Motors and mainboard are among the most important ones. Motherboards are slightly different as to the price, there are also models with dedicated software. At the other hand, at least four motors are needed to construct fully functional 3d printer, what may be associated with a higher expenses. At the moment, the entire 3D printer can be constructed for more or less one thousand dollars, but prices still tend to fall. Obviously the price, and above all, the construction of the 3d printer will be different depending on chosen printing method. These methods differ in materials which are used and layering method. Some methods melt material when another cure liquid. In case of printers made in home conditions, probably the most popular is the Fused Filament Fabrication method. But despite 3d printers popularity, it is still problematic to evaluate their accuracy. Devices differ among themselves in construction and in the materials used for printing, so errors can be caused in each case by different elements and systems. Therefore, it is hard to propose an uniform methodology which can be apply to all solutions. Laboratory of Coordinate Metrology at Cracow University of Technology proposed to use “test by work” method in order to ensure correct operation of 3D printers [4]. This method verifies the machine resultant accuracy. Obtained results suggest that precise measuring tools like Articulated Arm Coordinate Measuring Machines or Laser Tracker should be used during construction of 3d printer in order to achieve increased accuracy. 3d printer that fulfils these assumptions was developed at LCM. This paper presents an attempt to apply methods of rapid prototyping in the field of precise metrology, on the example of the optical encoder made using 3d printer.

2. The encoders

Generally, the encoders are devices that converts one form of signal to another. In metrology encoders are widely used in order to measure displacement or rotation of elements. Encoders can be divided into two groups: rotary encoders and linear encoders. First group is dedicated to angle measurements, while second directly measure linear displacement. Both groups can be also subdivided into incremental and absolute ones. The incremental encoders needed a zeroing every time the power is removed from the system, as they give information about displacement in relation to the start position. In turn, absolute encoders retain information about current position even when power is switched off, as the every position is determined unambiguously. So it can be said that the output of absolute encoders is current position, while an output of incremental one are impulses. These impulses are count by microprocessor and they can be used to calculate such parameters as element speed, distance or position. Of course encoders differ in construction and used phenomena. Most rotary optical encoders utilize a code disk made of plastic or glass. Another crucial elements are light source and photodetector. In such solution pulses are produced when the light beam is disturbed by code disk. A photodiode, generates current, when photons are absorbed. Thus each beam interruption causes the change of photodetector state. The working principle of discussed solution is showed at Figure 1.

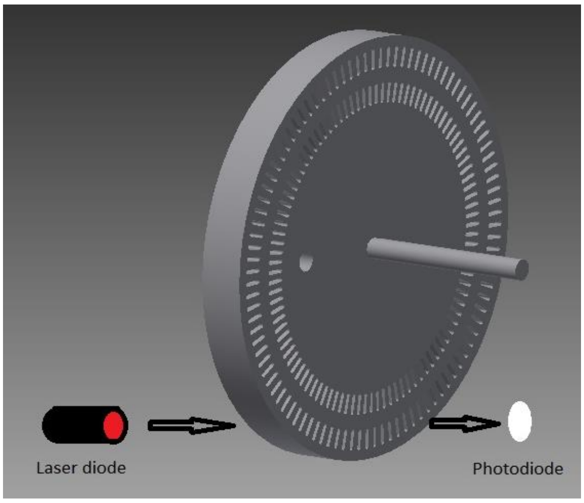

Fig 1: Incremental encoder working principle

3. 3d printers

3D printing is a process of creating three dimensional objects from a CAD file. Variety of materials can be used in 3d printing, however the most popular are different types of plastics. A real 3D object is obtained using additive processes. In such a process an object is created by successive addition of a material layers, one by one until whole model is finished. Of course before printing can be started, the 3d model of printed object have to be prepared using CAD software. Object can be designed from scratch by the designer, although, there is also the possibility of using 3D scanning technology in order to prepare a virtual representation of existing object. The CAD model should be then saved in one of the universal formats for 3d modeling, for instance the STL format. The object surface in STL format is a triangular mesh, based on the coordinates of apexes and the normal vector for each triangle. For more complex shapes such a method entails inaccuracies, which depend on the mesh density. After the model is developed it has to be transformed into form understandable for 3d printer driver. In most cases that means the model need to be cut to thin slices. As the printing cost is largely determined by the process duration, usually the smallest dimension designates the model z axis. This results in a smaller number of layers. Some objects of complex shape, requires special supports, which for example protects the object from collapsing. Special programs are used for slicing the object for example Slic3r or Kisslicer. They translate each layer as a sequence of machine movements. Typically, they utilize G Code which is numerical control (NC) programming language. Normally the printed objects require some additional finishing. These operations are aimed at improving the object appearance, cleaning surface and reducing roughness. Surfaces can also be varnished or painted [4]. Printing process itself may be carried out using various techniques, such as: Stereolithography (SLA), Laminated Object Manufacturing (LOM), Selective Laser Sintering (SLS), Three Dimensional Printing (3DP), Fused Filament Fabrication (FFF). The 3d printer constructed at LCM utilizes the last of mentioned methods so only this technique will be further explained. In FFF the object is created by successive application of layers of semi-solid, thermoplastic material on the heated machine's table. The material is fed by the head equipped with nozzle. This extrusion nozzle temperature has a crucial role in printing process, as well as cooling condition in which object congeals. Probably most common material used in FFF is the acrylonitrile butadiene styrene (ABS). This material is obtained by polymerization of butadiene and copolymerization of acrylonitrile with styrene. Models made from ABS are characterized by high durability and chemical and thermal resistance. This material is used for example in LEGO bricks production. The FFF may achieve accuracy of 0.13 - 0.18 mm, while the thickness of layers can differ between 0,05 mm to 0,8 mm.

4. Experiment and results

3D printer built at LCM has unusual structure (Figure 3). It was designed as a machine with movable table, so it has large working space that equals to 500 x 500 x 400 mm.

The printer design was modified for the entire period of its construction so as to minimized the various errors, which were affecting to the accuracy.

Since the first version of the machine some components have been changed for example the feed in x-axis of the machine which in the initial version was realized by the moving portal. However this concept, was fraught with a certain inaccuracy, caused by vibrations affecting the accuracy of the manufactured elements. The drivers and motors with a better resolution were used. A styrofoam casing shown in the picture (Figure 2) has been added which ensures better stabilization of thermal conditions during the printing.

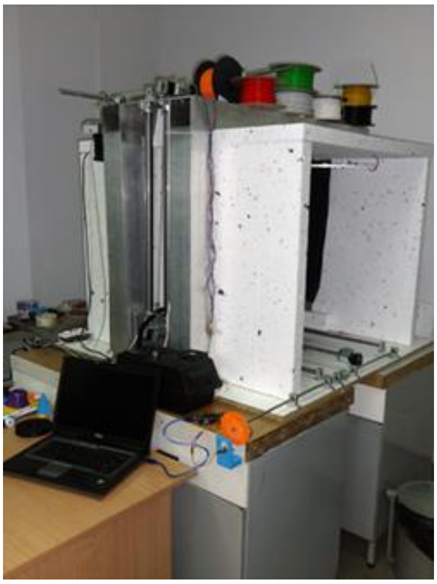

Fig 2: Overview of 3D printer built at LCM

This machine was used to print the special plastic code disc which is the main part of optical encoder. For the research purposes, the plastic disc with 200 points per revolution was designed and developed. The figure 3 shows the drawing of the plastic disc.

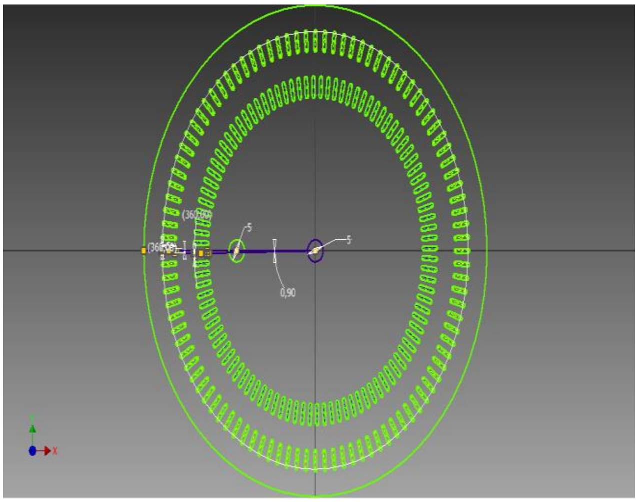

Fig 3: Drawing of encoder code disc

After plastic disc was designed, the object was printed. The process took about 4 hours. The parameters of the printer was as follows:

- 0,35 mm nozzle diameter
- 0,15 mm layer height
- 25 % infill
- 100 degrees table temperature
- 255 degrees nozzle temperature
- Aprox. 30mm/s printing speed

The next step was to connect printed disc with 3D printer ,assembly and adjust electronic elements. The Arduino Mega microcontroller board was used in described experiment. As the photodetector, the BPW 34 photodiode was chosen.
The figure 4 presents all components after assembly.

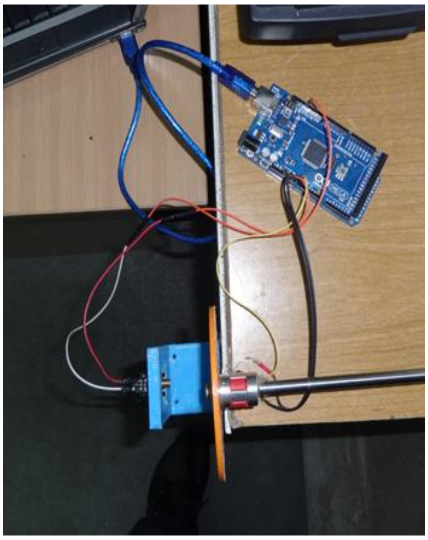

Fig 4: Assembly of encoder mechanism with printer

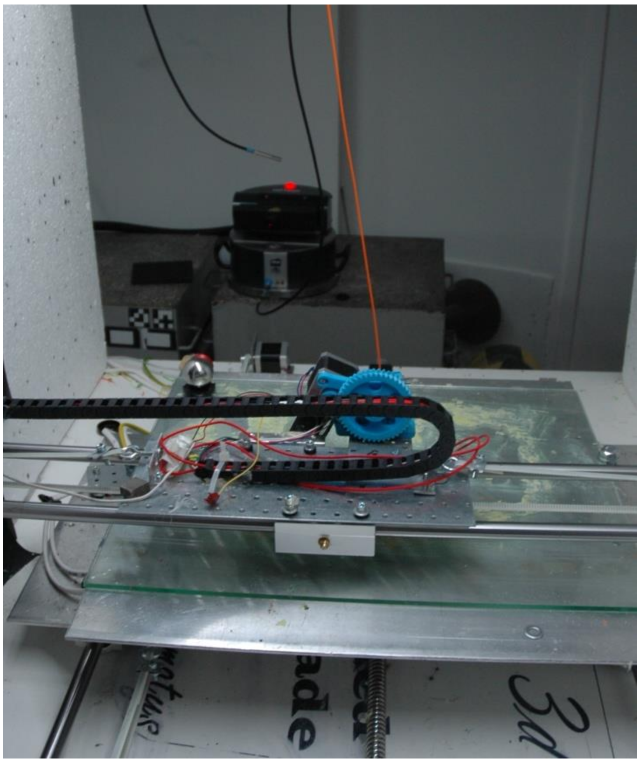

Fig 5: Checking the printer x axis with Laser Tracer

The first part of the study involved examining the maximum speed for which the encoder works correctly. For this purpose four motor speeds have been selected: 200, 300, 600, 800 rpm. The special program was used, in order to control the engine so that the appropriate number of steps were performed. The number of steps was 10,000 in all cases. As shown in the following table, encoder worked stable to a speed of 600 rpm. Above this speed, the number of registered pulses were different, it means that the encoder was given wrong results.

Table 1 Pulses obtained for different set speed (200, 300, 600, 800 rpm)

Measurement sequence	Number of pulses			
1	200	300	600	742
2	200	300	600	513
3	200	300	600	675

The second part of the study was conducted to check the accuracy of positioning of the x-axis by the test encoder (Figure 5). For this purpose, Laser Tracer was used. This system is successfully used in this type of studies performed on Coordinate Measuring Machines. This system gives the distance from the retro-reflector to laser interferometer. with an high accuracy. This accuracy is achieved thanks to this that during measurements the angular encoders were used only to determine the position of the device. Therefore before measurement of the axis, there was necessary to accurately set the laser tracer. During experiment a SMR (spherically Mounted Reflector) of 1.5 inches was used, mounted on a table in close distance to toothed belt. The experiment consisted of five times measurement of five distances. Each distance was measured from the starting (zero) point. For each distance the highest values were selected from the average value and standard deviation. The repeatability of the drive member of the x-axis was determined and it was less than 0.03 mm. To determine the accuracy of the encoder axis feed system driven by a stepper motor with belt drive, the following strategy was used. Five sequences of the measurement were used. Each sequence has begun from set the motor and encoder to zero position, showed on (Figure 4). Before starting the actual displacement, the distance from Laser Tracer to retro-reflector was read. Then, the engine performed specified motion and stopped for 5 seconds. At that time, the number of encoder pulses were counted. In this way five distance were measured after which the entire procedure was repeated.

Table 2 Results obtained during experiment

	Distance from interferometer, mm				
Tested positions					
1	100,032	100,032	100,032	100,030	100,039
2	200,080	200,074	200,082	200,080	200,084
3	300,016	300,021	300,022	300,022	300,022
4	399,920	399,916	399,901	399,920	399,928
5	499,938	499,934	499,940	499,941	499,931

	Number of steps from encoder				
Tested positions					
1	440	440	440	440	440
2	880	880	880	880	880
3	1320	1320	1320	1320	1320
4	1759	1759	1759	1759	1759
5	2199	2199	2199	2199	2199

6. Conclusions

The obtained data show that the encoder works correctly only under certain conditions. The maximum speed of the encoder has been set at 600 rev / min. Above this speed readings are becomes incorrect. This value for most low-cost stepper motors is sufficient. However, in terms of the pose accuracy, this device works well. The printed disc, had 200 slots what gives approx. 0.2 mm per step. The data presented in the Tables shows the repeatability of the encoder is correct. In order to apply this encoder in a 3D printer, this device should be printed with more slots per revolution because the current encoder resolution is too low to improve print quality. To fulfil this requirement the diameter of the disk should be increased so that the printer will be able to print such an element with sufficient accuracy.

7. References

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