Study behavior of Geneva mechanism using 3D printing technology

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Abstract. The authors developed a study for behaviour of Geneva mechanism considering different materials and technologies. Generally, there are three basic types of Geneva motion mechanisms named external, internal and spherical. In this paper the authors considered external Geneva mechanism. The design and machining of a conventional Geneva mechanism are generally well known, but there are some particularities, if we consider 3D printing technologies. Conventional, Geneva mechanisms are used to low-speed applications, or to those in which noise and vibration are of no importance. Using PLA+Copper or ABS materials noise and vibrations are reduced considerably. Also, the entire mechanism has a reduced weight. There were considered different fill factors for 3D printed parts. The experimental setup allows fast changing of mechanism parts. This research aims the study of behaviour of 3D Printed machine elements like: springs, bearings, clutches gears, bellows, diaphragms, bushes, brakes, sliders, etc developed by authors.

1. Introduction
There is well known that indexing mechanisms are of great practical importance in many applications, including weaving looms, precision measurement instruments, automated packaging and printing machinery, film movie projectors and movie cameras. One of the most common forms of indexing mechanism is the Geneva mechanism or Maltese cross mechanism. The design and machining of a conventional Geneva mechanism is generally straightforward since its structure consists primarily of no more than a driving crank and a wheel with straight slots which is Maltese Cross. However, in such mechanisms, a significant impact load is produced at the initial and final stages of the indexing operation as the roller enters and exits the slot, respectively. Consequently, conventional Geneva mechanisms are confined to low-speed applications, or to those in which noise and vibration are of no importance.

The authors developed a study for behaviour of Geneva mechanism considering different materials and technology. The design and machining of a conventional Geneva mechanism are generally well known but there are some particularities if we consider 3D printing technologies.

2. Geneva mechanism
The authors developed five Geneva mechanisms manufactured with different technologies. These mechanisms consist of five Maltese crosses, with the same dimensions, and five driving cranks with pins. There were considered five different materials as it follows:
1. Plexiglas. Plexiglas is a type of acrylic and someone will often find the two words (plexiglass and
acrylic) to be interchangeable;
2. PLA. Poly (lactic acid) or polylactic acid or polylactide;
3. ABS. Acrylonitrile Butadiene Styrene;
4. PLA + Copper;
5. PLA + Bronze.

The Geneva mechanism translates continuous motion to intermittent motion through the driving wheel whose crank pin is shown in figure 1. It drives the Geneva wheel as it slides into and out of the slot of the Geneva wheel. It thus advances it - one step at a time when engaged. The driver wheel usually consists of both the crank and a raised circular blocking disk that locks the Geneva wheel in position between steps to avoid excessive vibration while rotating. The driver angle of the pin is labelled with $\varphi_1$ and the driven angle of the Maltese Cross is labelled with $\varphi_2$. Using notations from figure 1 the relation between angles $\varphi_2$ and $\varphi_1$ is:

$$\tan \varphi_2 = \frac{R_1 \cdot \sin \varphi_1}{L - R_1 \cdot \cos \varphi_1} = \frac{\lambda \sin \varphi_1}{1 - \lambda \cos \varphi_1}$$

(1)

where

$$\lambda = \frac{R_1}{L} = \sin \varphi_2 = \sin \frac{\pi}{z}$$

(2)

$z$ = number of slots from Maltese cross.

Figure 1. Geneva mechanism

All five crosses, from experimental setups, have six slots, but a theoretical study was developed using Matlab environment. There were considered different Geneva mechanisms with $z = 3, 4$ and 6 slots. The driven angle $\varphi_2$ which represents the rotation of Maltese cross is represented in figure 2, depending on driver angle $\varphi_1$ which represents the rotation of driver crank. For example, the driver angle, $\varphi_1 = 2160^\circ$ for Geneva mechanism with 6 slots and $\varphi_1 = 1080^\circ$ for Geneva mechanism with 3 slots. Using Matlab function, diff, one can calculate the relative angular speed, $\omega_2 / \omega_1$, if there is assumed that $\omega_1 = d(\varphi_1)/d(t)$ and $\omega_2 = d(\varphi_2)/d(t)$. This is a numerical derivation and the results are presented in figure 2, considering the same number of slots, $z = 3, 4$ and 6, for different Geneva mechanisms.
3. Experimental setups

The authors developed experimental setups in order to determine cinematic parameters of Geneva mechanisms. There were designed five Geneva mechanisms. Considering only weight of cross and crank slider (neglecting shafts, bearings) the weights are presented in table 1.

| Material          | Weight [g] |
|-------------------|------------|
| Plexiglas         | 55         |
| PLA               | 33         |
| ABS               | 27         |
| PLA + Copper      | 68         |
| PLA + Bronze      | 65         |

In order to determine the time between two successive slots the authors uses reflective sensors. In figure 3 is presented the operating mode of a reflective sensor. When the slot of the Maltese cross is in front of the reflective sensor the reflected beam is interrupted. Then, the cross is rotating with an angle of 60°. The cross passes in front of the reflective sensor and the time is recorded until the next (successive) slot is reached. When the cross is in front of the reflective sensor the beam is reflected.

There are six time data to be recorded for one cross rotation. These data are stored in an excel file and then read with a Matlab script file [2].

![Figure 3. Operating principles of optical sensors](image-url)
4. Experimental results

The experimental test includes different angular rotation speeds for driver crank. There were used: \( \omega_1 = 24 \text{ rpm} \) and also \( \omega_1' = 66 \text{ rpm} \). These speeds allow studying the cinematic and dynamic behaviour of Geneva mechanisms.

Thermoplastic extrusion technology begins like other rapid prototyping processes by designing the virtual image of the future object in a 3D editor or CAD program. In the case of this study, the three-dimensional model that was based was a Geneva mechanism. When 3D modelling is completed, the resulting file is transferred to .stl format, which is recognized by most modern 3D printers. The STL file with future restoration is processed by a special slicing program, which translates it into a control code G for the FDM printer. The slicing program with which the file was processed is ReplicatorG.

3D printing technology is a well-planned and ready process for turning virtual models into physical objects. The steps of FDM technology are shown in the Fig.4. The most important elements of the 3D printer are the work platform and the printhead. The finished workpiece is formed on the work platform. During operation, the platform moves up and down the Z axis. The printhead extrudes a melted polymer thread onto the work platform layer after layer forming the finished structure. The printhead of the 3D printer moves horizontally and vertically (X, Y axis). The process of 3D printing itself is quite simple. The print head extrudes the first layer of molten material into the work area, after which the platform is lowered to the thickness of the layer, and the next overlapping layer begins to form.

After completion of the process, the sacrificial layers are removed and result the final pieces [3]. In figure 6 are two of experimental setups with Geneva mechanisms: with PLA material (left) and Plexiglas material (right). These experimental setups are connected to PC through a USB interface.
In figure 7 are represented all five setups at it follows: a) Plexiglas (PMMA), b) PLA, c) ABS, d) PLA + copper and e) PLA + bronze.

**Figure 6.** Experimental setups PLA (left) and PLEXI (right)

**Figure 7.** Geneva mechanisms from different material:

a) PMMA b) PLA c) ABS d) PLA+copper e) PLA+bronze

**Figure 8.** Geneva mechanism characteristic in function of rotation angle (24 rpm and 66 rpm)
5. Conclusions
In this paper a Geneva mechanism was studied and successfully realized with the help of additive technologies from five different materials. The models obtained are used as demonstration stands used in didactic applications. Of the five investigated materials, ABS and PLA + Copper have been proved to have properties and characteristics close to mechanical engineering applications and these results are demonstrated by graphs. ABS also has the advantage of lighter weight, which makes it suitable for applications where low mass is needed. It can also be concluded that the angular speed of the drive element is inversely proportional to the difference between the angular speeds of the Malta crosses.

The latest years have brought spectacular developments to these new 3D printing technologies, which makes it possible today to find a wide variety of products manufactured by these new technologies and many in development, making them more and more competitive in wider areas.

Applications of AM technologies in this area are gaining more and more importance. Challenges are related to finding and approving new materials that can be put into desirable physical forms with the most appropriate mechanical, increasing dimensional precision and surface quality, making parts from different materials with a functional gradient.

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Acknowledgments
This work has been funded by University POLITEHNICA of Bucharest, through the “Excellence Research Grants”, Program UPB-GEX 2017. Identify: UPB-GEX2017, Grant no. 48/25.09.2017, ME 14-17-05, ID98.