ADDITIVE TECHNOLOGIES AND MATERIALS FOR REALIZATION OF ELASTIC ELEMENTS

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Abstract: The paper presents a method of realization of representative types of elastic elements by means of additive technologies with the presentation of the main functional characteristics based on solid material deposition, FDM(Fused Deposition Modelling) technology, as well as the presentation of the main characteristics of the material used (PLA), highlighting domains and specific applications. Experimental results were obtained on a Hans Schmidt demonstration stand by comparing the deflections of various types of helical springs with circular, square and rectangular cross section.

Keywords: Additive Technologies, 3D Printing Materials, Elastic Elements.

1. Introduction

Characterized by a wide spread across all compartments of mechanical engineering and mechatronics, in which many functional purposes are met, helical elastic elements have the advantages of occupying a reduced space in the assemblies in which they are integrated and achieving a relatively constant effect of force at a bigger stroke. Typically known as helical springs, they are made of wires or rods of different sections: circular, rectangular, square, trapezoidal, elliptical and annular, wrapped by a helix on a guide surface. Depending on the shape of the surface of the helix winding body, the helical springs may be cylindrical, conical, parabolic, hyperboloidal [1,10].

The most common are cylindrical helical springs because of their manufacturing easiness. After the action force direction springs may be divided in: tension springs or compression springs. As regards the wire section this can be: a circular (most common), rectangular or square. The helical coiled spring load is mainly to the torsion but there is also a bending load, which may be disregarded if the wire angle α, it is small enough to α ≈ (6° to 9°). In the picture from Figure1. is presented a helical coiled spring subjected to tension load and spring with coils carried out.

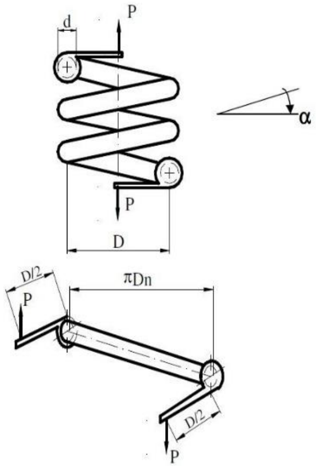


Figure 1. Helical springs with tensile load

The acting force is labelled with P, the diameter of the spring wire with d, the number of wire turns is labelled with n and d is the medium diameter of the helical spring. In the case that angle α should be considered, there are two moments which load the helical coiled spring: a moment of torsion or torque - Mt, and a bending moment Mb. .:

$$M_t = \frac{P \cdot D}{2} \cdot \cos\alpha \qquad (1)$$

$$M_b = \frac{P \cdot D}{2} \cdot \sin\alpha \qquad (2)$$

One can observe that when α = 0 then the torque Mt = P·D/2 [1]

2. Materials and Fabrication Methods

The emergence of additive technologies in the early 1990s was a milestone in research and technology development. The new additive manufacturing (AM) technologies are the result of intense research and progress in various areas: from fine mechanics to numerical controls, from laser technology to three-dimensional modeling packs, from IT to material science. Rapid Prototyping technologies allow a great flexibility in application, an advantage to exploit micro components with a good dimensional precision used as conceptual model/functional prototypes or indirectly used as master models for the production of flexible tools for the manufacture of metallic or non-metallic parts in individual or small series production.

In recent years, a large number of innovative (Rapid Prototyping) technologies have been developed to transform the concept of achieving a complex product into a solid replica in a short period of time [2, 3]. Generally, these systems are a new class of virtual physical realization technologies using a family of special equipment. They provide the addition or bonding of material in successive sections as much as needed and where it is necessary. One of these additive technologies is FDM (Fused Deposition Modeling), a process based on the extrusion of material using a thread of different material qualities (polyamide, nylon, wax), which it heats up to a temperature a few degrees below the melting temperature, then reduces its diameter to 0.12-0.15 mm by extruding it into a depositing device, a device moving in the XOY plane to materialize a section of the 3D virtual model. The key of the process is to rigorous control the temperature at which the material is heated and maintained during the deposition [2].

The design step in the CATIA V5 software environment involves the execution of CAD models for the three types of helical springs with circular, square and rectangular cross section for all characteristic elements, namely helical arc height h = 50 mm, step p = 10 mm, Counterclockwise orientation , the Helix Curve Definition generation tool in the menu [4, 5].

Starting Point: Sketch.1
Axis: Axis System.1\Z Axis
Type
Pitch: 10mm
Revolutions: 1
Height: 50mm
Orientation: Counterclockwise
Starting Angle: 0deg
Radius variation
● Taper Angle: 0deg Way: Inward
○ Profile: No selection

Figure 2. Left – Generating of 3D model; Right – Generating of helical springs in CATIA with option Helix Curve Definition

A set of helical springs having a circular cross section of 4 and 8 mm diameter, rectangular section 4 x 2 mm and 4 x 8 mm and a square section with sides of 4 and 6 mm were realized.

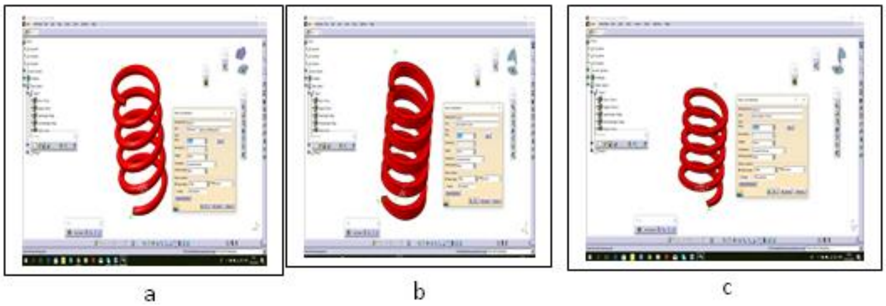


Figure 3. Construction of the three types of helical springs: a - circular section; b- square section; c - rectangular section

The manufacturing process using the FDM system comprises three main stages, namely the preprocessing stage, the proper construction stage of the part and the postprocessing step. During the preprocessing stage the CAD model of the piece in .stl format is loaded, fig. 4, designed in the CATIA V5 design environment in the QuickSlice specialized program - a program that generates the command code where the CAD model orientation in the work area of the depositing installation takes place so that the construction of the piece is optimal in terms of time work and material consumption.

After the orientation of the CAD model, its sectioning is carried out with planes parallel to the plane of the machine (horizontal planes), operation resulting in several sets of level curves called perimeters. The sectional section along the Z axis is 0.2 mm is selected according to the diameter of the extrusion nozzle diameter, in the case presented in the article the diameter of the extrusion nozzles is 0.4 mm. The QuickSlice program [8] generates the paths the extruder needs to follow in order to materialize a section of the piece, Fig.5. corresponding to the printer model and the Cura software used [7].

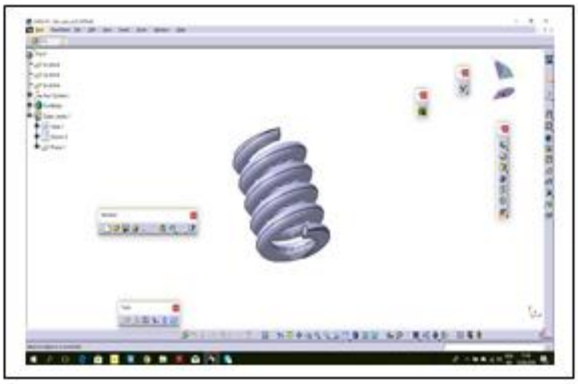


Figure 4. The CAD model of the circular cross sectional helical spring saved in stl format

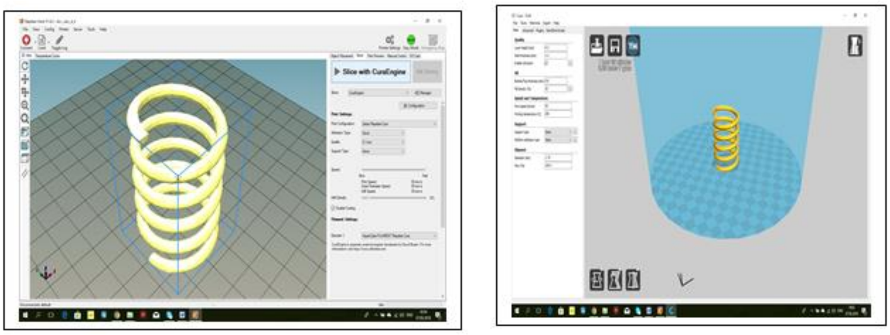


Figure 5. Generate trajectories with QuickSlice and Cura software command interface of 3D Delta printing machine

In the stage of construction of the piece, the layer with the layer is realized, the extrusion head of the machine deposits a thin thread of construction material along the curves defining the perimeter of the section and after the materialization of the perimeters, the deposition of the construction material takes place in the areas corresponds to the full areas of the piece, after the entire section is fully materialized, the platform descends with a step equal to the section of the virtual model and the entire process resumes for a new section until the last section of the virtual model of the piece is materialized, fig. 6.

Delta FFF (Fused Filament Fabrication) printer has the following technical characteristics (Tabel 1) and due to the drive mechanism, the inertial forces are deviated 45 degrees vertically and then discharged to pillars vertically.

Thanks to this system and due to optimization of the software, the vibrations of the Delta printer are extremely small, the resonance is virtually non-existent and it can increase the speed by up to 4-5 times more than the classic cartesian system printers [6].

Table 1. Technical characteristics of Delta printer

Naming	Value
Layer resolution	up to 50 microns
Max print speed	150 mm / s
Maximum print size	180 (diameter) x 300 (height) mm
Metal extruder	E3D V5 J-head
Positioning accuracy XYZ	0.01 mm
Nozzle diameter	0.4 mm
Filament	1.75 mm
Filament material	PLA(polylactic acid)

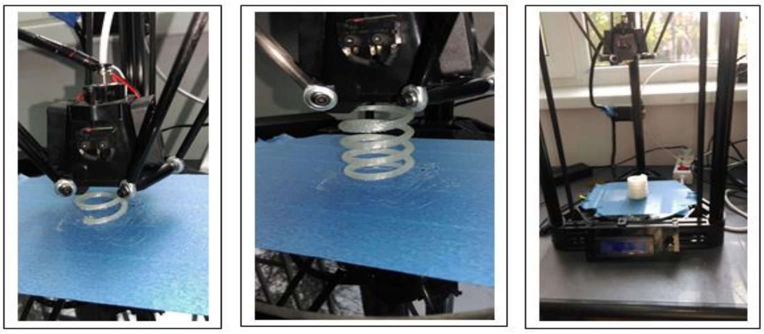
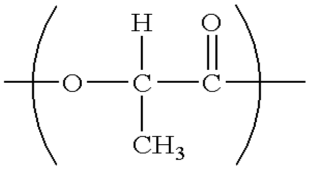


Figure 6. Construction steps of different types of springs on the Delta printer

Among the thermoplastic materials (solid plastics that become malleable by heating and hardened by cooling) used by FDM technology, was used as a base material the transparent PLA, from which some objects can be obtained at a slightly higher resolution weak compared to photopolymerizing resin, but with some superior structural properties. PLA is a bright, hard and biodegradable substance that chemically contains lactic acid and lactide. This has a low melting point - a temperature of 173-178 ° C and tensile strength of 2.7-16 GPa with several application areas, including medical implants and packaging materials. PLA is mainly derived from corn starch and therefore ecologically. Resistant and more rigid than ABS, the PLA is more complicated to use in assembling parts that require bonding, and the deformation property at lower temperatures than the ABS (about 65ºC) recommends it as the base material in making elastic elements.



$$\left(-O-\overset{\overset{H}{|}}{\underset{\underset{CH_3}{|}}{C}}-\overset{\overset{O}{\|}}{C}- \right)$$

Fig. 7. PLA chain structure

Flexible material can be used for objects that are subject to stretches or compressive forces, from fashion design (eg a shoe, a frame of glasses) to engineering (a robot with multiple components that can withstand small shocks etc). With 3D phosphorescent printing material, objects that light up in the dark can be created.

3. Experimental Results

In figure 8 is presented the experimental setup based on test stand, HV 500 N, which mainly consists of: 1- distance measuring system, 2 - Imada force transducer, 3 – case for helical spring. Maximum testing force is 500N. The Imada transducer is connected to PC for record the compression force and time [9].

Figure 8. Test stand Hans Schmidt [9]

Figure 9. Rectangle and circular spring wires realized by FDM (Fused Deposition Modeling)

In figure 10 are presented characteristics for square wire springs and in figure 11 for circular respectively. There were considered three helical springs with square wire PLA. For all these springs, there were determined the deflection and compression force as it is presented in figure 10.

The wires has the dimensions: 3,5 mm, 5 mm and 7 mm. The preload deflections are print on each characteristic: f01 = 6,96 mm , f04 = 2,17 mm , f05 = 0.382 mm, which correspond to preload forces P01= 1.37 N, P04= 2,47 N, P05= 9.97 N. The computed springs rigidities are: c01 = 0,125 N/mm, c04 = 0,225 N/mm, c05= 0,909 N/mm.

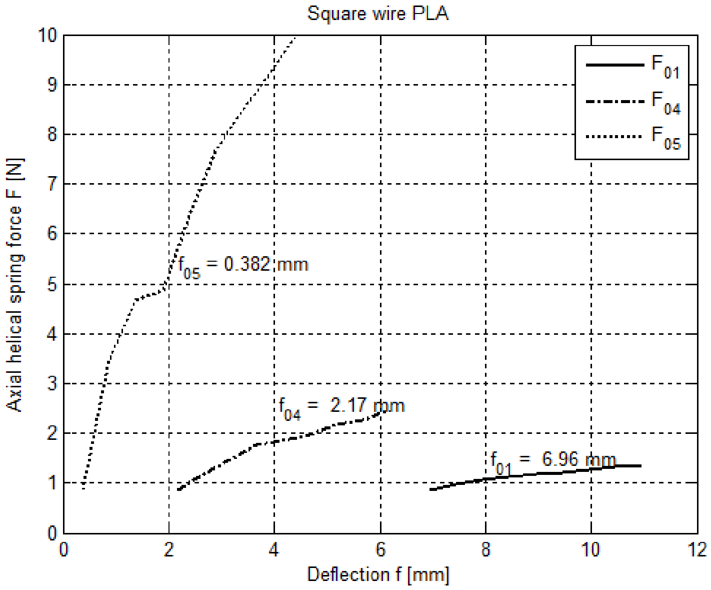


Figure 10. The strokes of square wire springs

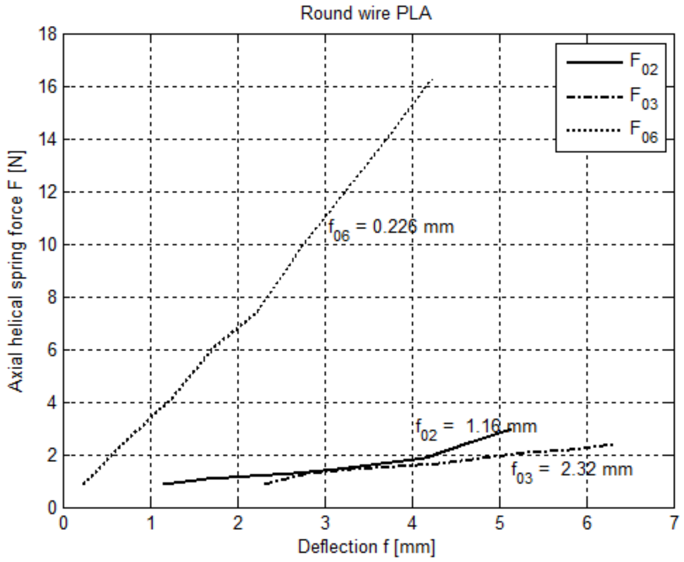


Figure 11. The strokes of circular wire springs

Also, there were considered other three helical springs with circular wire PLA. For these springs, there were determined the deflection and compression force as it is presented in figure 11.

The wires has the dimensions: 3 mm, 4,5 mm and 6 mm.

The preload deflections are print on each characteristic: f02 = 1,16 mm , f03 = 2,32 mm , f06 = 0,226 mm, which correspond to preload forces P02= 2.37 N, P03= 3,87 N, P06= 16,27 N. The springs rigidities are: c02 = 0,2162 N/mm, c03 = 0,271 N/mm, c06 = 1,484 N/mm.

4. Conclusions

Elastic elements made of plastics offer a number of advantages for spring applications. Lately, this area has grown strongly in response to increased demands of helical springs that combine the resistance of metallic materials with the special features of high-performance thermoplastics. However, it is important to understand when using plastic springs instead of traditional metallic springs. Plastic helical springs are designed to meet the specific requirements that involve the elastic element to be inert, non-corrosive and non-metallic.

In this paper, helical springs with different sections of PLA thermoplastic material have successfully been realised, the same 20% filling with help of FDM additive technology on a Delta printer. Also, the mechanical performances of the springs were studied by means of a Hans Schmidt test stand.

Considering the characteristics square wire, the spring rigidities grow with wire dimension. The lowest rigidity corresponds to the spring labelled with 01. For round wire, the spring rigidities also grow with wire dimension. The lowest rigidity corresponds to the spring labelled with 03. The preload deflection is the biggest. All investigated characteristics are very close to a linear behaviour. The square wire springs have lower rigidities than round wire springs.

Springs made from PLA (polypolylactic acid), which is an ecological material with a high degree of biocompatibility; surely find its place in medical and pharmaceutical applications. In addition, with relatively good physical and mechanical properties, the PLA springs can arise as a reliable solution for aerospace, automotive, marine, instrumentation applications or where metal analogues cannot be used for different reasons: water purification systems, chemical media, imaging equipment and radiography, etc.

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References

[1] T.Demian, D.D. Plade, T.Curita, Elemente elastice in constructia aparatelor de Mecanica Fina, Editura Tehnica, Bucuresti. 1994)
[2] Petru Berce, Nicolae Balc, Cristian Caizar, Razvan Pacurar, Adrian Sever Radu, Sorin Bratean, Ioan Fodorean, Tehnologii de fabricatie prin adaugare de material si aplicatiile lor, Editura Academiei Romane, Bucuresti, 2014.
[3] Ramji Pandey, Photopolymers in 3D printing applications, Degree Thesis Plastics Technology, 2014
[4] M.M.Popovici, Modelarea virtuala 3D in constructia de masini, Editura Printech, Bucuresti, 2005
[5] Ionut. G. Ghionea, Catia V5, Aplicatii in ingineria mecanica, Editura Bren, Bucuresti, 2009.
[6] www.build3dparts.com
[7] https://ultimaker.com
[8] Repetier-host V1.6.2 - QuickSlice software
[9] https://www.hans-schmidt.com/en/produkt-details/test-stand-hv-500n/
[10] Ciprian Ion Rizescu, Elemente si mecanisme de mecanică fină - Partea I, Editura Printech, Bucuresti, 2013.