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ARTICLE

Vibration Damper Design and Additive Manufacturing for Unmanned Aerial Vehicles

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ABSTRACT

The main focus of this study revolves around the problem of vibrations in unmanned aerial vehicles and aims to propose solutions using different designs of vibration dampers. Specifically, the study identifies the sources of vibrations in a Single Rotor Rotary Wing (Monocopter) type UAV. To assess the damping performance of the designed dampers, vibration tests were conducted in a controlled setup. Based on the measurement results obtained at three different speed stages, a particular damper, referred to as G2S2, exhibited the highest damping performance. At the first speed stage, it achieved damping percentages of 66% for the X-axis, 77% for the Y-axis, and 84% for the Z-axis. At the second speed stage, the percentages increased to 81% for the X-axis, 84% for the Y-axis, and 97% for the Z-axis. Finally, at the third speed stage, the damper demonstrated damping percentages of 85% for the X-axis, 84% for the Y-axis, and 98% for the Z-axis. This study successfully developed an experimental setup for measuring vibrations during UAV flight, particularly focusing on unmanned aerial vehicles. Furthermore, among the vibration dampers produced using additive manufacturing techniques, the damper with the highest performance, namely G2S2, was selected. Considering the measurement results, G2S2 emerged as the most effective vibration damper. It is worth mentioning that this damper can also be tested in real flight scenarios in the future, building upon the outcomes achieved through the experimental setup.

Keywords: Monocopter; UAV; Vibration damper; MPU6050; FFT; Transmissibility; Additive manufacturing

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1. Introduction

An unmanned aerial vehicle (UAV), commonly known as a drone, can be remotely controlled by a pilot or operated autonomously without human intervention. Due to their small size and long flight range during operation, modern miniature UAVs are widely used today, both commercially and militarily, to meet the needs in different scenarios. UAV is a set of integrated systems consisting of three components: the pilotless aircraft system, the remote piloting control system and the command-control communication medium between these two [1]. UAV is defined as follows in the US Department of Defense Military and Related Terms Glossary: It has a power transmission system, does not carry any person controlling the vehicle, provides the necessary propulsion through aerodynamic forces, can fly by itself (autonomously), or is an operator. It is an aircraft that can be controlled remotely by the aircraft and can carry payloads that do not harm or harm the other party [2].

Like many mechanical systems, vibration in UAVs can cause problems for many reasons. Fragile parts and electronic components wear prematurely due to mechanical fatigue caused by continuous vibration. Blurry photos and shaky videos from optical equipment are a problem for research or surveillance applications. The most critical reason is that sensing equipment used for inertial flight navigation can be adversely affected by vibration. Severe or high-frequency resonance vibration can cause momentary sensor reading errors. Even if there is no sudden sensor failure, sensor deviation can also occur for a flight if there is significant entanglement or tilting vibration.

Of the many causes of the vibration problem, the most worrisome are the rotating thrust elements and the mechanical structure resonating at its natural frequencies. In case of insufficient damping or no damping of such vibrations, various motion errors will likely occur in the UAV during the flight due to incorrect data received by the gyroscope or accelerometer [3]. Some elements store potential and kinetic energy in vibrating systems, and elements that provide energy dissipation in damped systems. Elastic elements (springs), inertial elements and damping elements are widely used in vibration damping. The process of affixing anti-vibration sponge and gel sheets to the base of the electronic card platform is used in small UAVs. This system is preferred because of the space problem in the assembly area [4]. Vibration-damping platforms are platforms formed by assembling the lower and upper frames with elastic damping elements [5]. Available on vibration-damping platforms with O-rings [6]. The T-type shock absorber which has a vibration reduction effect and the method of vibration reduction was verified by Changshuai et al. [7]. Hadden et al. [8] developed a high-performance vibration isolation system to isolate large-sensitive payloads from aircraft disturbances. In order to reduce the effect of micro vibration, a passive vibration method was used in this study. Deng et al. [9] designed and installed a rubber shock absorber on a satellite. Another paper was presented to affect the damping capability of the lathe tools under static and vibrational analysis by using computer simulation [10]. A method suggested the vibration damping of rotating machinery [11]. But there is no find study about vibration dampers in UAVs.

As seen in the literature, although vibration is an important problem in UAVs, no study has been found about which vibration damper is effective and how effective it is. In this study, vibration damper designs are proposed for UAVs. The sources of vibrations on Monocopter type UAV have been identified. The damping performance comparisons were performed by performing vibration test setup tests of the designed dampers. The damper designs were manufactured using additive manufacturing.

2. Computer-aided modelling of test setup and additive manufacturing

The vibration test setup, which was designed based on a monocopter type UAV, was modeled with the SolidWorks program as seen in **Figure 1**. The vibration test setup consists of 3 parts (**Figure 1**). The area where the motor, vibration damper and sensor slots are located is in circle 1, the control card is seen in circle 2 and the power source is seen in circle 3.

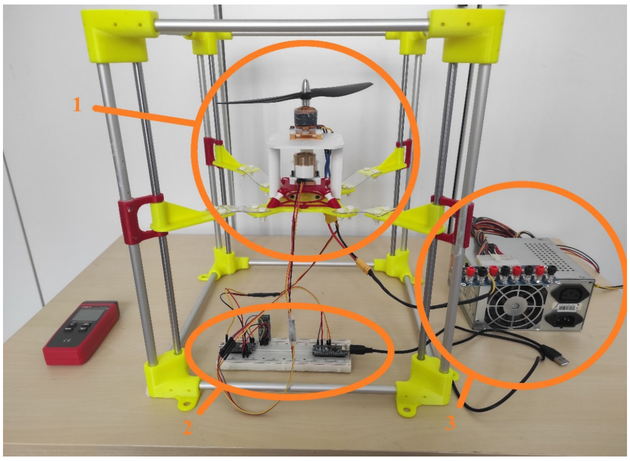

Figure 1. Vibration test setup.

Experiments were carried out using MPU6050 Acceleration/Gyro sensors and Arduino Nano type electronic developer boards. Arduino IDE interface is used for data acquisition. The data were read from the serial monitor and recorded throughout the experimental period. Engine start and speed level settings are made by remote control via mobile phone application with the help of bluetooth module.

Fused Deposition Modeling (FDM) was developed by Stratasys in Eden Prairie, Minnesota. Fused Deposition Modeling (FDM) is a 3D printing technology developed by Stratasys in Eden Prairie, Minnesota, that has become widely used in various industries. In this process, a plastic or wax material is extruded through a nozzle, which follows the cross-sectional geometry of the part, creating it layer by layer. The material is usually supplied in the form of a filament, but some installations use plastic pellets fed from the chamber instead. The nozzle contains resistive heaters that keep the plastic at a temperature just above its melting point so that it flows smoothly through the nozzle and forms the sheet. The plastic quickly solidifies after flowing from the nozzle, creating a bond with the layer below. Once a layer is formed, the platform lowers, and the extrusion nozzle repeats the process to create another layer. FDM has proven to be a cost-effective and efficient method for creating prototypes and small-scale production parts in a range of industries, such as aerospace, automotive, and medical [12].

The Creality Ender-3 is an FDM (Fused Deposition Modeling) type 3D printer manufactured by the Creality brand. FDM technology is employed in the Ender-3, where it operates by extruding molten filament material to construct a 3D object layer by layer. This method of 3D printing is widely adopted due to its widespread availability and cost-effectiveness.

8 items corner plastics, 12 items and Ø12 mm aluminum pipes and 4 items and Ø8 mm chrome shafts were used in the outer frame assembly of the vibration test setup. It was also shown Creality brand Ender-3 model FDM type 3D printer in **Figure 2**. Elastic fittings are manufactured from a 1.5 mm thick polyvinyl chloride (PVC) strip with Shore-A 55 hardness. All parts except damping elements and ready-made products are produced from Polylactic Acid (PLA) material in a 3D printer with an FDM process. As shown in **Figure 3**, 2 items of plastic damper bodies are designed. The names and abbreviations given from left to right are as follows: 90° Body Plastic (G1), 45° Body Plastic (G2). As shown in **Figure 3**, 4 items of silicon damping elements are designed. The names given from left to right and their abbreviations are as follows: Convex Silicon Damper (S1), Concave Silicon Damper (S2), Stepped Silicon Damper (S3), Cylindrical Silicon Damper (S4). It also was given the additive manufacturing parameters in **Table 1**. The damper body and damper silicon nomenclature were given in **Table 2**.

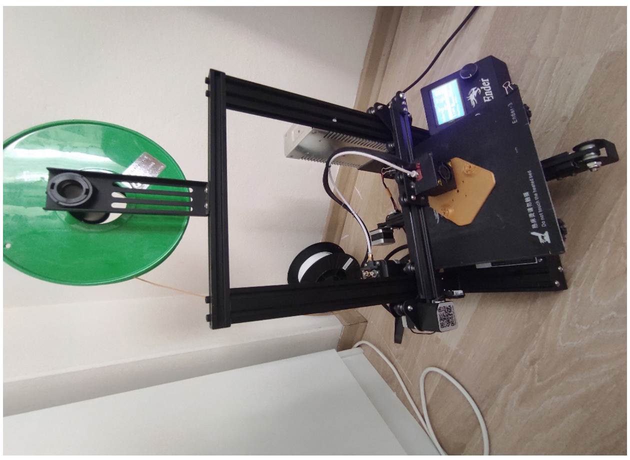

Figure 2. Creality brand Ender-3 model FDM type 3D printer.

The reverse engineering (RE) process is used to copy complex shapes and designs with specialized software and hardware [13]. After the 3D modelling process, molds for vibration dampers were easily manufactured using additive manufacturing. The dampers are manufactured using molds with the silicone injection method.

The 3D models of the mold designs prepared for the silicon damper element are shown in **Figure 3**. These mold designs were made using the SolidWorks program. The molds designed in the SolidWorks program (**Figure 3**) were saved in STL format and converted into G-Codes that can be processed by the 3D printer in the Cura program. This step was repeated for the manufacture of each plastic part. Cura program, STL, OBJ, X3D, 3MF etc. is software from Ultimaker BV, used to convert (slicing) 3D models in formats to G-Codes. Molds and cores produced from 3D printers were collected appropriately and silicone was injected into the molds. With this method, the production of silicon-damping elements has been realized.

Vibration analysis with experimental setup

Vibration tests were carried out to compare the performances of the dampers exposed to vibration generated by the engine operating at 3000 RPM, 4000 RPM and 5000 RPM respectively. In the experimental setup, the actual loading is 150 gr in total; this means a load of 37.50 g per silicon damper. The induced damping mass used here is 120 g to be consistent with the payload mass that must be protected from vibration by the damper in a real UAV.

The performance of each damper was calculated with percent efficiency by observing the collected output and input acceleration data. Acceleration-Time graphs were created by taking one of the repetitions for each damper. The damped vibration values as the output value are presented in dark blue color in the graphics, and the vibration values with the input value are presented as 50% transparent orange. with comparison charts. The difference between the input-output values can be seen clearly.

In the acceleration-time graphs, the unit of the acceleration data is given in mm/s^2. In FFT graphs (**Figures 4 and 5**), the unit of the vertical axis is g (gravitational acceleration) and the unit of the horizontal axis is given in Hz. In graphs and tables, data ending with “T” represent input value (pre-damping), and data ending with “S” represent output value (post-damping). For example, “AcX-T” refers to the input value on the X-axis, and “AcY-S” refers to the output value on the Y-axis.

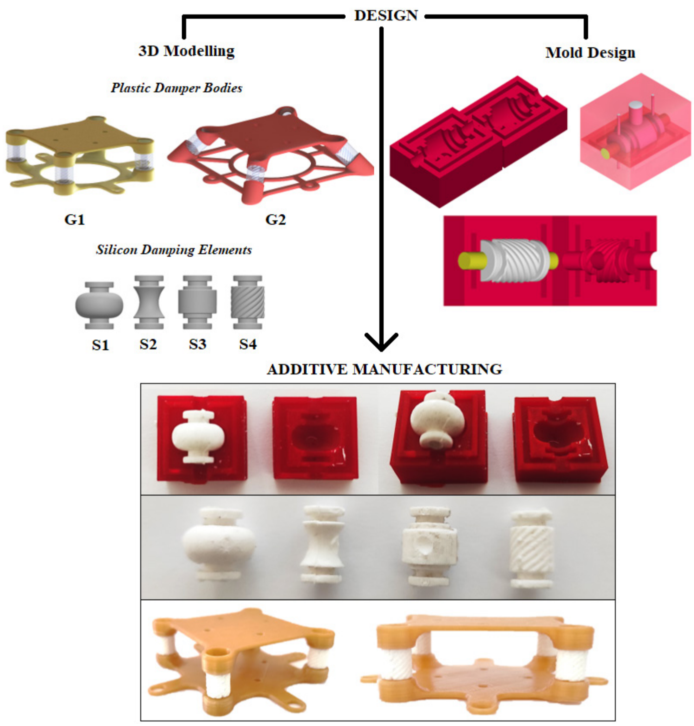

Figure 3. Design and additive process of the plastic damper bodies and the silicon damping elements.

Table 1. Additive manufacturing parameters.

Parameters	Values
Material	PLA
Layer thickness (mm)	0.1-0.2
Fullness	%100
Print speed (m/sn)	55
Table temperature (°C)	40
Print temperature (°C)	210

Table 2. Damper body and damper silicon nomenclature.

	Convex (S1) silicon damper elemrnt	Convex (S2) silicon damper element	Convex (S3) silicon damper element	Convex (S5) silicon damper element
90 degree body (G1)	G1S1	G1S2	G1S3	G1S4
45 degree body (G2)	G2S1	G2S2	G2S3	G2S4

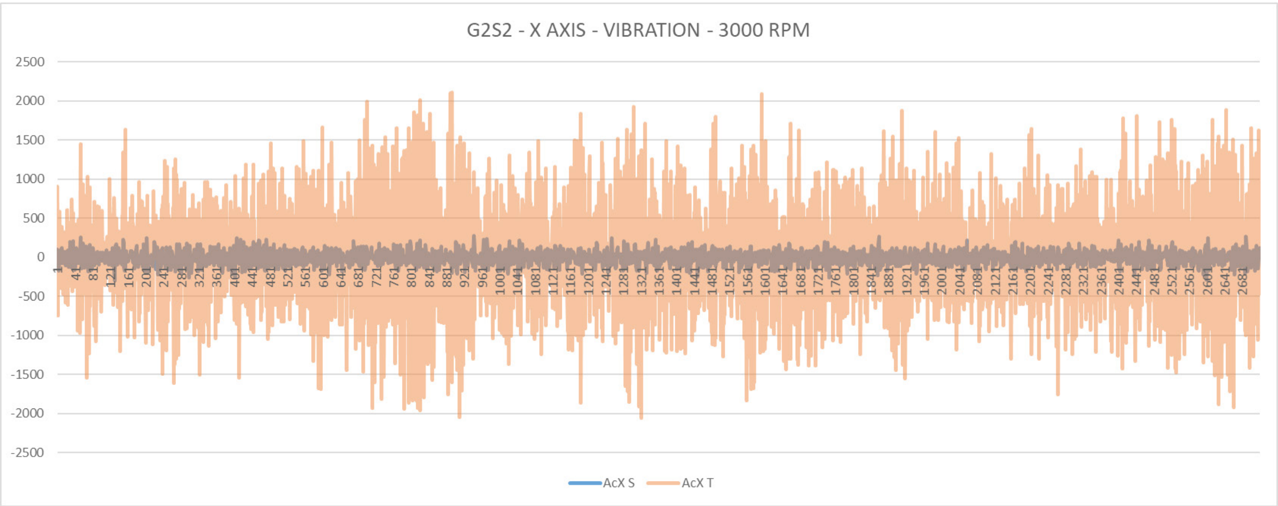

Figure 4. G2S2/3000 RPM-X-Axis acceleration-time graphs.

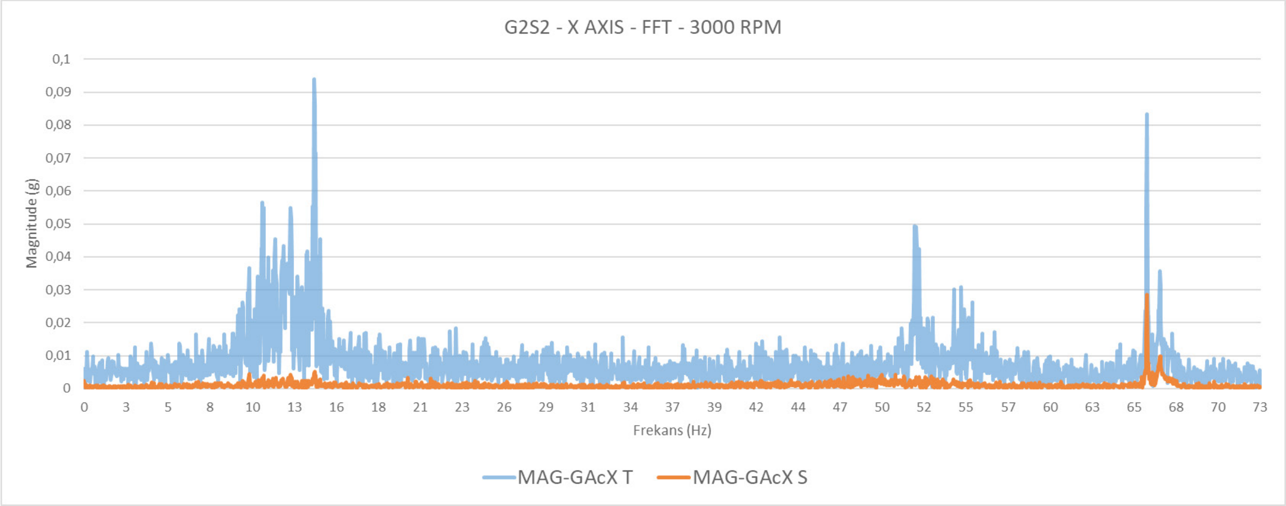

Figure 5. Graphics of vibration analysis and FFT analysis.

3. Results and discussion

In this study, the prevention of vibrations on a Monocopter type UAV by using vibration-damping equipment (2 different bodies, 4 different silicon damping elements) designed within the scope of the thesis is examined by experimental design method. In this context, damper selection criteria for UAVs with light-damping mass have been established to serve as a guide for future applications. The measurement results at 3 different speed stages for G1-90° body plastic were given in **Table 3** and other G2-45° body plastic in **Table 4**.

The first speed stage: 66% for the X-axis, 77% for the Y-axis, 84% for the Z-axis; the second speed stage: 81% for the X-axis, 84% for the Y-axis, 97% for the Z-axis; the third speed stage: 85% for the X-axis, 84% for the Y-axis, 98% for the Z-axis with the above damping performance values, it was the damper with the highest performance.

Table 3. Damper performance comparison chart for G1-90° body plastic.

G1S1		**G1S2**		**G1S3**		**G1S4**	
SPEED 1	3000 RPM	SPEED 1	3000 RPM	SPEED 1	3000 RPM	SPEED 1	3000 RPM
X	51%	X	–63%	X	51%	X	54%
Y	37%	Y	27%	Y	20%	Y	11%
Z	26%	Z	54%	Z	23%	Z	40%
SPEED 2	4000 RPM	SPEED 2	4000 RPM	SPEED 2	4000 RPM	SPEED 2	4000 RPM
X	72%	X	–2%	X	34%	X	36%
Y	91%	Y	15%	Y	73%	Y	65%
Z	62%	Z	73%	Z	53%	Z	65%
SPEED 3	5000 RPM	SPEED 3	5000 RPM	SPEED 3	5000 RPM	SPEED 3	5000 RPM
X	60%	X	62%	X	0%	X	44%
Y	64%	Y	60%	Y	39%	Y	59%
Z	62%	Z	89%	Z	62%	Z	72%

Table 4. Damper performance comparison chart for G2-45° body plastic.

G2S1		**G2S2**		**G2S3**		**G2S4**	
SPEED 1	3000 RPM	SPEED 1	3000 RPM	SPEED 1	3000 RPM	SPEED 1	3000 RPM
X	–72%	X	66%	X	18%	X	–129%
Y	–273%	Y	77%	Y	56%	Y	–74%
Z	82%	Z	84%	Z	81%	Z	73%
SPEED 2	4000 RPM	SPEED 2	4000 RPM	SPEED 2	4000 RPM	SPEED 2	4000 RPM
X	95%	X	81%	X	62%	X	33%
Y	58%	Y	84%	Y	68%	Y	37%
Z	67%	Z	97%	Z	85%	Z	93%
SPEED 3	5000 RPM	SPEED 3	5000 RPM	SPEED 3	5000 RPM	SPEED 3	5000 RPM
X	84%	X	85%	X	74%	X	61%
Y	66%	Y	84%	Y	73%	Y	58%
Z	96%	Z	98%	Z	93%	Z	94%

The operating target frequency of the UAV is between 50 Hz and 83 Hz. The fact that the examined output values are very low at low frequencies shows that the damper combinations generally dampen effectively at low-frequency values. The fact that the values are low and the damping is successful at a high rate shows that there is no problem at low frequencies. However, it is observed that the damping performance values given as a percentage of some dampers between 50-83 Hz, which is the operating frequency range, are negative and transmit the vibration by not doing the damping process. This indicates that those dampers are not suitable for use at 50-83 Hz operating frequency.

4. Conclusions

In this study, vibration damper designs are proposed for UAVs. The sources of vibrations on a Monocopter type UAV have been identified. The damping performance comparisons were performed by performing vibration test setup tests of the designed dampers. According to the measurement results, G2S2 was found to be the best result. It was also carried out using the experimental setup, which can also be tested with real flight experiences in the future. Thus, solutions to vibration problems, which are very important parameters, can be obtained.

There are various types of vibration damper bodies and silicon damper (cylindrical, convex) designs on the market. A test device was developed for a monocopter carrying a 150 gr load, which was determined as a vehicle in the thesis. In this article, G2S2 damper, which is formed as a result of the combination of the new damper body named S2 (concave and evacuated S4, the lightest among these four silicon damper elements) and the plastic body with a 45° arm angle of the G2 type, which was developed within the scope of the thesis, is presented in the other type (**Table 2**). It is mentioned that it has been experimentally proven to perform better than the dampers (as mentioned above). The acceleration-time graphs and FFT graphs obtained as a result of the analyzes are presented in the appendix.

Author Contributions

Kadir Gök: Conceived and designed the analysis, collected the data.

Görkem Karagöz: Contributed data or analysis tools, the manufacture of UAV parts.

Arif Gök: Wrote the paper, reduction, performed the analysis and assembly of components.

Conflict of Interest

There is no conflict of interest.

References

[1] Torun, A., 2017. İnsansız Hava Aracı (İHA) Sektörü Ve İHA Fotogrametrisinin Ölçme Bağlamında Konumlandırılması (Turkish) [The Sector of Unmanned Aerial Systems and Positioning UAS Photogrammetry Regarding Surveying Discipline] [Internet]. Available from: https://www.hkmo.org.tr/resimler/ekler/ee7bb-21c93fa52e_ek.pdf

[2] DOD Dictionary of Military and Associated Terms [Internet]. Available from: https://irp.fas.org/doddir/dod/dictionary.pdf

[3] Li, Z., Lao, M., Phang, S.K., et al. (editors), 2017. Development and design methodology of an anti-vibration system on micro-UAVs. International Micro Air Vehicle Conference and Flight Competition (IMAV). 2017 Sep 18-22; Toulouse, France. p. 223-228.

[4] Palaniswamy, H., Ngaile, G., Altan, T., 2004. Optimization of blank dimensions to reduce springback in the flexforming process. Journal of Materials Processing Technology. 146(1), 28-34.

[5] McCaldin, G. 3D Printed Anti Vibration Mount [Internet]. Available from: https://discuss.ardupilot.org/t/3d-printed-anti-vibration-mount/11472

[6] Review and Tests of Anti-vibration Systems [Internet]. Available from: https://diydrones.com/profiles/blogs/videophotography-gimbal-anti-vibration-systems-tests

[7] Changshuai, Y., Haitao, L., Siwei, G. (editors),

2019. Vibration test and vibration reduction design of UAV load radar. Proceedings of the 2019 4th International Conference on Automation, Control and Robotics Engineering. 2019 Jul. p. 1-6.
DOI: https://doi.org/10.1145/3351917.3351980

[8] Hadden, S., Davis, T., Buchele, P., et al., 2001. Heavy load vibration isolation system for airborne payloads. Smart Structures and Materials: Industrial and Commercial Applications of Smart Structures Technologies. 4332, 171-182.

[9] Deng, C., Mu, D., An, Y., et al., 2017. Reduction of satellite flywheel microvibration using rubber shock absorbers. Journal of Vibroengineering. 19(3), 1465-1478.

[10] Rogov, V.A., Ghorbani, S., 2015. Research on selecting the optimal design of antivibrational lathe tool using computer simulation. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering. 229(3), 162-167.

[11] Zhao, H.M., Li, D.Y., Deng, W., et al., 2017. Research on vibration suppression method of alternating current motor based on fractional order control strategy. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering. 231(4), 786-799.

[12] Fused Deposition Modeling (FDM) [Internet]. Available from: http://www.custompartnet.com/wu/fused-deposition-modeling

[13] Varady, T., Martin, R.R., Cox, J., 1997. Reverse engineering of geometric models—an introduction. Computer-aided Design. 29(4), 255-268.