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THE NATURAL FREQUENCIES CHARACTERISTICS OF A MECHANICAL SYSTEM USING MODAL ANALYSIS

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Abstract. The paper presents some results obtained during the finding optimal solution process for a ground movement system of an aerial / terrestrial drone. Using drones in observation and surveillance missions has numerous advantages, especially when talking about calamity areas, or impossible to reach by humans due to terrain obstacles or due to mission restrictions (the danger of getting close to a certain position, large area to observe etc.). In every case, using an aerial / terrestrial drone is an optimal solution. The advantages of combining aerial with terrestrial observation in one drone are explained in the paper. There are presented some aspects related to modal analysis of the ground movement system and some experimental results obtained using the vibration stand. An analysis of the results is made and further work tasks are established.

Key words: natural frequency, modal analysis, 3D printing.

1. INTRODUCTION

The purpose of this paper is to present the results of researches conducted during a solution identification process for the movement system of a drone which can move both in the air and on the ground.

The advantages of combining the ground movement with the aerial movement are: *high mobility* – it can reach the area of interest by alternating the two movement types (aerial and terrestrial); *low noise profile* – the observation of interest points can be accomplished from close proximity due to the reduction of noise level, in case of ground movement, compared with the aerial movement; and *increased observation time* – the ground movement consumes less energy than aerial movement.

The solution identified for the ground movement system of the drone (Fig. 1) consists of an internal spur gear, which is in contact with the ground and geared, in the upper side, with a spur gear mounted on the axis of an electrical motor.

The weight of the drone is sustained with the help of two gears, identical with the one mounted on the motor axis, and support elements for the gears and motor. The internal spur gear transfers the power to the ground. The three identical spur gears are positioned on the internal spur gear at 120 degrees angles relative to each other. The main characteristic of the ground moving system of the drone is that the wheel which is in contact with the ground is eccentrically motorized.

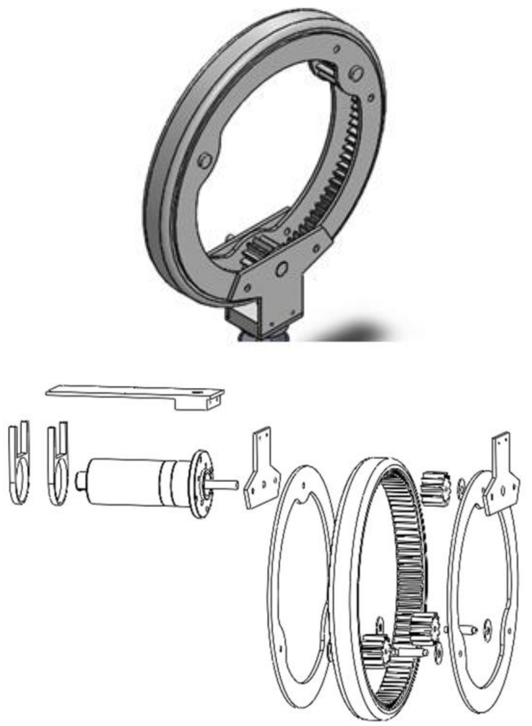


Fig. 1 – Schematic view of the ground movement system unit.

There are numerous studies which prove that using simulations, virtual experiments and technology in general can lead to a change of the negative perception regarding physics, since the understanding of concepts becomes easier and deeper [1–6]. Thus the paper presents the design, the simulation and the experimentation of the phenomena.

2. PURPOSE AND OBJECTIVES

The purpose of the work presented in the paper is to identify the natural frequencies of the ground movement system. Knowing the natural frequencies allows the developer to predict the behavior of the system when used in real scenarios. As a general remark, there is no interest in obtaining low values for the natural frequency. The values must be analyzed together with the functionality of the entire system. Attention must be paid for those situations when the system could reach the frequency obtained through simulations and further developments must be made to avoid working at that value of the frequency.

The main objectives of this paper are presenting the: *performed modal analysis* for the ground movement assembly unit; *ground movement assembly* unit *manufactured* using 3D printing with ABS and classical machining; *testing* the manufactured system using the vibration stand to verify the simulation obtained data; and *analysis* of the natural frequency with respect to real use of the aerial / terrestrial drone.

3. SIMULATION ANALYSIS

The model of the system was designed to obtain a solution to facilitate ground movement (high terrain clearance) and to be easily mounted in the drone assembly, all by keeping the total weight as low as possible.

Every structure has the tendency to vibrate at certain frequencies, called natural or resonant frequencies. Each natural frequency is associated with a certain shape, called mode shape that the model tends to assume when vibrating at that frequency. When a structure is properly excited by a dynamic load with a frequency that coincides with one of its natural frequencies, the structure undergoes large displacements and stresses [7]. This phenomenon is known as resonance. For un-damped systems, resonance theoretically causes infinite motion. Damping, however, puts a limit on the response of the structures due to resonant loads.

The mesh used for this model is a solid type mesh, with a curvature based mesher and 4 Jacobian points.

After the modal analysis was run, the modes and the natural frequencies obtained are presented in Table 1.

Table 1

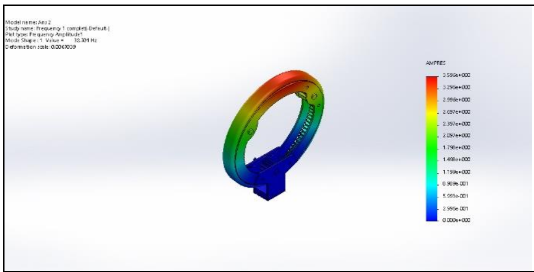
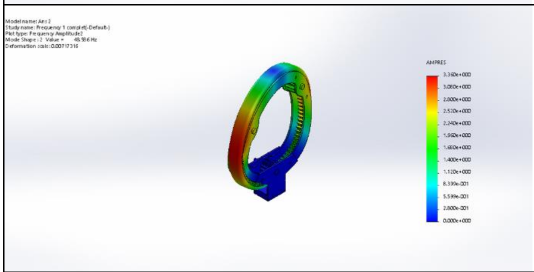
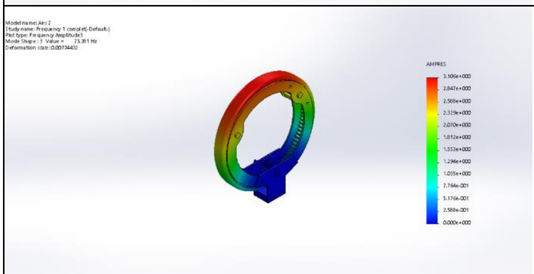
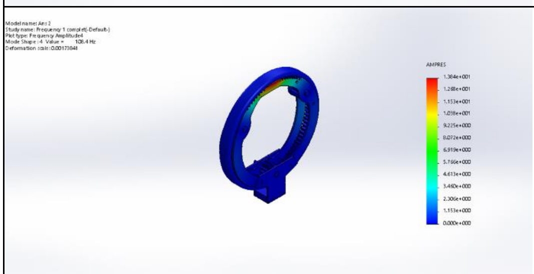
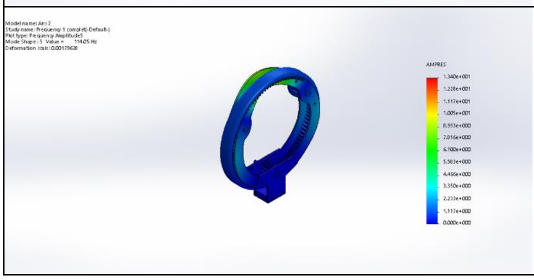
The mode and natural frequencies

Frequency Number	Rad/sec	Hertz	Seconds
1	205.47	32.701	0.03058
2	305.27	48.586	0.020582
3	460.44	73.281	0.013646
4	681.07	108.4	0.0092254
5	716.62	114.05	0.0087678

Table 2 presents the resultant amplitude plot for each of the five mode shapes.

Table 2

Resultant amplitude plot

	Resultant Amplitude Plot for Mode Shape: 1 (Value = 32.7013 Hz)
	Resultant Amplitude Plot for Mode Shape: 2 (Value = 48.5859 Hz)
	Resultant Amplitude Plot for Mode Shape: 3 (Value = 73.2806 Hz)
	Resultant Amplitude Plot for Mode Shape: 4 (Value = 108.396 Hz)
	Resultant Amplitude Plot for Mode Shape: 5 (Value = 114.054 Hz)

4. EXPERIMENTAL RESULTS

Virtual experiments can raise interest but there are no guarantees that they do improve the understanding of the fundamental concepts [8].

After the simulation, the work needed to be continued with some experimental tests, using a vibration stand (TIRA VIB THS 50-180) as a source of periodic vibrations.

The periodic phenomenon is the phenomenon which identically reproduces itself at equal intervals of time. To a system that evolves in a periodic manner one can attach at least a physical quantity that varies periodically between a minimum and a maximum value. The variation in time of such a physical quantity is a periodic signal [9].

In this way, the study of the electrical signals given by the accelerometers during the vibration test can identify both the moment when the system reaches its natural frequency and the displacement amplitudes of the vibrations.

The solution for the ground movement was manufactured using ABS 3D printing with a honeycomb structure. The system was mounted on the stand as shown in Fig. 2.

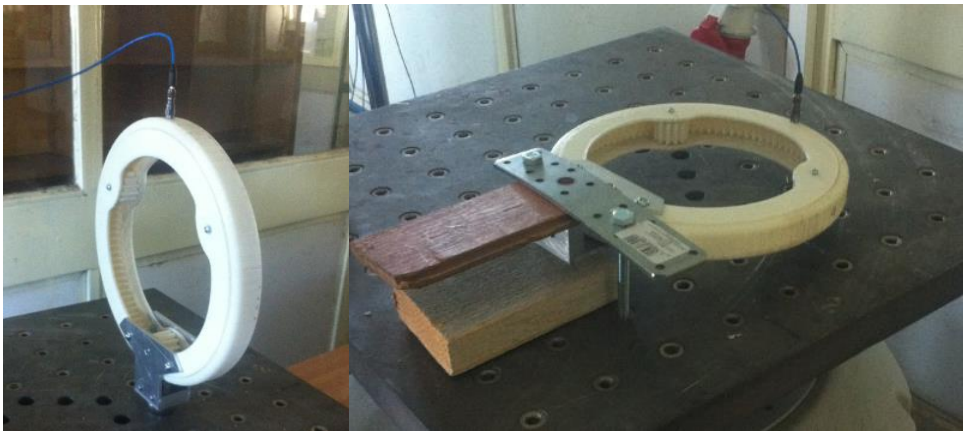


Fig. 2 – Setting the experiment.

During the testing an acceleration sensor was mounted on the wheel in order to record the values of the acceleration obtained at the extremities of the system.

During the experiments, which were nothing but complex phenomena (structural oscillations of ABS material) studied with simple tools, involving stages of design, simulation, data processing and modeling [10], the following results were obtained (Figs. 3, 4, 5 and 6).

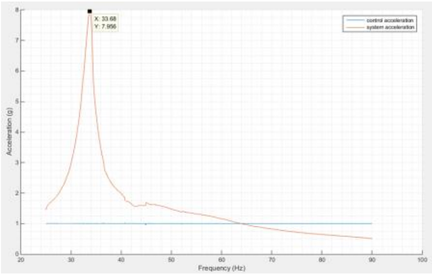


Fig. 3 – Transversal natural frequencies.

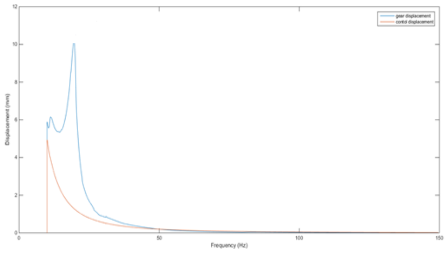


Fig. 4 – Displacement amplitude for transversal vibration.

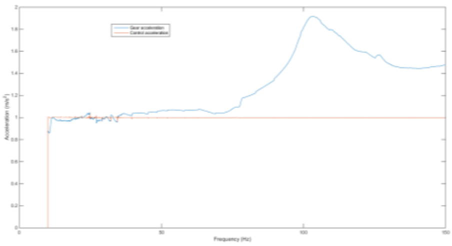


Fig. 5 – Radial natural frequencies.

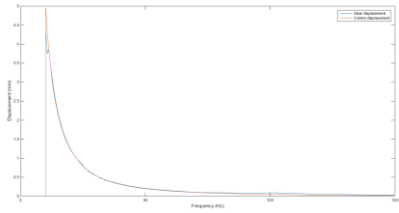


Fig. 6 – Displacement amplitude for radial vibration.

5. CONCLUSIONS

The first conclusion drawn after the values were compared (for the natural frequencies obtained both by simulation and experimentation) is that the obtained values during simulation are higher than those obtained through experimentation. One possible explanation could be the presence of the mesh which can increase the stiffness of the model. The finer the mesh the smaller its impact on stiffness is.

Secondly, the natural frequency is quite low and further work is needed because during real operation, the frequency of 20–30 Hz is reachable and dangerous for the system. As a starting solution, a damper can be used to absorb vibrations and to increase the value for the natural frequency of the ground moving system.

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