In His Name

VIBRATION ANALYSIS AND DESIGN OPTIMIZATION OF A LIGHT QUAD-COPTER

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Abstract

In this project, we analyze the vibrations of a light custom-made quad-copter. Our main goal is to optimize the vibration characteristics of the quad-copter. Previous condition was that high vibrations affected the structure and thus drastically reduced the performance of the control system. Therefore, with the help of CAM and CAE software, vibration analysis, and implement of a variety of ways to reduce it, the performance of control system was highly improved. However, even after reducing the vibrations of the structure to less than the standard limits, the quad-copter failed to maintain a stable flight. Because of this, along with the vibration analysis, control algorithm parameters were analyzed and proper solutions were suggested.

Keywords: Quad-copter, Vibrations, Control, Structural vibrations

I. INTRODUCTION

Quad-copters are one of the most complicated unmanned aerial vehicles [1]. Since the control and the flight system of such UAV is highly complicated, the development in this field happened only after the huge development in the field of electronics that made controllers much simpler and cheaper to design [2].

Our project includes vibration analysis and design optimization of the structure of a light quad-copter. This research quad-copter had a flight problem and we needed to analyze and eliminate the vibrations of its structure. Therefore, the main goals of this project are:

- ✓ Find and analyze the vibrations' source
- ✓ Analyze the frame of the quad-copter in terms of vibrations, natural frequency, and material.
- ✓ Analyze and apply solutions to eliminate the vibrations
- ✓ Overall optimization of the quad-copter's structure

II. MAIN PROBLEM

A research Quad-copter designed and made by researchers of SDRA engineering company [3] had a flight problem and was highly uncontrollable. The current situation is that the vibrations affecting the sensors are higher than the standard level and data sent via sensors was highly noisy, and therefore the quad-copter suffered from poor control.

A. *Natural Frequencies*

First, we analyzed the frequencies applied via motors. Using the following formula, we calculated these frequencies:

$$f(Hz) = \frac{w(rpm)}{60} \qquad (1)$$

And as result, the highest frequency applied is 138 Hz.

Analyzing the natural frequencies of the frame using ANSYS software led to the conclusion that the material used in our quad-copter's frame (which is ABS plastic) is not favorable, because it undergoes resonance 7 times (42.3, 51.2, 96.971, 96.978, 117.62, 128.29 and 128.42 Hz). This is a sign of the bad situation of our frame.

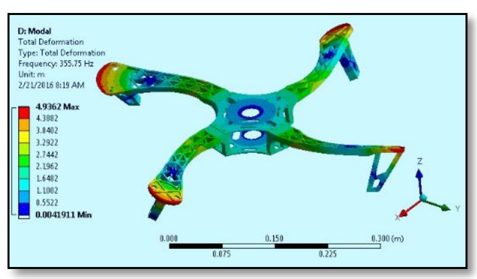

Fig. 1. Analysis of natural frequency modes via ANSYS

Further researches concluded that using other materials, such as fiber carbon or fiberglass, would highly improve the situation.

B. *Propeller's Balancing*

Balancing the propellers of the quad-copter is of high importance in order to eliminate the unwanted vibrations transmitted from the motors to the quad-copter. In our project, we used the professional commercial balancer "ATG" that provided acceptable results for the static balancing of the propellers.

C. *Damper and Vibration Isolation*

Vibration Isolation: Placing special materials in order to prevent the vibration transmission into the desired system [4]. In our project, we used 4 pads that are screwed into the center of the quad-copter's frame while the flight controller is installed on their top plate. This system isolates the vibrations and damps them at the same time.

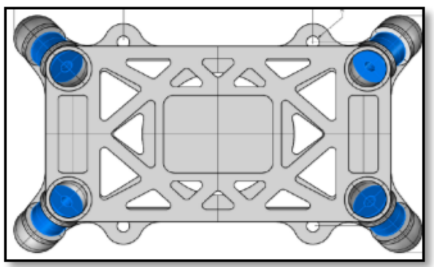

Fig. 2: Damping System used in the project

In order to reduce the vibrations applied from the motors, we used the new, unused before idea of Polyurethane pads. Polyurethane is a material used in the isolation of houses and roofs [5]. Polyurethane is synthesized using two materials: Polyol and Isoctanate. According to the composition percentage of these two materials, the mechanical characteristics of Polyurethane are assigned. The composition used in our project is 40% Isoctanate and 60% Polyol, and the output had good damping state with acceptable hysteresis.

After the preparation of Polyurethane, the needed thickness for the Polyurethane pads was calculated using this formula:

$$f_n = 3.13 \times \sqrt{\frac{1}{static\ deflection}} \qquad (2)$$

Using the curve in Fig.3, and assuming a damping ratio of 0.1, and assuming that 75% of the vibrations are to be eliminated, then the frequency ratio must be at least 2.5.

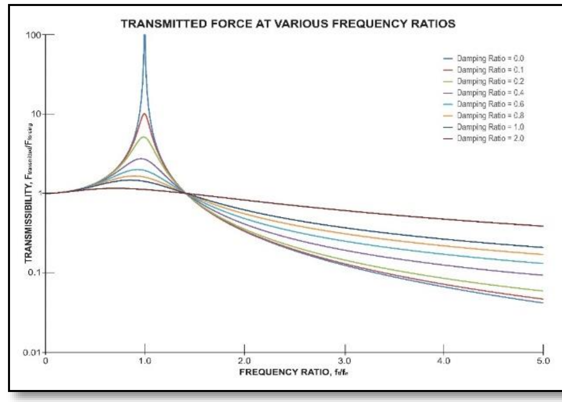

Fig. 3: Vibration transmissibility curve for elastomers such as polyurethane

Hence:

$$2.5 = \frac{f}{f_n} = \frac{138}{f_n} \rightarrow f_n = 55.2\ Hz \qquad (3)$$

And therefore, the static deflection is 0.0817 mm, or in other words, for 1 mm thickness, we'll have a deflection of 0.1 mm.

D. *Results and Discussion*

The grand quad-copter designers assigned a standard for the vibrations of a quad-copter to be between -3 and +3 m/s^2 along x and y axes, and between -15 and -5 m/s^2 along z axis. Our final test analysis shows that our vibrations are within the desired range:

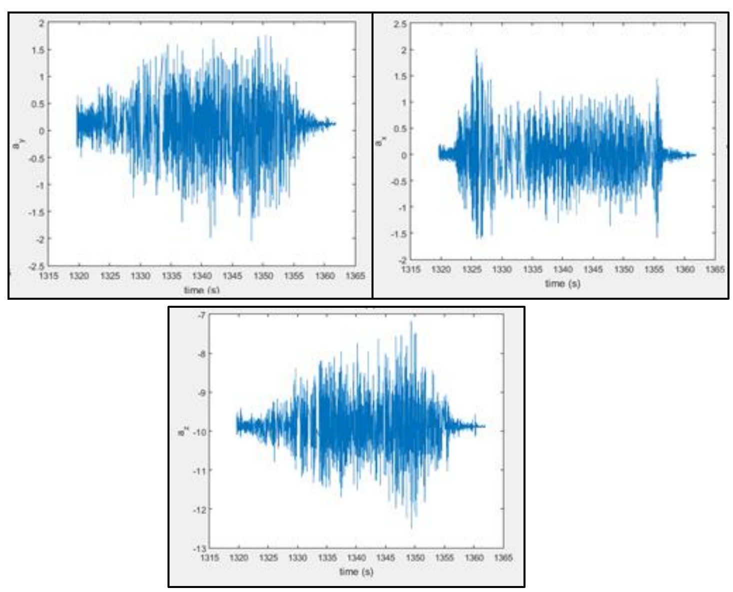

Fig. 4: Graphs of the final tests for our quad-copter

However, even though the vibration problem was solved, the quad-copter wasn't able to fly, and this revealed another problem with the controller system and the PID coefficients. To solve this problem it was suggested that the IMU of the quad-copter must be changed and it was recommended to use the aspect of TPA breakpoint in dealing with the PID controller.

E. *Acknowledgement*

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F. *References*

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