To: Tony Stark, President

From: Ross Smyth, Student, Lead Test Engineer

Date: January 24, 2020

Subject: Quadcopter Camera Mounting System Characterization

Introduction

As requested of you I have carried out a simplified, representative, model of a quadcopter camera suspension system and quantified its vibration characteristics. Based upon this, I have determined that the current suspension system is adequate for being used with the current quadcopter design, and image blurring should not occur. There are no design changes needed based upon the model tested, but potential changes could be done to further improve upon the system.

Discussion

The representative model of the camera suspension system included a spring that represented the suspension itself, a base plate the spring were mounting on, a platform the springs attached to, vertical rails the platform rode upon, a mass representative of the camera mass, and an adjustable damper. Using this model, an accelerometer was place on the platform and then data collected from it. Six different configurations were tested:

1. No camera mass, no damper
2. Camera mass, no damper
3. No camera mass, light damper
4. Camera mass, light damper
5. No camera mass, heavy damper
6. Camera mass, heavy damper

Using these six trials, the collected data was used to characterize the suspension's vibration characteristics. Before the six trials, using different masses the spring coeffiecent was measured by statically placing weights on the platform and measuring the displacement. Data was acquired using Siemens LMS Testlab, and in that software the accelerometer was properly setup before the trails using predetermined calibration settings. Each trial was carried out in the following fashion:

1. Camera mass was added if needed, or removed if not needed for trial
2. Damper was adjusted to the amount of damping qualitatively and screwed to platform and test stand if needed for trial
3. The platform was lightly pushed down and then let go to let the platform oscillate.
4. If the accelerometer over-ranged, the platform was pushed down and released again until it is light enough to properly collect data

After all, six of the trials concluded the data was exported from LMS Testlab and imported into MATLAB, where it was post-processed to find the frequency of the oscillations and the damping characteristics. For each trial the acceleration vs. time, acceleration vs. frequency, and the frequency response function were calculated and plotted. The trial data is shown below in Table 1.

Table 1*: Each camera suspension vibration characterization trial and resultant data*

Trial	Fundamental frequency in Fourier transform (Hz)	Damping coefficient	Peak frequency in frequency response function (Hz)
1	17.2	0.0263	27.5
2	12.9	0.0267	19.5
3	17.3	0.0468	27.5
4	12.5	0.0776	19.5
5	17.4	0.0498	27.5
6	13.0	0.0585	19.5

The results shown in the table above qualitatively meet expectations, since the damping coefficient is small in each trial the fundamental frequency is primarily dependent upon the mass attached to the spring. The surprising part is how small the damping coefficient is for all the trials, even the ones with "heavy damping." The damper was adjusted to have heavy damping, but possibly the displacement from vibration was so small that it did not do as much as expected. The damping coefficient was calculated using a log-decrement technique in MATLAB using its symbolic manipulation functions for each trial alongside the local maxima finding functions in MATLAB. The Fourier transform was done using the fast-Fourier transform built into MATLAB, and the frequency response function was calculated by using the spring coefficient calculated earlier, the calculated damping coefficient, and the total oscillating mass. Below in **Figure 1** trial 1's frequency response plot is show. All the frequency response are similar, and so this one can be representative of the other trials as well qualitatively.

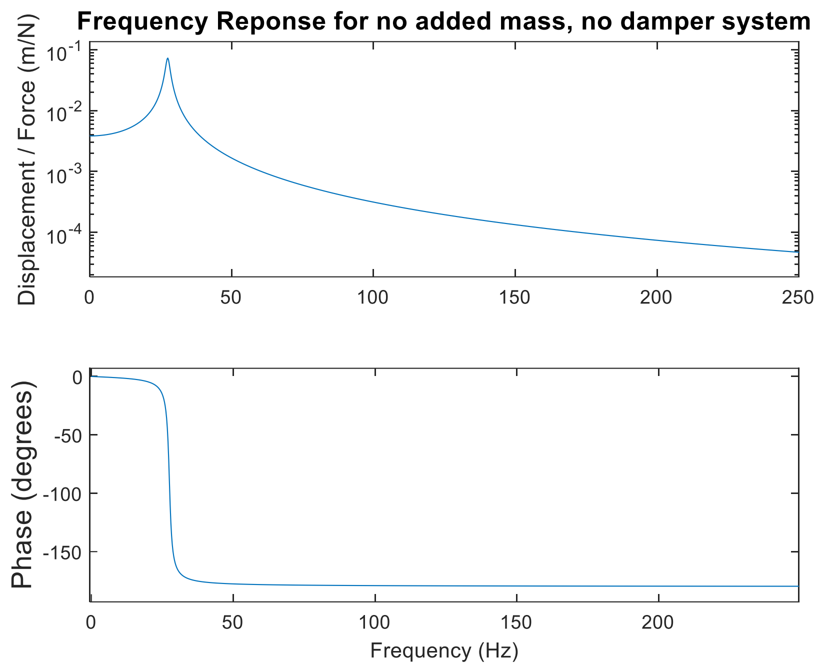

***Figure 1**: Trial 1 frequency response plot*

Based upon the results shown in Table 1, because the quadcopter has two blades and they rotate between 3000 rpm and 75000 rpm as stated in your memo, which correspond to a range of 100 Hz to 250 Hz, the current suspension system will not be effected by the motor rotation, which the frequency response function shows as at 100 Hz the response is about 250 times lower than the peak response, and at 250 Hz even lower. Because of this the current design does not need to change. But the current design's fundamental frequency is very low due to a lower spring constant in the suspension, and the coefficient could be raised with tighter springs in case the weaker springs cannot support the camera properly, but further testing would need to be done to show that.

<u>Action Items</u>

Having this characterization test complete shows that the current design can function as needed, but a more representative test should be done before full production is done. Moving forward a prototype of the real camera mount should be created, and then either placed on a vibration table to precisely control the vibration environment, or place on an actual quadcopter and images taken in either case. During these tests the springs should be observed if they are tight enough to properly maintain control of the camera, outside of the vibration environment tested in this characterization. These items are summarized below as a recommended path forward:

- Prototype suspension system fabricated.
- Prototype validated on quadcopter or vibration table that images are clear.
- Springs are verified to maintain control of the camera outside of a vibration environment.

Thank you for your time, and I look forward to working together with you more in the future,

Ross Smyth