Application Note #CUBE-001

Estimating CUBE System Performance

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ABSTRACT

This application note presents a simplified technique for estimating the single axis performance of a Team CUBE in each of the three linear directions of motion.

The key to applying this technique is knowledge of the location of the payload center of gravity. Without this knowledge, it is not possible to estimate the performance capability of the CUBE.

INTRODUCTION

The most frequent question asked, and one that is most important, is whether the CUBE can do a particular test. In order to answer that question, one needs to know many things about the test and the test article. A clear understanding of how the CUBE works is also essential to answering the question.

ANALYZE THE APPLICATION

First, analyze the vibration to be applied to the test article. Answer these questions:

- Is the vibration single axis translation? If so, which axis?
- Is it three simultaneous translations, with no rotations?
- Is it full 6 degree of freedom motion, including rotations?

Next, assess the test article.

- What is it's mass?
- Where is the Center of Gravity (CG)?

For tests that include 6 degrees of freedom, what are the moments of inertia of the test specimen?

With this information, one can estimate whether the CUBE can do the test or not.

DESIGN OF THE CUBE

Understanding how the CUBE is designed is essential to the remaining analysis. As shown in Figure 1, the CUBE has pairs of actuators aligned along the three principal axes.

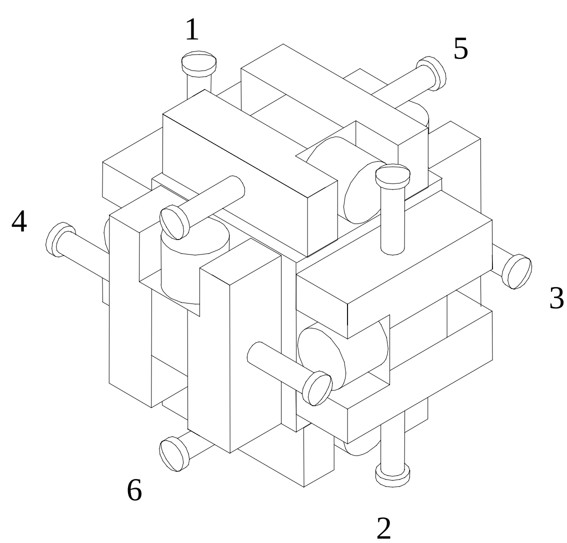

Figure 1 – Arrangement of actuators inside a CUBE module.

Each actuator pair provides force to move the CUBE in translation, along it's respective axis, and generate a moment (torque) about the axis perpendicular to the plane of the actuators***.***

The maximum force available from each shaker is the sine force rating. The actuators can produce a simultaneous translation and rotation, but the maximum instantaneous force from any shaker cannot exceed the sine force rating.

ESTIMATING PERFORMANCE

The general solution involves the simultaneous solving of the six equations of motion with six unknowns to estimate the forces and moments that will be needed to do the test as a function of time. Convert the moments into equivalent linear forces at each actuator. Add the “moment forces” to the linear forces at each time point to find the peak forces required from each of the CUBE actuators. If the peaks exceed the sine rating, the CUBE will not be able to do the test with complete fidelity.

A complete analysis would also decompose the desired motion into equivalent accelerations at each actuator. The actuator accelerations would then be integrated and double integrated to obtain velocity and displacement histories respectively. The velocity and displacement histories are then examined to assure that the peak velocity and peak displacement do not exceed the capability of the CUBE.

Such an exhaustive analysis is time consuming and often impractical. Often a simplified approach is enough to verify that the test demand is within the operational range of the CUBE. For example, at higher frequencies, above 10 Hz, the maximum attainable acceleration for a given loading condition is the parameter of interest.

Further, the rotational motions under these conditions are often small relative to the linear motions. Therefore, a simplified analysis based only on linear motion can be used to estimate the ability of the CUBE to achieve a given level.

SIMPLIFIED ANALYSIS TECHNIQUE

This simplified analysis is done for one direction at a time. The results may be superimposed to determine if enough actuator force is available to achieve the desired level in multiple directions simultaneously. The analysis technique is also useful for estimating the performance capability of the CUBE for a single axis test.

The analysis is based on the equations describing the moments about the combined center of gravity of the payload and CUBE box. This approach yields relatively simple, direct equations for the maximum acceleration attainable in each direction.

Important to note is that the acceleration estimates obtained by this analysis are just that, estimates. Many simplifying assumptions have been made to make the calculations more manageable. While the estimates obtained will be suitable for many applications, remember that the acceleration levels will likely not be achievable at all frequencies. This is due to many factors, including the dynamic response of the fixture, payload, and the CUBE itself.

<u>Location of the Center of Gravity</u>

When no payload is present, the center of gravity (CG) of the CUBE box is located at it’s geometric center (see Figure 2).

The addition of a payload to the top of the CUBE will cause the CG of the combined CUBE box and payload to shift upward, away from the line of action of actuators 3 and 4 as shown in Figure 3.

To calculate the amount of the CG shift use the following equation:

$$z = \frac{W_{payload}(h + y_1)}{W_{payload} + W_{CUBE}} \qquad (1)$$

Where,

z = distance of the combined CG from the plane of actuators 3 and 4.

$W_{payload}$ = weight of the payload in lbs.

h = height of the payload CG from the top surface of the CUBE.

Y_1 = distance from the plane of actuators 3 and 4 to the top surface of the CUBE in inches. For standard CUBE’s use 16.0 inches; for long stroke CUBE’s use 21.5 inches.

W_{CUBE} = weight of the CUBE box in lbs. For standard CUBE’s use 1,000 lbs; for long stroke CUBE’s use 1,300 lbs.

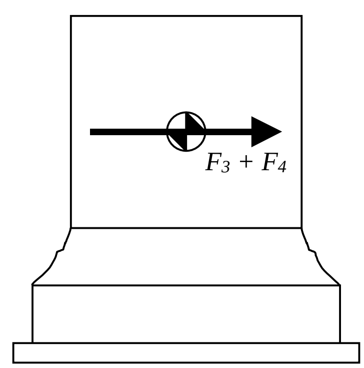

Figure 2 - Location of force vector for actuators 3 and 4.

With the location of the CG known, the analysis can proceed.

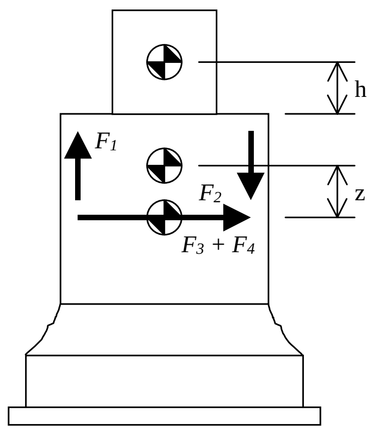

Figure 3 - Illustration of CG shift and moment reacting forces for CUBE with payload.

Vertical Performance Estimation

The simplest axis to work with is the vertical. For the vertical axis the maximum achievable acceleration in g's is determined by the following equation:

$$a_{vert} = \frac{F_{\max}}{W_{payload} + W_{CUBE}} - 1 \qquad (2)$$

where:

a = acceleration in g's

F_{max} = maximum dynamic force output. (3,000 lbs for Model 1's; 14,000 lbs. For Model 3's)

$W_{payload}$ = weight of the payload in lbs.

W_{CUBE} = weight of the CUBE box in lbs. For standard CUBE's use 1,000 lbs; for long stroke CUBE's use 1,300 lbs.

Longitudinal Performance Estimation

Recall that actuators 3 and 4 are responsible for longitudinal motion. These actuators are in a horizontal plane along the midpoint of the CUBE box. In this location, the actuators are driving through the center of gravity (CG) of the box as shown in Figure 2.

Note that the shift in CG location caused by the presence of a payload gives rise to a pitching moment about the new CG location. This moment must be reacted by actuators 1 and 2 to constrain the motion to pure longitudinal translation as shown in Figure 3.

The maximum longitudinal acceleration is limited by the lessor of the moment-reacting capabilities of actuators 1 and 2 and the dynamic force available from actuators 3 and 4. Which of these factors limits the lateral acceleration is dependent on the amount of CG shift, *z*, caused by the payload.

Specifically, if $z > 8.43$, then the moment-reacting capability of actuators 1 and 2 is the limiting factor. If $z < 8.43$, the dynamic force from actuators 3 and 4 is the limiting factor. The value 8.43 is related to the geometry of the CUBE and the spacing between actuators 1 and 2.

For values of $z > 8.43$:

$$a_{long} = \frac{8.43 F_{\max}}{z(W_{payload} + W_{CUBE})} \qquad (3)$$

For values of $z < 8.43$:

$$a_{long} = \frac{F_{\max}}{(W_{payload} + W_{CUBE})} \qquad (4)$$

where:

a = acceleration in g's

F_{max} = maximum dynamic force output. (3,000 lbs for Model 1's; 14,000 lbs. For Model 3's)

$W_{payload}$ = weight of the payload in lbs.

W_{CUBE} = weight of the CUBE box in lbs. For standard CUBE's use 1,000 lbs; for long stroke CUBE's use 1,300 lbs.

z = CG shift in inches (computed from equation 1).

Lateral Performance Estimation

Actuators 5 and 6 are responsible for lateral motion. They are also responsible for reacting the moments created by lateral motion. This "self-reacting" property makes the lateral axis the weakest axis of motion because the other actuators are not helping to react the moments.

Referring to Figure 4, the equations of motion for the lateral direction and the moments about the CG yields, after some manipulation, the following relationship:

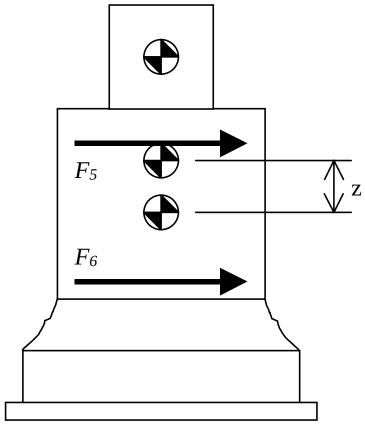

Figure 4 - Illustration of CG shift and moment reacting forces for CUBE with payload.

$$a_{lat} = \frac{F_{\max}}{2(W_{payload} + W_{CUBE})}\left(1 + \frac{y_2 - 2z}{y_2 + 2z}\right) \quad (5)$$

where:

a = acceleration in g's

F_{max} = maximum dynamic force output. (3,000 lbs for Model 1's; 14,000 lbs. For Model 3's)

$W_{payload}$ = weight of the payload in lbs.

W_{CUBE} = weight of the CUBE box in lbs. For standard CUBE's use 1,000 lbs; for long stroke CUBE's use 1,300 lbs.

Y_2 = distance between actuators 5 and 6 in inches. For standard CUBE's use 16.86 inches; for long stroke CUBE's use 26.50 inches.

z = CG shift in inches (computed from equation 1).

EXAMPLE

Given a 1,000 lb payload with CG locate 3 inches above the mounting surface, estimate the maximum sine acceleration that could be obtained on Model 3 CUBE.

SOLUTION

From Equation 1:

$$z = \frac{1000(3+16)}{1000+1000} = 9.50$$

From Equation 2:

$$a_{vert} = \frac{14000}{1000+1000} - 1 = 6.0g$$

Since $z > 8.43$, use equation 3:

$$a_{long} = \frac{8.43(14000)}{9.50(1000+1000)} = 6.2g$$

Finally, from equation 5:

$$a_{lat} = \frac{14000}{2(1000+1000)}\left(1 + \frac{16.86 - 2(9.5)}{16.86 + 2(9.5)}\right)$$
$$a_{lat} = 3.2g$$

CONCLUSION

Although this is not a rigorous analysis of CUBE performance, its simplicity lends itself to frequently needed "back-of-the-envelope" feasibility calculations.

Using a few key pieces of information about the payload and about the CUBE, and the technique presented here, the CUBE user can easily judge the ability of the CUBE to perform a given test scenario.

CONTACT

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