STUDY AND EVALUATION OF CROSS AXES MOTION ON SHAKERS USING DIFFERENT CUBIC FIXTURE DEVICES FOR VIBRATION TESTING

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ABSTRACT

This paper presents a study and evaluation of the cross-axes motion on shakers using different cubic fixation devices for vibration tests of automotive products in general. The cubes were fitted to different shakers and submitted to a sine sweep with known acceleration in a specific frequency range. The cross axes acceleration on the cubes were measured and, based on the results, a quality rank of cube setups was created and an analysis was done to check if the high levels of cross-axes motion were originated from the cube vibration mode, armature vibration mode or from any wear in the shaker armature suspension system.

INTRODUCTION

In the automotive components supply chain, one important step in the development phase is the product validation using samples. Several types of vibration tests are used in the automotive component validation phase. For vibration testing on electrodynamic shakers it is necessary to have a device to fit one or more samples under test (SUT) according to the fixation on the vehicle. One of the most common auxiliary devices is the cubic fixture. However, this kind of fixture can generate cross axes motion due to its vibration modes or due to its influence on the dynamic behavior of the shaker armature, especially if there is wear in its suspension system. The cross-axes motion is one of the parameters that must be controlled according the international vibration standards IEC 60068-2-6 for sinusoidal test and IEC 60068-2-64 for random test.

1. PURPOSE

The purpose of this paper is to evaluate the quality of the vibration test setup based on the cross-axes motion measured on the cubes. The results will be used to propose the best setup configuration to improve the vibration test quality.

2. CUBIC DEVICE

The cubic device is frequently used for vibration tests on electrodynamic or hydraulic shakers to allow the samples excitation on the three orthogonal directions. It needs to be structurally robust so that its resonance frequencies be above the frequency range of the vibration test. It means that the device must have high stiffness and low mass. This can be noticed in the natural frequency equations (1) e (2) for undamped and damped systems respectively according to Vierck [1].

$$\omega_n = \frac{\sqrt{k}}{m} \qquad (1)$$

$$\omega_d = \sqrt{\frac{k}{m}}.\sqrt{1-\zeta^2} \qquad (2)$$

where ω_n is the undamped natural frequency, ω_d is the damped natural frequency, k is the stiffness, m is the mass and ζ is the damped factor.

The cube vibration modes besides affect the vibration on the vertical direction (amplifying and damping the vibration excitation level), they generate lateral vibration that is not noticed if it is not measured. So, be aware the samples on the cube can be submitted to undesirable and stressful lateral loads.

2.1. CUBIC DEVICES CONSIDERED FOR THE STUDY AND EVALUATION

For the study and evaluation, it was chosen three different cubic devices used for vibration tests on electrodynamic shakers.

The figures 1, 2, 3 and 4 show the four cubic devices separately.

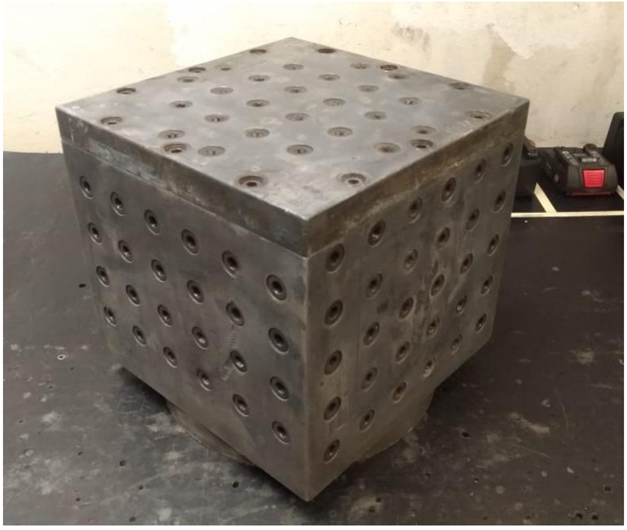

Figure 1 - Aluminum cube device (Cube 1) with steel sleeves and 40 mm of distance between threaded holes.

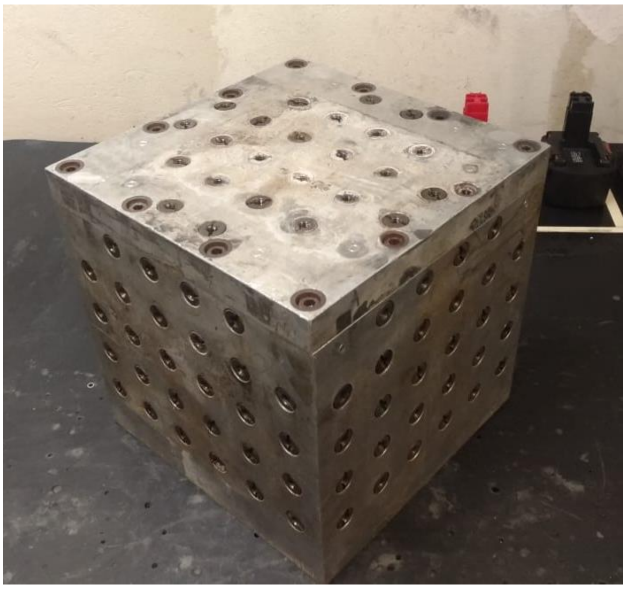
Figure 2 - Aluminum cube device (Cube 2) with steel sleeves and 40 mm of distance between threaded holes

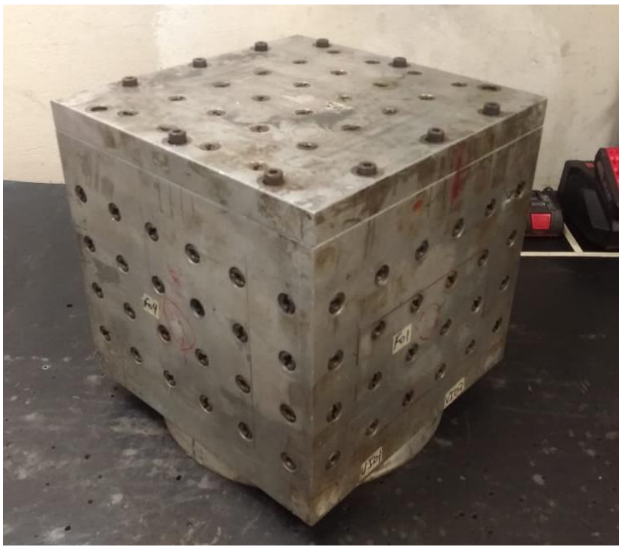
Figure 3 - Aluminum cube device (Cube 3) with steel sleeves and 50 mm of distance between threaded holes

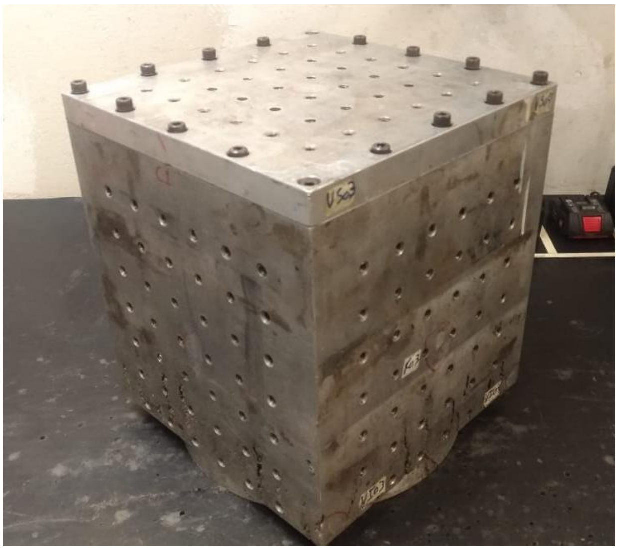

Figure 4 - Aluminum cube device (Cube 4) without steel sleeves and 40 mm of distance between threaded holes

The characteristics of the four cubic devices are shown in the table 1.

Table 1 - Characteristics of the three cubic devices.

Cubic device	Item	Material	Dimension width length height	Threaded holes pattern	Mass
1	Cube	Magnesium AZ31B-F	250 mm 250 mm 250 mm	40 x 40 mm	18,5 kg
	Cover	Magnesium AZ31B-F			
	Sleeves	Steel SAE1020			
	Threaded holes	Steel SAE1020			
2	Cube	Aluminum 6351-T6	250 mm 250 mm 253 mm	40 x 40 mm	27,6 kg
	Cover	Aluminum 6351-T6			
	Sleeves	Steel SAE1020			
	Threaded holes	Steel SAE1020			
3	Cube	Aluminum 6351-T6	300 mm 300 mm 321 mm	50 x 50 mm	45,8 kg
	Cover	Aluminum 6351-T6			
	Sleeves	Steel SAE1020			
	Threaded holes	Steel SAE1020			
4	Cube	Aluminum 6351-T6	303 mm 303 mm 353 mm	40 x 40 mm	48,0 kg
	Cover	Aluminum 6351-T6			
	Sleeves	Steel SAE1020			
	Threaded holes	Steel SAE1020			

3. SHAKER

Shaker is the equipment that generates controlled vibration. There are a lot of models according to the required application. For this study it was considered only the electrodynamic shakers. Its operation principle is very similar to a loudspeaker. The two field coils produce a constant magnetic field and the high current that flows in the armature coil produces a variable magnetic field. The interaction between these two magnetic fields produces the armature displacement where the samples are fitted.

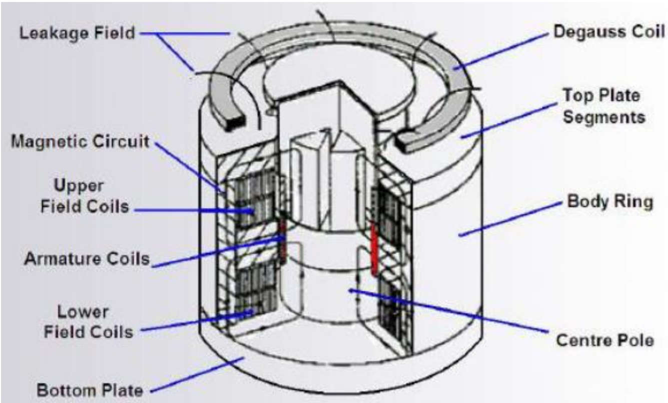

Figure 5 - Electrodynamic Shaker Cross Section

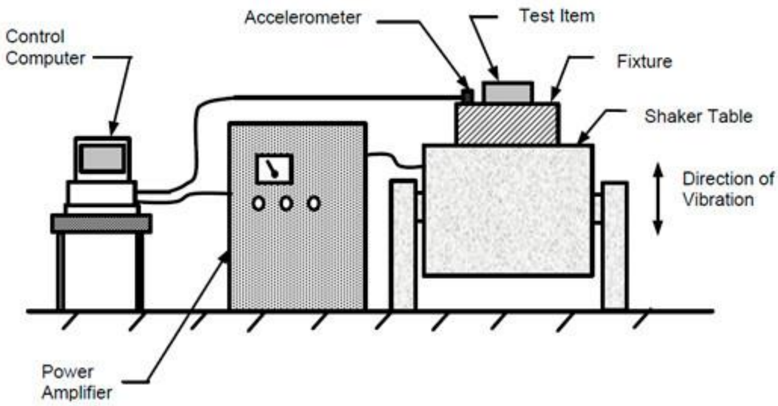

Figura 6 - Typical Vibration System

3.1. SHAKER CONSIDERED FOR THE STUDY AND EVALUATION

It was used three different shakers for the study and evaluation. The shakers are shown in the table 2 and figures 7, 8 e 9.

Table 2 - Characteristics of the three shakers.

Shaker Model	Force [kN]	Table Diameter [mm]	Armature Mass [kg]
LDS V850	22	440	23,84
LDS V954	40	330	26,36
LDS V8	60	440	42,00

Figure 7 - Electrodynamic Shaker LDS V850

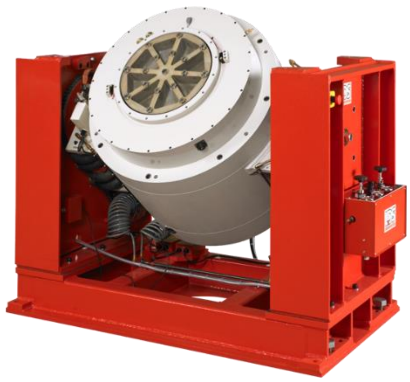

Figure 8 - Electrodynamic Shaker LDS V954

Figure 9 - Electrodynamic Shaker LDS V8

4. STANDARDS FOR VIBRATION TEST

There are several types for vibration tests and the choice depends on the product application. For each test type there is a specific international standard that ensures the test quality.

The main standards are listed in the table 3.

Table 3 – Main standards for vibration tests.

Vibration Test	International Standard
Sinusoidal	IEC 60068-2-6 [1]
Mechanical Shock	IEC 60068-2-27 [2]
Broad Band Random	IEC 60068-2-64 [3]
Mixed mode (Sine on Random)	IEC 60068-2-80 [4]

The cross axes motion is a parameter that must be controlled. According to the standard IEC 60068-2-6 [1] the cross axes motion limit for a sinusoidal test is

$$f < 500\,Hz : a_{cross\ axes\ max} \leq \frac{a_{test}}{2} \tag{3}$$

$$f > 500\,Hz : a_{cross\ axes\ max} \leq a_{test} \tag{4}$$

where $a_{cross\ axes\ max}$ is the maximum acceleration in the horizontal directions and a_{test} is the acceleration of the test in the vertical direction. And according to the standard IEC 60068-2-64 [3] the cross axes motion limit for a broad band random test is

$$f < 500\,Hz : PSD_{cross\ axes\ max} \leq PSD_{test} - 3dB \tag{5}$$

$$f > 500\,Hz : PSD_{cross\ axes\ max} \leq PSD_{test} \tag{6}$$

where $PSD_{cross\ axes\ max}$ is the maximum power spectral density in the horizontal directions and PSD_{test} is the power spectral density of the test in the vertical direction.

5. METHOD FOR MESUREMENT OF CROSS AXES MOTION

The cross axes motion can occur due to vibration modes of the cube, vibration modes of the armature or due to any excessive wear in the armature suspension.

To find the cause of cross axes motion it was proposed to measure the vibration in four points of the cube according to the figure 10.

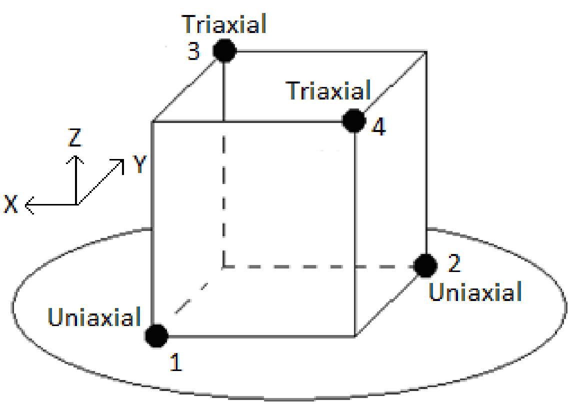

Figure 10 - Measurement points

In order to obtain a good control of the vibration, it was used four channels as control being two channels (Z1 and Z2) at opposite vertices on the bottom and two channels (Z3 and Z4) at opposite vertices on the top of the cube. The vertices alignment on the top and on the bottom are perpendicular between themselves.

The lateral vibration was measured on the opposite vertices on the bottom of the cube being two channels (X3 and X4) measuring the vibration on the X direction and two channels (Y3 and Y4) for the Y direction.

6. EQUIPMENT

For the study it was used the following equipment:

- Electrodynamic Shaker LDS type V850-440 (22kN);
- Electrodynamic Shaker LDS type V954-330 (40kN);
- Electrodynamic Shaker LDS type V8-440 (60kN);
- 2 charge uniaxial accelerometers B&K type 4384;
- 2 charge tri-axes accelerometers B&K type 4326A;
- 2 conditioning amplifiers B&K, Nexus, type 2692-C;
- Shaker Control System LDS type LaserUSB.

7. EXPERIMENTAL RESULTS

The cubes were fitted to the shakers and it was performed one sine sweep with 50 m/s² between 5 and 3.000 Hz limited to 10 mm peak to peak with logarithmic sweep of 1 octave per minute. As mentioned on item 4, this acceleration profile was controlled by the average of the control points: Z1, Z2, Z3 e Z4. The cross axes motion was measured on the monitor points X3, X4, Y3 e Y4.

The graphics are showed in the pictures 11 to 21. The red line is the limit for the cross axes motion for the sinusoidal test according to the standard IEC 60068-2-6.

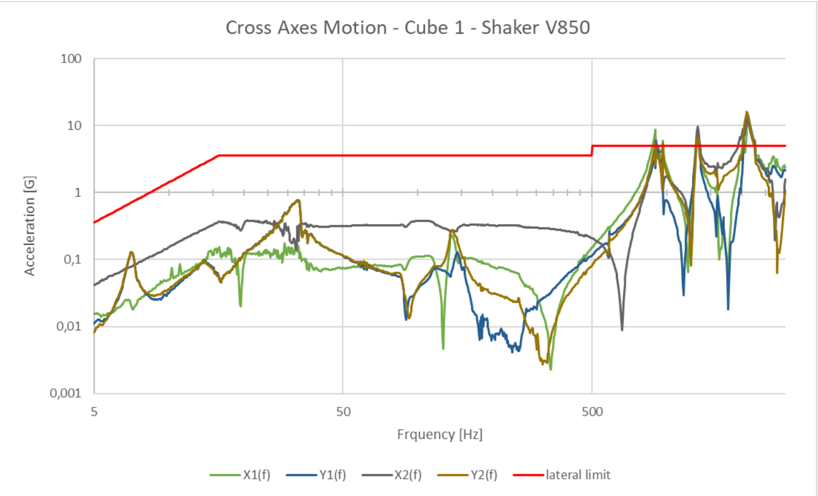

Figure 11 – Cross axes motion measurements from Cube 1 on Shaker V850

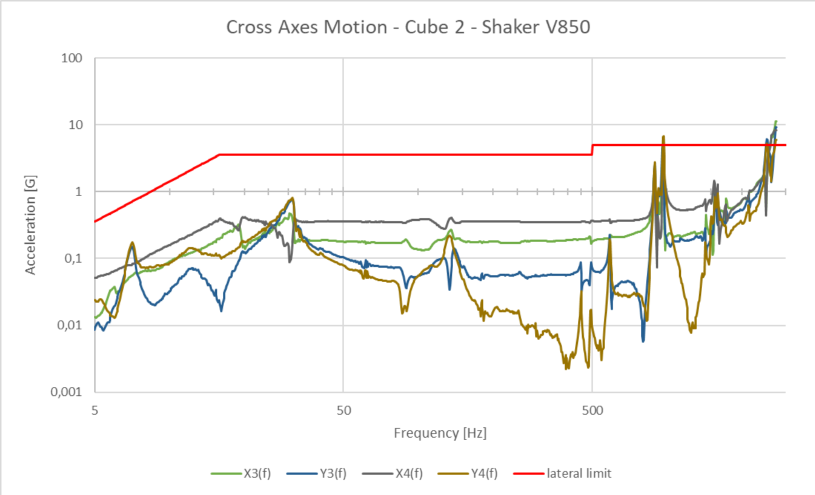

Figure 12 – Cross axes motion measurements from Cube 2 on Shaker V850

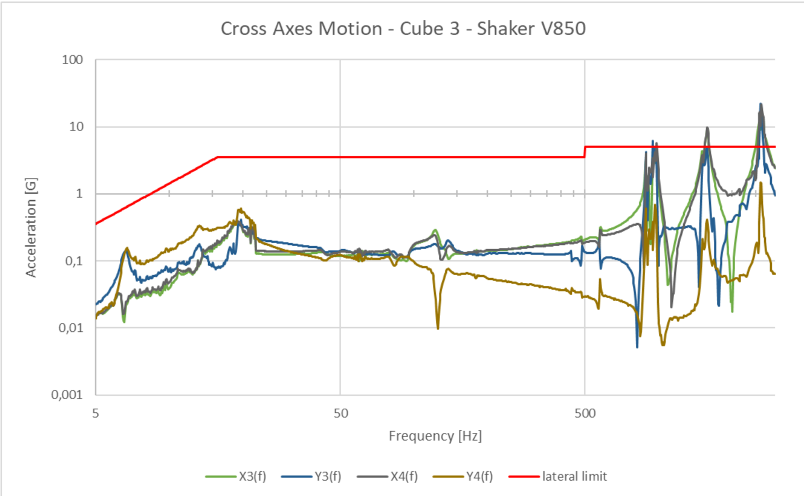

Figure 13 – Cross axes motion measurements from Cube 3 on Shaker V850

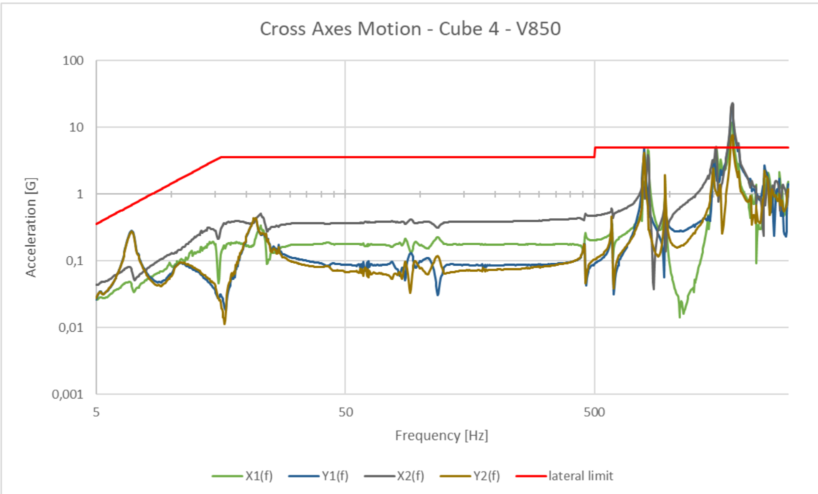

Figure 14 – Cross axes motion measurements from Cube 4 on Shaker V850

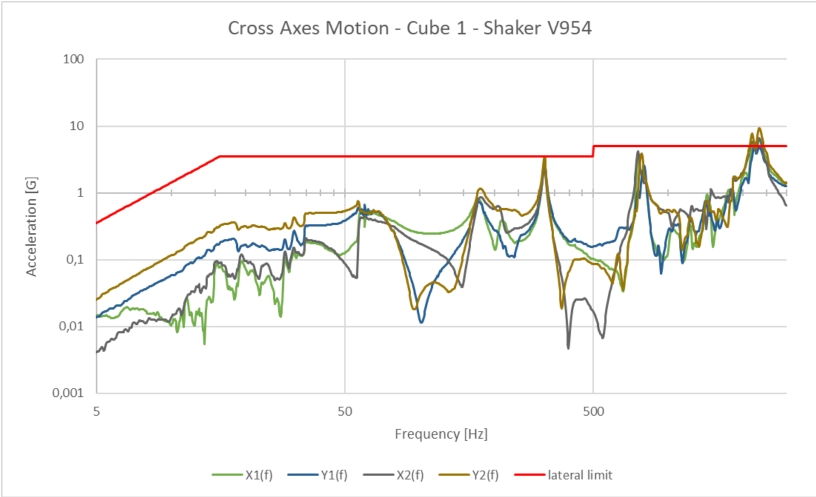

Figure 15 – Cross axes motion measurements from Cube 1 on Shaker V954

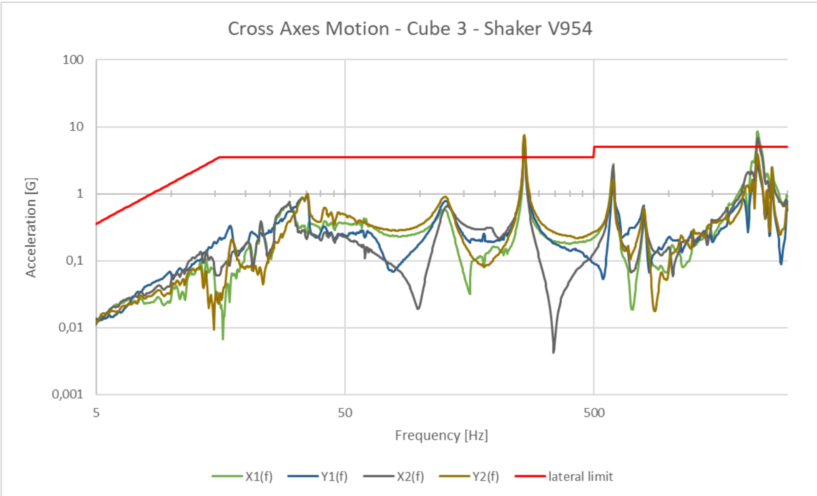

Figure 16 – Cross axes motion measurements from Cube 3 on Shaker V954

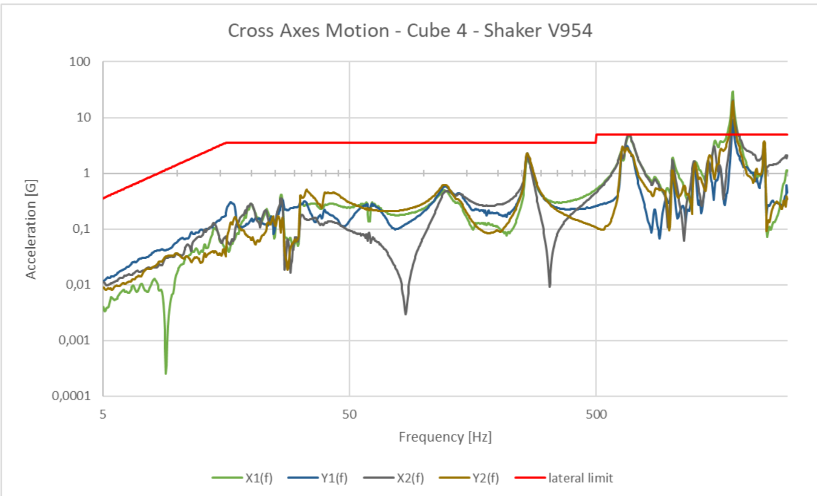

Figure 17 – Cross axes motion measurements from Cube 4 on Shaker V954

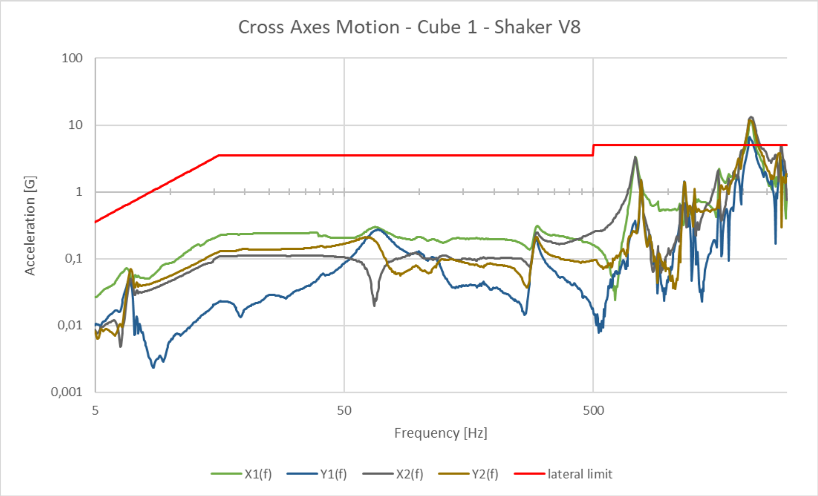

Figure 18 – Cross axes motion measurements from Cube 1 on Shaker V8

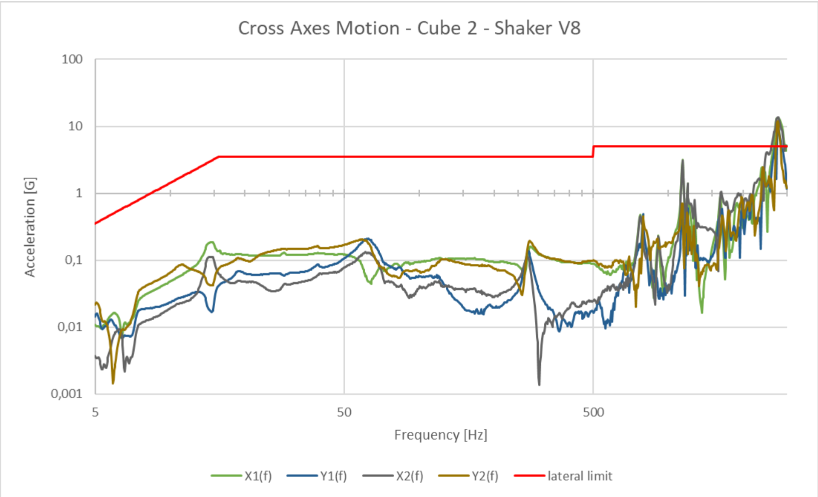

Figure 19 – Cross axes motion measurements from Cube 2 on Shaker V8

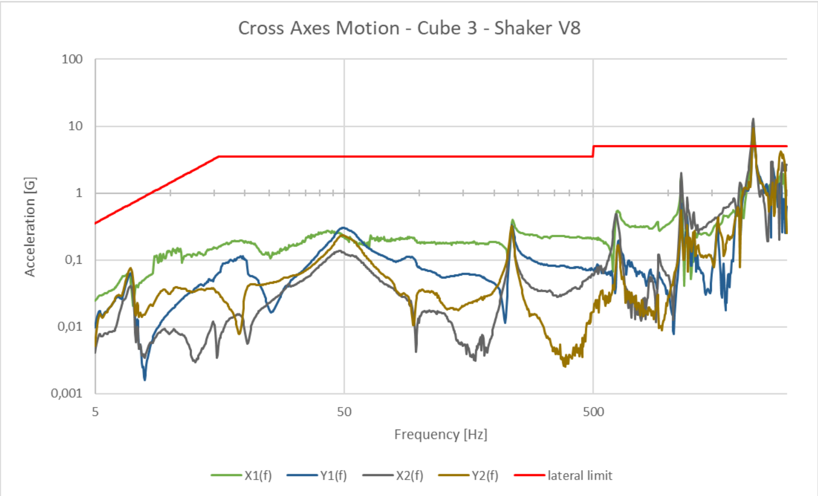

Figure 20 – Cross axes motion measurements from Cube 3 on Shaker V8

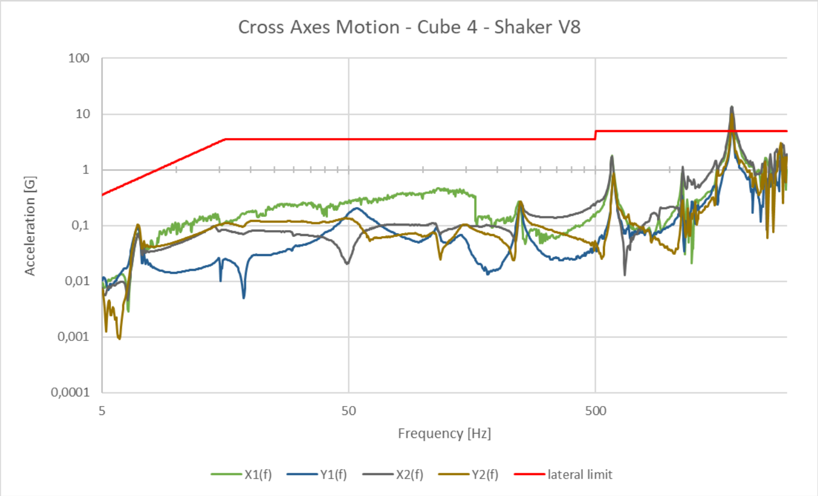

Figure 21 – Cross axes motion measurements from Cube 4 on Shaker V8

8. DATA ANALYSIS

Based on the comparison among the measurements by type of shaker it is possible to identify common frequencies (with very small deviation) from the shaker and different frequencies from the cubes according to the pictures 22, 23 and 24.

The common frequencies are related to cross axes motion due to resonances from armature plus suspension system including rollers and bearings. The comparison lines (in blue color) have a smoot inclination due to the different mass of the cubes. As higher the mass of the cube, lower the resonance frequencies of the system (armature and the suspension system). It can be verified through equation (1).

For the shake V954 there are only three graphics because the holes pattern of the cube 2 does not permit its assembly on this shaker.

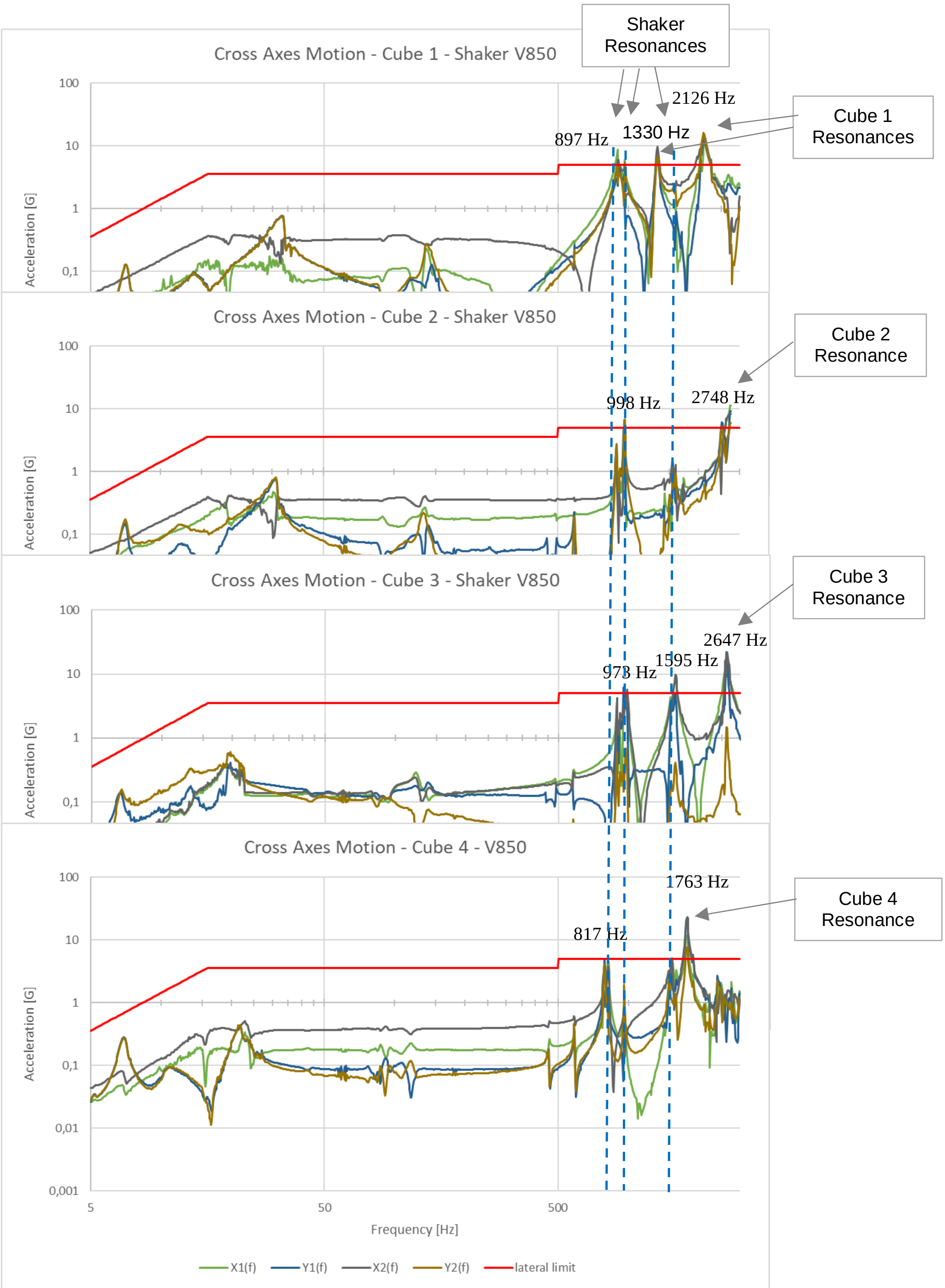

Figure 22 – Frequency analysis for shaker V850

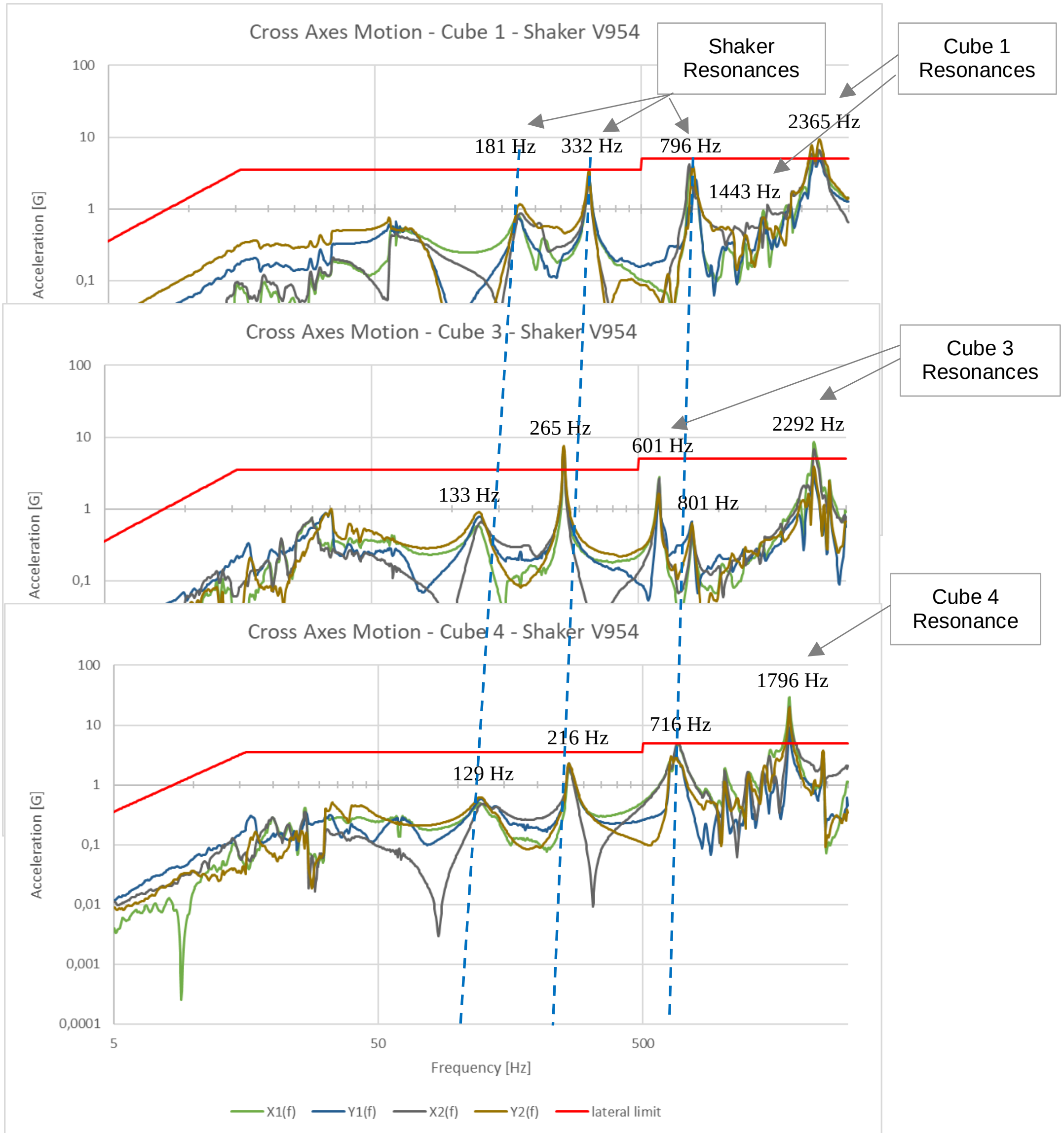

Figure 23 – Frequency analysis for shaker V954

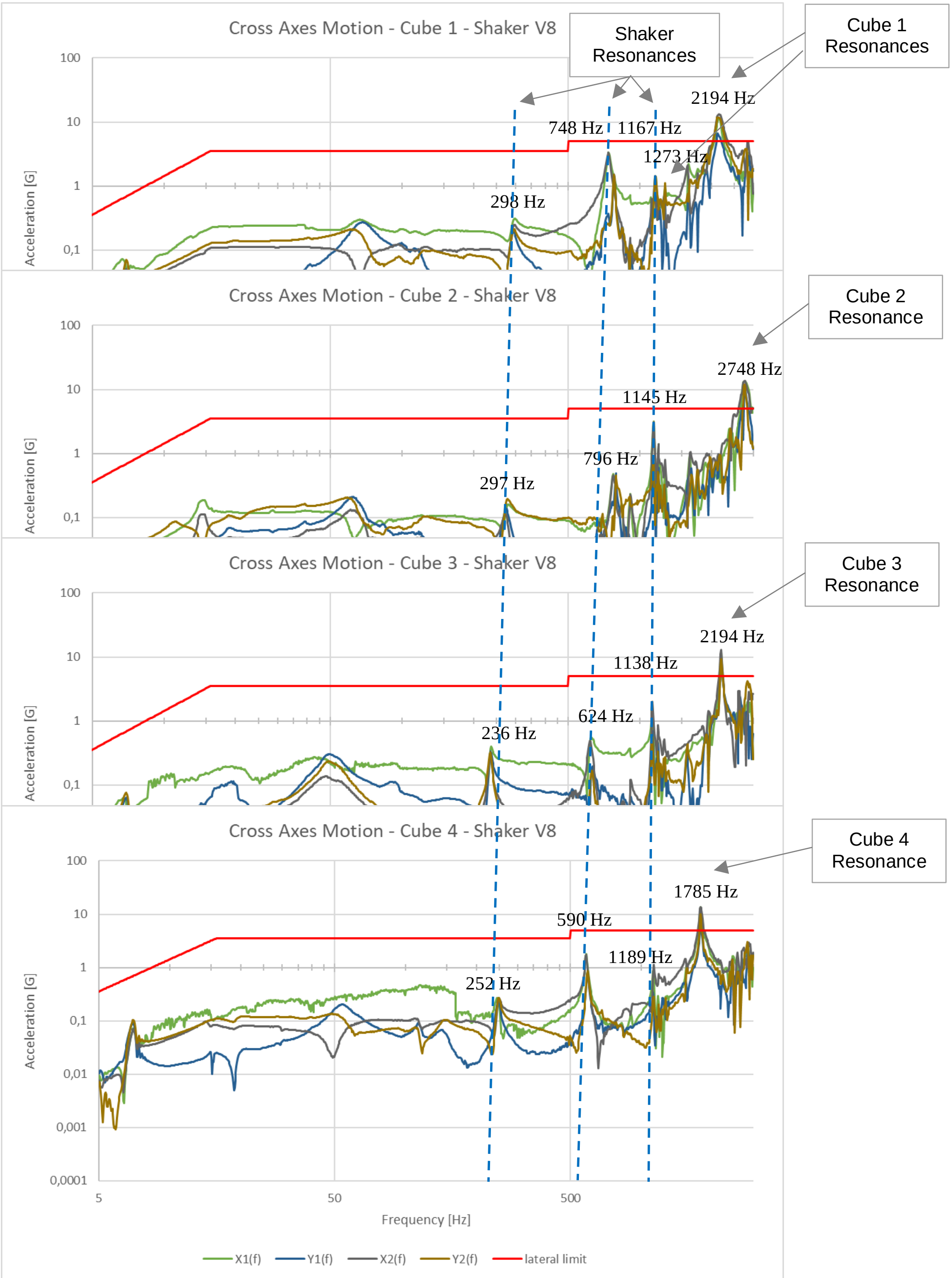

Figure 24 – Frequency analysis for shaker V8

CONCLUSIONS

Cross axes motions are always present in every vibration test and they must be monitored in order to check if the levels are within the limits defined by vibration standards.

Based on the data analysis we can conclude that the better setup for a vibration test is the cube 4 up to 1.700 Hz on shaker V850, cube 4 up to 1.700 Hz on shaker V954 and cube 3 up to 2.100 Hz on shaker V8.

It is important to say that periodic and appropriated preventive maintenance of the shaker is fundamental to keep the cross axes motions at low levels. Shaft, bearing, rollers and flexures wears increase the cross axes motions levels.

Another factor that has a big influence on the cross axes motion is the assembly balance of fixtures and samples on the vibration table. If the fixture is not symmetric, it is necessary to sure that the mass center be aligned to the armature center.

For further or complementary work, it is suggested to use Finite Element Analysis to find the vibration modes of the cubes in order to compare with the experimental results.

REFERENCES

[1] Harris Cyril. **Shock and Vibration Handbook**. 5ª Edição. New York: McGraw-Hill.
[2] IEC 60068-2-6 Standard, **Environmental Testing – Part 2-6**: Tests – Test Fc: Vibration, sinusoidal
[3] IEC 60068-2-27 Standard, **Environmental Testing – Part 2-27**: Tests – Test Ea and Guidance: Shock
[4] IEC 60068-2-64 Standard, **Environmental Testing – Part 2-64**: Tests – Test Fh: Vibration, broad-band random and guidance
[5] IEC 60068-2-80 Standard, **Environmental Testing – Part 2-80**: Tests – Test Fi: Vibration, Mixed mode

DEFINITIONS/ABBREVIATIONS

SUT	Samples Under Test	a_{test}	Acceleration from the test profile
m	Mass	$a_{cross\ axes\ motion}$	Maximum cross axes acceleration
ω_d	Damped Natural Frequency	PSD_{test}	Power Spectral Density from the test profile
ζ	Damped Factor	$PSD_{cross\ axes\ max}$	Maximum cross axes Power Spectral Density
IEC	International Electrotechnical Commission		