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## Nanosatellite Vibration Test Equipmentn

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### Abstract

There is now a considerable increase on the part of universities in the incursion into the development of nanosatellite missions. In the aerospace sector, almost every operation is full of risks and big investments of time and money, and to locate a nanosatellite in orbit, even smaller, is not the exception. Therefore, it is imperative to know if the nanosatellite will be prepared to surpass any critical moment. The rockets or launchers in which the nanosatellites are placed for going to space, produce strong vibrations that can affect the nanosatellite. The primary objective of this work is to design a vibration test equipment that will help determine the resistance of a nanosatellite against the sudden movements that can be experienced within the space launcher. And for that, what is wanted, is that this equipment can generate the vibrations and recreate them as equal as they are in an original launcher. The idea is to guarantee that the nanosatellite will not present problems or failures during the launching and putting in Orbit. This step would be the most critical moment for a nanosatellite, therefore, what is sought with this is to ensure the significant investments of study time and money made by the government or any entity dedicated to the scientific and technological development, since this would have the security that will fulfil the objective for which was planned.

**Keywords:** Vibration test, nanosatellite, cubesat, test equipment, vibration

### 1. Introduction

Nowadays, the aerospace sector has been taking a lot of field in the research areas and development mainly at academic and commercial level. The aerospace application is very useful regarding communications, observation, tracking, information transfer, monitoring and in general any activity that is related to the communication and information of long reach and distance. Given this space revolution, it is needed to be able to transport these space equipment as satellites, telescopes, soundings, unmanned missions, among others. As a consequence of this need, we had to design and build vehicles that transport space cargo from the Earth to space. These are the so-called "rockets" or space "launchers", which are responsible for placing the different space devices in orbit. These vehicles are currently being presented by companies and the aerospace industry exclusively dedicated to the development of rockets and space launchers. There are different types of launchers, which depend mainly on the application that will be given taking into account the positioning orbit, the weight and dimensions of the apparatus to be transported, and even the cost that will demand the construction depending on the size of the rocket [1].

In the academic sector, significant work has been devoted to the research level to obtain the maximum benefit of the applications in aerospace studies. The development of smaller scale space devices has been developing more frequently in recent years since it is feasible to be able to design equipment and prototypes capable of sending information at high altitude from the

ground. The most particular and typical case that has been carried out is the development of nanosatellites for different functions and applications oriented to the research environment with more exclusively academic purposes than commercial or business purposes. In fact, its design and manufacture turn out to be of little cost in comparison to an ordinary large-scale satellite that can easily exceed millions of dollars in design, construction, and orbital value. Nanosatellites are satellites of small dimensions in scale in centimeters. These equipment operate in the low orbit, and they contemplate a life between 3 and six months, the reason why the nanosatélites are denominated like disposable equipment with different payloads [2]. Since we know the space equipment to be used by specialized institutions or universities, the need to transport them and put them into orbit, we are aware that rocket launchers capable of surpassing the skies and leaving the atmosphere are used, a problem arises in which we will focus hereafter on the present research work. This issue occurs when pitchers, having to have enough power to overcome the gravitational pull of the Earth, cause an excessive vibration from the propellers and the resistance of the air to rise at more than 20000 kilometers per hour. This vibration, directly and indirectly, affects the payload since it is induced by the rocket to the same, being able thus to damage it or in the worst of the cases to destroy it, having as considerable economic losses and invested the time of work.

Having established the general problem of research, we can determine the primary objective of this study and proceed to mention the methodology that will be

carried out in the development of the entire work. The central purpose of this work is to design a vibration test equipment to determine the strength and operability of a nanosatellite in the face of the strong vibrations that it experiences in the launcher. In the first place, it is imperative to seek all the information necessary to obtain an overview. Following this important information, the first phase is related to the different space launchers, it is necessary to take into account their technical specifications of operation, and it is determined in which it will be based to reproduce its environment of vibration during the transport and orbit of its load.

## 2. Methodology

The methodology used in the present research lies primarily in the search for information such as bibliographical sources, theses, articles or other research related to the subject of interest. That can provide us with the necessary information both in the generation of vibration and in banks vibrator, then run and start with the development of the design having a bright idea that is what we want to accomplish. Following this arduous but necessary first step, we will identify the software programs that will be used to carry out the mathematical modeling, the structure analysis in response, the design of the equipment itself, and the structural and electronic simulation. Firstly, it is necessary to identify and characterize the vibration situations and for this, firstly, different pitchers are compared and then chosen with the one that has the best technical specifications of operation that are suitable for the particular purpose of this research, as mentioned above.

Having selected the appropriate space launcher to be able to shape their vibration situations considering the weight and dimensions of the payload, we proceed to perform the mathematical model of the vibration structure, after having the necessary mathematical model and the respective equations, is established the design of the electrodynamic exciter equipment, the LMS Imagine.Lab Amesin R15 software is used for this after the design the results obtained are analyzed by entering the appropriate values in the machine comparing them with a real electrodynamic exciter.

Finally, we present the results obtained in the present research, the conclusions and recommendations to be proposed mentioning the contributions and the purposes reached of the one whose purpose was the realization of this article.

### 2.1 Identify and characterize vibration situations

For the development of this first part as indicated textually, we have the requirement to identify and

describe the critical conditions of vibration, and for this, it is necessary to have the technical data of the same launcher that will carry the payload, in this case, a nanosatellite CubeSat of a unit. In this way and having these references or technical specifications we can focus on a clear perspective of the frequencies that we need in vibration and that allows us to recreate them since they are the same frequencies of the rockets exposed in their manuals by the same manufacturer.

Different launchers will be considered with their respective manufacturers and then select one of them that will be taken as a reference. It will have higher performance or provide a better feature regarding the application, which is to transport a smaller satellite and take it out of the Earth's atmosphere, placing it in the LEO orbit which is where a nanosatellite of these characteristics and specifications usually works.

#### 2.1.1 Soyuz

First, the "Soyuz" rocket of the European space company Arianespace is selected, to analyze its characteristics and work operation. This launcher has its origins in the former Soviet Union since the design was based on an intercontinental missile of that time. In addition to this, this launcher marks a legacy in aerospace history by transporting and locating the first artificial satellite, "Sputnik", in 1957, as well as the first man in space who was Yuri Gagarin in 1961. This vehicle has performed a different range of missions in different orbits as well as in low orbit (LEO), medium orbit (MEO), geostationary orbit (GEO), among others [3].



Figure 1: Soyuz launcher.

Source: [www.infofet2012.blogspot.pe](http://www.infofet2012.blogspot.pe) [4]

Sinusoidal excitations affect the launch vehicle during the flight to the engine (especially in the atmospheric flight), as well as in some of the transitory phases. The typical duration of this trip is 6 minutes.

For the single configuration spacecraft to meet defined and stated rigidity requirements, it must tolerate the equivalent sine-wave vibration limits at the interface of the craft to the adapter. These levels must be taken into account for the design and dimensioning of the spacecraft. These are shown in the following tables [3].

Table 1: Vibration Frequency Bands

FREQUENCY BAND (Hz)					
1 - 5	5 - 10	10 - 20	20 - 30	30 - 40	40 - 60
60 - 100					

As next point, we have random vibrations.

The random waves at the base of the craft are generated by the operation of the propulsion system and by the vibro-acoustic response of the adjacent structure. Given this, maximum levels of excitation are obtained during the flight of the first stage. The following table shows the frequency vibration levels along the three axes.

Table 2: Random Vibration Frequency Bands

FREQUENCY BAND (Hz)					
20 - 50	50 - 100	100 - 200	200 - 500	500 - 1000	1000 - 2000

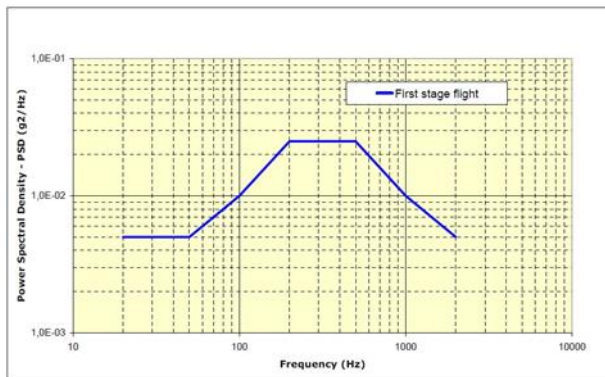


Figure 2: Random vibration at the base of the spacecraft.

Source: Soyuz rocket manual.

As we can see in the figure, the scale of the frequency range of random vibration starts at 20 Hz and extends to 2000 Hz, but with different level of power spectral density.

### 2.1.2 Vega

Secondly, we have the launcher rocket "Vega" from the same aerospace company Ariespace. This launcher has very particular characteristics and

necessary to use it in different transports of a small and medium load. The Vega program originated in the early 1990s when studies related to the complement of the Ariane family were carried out, where it was intended to have a small launch vehicle using Ariane technology. El Vega began as an Italian space program of the company BPD Difesa Spazio who proposed in 1988 a space vehicle to the Italian Space Agency (ASI) to replace a US space launcher. By a new one that was based on the Zefiro engine developed from the experience of the Ariane [5].



Figure 3: Vega space launcher.

Source: www.esa.int [6]

The Vega launcher consists of three stages and mainly of the following components. A lower composite consisting of three solid fuel stages, a payload fairing adapter, a payload dispenser with separation system, a variety of different adapters, distributors and used structures [5].

Each stage of the rocket has its propulsion, taking it to the specified orbit. The Vega launcher can carry loads of up to 1500 kg, making it ideal for carrying light loads in generally low operating orbits [5].

Sinusoidal excitations affect the launch vehicle during its flight because of the engine (mainly in the atmospheric flight), as well as some of its transitory phases. For the single configuration spacecraft to meet the defined rigidity requirements and avoid dynamic coupling, it must be designed with a structural rigidity that ensures it [5].

Table 3: Vibration frequency bands.

FREQUENCY BAND (Hz)			
1 - 5	5 - 45	45 - 110	110 - 125

Continuing with the environment, there are random vibrations.

The random vibrations at the base of the craft are generated by the operation of the propulsion system and

by the vibro-acoustic response of the adjacent structure. Given this, maximum levels of excitation are obtained during the flight of the first stage. For payloads above 300 kg, the manufacturer mentions that the broadband vibrations are covered by the acoustic environment [5].

Table 4: Random vibration frequency band.

FREQUENCY BAND (Hz)						
20 – 50	50 – 100	100 – 200	200 - 500	500 – 1000	1000 - 2000	

Concluding all of the above, it can be determined that the differences between the vibration and frequency parameters in which these launch vehicles operate are not significant since they cover a range from 20 Hz to 2000 Hz with time variant proportional to the increase in frequency. However, the amplitude of vibration between one and the other is affected and mark some distinctions, which can be seen in the spectral graphs, both longitudinally and laterally.

Therefore, we conclude with the purpose of the information process with the selection of the space launcher that will be used as a reference to reproducing the vibrations it produces in the actual flight process. This chosen launcher is the space launcher Vega. It presents better performances and alternatives that are appropriate to the application that would be given, since of the two launchers that were presented in this objective. This vehicle has features oriented to the transport of relatively (up to 1500 kg), which prove to be accurate for sending and positioning a nanosatellite in orbit without problems.

Therefore, the development of following objectives will be realized in function of the vibration generated by a vehicle launcher Vega. [3] [5]

### 2.2 Structural approach and mathematical analysis.

Continuing with the development of the present research, we proceed to select the structural and functional model that will be based on the design to be performed to ensure the purpose set out optimally. Therefore we will be based on an equipment of industrial use but also has a direct application in the aerospace sector. This device turns out to be an "electrodynamic exciter or exciter" since this equipment delivers a variable range of vibration to very high frequencies and can position in different directions, which is very useful.

#### 2.2.1 Electrodynamic stirrer

Electrodynamic stirrers generate motion using the principles of operation of an electric motor. Specifically, the excitation force occurs when a variable

current passes through a moving coil placed in a magnetic field.

A constant magnetic field is created by a stationary electromagnet consisting of coils on the ground located on a ferromagnetic base. The stirring head, which is supported by a mounting flex, is also located in a loop. When the electrical excitation signal passes through this excitation coil, the stirring head is set in motion.

This agitator marks its difference from the others to be able to produce a very high vibration of up to 10000 Hz. However, the range that is commonly used practically is between 2000 to 3000 Hz with a displacement of 2.5 cm being able to generate forces up to 450 lbf.

Operation goes back to the passage of current through a coil placed in a magnetic field. That is where a current proportional to the current  $I$  (amperes)  $F$  (Newtons) force and intensity of magnetic flux  $B$  (tesla, occurs  $1\text{Kg} \cdot \text{s}^{-2} \cdot \text{A}^{-1}$ ), which accelerates the component placed on the agitator table [7].

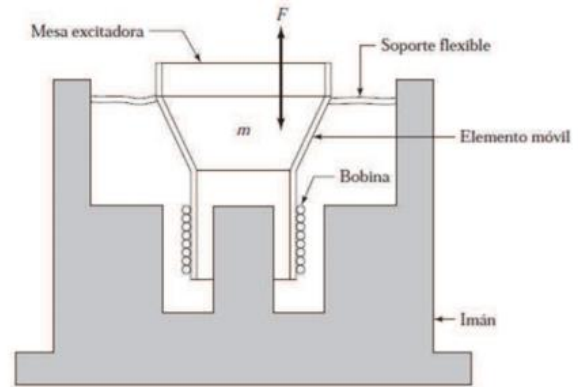


Figure 4: Schematic of an electrodynamic vibrator  
Source: Rao, 2012 [8]

#### 2.2.2 Mathematical model

The mathematical model of the electrodynamic exciter is proposed both in structure and in the electrical part which turns out to be an important variable to consider. Starting from the second law of Newton is obtained. [9]

$$\sum F = m * a$$

(a):

$$m_c \ddot{X}_c + \dot{X}_c C_c - C_c \dot{X}_t + K_c X_c - K_c X_t = F$$

(b):

$$m_t \ddot{X}_t + \dot{X}_t (C_s + C_c) - \dot{X}_b C_s - C_c \dot{X}_c + X_t (K_s + K_c) - K_s X_b - K_c X_c = 0$$

(c):

$$m_b \ddot{X}_b + \dot{X}_b (C_b + C_s) + \dot{X}_t C_s + X_b (K_b + K_s) - K_s X_t = -F$$

The modal analysis of these equations is performed taking into account the electromagnetic force.

$$F = B.L.n.i$$

$$B.L.n = K_f$$

Where the following matrix is obtained.

$$\begin{bmatrix} m_c & 0 & 0 \\ 0 & m_t & 0 \\ 0 & 0 & m_b \end{bmatrix} \begin{bmatrix} \ddot{X}_c \\ \ddot{X}_t \\ \ddot{X}_b \end{bmatrix} + \begin{bmatrix} C_s & -C_s & 0 \\ -C_c & C_c + C_s & -C_s \\ 0 & C_s & C_b + C_s \end{bmatrix} \begin{bmatrix} \dot{X}_c \\ \dot{X}_t \\ \dot{X}_b \end{bmatrix} + \begin{bmatrix} K_c & -K_c & 0 \\ -K_c & K_s + K_c & -K_s \\ 0 & -K_s & K_b + K_s \end{bmatrix} \begin{bmatrix} X_c \\ X_t \\ X_b \end{bmatrix} = \begin{bmatrix} 1 \\ 0 \\ -1 \end{bmatrix} K_f i$$

This results in the equation of the second order that has been intended to arrive.

$$[M][\ddot{X}] + [C][\dot{X}] + [K][X] = [F]$$

With this factor, we can determine critical parameters such as mass, stiffness, elasticity constant, etc. which will be useful when comparing it to a real driver in operation.

### 3 Design of exciter equipment

Continuing the development of this research, the design of mathematical model in LMS Imagine.Lab-made Amesin R15 [9] software is presented. Since this way the physical and mathematical representation of electrodynamic exciter shown with an optimal performance that can provide very accurate data and approximations and thus show reliable operating parameters, such as the conditions of acceleration or force concerning time during the oscillatory movement.

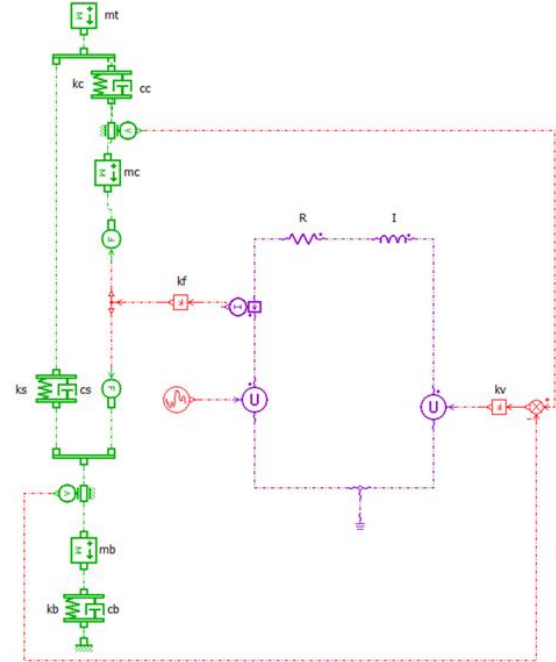


Figure 5: Design of the electrodynamic exciter.

In the software can be input data from different magnitudes and driving parameters according to a real electrodynamic exciter such as mass, stiffness, elasticity constant, inductance, resistance, voltage, etc., and compare viewing frequency response versus time. In Figure 11 we can see that the design is divided into three parts that will have variable behavior. The first composed by "mb" that corresponds to the body of the exciter and that includes the magnets. The second "mc" corresponding to the mass of the winding and the third "mt" corresponding to the surface where the test weight (nanosatellite) is supported, also the electrical circuit that feeds the coil is added.

### 4. Conclusions

You can check and verify that the design complies with the necessary parameters and comparable appropriate characteristics with real electrodynamic exciter regarding authenticity is concerned, since their values as mass and stiffness approximating the actual values that will work. That is, the design shows the optimal working representation of an electrodynamic driver that resembles a real one. So you can set mechanical, electrical and constant coupling parameters according to actual data that you can expect a driver and thus be able to work on the design with the assurance of an efficient operation according to the requirements established at the time of its construction.

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