Didactic bench for the analysis of cantilever beams submitted to harmonic vibrations from a cam-follower system

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Abstract. Practical classes are essential for learning in engineering courses, but there are many difficulties in implementing them. Therefore, the development of equipment, which help in carrying out practical activities in the course, facilitates the absorption of theoretical concepts. This work describes the procedures adopted for the development of a didactic bench for vibration analysis. The system is consisting of a cantilever beam, where the shaker is represented by a cam-follower system that apply a harmonic excitation force at the free end of the beam. The project involved the implementation of a frequency control system and the development of routines on the software LabVIEW for data collection and signal process from the bench. The LabVIEW application allows comparisons between the theoretical signal simulated from the mathematical modeling of the beam and the experimental signal collected by the accelerometer sensors. The construction of the didactic bench was satisfactory because the cam-follower system was able to generate the harmonic force and control its frequency. In addition, the application developed in LabView offered a simple interface to help students absorb the concepts of vibration and machine design.

Keywords: beam, mechanisms, cam-follower system, vibration analysis, data acquisition.

1 Introduction

Most of the time, vibration in machines occurs in a forced way and if the frequency of this excitation coincides with the natural frequency of the system [1], the response will have high values. Thus, during the development phases of a project, it is vital to know the dynamic behavior of the new structure. To predict this behavior with a given initial condition, it is necessary to perform a mathematical modeling of the system. The modeling is intended to represent all important aspects of the structure to obtain the equations that govern its dynamics [1]. In addition, carrying out the experimental analysis allows the comparison between theoretical and practical results, thus being able to validate the mathematical model.

In mathematical modeling, several mechanical systems can be represented by a beam, such as an airplane wing. Therefore, this work describes the development of a didactic bench for the analysis of cantilever beams submitted to harmonic vibration. The built bench allows mounting a cantilever beam where its free end is submitted to a force from a mechanical vibration exciter. The excitation is produced by the cam-follower system where a spring transforms the Simple Harmonic Motion (SHM) of the follower into a harmonic elastic force. Its frequency is regulated and controlled by a microcontroller, acting on the cam engine. An accelerometer coupled to the beam is used to determine the accelerations at each point of the structure. The signal from this sensor is treated and analyzed by the application developed in LabView that builds time-domain and frequency-domain graphs.

2 Methodology

In this topic, the important steps for the development of the test bench will be described and an approach about its various elements will be made. For a general understanding of the bench system, the block diagram was created and shown in Fig. 1. This represents in structural blocks the main components of the test bench with its main connections and the external devices that communicate with it.

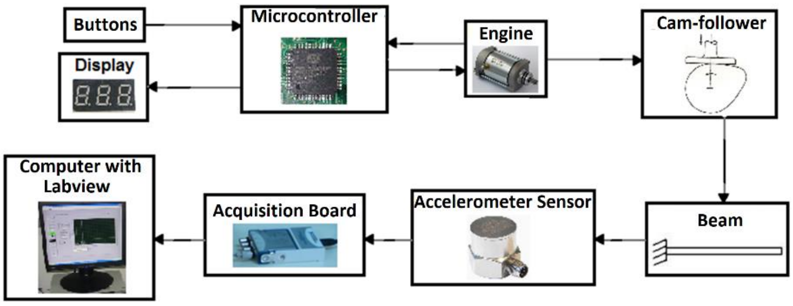

Figure 1. Functional block diagram proposed for the project.

2.1 The mounting of the test bench

The construction of the test bench was carried out according to the design projected in the Solidworks, as shown in Fig. 2. The beam support has a height of 35 cm and it is designed to allow analysis of multiple beams.

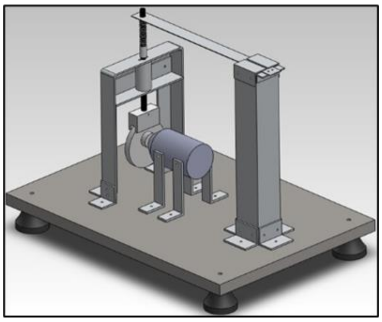

Figure 2. Test bench design created in Solidwork.

The test bench should interfere as little as possible with the beam's vibration response, so the base was made of a carbon steel plate with a thickness of 1.5 cm and a weight of 21 kg. In addition, four vibration dampers were attached to the bar and together with the weight of the bar, they prevent the transfer of vibration to the ground and consequently the displacement of the structure.

2.2 Cam-follower system design

The cam-follower system is a mechanism that transforms rotations into linear movements or other rotations of generally limited amplitude [3]. There are several types of cam-follower system, but in order to achieve a simple harmonic force, the follower must have an acceleration of the same nature. Therefore, the follower was chosen as being of translation and flat face, and the cam as being radial and eccentric. This scheme performs a SHM only with the circular disk. This avoids building a profile related to the SHM, through the graphical or algebraic method which machining is difficult to carry out.

The built cam-follower system has a circular disc with a diameter of 8 cm and an eccentricity of 1 cm. Its coupling with the engine is mobile to allow the use of cams of different eccentricities in order to change the force amplitude. Due the cam-follower system is of the force joint type, a spring with an elastic constant equal to 80 N/m was used to maintain the contact between the cam and the follower.

2.3 Instrumentation and control

In this topic, the components of the engine speed control system and the data acquisition of the test bench are specified. The component responsible for motor speed control is the microcontroller. In the project, the MSP430 was used, which has a low consumption in the order of 250 µA/MIPS, a low operating voltage, and a high performance that allows the realization of complex tasks with simple codes [4]. This microcontroller was programmed in the C language.

The accelerometer chosen was the type 4513-001 from Brüel & Kjaer, which has a sensitivity of 100 mV/g ± 10%, a measurement limit of ± 50 g and a frequency response of 1 to 12000 Hz ± 10% [5] . This sensor is a piezoelectric accelerometer with a charge-sensing amplifier to increase the very small voltage produced by the transducer [5]. To perform the measurements through the LabVIEW platform, the NI USB-9234 acquisition board was chosen, which consists of the NI USB-9162 portable platform and the NI 9234 module. The NI 9234 module has a 24-bit resolution and a voltage range ±5V. Its input channels acquire sampling rates from 2 to 51.2 kS/s simultaneously. In addition, it has a signal conditioning for accelerometers with a current selector between 0 and 2 mA through LabVIEW.

The application developed for acquisition and analysis of vibration signals was based on the LabVIEW platform. LabVIEW is a data flow-based graphical programming language that uses icons to create applications [2]. The purpose of the application was to monitor the experimental vibrations and offer the user the visualization of the graphs in the domain of time and frequency, in acceleration, velocity or displacement. An interface for the simulation was also created to allow the understanding of the behavior of the functions found in the mathematical modeling, as well as its comparison with the experimental results.

For the construction of the signal generated by the application simulation, the beam movement function was used, due to the harmonic excitation of the spring elastic force. This function was found through mathematical modeling and is related to the sum of infinite modes of vibration. Therefore, in order to know how many vibration modes would be considered in the construction of the simulated signal, a numerical analysis of the calculations was performed using the wxMaxima program.

3 Results

3.1 Final appearance of the test bench

Once the construction of the test bench is finished, the figure shows its final appearance with the signaling of its main elements. The test bench proved to be quite robust, with no gaps and weighed a total of 23 kg, so it did not offer significant interference from vibrations in the cam-follower system, considering that the analyzes are in the didactic scope.

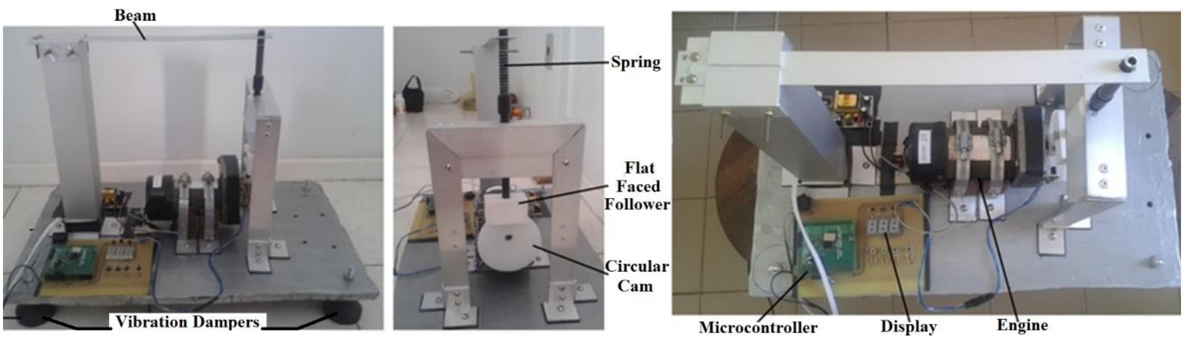

Figure 3. Final appearance of the test bench.

The cam-follower system was able to perform the simple harmonic movement, without major interference from friction forces and without the presence of gaps. Its frequency controller also proved to be efficient, managing to keep the frequency at the values desired by the user, in addition to offering a simple and easy-to-handle interface.

3.2 Numerical modeling results

The simulated beam has the following characteristics: base = 0.252m; height = 0.0015m; length = 0.2438m; Elasticity Modulus = 7.1·1010 N/m^2; density = 2800kg/m^3; and weight = 0.2744N. With these parameters, it was possible to numerically calculate the first ten natural frequencies and create the real movement curve of the beam. This curve is the sum of the infinite modes of vibration, however, with the result of the numerical analysis shown in Fig. 4, it is observed that the sum of the ten first modes of vibration (green curve) is not far from the result of the first mode (blue curve) and is practically equal to the sum of only three modes (red curve). Thus, it becomes feasible to use only the first three vibration modes to build the simulated signal in the application.

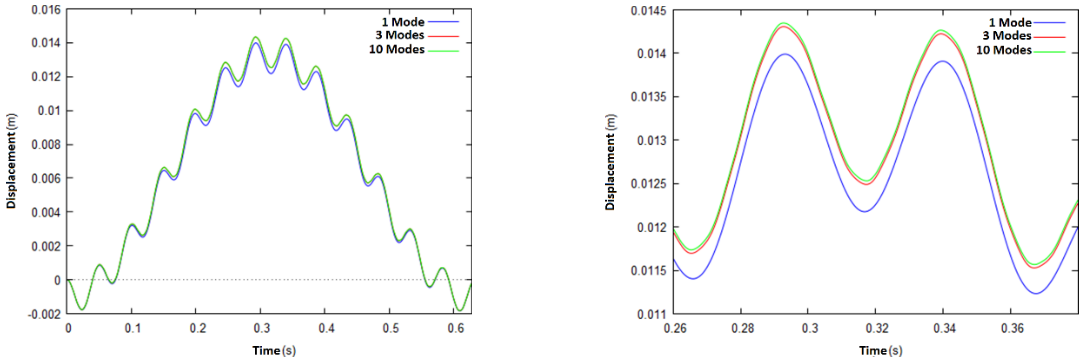

Figure 4. Response for different sums of vibration modes.

3.3 Final application interface

The developed application was named "Programa para Coleta e Visualização de Dados Experimentais" and contains four modules for acquisition and visualization of signals: Visualization of the Acceleration, Visualization of the Velocity, Visualization of the Displacement and Visualization of the Collection. The Acceleration, Velocity, and Displacement modules are similar and feature simulation and experiment options. Fig. 5, for example, illustrates the Acceleration module screen for the experimental analysis.

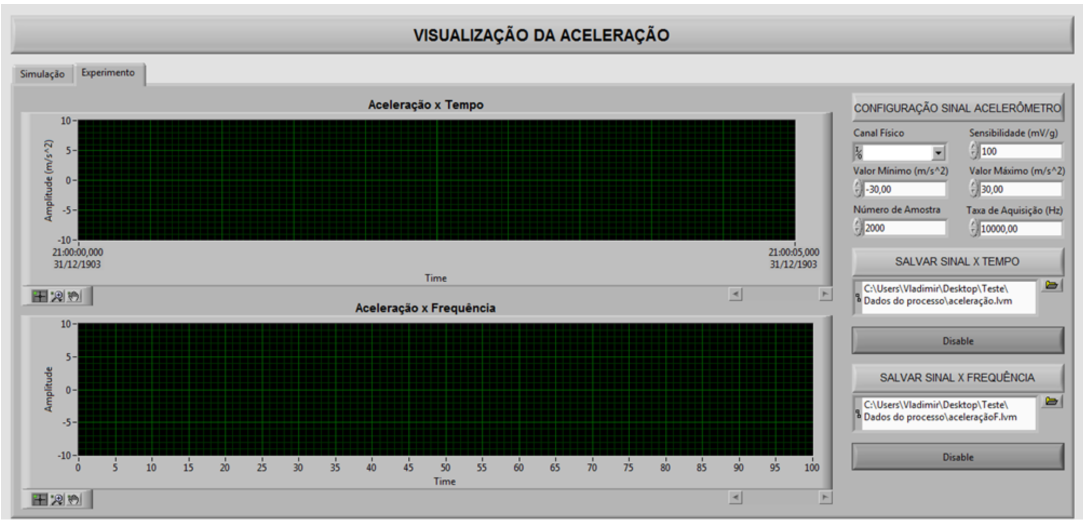

Figure 5. Acceleration view for experiment.

The interface has two graphs that display the accelerometer signal, in the time and frequency domain. This signal is configured through the buttons located on the upper right portion of the panel. Thus, it is possible to determine the channel that will make the signal acquisition, the desired measurement range for the acceleration (m/s^2), the sensor sensitivity (mV/g), the number of samples and the acquisition rate (Hz).

On the Simulation tab, the response referring to the sum of the first three vibration modes and the spectra of the first three natural frequencies is built in the graphs, as shown in Fig. 6. The user is able to determine the system parameters using the buttons located in the upper right portion of the panel. This field allows you to choose beam characteristics such as density (kg/m^3), Elasticity Modulus (N/m^2), height and base of the cross section (m), and weight (N). In addition, it is possible to vary the forced frequency (Hz) and x-position along the beam, and perceive in real time any interference of this variation in the simulated response of the beam.

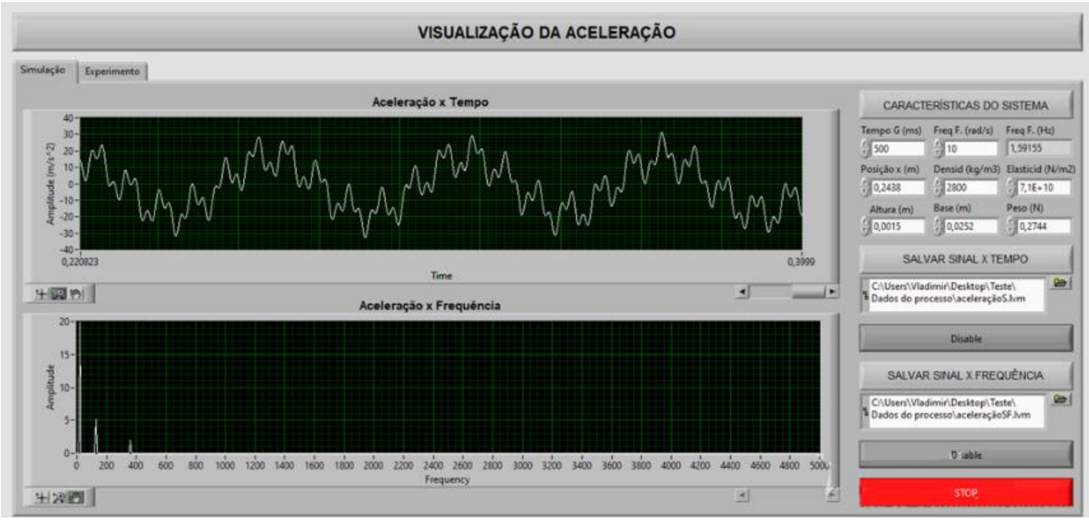

Figure 6. Acceleration view for simulation.

Fig. 6 also shows the result of simulating the behavior of the beam in question. Note that the spectra presented in the frequency graph are located in the values of the three natural frequencies found in the numerical analysis ($\omega 1$ = 128.9 rad/s, $\omega 2$ = 808.3 rad/s, $\omega 3$ = 2263.3 rad/s). This validates the construction of the simulated signal through the mathematical modeling functions of the beam.

4 Conclusions

The test bench proves to be very flexible to experimental tests because it allows the variation of the amplitude and frequency of the excitation elastic force through the cam eccentricity and the engine speed control. This flexibility combined with the application's simulation offer easier understanding and visualization of vibratory phenomena, such as resonance, beat frequency and vibration modes

The application's interface allows the user to compare theoretical and practical results in real time and in a more practical way, through the “Simulation” and “Experiment” tabs. Furthermore, the final version of the application proved to be simple, self-explanatory and able to quickly guide the user through the steps. The developed acquisition system can be transported anywhere if this application is installed on a portable computer, which has a signal acquisition board.

Finally, the development of the test bench allows the student to integrate knowledge from various areas such as vibrations, mechanism, instrumentation and programming, considering that it is possible to understand the mathematical modeling of the beam, analyze the cam-follower dynamics, configure and visualize the accelerometer signal, and manipulate the HMI (Human Machine Interface) of the engine speed control.

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