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A DIDACTIC TEST-RIG FOR TEACHING VIBRATION MODES

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Abstract. *The gap between what is taught at undergraduate classes and what is required in engineering practice often brews disinterest and hinders the students understanding of the subject. In the last couple of decades, many engineering colleges have slowly implemented experimental classes in their schedules to approximate concepts presented in class to practical problems. To this goal, many simple designs can be explored as educational examples of real engineering problems. Such systems should be portable, present high vibration amplitudes and movement ranges, and operate at low frequencies to be easily understood. In this context, an educational test-rig design is presented, favoring the understanding of mechanical vibration modes. The proposed experiment enables the students to witness string vibration modes as a function of an engine rotation speed, which is synchronized with LED lights. As a result, a strobe effect is created, allowing clear visualization of the first few mode shapes. The use of this experiment during undergraduate engineering classes increased the interest of the students and promoted a better understanding of physical and practical concepts. The final test-rig is portable, low-cost, and easy to be reproduced.*

Keywords: *mechanical vibrations, experimental design, learning methods, didactic test-rig*

1. INTRODUCTION

The idea of searching for techniques that may improve the dynamics of college and technical school classes have risen from a high student evasion rate at some institutions. According to researches performed with undergraduate evaded students at CEFET-RJ (Gomes and Bastos, 2016), 57.9% of the students justified giving up the courses due to lack of interest or lack of motivation. In the long term, high evasion rates are costly to the institution, both as financial cost and as a demotivating factor for other students.

Being a common occurrence in many universities in Brazil, student evasion has drawn the attention of researchers and professors alike. In the context of engineering courses, the complexity of the subjects, and the historical factor of them being considered challenging courses present additional problems. Some techniques such as Team-Based Learning (TBL), Ludic Based Learning (LBL), and Project Based Learning (PBL) are useful to overcome the mentioned limitations and to make the classes more interesting for the students.

According to (Michaelsen *et al.*, 2002), the TBL technique consists in applying an individual test for the students, concerning the theory yet to be taught, assuming that all this content has been previously read. After the first evaluation, the students perform the same test, organized as teams. In a third step, they have immediate feedback by using an answer sheet and being capable of measuring how well each student and each team scored the test. At the end of the self-evaluation, the students can write an appeal to claim part of the points of the test, whether they used arguments based on literature. At last, the teacher evaluates the group's performance and explains every misunderstood part.

The LBL aims at teaching the students by using games that interact with the subject that will be presented in class.

According to (Cireceie, 2015), the Ludic process gains progress in student learning through gradual increases in difficulty, as well as the need to apply various skills to win the game. It could be implemented at engineering courses through the use of increasingly complex challenge problems, in a problem-solving oriented course.

Finally, the PBL, according to (Barron and Darling-Hammond, 2008) and (Thomas, 1999), consists of a teaching approach that engages students to solve complex real-world problems related to their future professions. Moreover, (Amamou and Cheniti-Belcadhi, 2018) mentions that this method allows bachelors to acquire knowledge by working together with their peers and interacting with the university environment. The author also affirms that this technique will enable students to develop their creative skills and their study style.

Although the mentioned methods present better practices from the student point of view, the traditional approach of teaching-blackboard notes and oral explanations-still is the most common in the majority of Brazilian universities. For the students, it presents a particular problem in engineering courses, where lectures full of theoretical concepts are the standard, which may be too abstract, complex, or unattractive to promote a good understanding. According to (Vlassi and Karaliota, 2013), in the traditional method, the teacher follows an immutable semester plan, which is proposed at the beginning of the classes. This author and (McCarthy and Anderson, 2000) mention that the professor opinion overlaps the students', forcing them to play the unique role of memorizing and reproducing the content given in class. It is not only ineffective as a teaching method but tends to promote a poor understanding of being unattractive to the students.

In this context, this work proposes the implementation of an educational test-rig used to upgrade the traditional method, drawing students interest during classes, besides promoting a better understanding of the subject vibration modes. The system is designed to be portable, easily understood, low-cost, and easy to be reproduced by other educational institutions. In this project scope, the developed test-rig should also be used in-class during an undergraduate course to evaluate its impact on the student's interest and overall understanding of the subject.

2. METHODOLOGY

The didactic test rig was designed aiming at presenting to the students the natural modes of a rotating machine, as well as permitting them to comprehend how it works. In this way, the test rig is divided into three parts, which are depicted in the figure below:

1. structural supports;
2. dynamic components;
3. electronics.

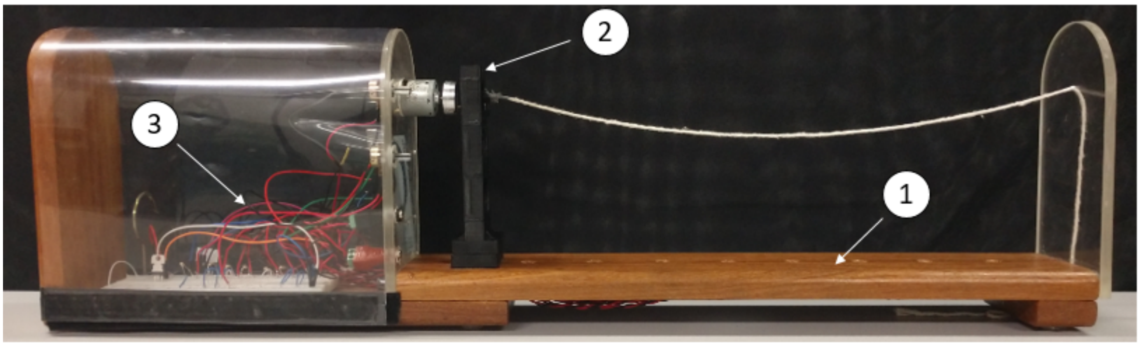


Figure 1: Didactic test-rig overview.

2.1 Structural supports

The structural part of the test-rig is composed mainly of hardwood and acrylic plates, featuring a flexible acrylic cover to protect the circuit parts, while leaving them visible to the public. The mainboard supports the LEDs and two vertical acrylic columns. The secondary board supports the protoboard and the Power PWM SPM620 module. Finally, an acrylic structure accommodates the electric motor, both potentiometers, an Arduino mega 2560, and two power supplies. The left vertical acrylic column serves as a bearing for the string, while the right one supports the motor and the excitation mechanism.

As previously stated, the primary concerns on the design phase were the cost and replicability, while maintaining the manufacture process as simple as possible. In this sense, using hardwood provides easy access to the materials and also easy machining processes. To cover the replicability, as each individual piece of wood is similar but not equal to others in terms of mechanical properties, the system supporting structures were designed in a highly superdimensioned manner.

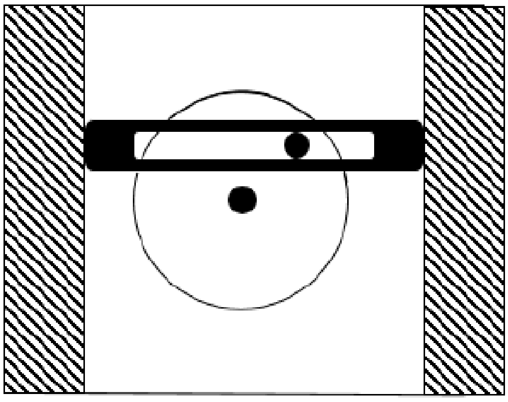
Following this design, a number of readily available types of wood are made adequate for use in this project manufacture. In opposition to that, the usage of acrylic and transparent plastic parts was made necessary to provide visibility and accessibility to the mechanical parts and inner workings of the system. The two main acrylic support plates are designed in a superdimensioned manner, similar to the wooden parts.

Below is presented a components manifest, Tab. 1, detailing the structural parts needed for the design. The wooden pieces were subjected to multiple scalonated drilling processes to produce the LEDs inserts and the bolts guide holes. These pieces were also carved using chisels, to produce the internal channels for the wiring. Alternatively, a milling process could be applied in place of the carving, but this was deemed uneccessary, due to producing equivalent results. The wood pieces were then sanded to shape and all remaining live edges were deburred. In addition to bolting the pieces together, epóxy resin was also applied to increase the bond durability and overall resistance. A last sanding was performed up to grid 300 sandpaper, and Danish oil (varnish, linseed oil and thinner mixture) was applied in 3 layers to provide waterproofing and suface gloss.

2.2 Dynamic parts

The dynamic part of the test-rig is a Scotch Yoke (Mabie and Ocvirk, 1980), which has the function of generating a sine wave that propagates along the string, producing the visual effect of the vibrating modes of a bi-supported beam. This effect was obtained via additive manufacture (3D printing) produced parts, attached to the motor shaft and to the string starting point. Again, this design is simple to manufacture and replicate, and in the case of 3D printing being unavailable, substitute manufacturing processes can be applied.

(a) Scotch Yoke.



(b) Dynamic model.

Figure 2: Test-rig dynamic parts

2.3 Electronics

The electronic part of the test-rig was made by the circuit scheme shown in Fig. 2. The system must provide a stable speed for the string, while matching that frequency with the LEDs blinkin speedg, generating a strobe effect on the string. This design was adopted mostly due to its reliability and low cost. The code used on Arduino mega 2560 is presented at annex 1 in the end of this document.

The circuitry assembly was performed manually, avoiding the usage of printed circuit boards (PCBs) to reduce manufacturing costs. While the advantages of PCBs over standard manual soldering are many, in this particular didactic test-rig the goal is to provide a clear, visual explanation of the system, and by having an open circuit that can be better achieved. For that end, a protoboard allowed for the components to be readily mounted, while still kept them visible and easily accessible. The system assembly was made by manual soldering, making use of a number of electronic components listed ahead.

- 8 white leds;
- 8 180 Ω resistors;
- 1 DC motor;
- 2 sources with 1A supply;
- 2 adapters to power supply connector;
- 2 multi turn potentiometer;

- 1 transistor TIP 120;
- 1 Arduino PWM driver for constant current (represented in Fig.2 by P transistor);
- 1 Arduino;

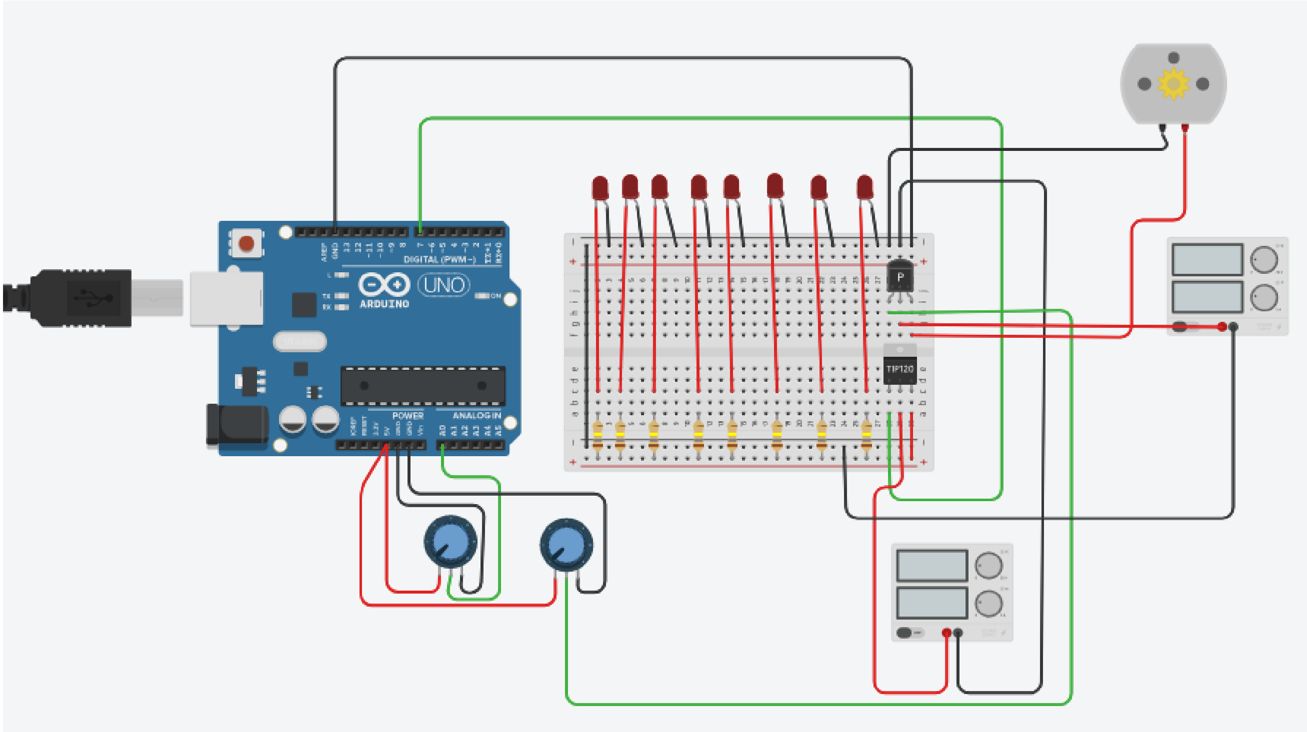


Figure 3: The test-rig electronic components.

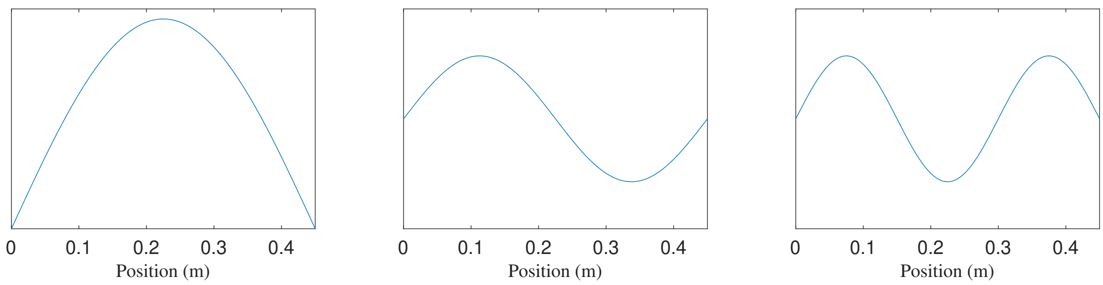
3. Results

3.1 Analytic Results

The mathematical formulation associated with the test-rig is the continuous bi-supported string approach. This expression allows the identification of the shape of each vibration mode, allowing the comparison of the theoretical and the experimental string mode shapes. The mentioned formulation is presented by Eq. (1).

$$U_r = \sqrt{\frac{2}{\rho L}} \sin(\frac{r\pi x}{L}) \quad (1)$$

where L is the useful string length, ρ is the string density, x is the position on the string, and r presents the first, second, third, ..., n^{th} modes. The first, second, and third modes were generated using Eq. (1), as given by Fig. 4.



(a) First vibration mode. (b) Second vibration mode. (c) Third vibration mode.

Figure 4: Analytic vibration modes

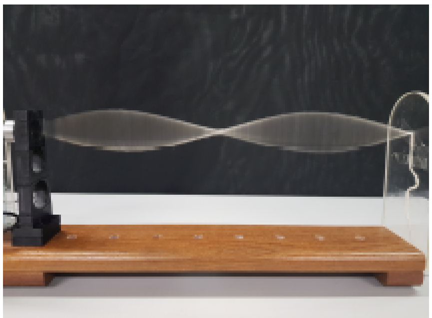
3.2 Experimental Results

It is worth mentioning that the experimental results of the present work are qualitative. Thus, only the shapes of the first, second, and third vibration modes are compared with the corresponding analytical ones. For this aim, the tension in the string was fixed on its free end, while the engine rotation speed was modified by using a potentiometer. After that, the LEDs blinking frequency was tuned for matching the natural frequency associated with each considered vibration mode, causing a stroboscopic effect for highlighting the string mode shapes.

Figure (5) presents the obtained results. Note that the three first vibration modes of the bi-supported string can be visualized both with and without using the stroboscopic effect. Moreover, this effect highlights all the mode shapes, in a static view, resembling the presented analytic results. Thus, the test-rig increased students' interest during the classes, fixing their attention and making easier the understanding of the subject, as can be seen at the following student testimonials.

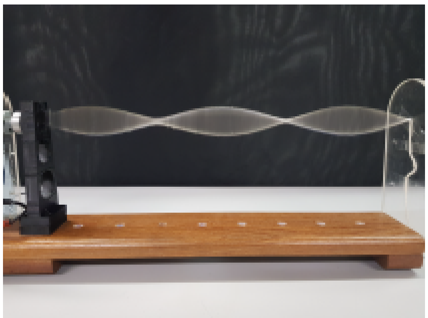
(a) First vibration mode.

(b) First vibration mode with stroboscopic effect



(c) Second vibration mode.

(d) Second vibration mode with stroboscopic effect.



(e) Third vibration mode.

(f) Third vibration mode with stroboscopic effect.

Figure 5: Comparison between vibration modes with and without stroboscopic effect.

"The didactic test rig presented at the classroom represented an extra comprehending tool for me. It became much clearer how the vibrating modes of a structure work. Besides that, it is capable of representing that the natural modes of a rotating machine are speed (frequency) dependent. Finally, I may affirm that the presence of the didactic test rig at the lectures increased my interest for the subject and made easier to understand the theoretical concepts presented."

"The didactic test rig presented at the lectures about the Dynamics of the Rotating machines was valuable, since it was capable of presenting me in a practical and simple manner, how the natural modes of a structure behave. Although some software are capable of depicting visually the dynamic behavior of a structure, the test rig presents this idea with deeper meanings. It is much more interesting to see something in front of you behaving the way it was predicted with the theories presented in class. Moreover, it becomes clear that the rotating speed of the machine and the length of the chord have influence on the natural modes."

4. CONCLUSIONS

In this research effort, the proposed educational test-rig was designed and manufactured for presenting the mode shapes of the first vibration modes of a bi-supported string to facilitate the students' understanding of basic concepts of vibration. The manufacturing process was perceived as reasonably simple and low-cost, allowing easy replication. The test-rig dynamics was explored in class to a limited extent, because this was an initial attempt to upgrade the traditional method. It was concluded that the experiment achieved its goal, providing a clear visualization of the string mode shapes, besides obtaining a positive feedback from the students, who affirmed that the experiment was quite helpful on the understanding of the theory. Finally, it also can be conclude that the experimental shape modes present the same behavior of the ones derived from the analytic formulation.

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6. RESPONSIBILITY NOTICE

The authors Iago Alves Pereira, Vergílio Torezan Silingardi Del Claro, Leandro de Souza Leão, Fabício Vieira de Oliveira, Aldemir Ap Cavalini Jr, and Valder Steffen Jr are the only responsible for the printed material included in this paper.

7. ANNEX 1

```
// Defining the pin which will be used to receive
//the signal of the potentiometer to active the electrical engine
int const potenciometro = 0;

// Defining the pin which will be used to send the signal of
//the Arduino to the transistir responsabel to the engine
int const transistor = 8;

// Declaring a variable which will be used to receive
//the value of the potentiometer
// ( Potentiometer send values into  the [0 1023] interval )
int valPotenciometro = 0;


void setup() {
// Seting the pin fuction. It will works like an output
  pinMode(22,OUTPUT);
// Seting the pin fuction. It will works like an output
  pinMode(transistor, OUTPUT);
}

void loop() {

// Reading and transforming 16 bits potentiometer value
//in to 8 bits values once the transistor works with 8 bits
  valPotenciometro = analogRead(potenciometro)/4;

// Sending the signal to the transistor responsabel to the engine.
  analogWrite(transistor,valPotenciometro);

// Reading the potentiometer value responsible
//to produce the stroboscopic effect
  int tempo= analogRead(2);
// Seding signal to turn leds on
  digitalWrite(22,HIGH);
// Leds delay to turn it off
  delay(tempo);
// Seding signal to turn leds off
  digitalWrite(22,LOW);
// Leds delay to turn it on
  delay(tempo);
}
```