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DEVELOPMENT OF A PNEUMATIC BENCH FOR TESTING TRUSS BRIDGES

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Abstract. This work presents the design of a pneumatic bench for testing truss bridges as a teaching tool in the classroom, making easier the understanding of the content by the students. When the students are in the early phases of the engineering degree, they frequently find difficulties to learn, so a practical example of what was ministered in class can help the students to have a better comprehension of the course. The bench can be particularly helpful to statics students because they can test the theories learned in class by creating bridges of wood sticks and using the bench to test the maximum amount of load that the bridge support and how it brakes. The work aim is to decrease the difficulties to comprehend the more advanced semesters content by reducing the miscomprehension in the early stages. The pneumatic systems have cheaper manutention and are lighters and have a better cost benefit, also it's secure to use because the system use compressed air so don't have the risk of intoxication, short circuit, and in cases of overpressure have less risk of leaking, and don`t present oil leak. But its behavior is more difficult to model, since they have inherent non-linear characteristics. The project was divided into: literature review and design. The literature review was responsible for searching for previous works of test bench for spaghetti bridge contest and systematize the knowledge of pneumatic systems. After the bibliographic review, a CAD modeling of the bench and the actuator was made and was projected a frugal solution for the pneumatic system to make the load in the bridge.

Keywords: Pneumatic, testing structures, education.

1. INTRODUCTION

This study aims to develop detailed project of a didactic pneumatic bench for testing truss structures, to assist undergraduate students in the early semesters in gaining a better understanding of the content taught, especially in the disciplines of statics and solid mechanics. According to Barbieri (2009), students often struggle to visualize and comprehend the content ministered in the early semesters. With the rapid advancement of technology, engineers can quickly become obsolete in the job market, necessitating innovation in teaching methods compared to the traditional European approach (Valdiero, 2006). According to Guo et al. (2020), project-based learning (PBL) is a learning approach that involves students working on a project or task for an extended period of time. In this approach, students are encouraged to engage in problem-solving, critical thinking, and collaboration to complete the project. Several authors have developed didactic benches for engineering education in various fields.

1.1 Bridges competitions

Various universities organize bridge competitions aimed at encouraging students to develop both hard skills, such as the application of content taught in the classroom, and soft skills, such as interpersonal skills, problem-solving, and teamwork, among others. The dimensions of the workbenches presented below were used as a basis for the design of the didactic workbench, aiming for standardization with other universities.

At Federal University of Rio Grande do Sul (UFRGS), the annual spaghetti bridge competition takes place with the objective of constructing a bridge that can support the greatest weight. For the competition, students must build a bridge that spans a free span of one meter and weighs less than 750g. During the structure testing, weights are gradually added to a support attached to the bridge at the center of the free span. The test bench is shown in Figure 1.

Figure 1. Spaghetti test contest in UFRGS

At Federal University of Santa Catarina (UFSC), the truss competition used to take place. The trusses were constructed using wood in teams of 5 students, with the objective of achieving the highest weight/load ratio. The actuation was performed by a hydraulic actuator connected to a pump, and the actuator was manually controlled through a valve. Measurement was carried out using sensors that sent signals to be processed in microprocessors. The trusses were loaded until failure occurred (Valdiero, 2011). The test bench is shown in Figure 2.

Figure 2. Hydraulic test bench for test of Truss in UFSC.

Annually, an international spaghetti bridge competition takes place in Canada at the Okanagan College. The bridges must span a free span distance of 1 meter and must have an element for load attachment in the middle of this distance. The measurement is done continuously, and the values are displayed in real-time on the projector, indicating the applied load value. The bridge contest is shown in Figure 3.

Figure 3. Okanagan bridge contest in Canada (Spaghetti Bridge - Okanagan College, 2023).

2. METHODOLOGY

The methodology adopted in the development of the present study consists of bibliographic research on didactic benches for testing truss structures as educational objects. Subsequently, a 3D modeling of the structure was performed using CAD software, followed by the sizing of the pneumatic cylinder and the modeling of a pneumatic system.

For the bibliographic research previous works on didactic benches for various purposes was analyzed and was searched for benches for testing structures and bridge contests. Also was searched for the efficiency of PjBL and it effecs on education. For the modeling phase, the structure was modeled in Solidworks, aiming for a rigid structure for appropriate bridge testing, yet one that could be easily assembled and transported for practical use in the classroom. For the application of force, a pneumatic system was chosen as it is a clean energy source, with a good power-to-weight ratio, and easy integration with microelectronics (Bollman, 1997). However, pneumatic systems can be challenging to model due to the nonlinearities involved in the process (Richter, 2012). Based on this, a pneumatic circuit diagram was created using FluidSIM software.

In order to increase the probability of design success of the pneumatic bench for testing truss bridges, the design process was planned carefully and executed systematically. In particular, an engineering design method must integrate the many different aspects of designing in such a way that the process becomes logical and comprehensible (Valdiero and Rasia, 2016). To that end, the design process of bench system must be broken down, first into phases and then into distinct steps, each with its own working methods. It is with these aims in mind that several authors (Valdiero and Rasia, 2016) split the design process into main phases that can be translated as Need Analysis, Conceptual Design, Preliminary Design, Detail Design, Prototype Construction, Test and Evaluation, and Final Documentation of Drives and Mechanism as shown in Figure 4.
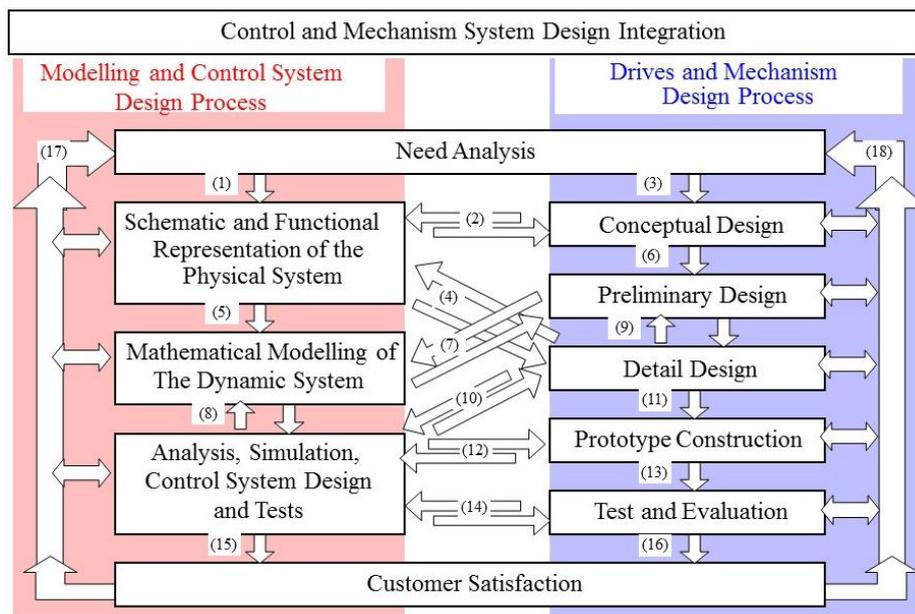

Figure 4. Design Methodology of smart machines and mechatronics system (adapted from Valdiero and Rasia, 2016).

3. RESULTS

3.1 Bench structure

In the bibliographic research several benches used in universities were found. Most of them utilize the addition of discrete weights for measurement. The major disadvantage of this method is that it hinders standardization among competitions and has reduced precision since the measurement is not continuous.

V-slot profiles were selected to compose the bench structure, specifically the 40x40 aluminum V-slot profile, as they are lightweight and sturdy. These profiles are compatible with corner brackets, facilitating connections between bars without the need for drilling, ensuring reliable connections, maintaining structural rigidity, and allowing for easy assembly and disassembly if necessary. Special nuts, known as hammer nuts, are utilized for secure fastening of the corner brackets, fitting well into the profile surface. The components were modeled in SolidWorks and are depicted in Figure 5.
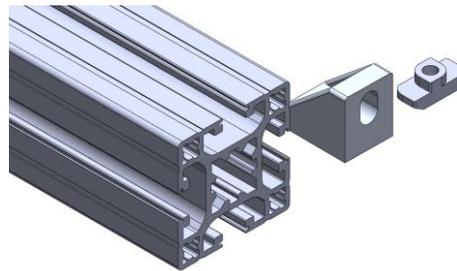

Figure 5. Virtual representation of the components

In base of this previous information the proposed bench structure is shown in Figure 6 and it was modeled in Solidworks. The bench is composed of V-slot profiles (5) to facilitate assembly and provide support to the bench. The testing structure has a height of approximately 1.1 meters to ensure ergonomics for the user conducting the tests. At the top, there are two metal plates (2) with a distance of 1 meter to support the ends of the truss structures (1), providing a standard free span distance for the testing. Additionally, it features levelers (6) on the lower parts to ensure precision even on uneven or irregular surfaces. The fastening is done entirely using nuts and bolts. In the center, there are 2 T-track profiles (4) to support the pneumatic actuator (3) for destructive testing.
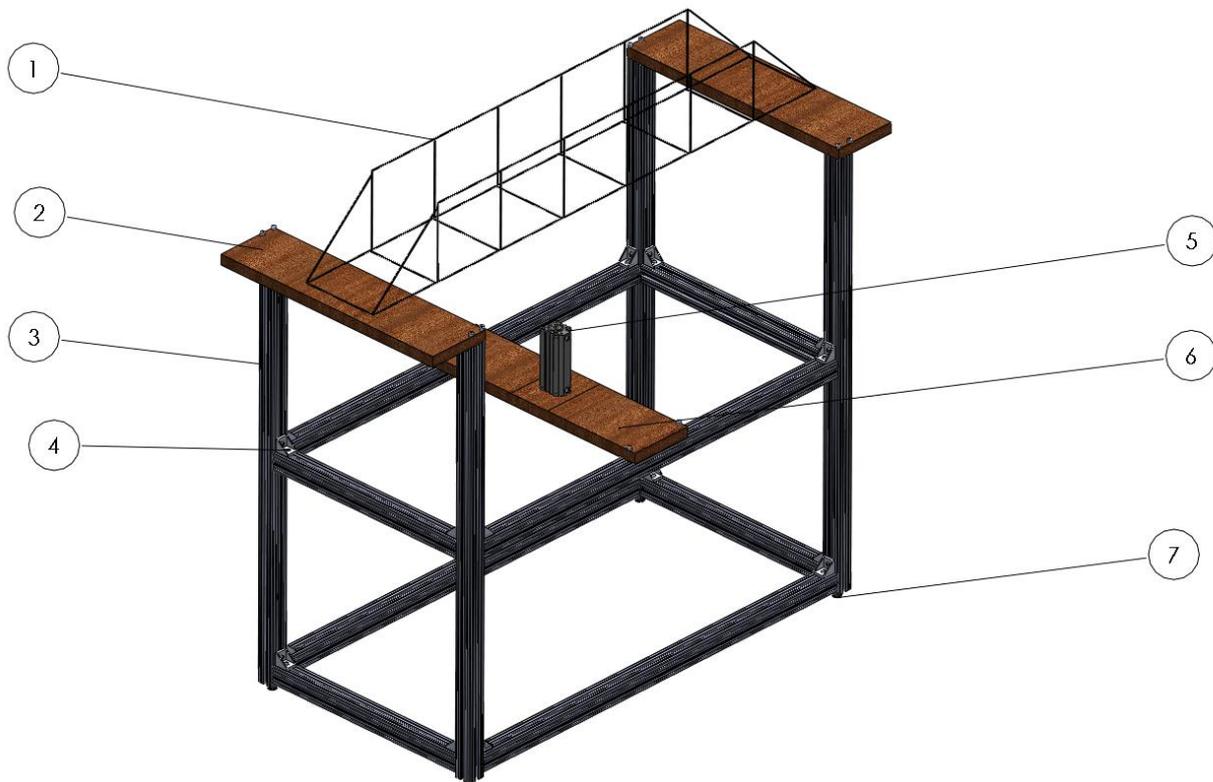

Figure 6. Structure of the pneumatic bench.

After modeling in SolidWorks, the software Inventor was used to conduct the stress simulation, as shown in Figure 7, to determine the stresses and displacements that may occur in the workbench, aiming to assess whether the workbench would withstand the required forces without significant deformation. According to the simulation, it was observed that the maximum deformation of the workbench under a force of 5000 N was 10 mm, which was considered acceptable. Additionally, it was noted that the workbench withstands the forces without material failure.
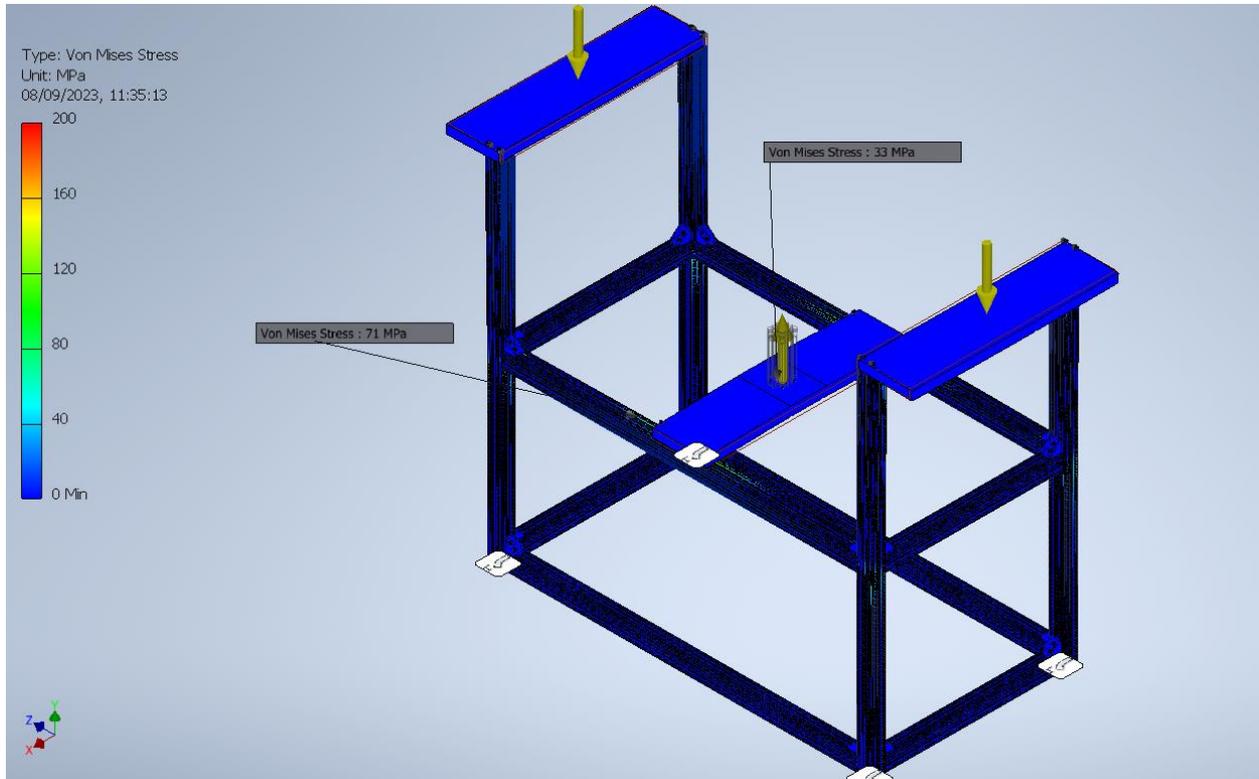
(a)
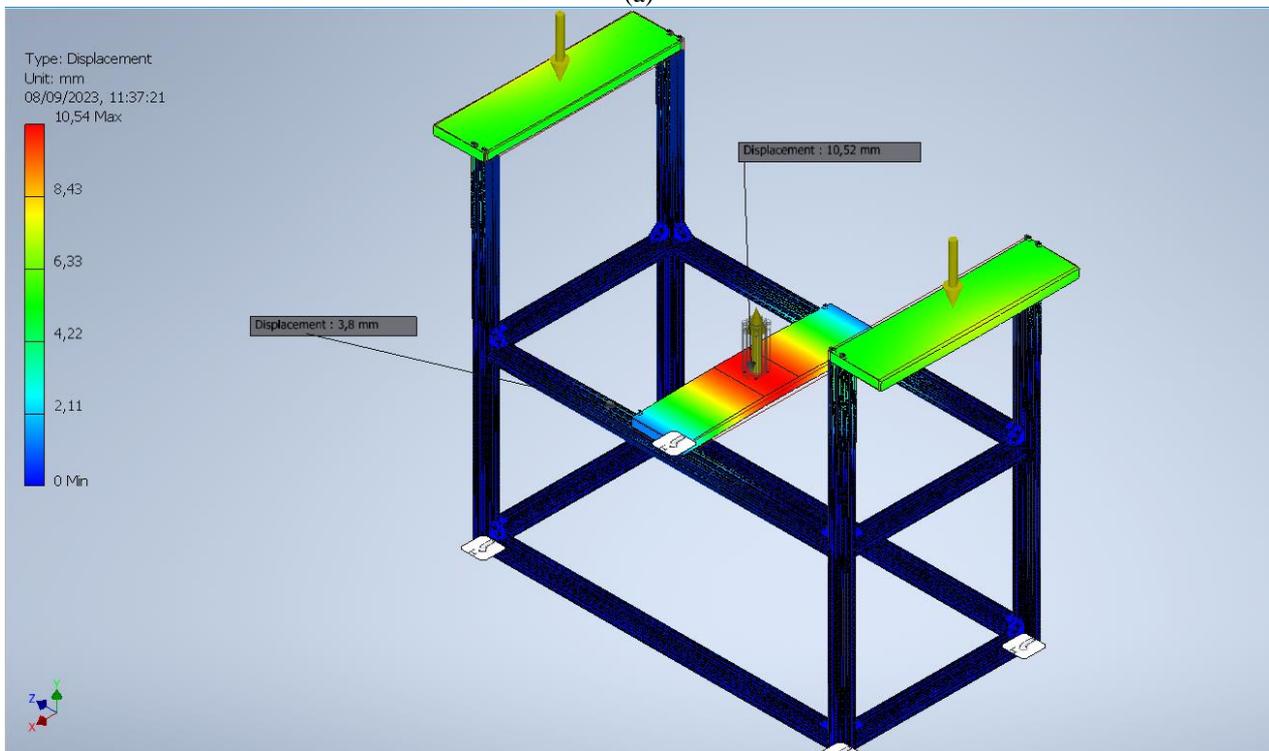
(b)

Figure 7. Static simulation of the didactic bench: (a) Von Mises stress; (b) displacement.

3.2 Pneumatic system

To ensure that the pneumatic cylinder reaches the required maximum capacity, it is necessary to dimension the actuator. For this purpose, it was considered that the force F made by the cylinder is equal to the pneumatic force F_p minus the friction force in the actuator F_{atr}, as given by Eq. (1).

$$F = F_p - F_{atr} \tag{1}$$

where

$$F_{atr} = m\,a \tag{2}$$

If the time interval in which the cylinder velocity is constant is considered, with a = 0 and F_a = 0, the cylinder can be sized using the following equations described by Bollman (1997):

$$F_p = (p_1 A_1 - p_2 A_2)\eta \tag{3}$$

$$A_1 = \pi\,D^2/4 \tag{4}$$

$$A_2 = \pi\,(D^2 - d^2)/4 \tag{5}$$

In which p_1 and p_2 represent the effective pressures on the piston and rod sides, respectively. A_1 is the area on the piston side, as defined by Eq. (4), and A_2 is the area on the rod side, as given by Eq. (5). D and d denote the diameters of the cylinder and rod, respectively, and η represents the actuator's efficiency. Since the force exerted by the cylinder will predominantly be in the direction of retraction, p_1 can be considered gauge pressure. Therefore, we can determine the required cylinder diameter as follows:

$$D^2 - d^2 = \frac{4F}{p_2 \pi \eta} \tag{6}$$

The diameter of the pneumatic actuator was dimensioned for a force of 5 kN, considering an efficiency of 0.9 (Bollman, 1997), and a pressure drop at the cylinder port relative to the supply of 0.5 (Vigolo et al., 2022), with a supply pressure of 10 bar. Standard industry diameters were used to make the table 1 and determine which diameter can support the required forces.

D(mm)	d(mm)	D^2-d^2	4F/pπη
10	4	0,000084	0,007449622
12	6	0,000108	0,007449622
16	6	0,00022	0,007449622
20	8	0,000336	0,007449622
25	10	0,000525	0,007449622
32	12	0,00088	0,007449622
40	16	0,001344	0,007449622
50	20	0,0021	0,007449622
63	20	0,003569	0,007449622
80	25	0,005775	0,007449622
100	25	0,009375	0,007449622
125	32	0,014601	0,007449622

Table 1 – Table of the minimum diameter for the pneumatic cylinder

According to the table, the minimum diameter of cylinder capable of making the proposed force is 100 mm, with a rod with 25mm diameter.

The pneumatic system shown in Figure 8 was adapted from Vigolo et al. (2022), proposing a frugal solution for force measurement, considering that many Brazilian universities have limited funding. The system consists of an air service unit, a two-way valve 3/5, a one-way control valve, and the pneumatic cylinder.
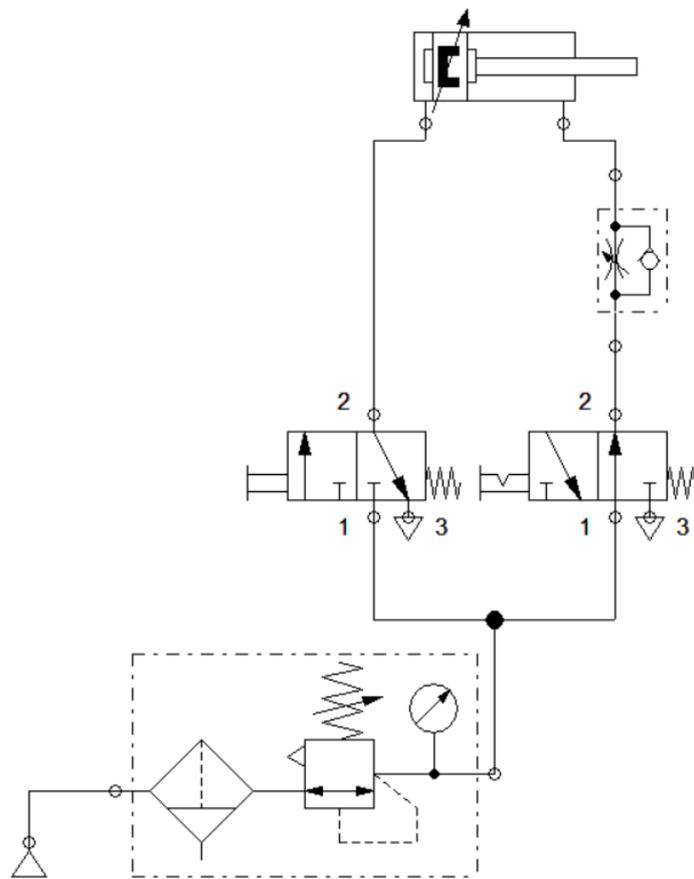
Figure 8. Frugal pneumatic system for the testing bench.

The force would be measured through pressure transducers positioned at the entrances of the pneumatic cylinder. The signal is sent to an Arduino Uno board, where the force calculation is performed, and the result is displayed on the screen of the connected notebook.

4. CONCLUSION

This study proposed the development of a pneumatic bench for teaching structures in the early stages of engineering courses. In preliminary results this work contributes to the improvement of education by creating a compact, cost-effective, and more accurate bench for truss testing. A side effect of this work is the participation of undergraduates in the project, promoting the capacitation of futures professionals and the ideas that the academic can contribute actively in a better quality of education in the educational institutes. In future perspectives, it is proposed to assemble and use the bench in the classroom to evaluate its effectiveness in teaching.

5. ACKNOWLEDGEMENTS

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