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Developing a Dynamics Lab on a Shoestring Budget

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Introduction

This work discusses the design and implementation of a Mechanical Engineering (ME) laboratory course intended to provide an introductory vibration and system dynamics experience for undergraduate ME students. Prior to the development of this course, a limited number of hands-on experiments were incorporated into the system dynamics course required for all third year ME students. These measurements were designed to help students learn abstract ideas such as frequency domain analysis. However, after observing that many students failed to develop a practical understanding of dynamic systems through this limited exposure, the faculty recognized that an independent course should be tailored to provide hands on exposure to dynamic systems with the goal of connecting the gap between the material taught in dynamics and the concepts from system dynamics. After developing and implementing the course, we identified number of unique aspects of this laboratory course that could be incorporated, in whole or part in our other laboratory courses. Additionally, we felt that some of the unique features of this course could be useful for faculty in other institutions responsible for laboratory style courses. The purpose of this GIFT is to share the features we felt were most significant.

Placement of the lab within the ME program / Order of the labs within the course

The intent of this course is to use hands-on experimentation to bridge the gap between what the second year students have learned in dynamics and what will be covered for third year students in system dynamics. Based on the idea that a simplified hands-on introduction to the concepts provides a foundation on which to build mathematical understanding. The lab is placed in the program to provide hands on experimenting prior to introduction of theoretical concepts.

Additionally, the labs have been organized such that each lab builds on concepts introduced in the previous labs, providing a cohesive structure designed to facilitate maximum retention of conceptual ideas. Because the lab was offered without a co-requisite lecture, the experiments were ordered to increase in breadth and technicality as the semester progressed. For example, the natural frequency lab was followed by the damped frequency, and then resonant frequency labs. Using the same demonstrator for multiple purposes not only reduced the amount of required equipment, but more importantly, reinforced the interrelation between concepts as they were introduced, allowing the students to utilize knowledge from previous labs while learning new concepts. A description of the labs included in the course can be found in the Appendix.

Lab Equipment Development

The equipment used throughout the course was developed using a combination of existing/retrofitted hardware and student designed experiments. In some cases, accessories were developed by faculty to fit existing equipment using simple fabrication and 3D printing. As necessary, sensors and materials were purchased to create additional experiments. In the academic year leading up to the fall roll out of the course, two test stands (Pendulum Test Stand, Variable Speed Single-Plane Balancer) were designed by students as senior design projects. For data acquisition and processing, low-cost, National Instruments USB data acquisition cards were used together with MATLAB data processing applications. Prior to the initial implementation of the course, faculty refined the basic equipment to meet the needs of each experiment. During the term modifications were made based on student response and effectiveness of the demonstrations.

Goals of Laboratory Assignments

To develop skill in discipline-specific writing, students were tasked with providing written accounts of their experimentation in a number of ways. Our primary writing requirement were memos, as opposed to traditional laboratory reports, with regular feedback to help students develop skill in concise interpretation of laboratory findings. Pre-lab activities and engineering notebooks served to further document consistent progress and created the opportunity for extra practice by providing tangible demonstration of learning before, during, and after experimentation. For our first iteration of the course, we also added a journal paper presentation, written pre-labs, notebook entries, and a student-designed experiment. The student designed experiment provide experience with background theoretical research, hypothetical model development and prototype fabrication. In this way, students re-contextualized their learning, and faculty could collaborate to generate new lab ideas.

Current and Future Plans

Through assessment and observation, we have found that this experience provided an important introduction to core system dynamics concepts the students will encounter in the future. Based on the results from the first semester, several modifications have been implemented in the second iteration of this course, which is currently being offered.

First, the timing of the Forced vibration and the Single Plane Balancing lab have been switched, which moves all of the 1 degree of freedom spring mass damper based labs to the first half of the semester, and provides a smooth transition from more theoretical labs to labs which demonstrate practical applications. The second major change is the implementation of additional styles of technical writing in the lab reports. In addition to memo style reports, alternative discipline-specific media such as press releases, training seminars, specification sheets and info-graphics will be implemented throughout the semester.

Our experiences with this lab course demonstrate that developing a robust and meaningful dynamics laboratory is possible on a limited budget, with minimal overhead by leveraging student initiatives, existing equipment and faculty expertise.

Appendix

Learning outcomes
For the Fall 2022 semester, the following learning outcomes were provided: Collect, analyze, and report Kinematic and Dynamic experimental data. To be met through:

- Measure, process and interpret quantitative/qualitative data from dynamic systems.
- Calculate and identify parameters related to mechanical systems.
- Apply dynamics-based solutions to dynamics related problems.
- Identify and predict a system's dynamic response to its inputs.

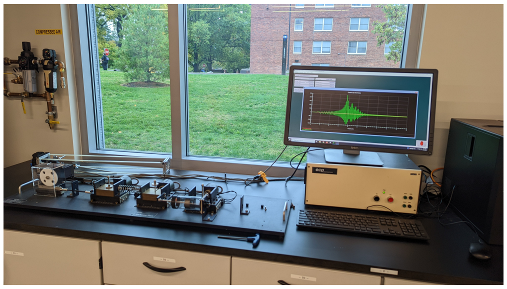
Lab Equipment List
The following equipment was utilized for completing the labs.

Table 1: List of Lab Equipment

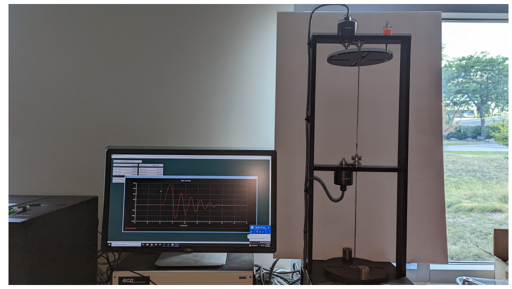
Test Equipment	**Abbreviation**	**Developed by**
Rectilinear Test Stand	R	ECP Systems
Torsional Test Stand	T	ECP Systems
Pendulum Test Stand	P	Student Project
Variable Speed Single-Plane Balancer	B	Student Project
Mechanical Wave Generator	W	Vibration and Waves Kit
Vibration Absorber	A	Faculty
Ball Bearing Shock Stand	S	Faculty
Vibration Isolation	I	Faculty

Images of the equipment are included on the following page.

Images of Equipment

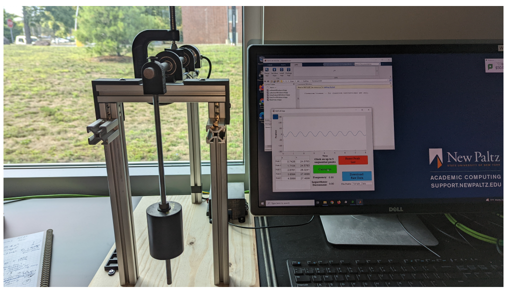


(a) Rectilinear Test Stand

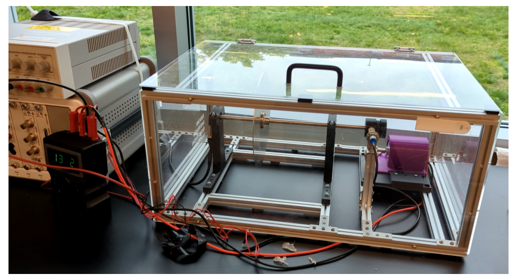


(b) Torsional Test Stand

Figure 1: ECP Systems Equipment

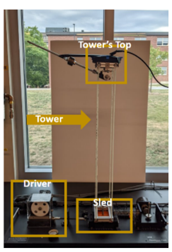


(a) Pendulum Test Stand



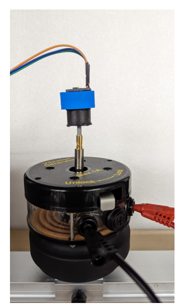
(b) Variable Speed Single Plane Balancer

Figure 2: Student Built Test Stands



(a) Vibration Absorber

(b) Shock Isolation



(c) Vibration Isolation

Figure 3: Faculty Developed Equipment

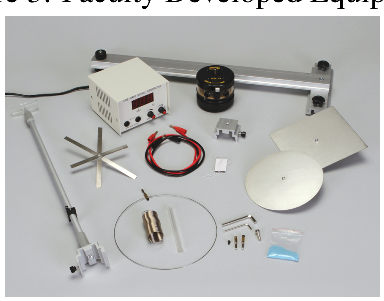


Figure 4: Vibration and Waves Kit

Lab Order and Description

The order of the labs for the first implementation was as follows:

Table 2: List of Labs

Lab	Title	Equipment
1	Natural Frequency	R, T, P
2	Parameter Estimation	R, T, P
3	Damped Frequency	R, T
4	Single Plane Balancing	B
5	Resonant Frequencies	R
6	Continuous Systems	W
7	Vibration Absorption	R
8	Vibration Isolation	S, I

Free Vibration, 1 DOF (Labs 1-3)

Single degree of freedom under free vibration were introduced during the first three labs. First, natural frequencies were estimated and measured. Then, concepts learned from the first were harnessed to perform to determine unknown system parameters. Last, damping is introduced. Applying logarithmic decrement, students measure damping ratios of oscillating systems. Then, use the response parameter, damping ratio to estimate a new system parameter: the damping coefficient.

Forced Vibration (Labs 4-6)

In this series of experiments, forced responses are measured. Additional concepts are introduced: impulse, systems with multiple degrees of freedom, and continuous systems. To introduce, single-plane balancing is performed using an unbalanced thin rotating disk. Then, resonance of a single degree of freedom system to measure the amplitude and phase response below, at, and above resonance in response to sinusoidal excitation. Lastly, and to acknowledge the complex nature of continuous systems, qualitative and quantitative identification of resonant behavior of continuous systems using a mechanical wave generator in 1, 2, and 3 dimensions is performed. Here, students learn to predict, and measure the forced response of systems.

Vibration Remediation (Labs 7-8)

These final experiments demonstrate how vibration can be remediated by the addition of elements intended to absorb or dissipate energy. They involve an understanding of the concepts previously addressed and the application of engineering judgement to choice suitable materials to modify a system's performance. First, students tune a vibration absorber to eliminate the problematic resonance of a slender tower under sinusoidal excitation using their understanding of concepts previously introduced: mode-shapes, forced vibration, and natural frequency. Then, students identify the effect that adding vibration isolation has on system undergoing impulsive loading, and in response to harmonic excitation.