A Unique Horizontal Shaft/Slider Apparatus Capstone Design Project for a Hands-On Senior-Level Laboratory Design Experience

Yin-ping (Daniel) Chang, Oakland University

Abstract

This paper describes a particle kinetics work/energy measurement experiment for the senior level *Engineering Mechanics – Dynamics* course. This course is geared towards introducing students to the fundamental principles of kinematics and kinetics of particles and rigid bodies, including displacement/velocity/acceleration kinematic relationships and kinetic analyses through Newtonian laws of motion, work/energy conservation laws, and impulse/momentum principle approaches. It has been the Mechanical Engineering Department's philosophy that theory learned in the classroom be augmented by experiential knowledge gained by hands-on laboratory experience. In this light, laboratory experiments have been developed that are integrated with the course material. This paper presents a unique experimental apparatus, designed and built at Oakland University, which is a precursor to the *Capstone Design Project* at Oakland University, to introduce students to particle kinetics properties measurement techniques to measure particle displacements, energy transfer and dissipation, and the coefficient of friction on a horizontal shaft/slider apparatus. The *Capstone Design Project* is geared to taking students through the entire taxonomy of the design process; from knowledge, comprehension and application, to synthesis, analysis, and finally evaluation. The experiment covers basic concepts of kinetics of particles, specially focusing on work/energy conservation related principles. A slider/collar was mounted on a horizontal shaft in this apparatus. The sliding collar deflected a spring at one end of the shaft to temporarily store the potential energy, and released to transform the potential energy into kinetic; traveling on the horizontal shaft, the friction dissipated part of the energy, and then the collar met and deflected the other spring at the other end of the shaft and bounced back. A non-contact linear displacement sensor and LabView based data acquisition system were implemented to facilitate the complex measuring and to increase the accuracy of the data in this experiment. The students were asked to validate the particle kinetics principles of conservation of energy. Results of the students' experiences will be presented in this paper.

Key Words

Engineering Curricula

A Unique Horizontal Shaft/Slider Apparatus Capstone Design Project for a Hands-On Senior-Level Laboratory Design Experience

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1. ABSTRACT

This paper describes a particle kinetics work/energy measurement experiment for the senior level *Engineering Mechanics – Dynamics* course. This course is geared towards introducing students to the fundamental principles of kinematics and kinetics of particles and rigid bodies, including displacement/velocity/acceleration kinematic relationships and kinetic analyses through Newtonian laws of motion, work/energy conservation laws, and impulse/momentum principle approaches. It has been the Mechanical Engineering Department's philosophy that theory learned in the classroom be augmented by experiential knowledge gained by hands-on laboratory experience. In this light, laboratory experiments have been developed that are integrated with the course material. This paper presents a unique experimental apparatus, designed and built at Oakland University, which is a precursor to the *Capstone Design Project* at Oakland University, to introduce students to particle kinetics properties measurement techniques to measure particle displacements, energy transfer and dissipation, and the coefficient of friction on a horizontal shaft/slider apparatus. The *Capstone Design Project* is geared to taking students through the entire taxonomy of the design process; from knowledge, comprehension and application, to synthesis, analysis, and finally evaluation. The experiment covers basic concepts of kinetics of particles, specially focusing on work/energy conservation related principles. A slider/collar was mounted on a horizontal shaft in this apparatus. The sliding collar deflected a spring at one end of the shaft to temporarily store the potential energy, and released to transform the potential energy into kinetic; traveling on the horizontal shaft, the friction dissipated part of the energy, and then the collar met and deflected the other spring at the other end of the shaft and bounced back. A non-contact linear displacement sensor and LabView based data acquisition system were implemented to facilitate the complex measuring and to increase the accuracy of the data in this experiment. The students were asked to validate the particle kinetics principles of conservation of energy. Results of the students' experiences will be presented in this paper.

2. OBJECTIVES

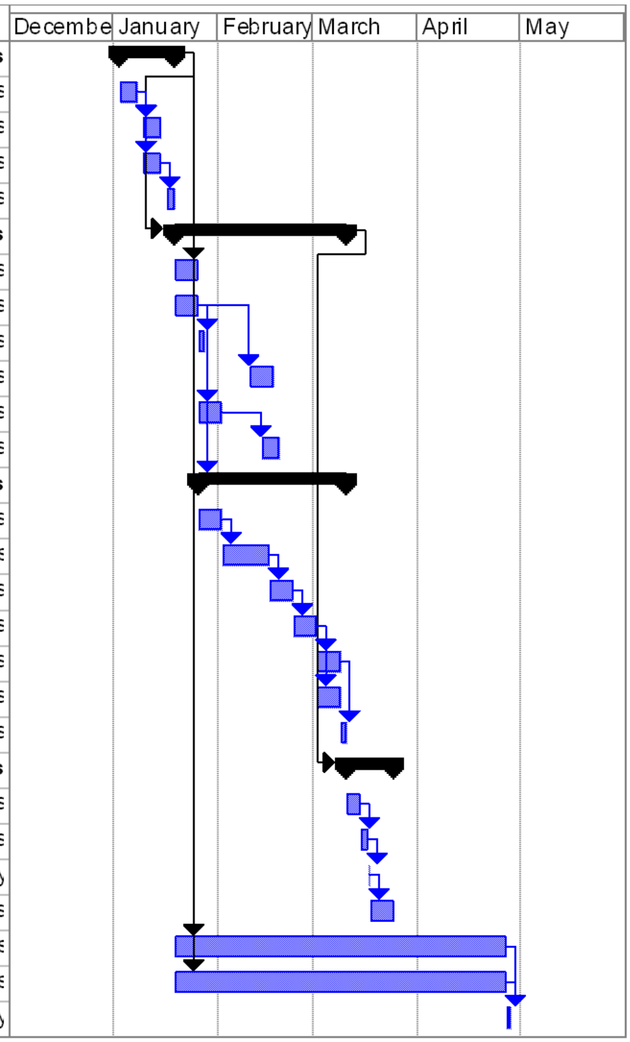
The objective of this project was to design and manufacture a laboratory experiment for Oakland University's ME321 Dynamics and Vibrations course. The addition of this experiment will enhance the current curriculum by exposing the students to a real life application of the existing lecture material. In addition, this experiment will give the students a hands-on experience with a state of the art sensor and data acquisition system.

From the design standpoint, this project gives invaluable experience with regards to origin, design, and production of a project as a whole. This project has been broken down into these four major categories:

- Origin
- Design
- Manufacture
- Validation

3. TIMELINE

ID	Task Name	Duration
1	**Research/Development**	**12 days**
2	Research Problems	5 days
3	Research Feasiblility	5 days
4	Preliminary Sketches	5 days
5	Proposal	2 days
6	**Design/Manufacturing**	**37 days**
7	Mock Up	5 days
8	Design	5 days
9	Create Detailed Prints	2 days
10	Prototype	5 days
11	Research Components	5 days
12	Order Components	5 days
13	**Machining**	**32 days**
14	Base	5 days
15	End Clamps	10 days
16	Guide	5 days
17	Sliders	5 days
18	Spring Retainer	5 days
19	Position Sensor Brackets	5 days
20	Assembly	2 days
21	**Testing/Validation**	**10 days**
22	Preliminary Tests	2 days
23	Statistical Analysis	2 days
24	Run Trial Lab Experiment	1 day
25	Write Sample Lab Report	5 days
26	Presentation	70 days
27	Report	70 days
28	Final Presentation	1 day



4. ORIGIN

The laboratory experiment chosen for this project was based off of an idea to focus on intermediate and advanced principles involving system variables that can be easily changed so that there is sufficient variability from one semester to the next. The problem consists of a sliding collar on a horizontally oriented shaft, with fixed springs, on both ends of the shaft. The experiment is capable of incorporating concepts from multiple sections in the course. A sample problem can be stated as follows:

> A 1-kg collar C Slides on a horizontal rod between springs A and B. If the collar is pushed to the right until spring B is compressed 50 mm and released, determine the distance through which the collar will travel, assuming (a) no friction, (b) a coefficient of friction $\mu_k = 0.35$.

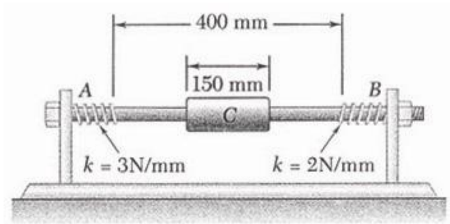


Figure 1 - A Sample Horizontal Shaft/Slider Problem

The initial state of this problem consists of sliding the collar to one side and partially compressing the spring a known deflection. The collar is then released, allowing it to slide along the shaft. Given mass of the slider, it is up to the student to measure the coefficient of friction and calculate whether or not the slider will travel far enough to compress the opposite spring. If so, the compression of the opposite spring is required to be calculated and compared to the measurement.

5. FEASIBLITY STUDY

Before any design could be produced, various calculations were made to ensure the size and characteristics of the intended apparatus meet standards set forth beforehand. These standards included weight and size restrictions with a focus on portability, durability, cost and ease of use. Many variables were taken into account when considering these restrictions, these variables included:

- Spring rate of individual springs
- Coefficient of friction
- Cost
- Overall size and weight of completed assembly
- Durability
- Material machinability

Preliminary calculations were performed to determine the overall weight of the proposed design, as well as to determine spring rates necessary to effectively move two collars of different masses. These calculations helped to determine material and component selection.

6. Mock Up

Mocking up an assembly proves to be beneficial especially when it comes to functionality of a component. It was decided that a wooden mock up of the preliminary design was the best way to determine whether or not design changes were necessary. The wooden mock up of the experiment shows the concept of the apparatus. The use of this mock up showed that a number of design alterations and additions were necessary in order to meet the objectives set forth beforehand. It also allowed the possibility of a demonstration of the functionality of the apparatus for review and approval.

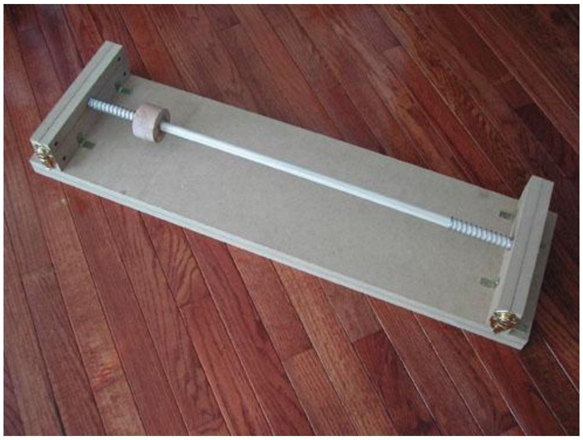


Figure 2 - A Wooden Mockup

7. Design

The main specifications of the design were as follows:

Ease of use:
The laboratory experiment must be simple to perform. No special skills are required to perform the experiment. The design must be simple and easily adjusted to perform the different phases of the experiment. (student friendly design)

Portability:
Since the laboratory may be moved or the class taught at another facility, the apparatus must be relatively compact and easily dismantled for transportation. In addition, the apparatus must be relatively lightweight for carrying purposes.

Quality Product:
Since this laboratory apparatus is considered an investment by the university, the unit must be designed so that it is durable and robust. In order to achieve this, detail must be observed when selecting the material and individual components to ensure a long lifetime of use by students. Aesthetics would also be a factor since the apparatus may serve as a demonstration of what OU students are exposed to.

Relate Class Material to Real Life Application:
The apparatus must be able to effectively and accurately demonstrate the concepts discussed in the classroom.

Ease of use is very important when designing a laboratory experiment for use by students. If a laboratory experiment is frustrating to use, some students may resort to making up data for the sole purpose of avoiding performing the experiment. This defeats the entire purpose of creating the laboratory. One of the goals of the project is to help students better understand the theories taught in class through experience, it is therefore important that the students perform the experiment. Ease of use was one of the steps taken to try to ensure that the majority of the students would perform the experiment.

It has not gone unnoticed that some laboratory experiments are not at all portable. Since many mechanical engineering classes are taught off campus, this means that if students at these other locations are to perform these experiments, they either have to travel to Oakland University's main campus, or an identical setup has to be assembled at the off campus site, which would double the cost. Not having the desire to have students travel unnecessarily, or double the cost of production at this stage, it was decided that producing an apparatus that was compact in both weight and size would be an advantage.

A quality laboratory experiment is mandatory when the experiment is to be subjected to use by multiple students a semester for many years. It was suggested by the department that the apparatus must withstand at least ten years of repeated use. This helped influence the choice of an all metal construction. It is suspected that with proper care and maintenance the apparatus will easily withstand over thirty years of use.

The laboratory experiment is related directly to what has been taught in class. In addition, the experiment, through the use of Microsoft Excel and LabView based National Instruments Data Logger, propels students to display abilities sought in the real world as they learn to use modern engineering tools.

All of these points must be followed while maintaining a budget. Keeping these main points in mind, the design process began. Two main software packages were used for the design process, *AutoCAD 2002* and *3ds MAX 5*.

AutoCAD was used for the initial design phase. This software package allowed three-dimensional components to be modeled and assembled together to create a dimensionally accurate three-dimensional model of the apparatus. It allowed for the design to be quickly and easily changed, if needed. In addition, using the *AutoCAD* software allowed the size of the design to be as compact as possible while maintaining functionality. It also has the ability of allowing design flaws, such as interferences or crashes between parts to be detected, which can be remedied before the components are manufactured, saving time and money. For instance, the close tolerances between the position sensor and end clamps were calculated using *AutoCAD*. This close tolerance was absolutely necessary in order for the sensor to be close enough to detect the magnet on the slider while still allowing the end clamps to function properly. *AutoCAD* was also used for creating detailed and dimensioned plots of every component in need of machining as well as dimensioned plots of the complete assembly.

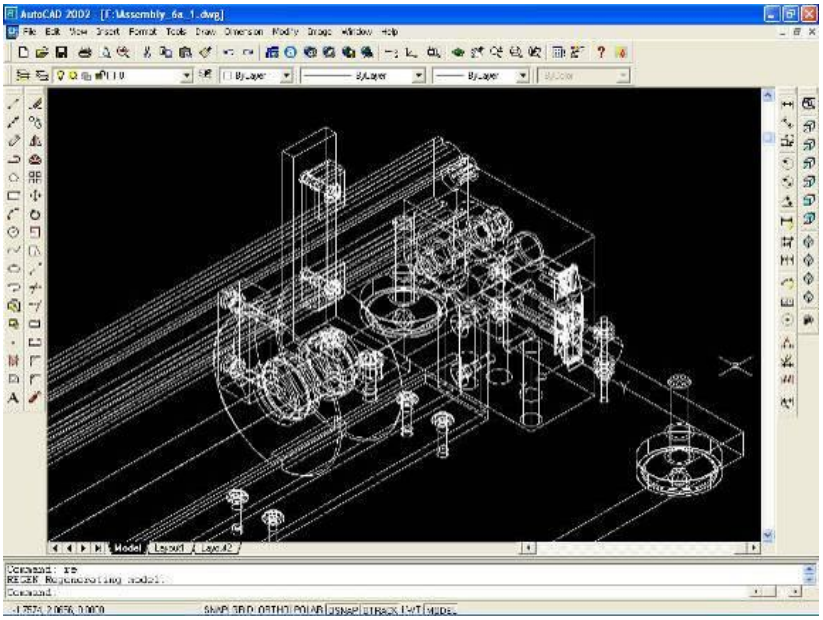


Figure 3 – *AutoCAD 2002* Screen Shot

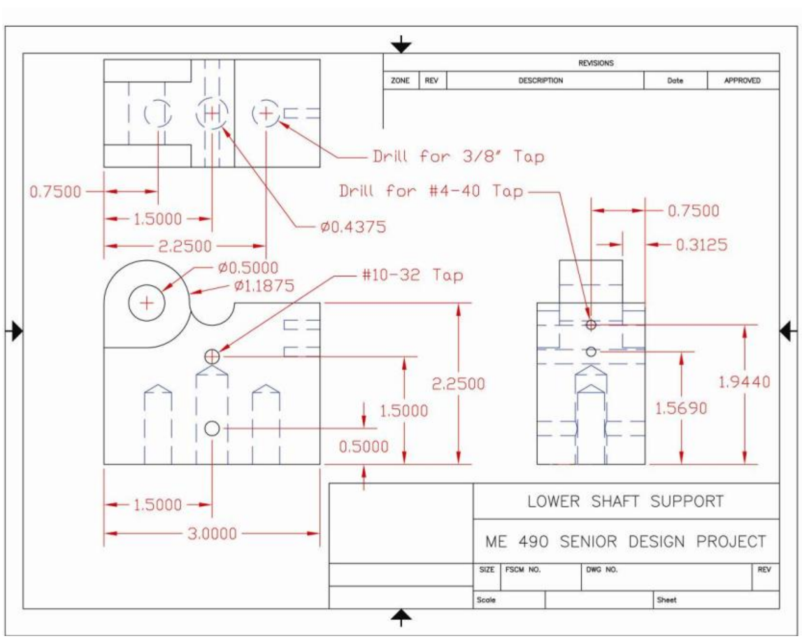


Figure 4 – Example Dimensioned Drawing from *AutoCAD 2002*

3ds MAX 5 is another powerful tool which was used in this project. Unlike *AutoCAD* which was used for its modeling and dimensioning qualities, *3ds MAX 5* was used for its rendering and presentation abilities. *3ds MAX 5* supports multiple file types which can be imported into the software. From there, material images can be applied to the objects, giving the component the look of the actual material. With the addition of lights and shadow, the result is a life-like image of the component. Another feature of *3ds MAX 5* is its animation capabilities. This feature allowed the apparatus to be modeled while in motion.

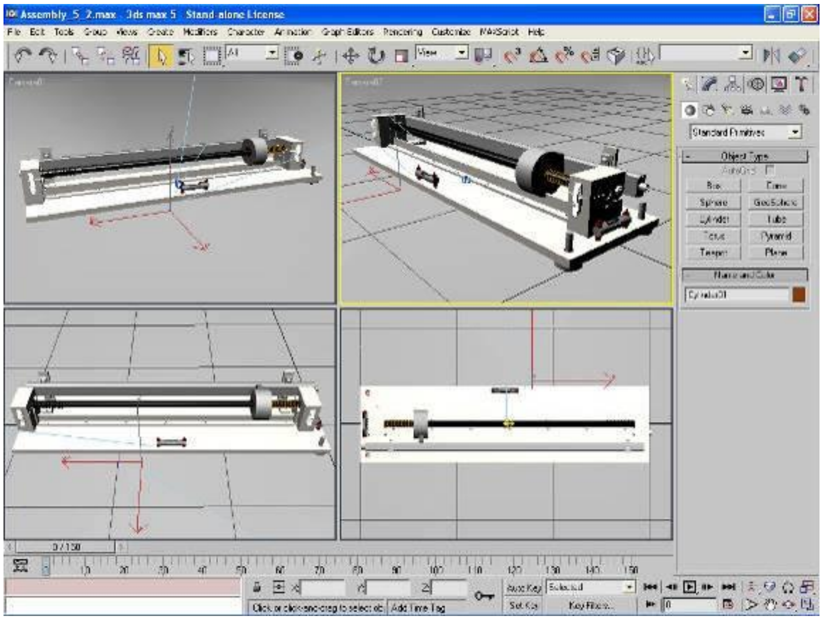


Figure 5 – *3ds MAX 5* Screen Shot

8. MANUFACTURE

Once the design was final, the manufacturing process began. In order to save money, all of the machining was performed in Oakland University's Manufacturing Processes Lab by undergraduate students. The only cost was that of the material. Before any machining was started, the final prints of the individual components were reviewed to determine the best manufacturing process for the component.

The CNC Bridgeport Mill and CNC lathe supports both manual and program based operation. These two machines were used for machining the majority of the components, including the base, end clamps, gage blocks, spring retainers, and guide.

6061-T6 aluminum was chosen for a majority of the components. These components include the base, guide rail, end clamps, brackets, and one of the sliders. While aluminum is generally more expensive than steel, it was chosen for its ease of machinability and its high strength to weight ratio. Aluminum makes the completed assembly much lighter than if it were made of steel which adds to its portability.
1020 grade mild steel was chosen for the other slider. This was chosen due to its higher density, which ensures a definite, noticeable difference in mass between the two sliders. This difference in weight allows for twice as many variations as is allowed with one slider.

C1060 hardened steel was chosen for the shaft. This grade of steel was chosen because of its wear resistance and low coefficient of friction with the ceramic coated linear bearings that were chosen for the sliders.

Figure 6 – Prototype End Clamp – Open

Figure 7 – Wooden Mockup

Figure 8 – Boring a Hole

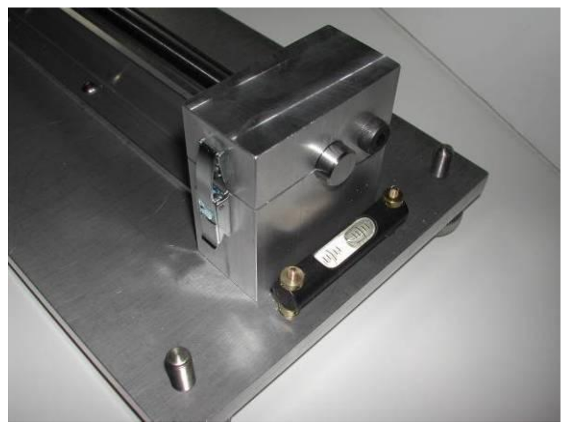


Figure 9 – Completed and Installed End Clamp

Figure 10 – Boring the Slider Center Hole

Figure 11 – Completed Aluminum and Steel Sliders

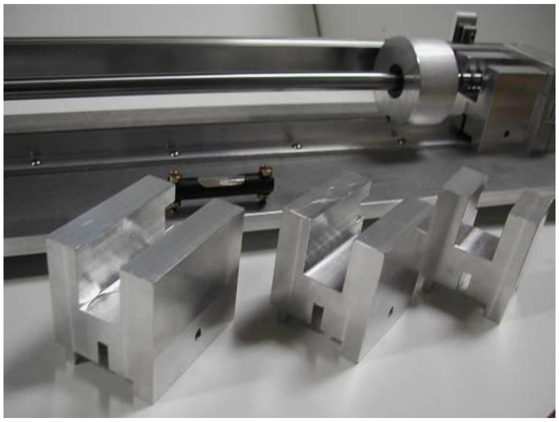


Figure 12 – Gage Blocks

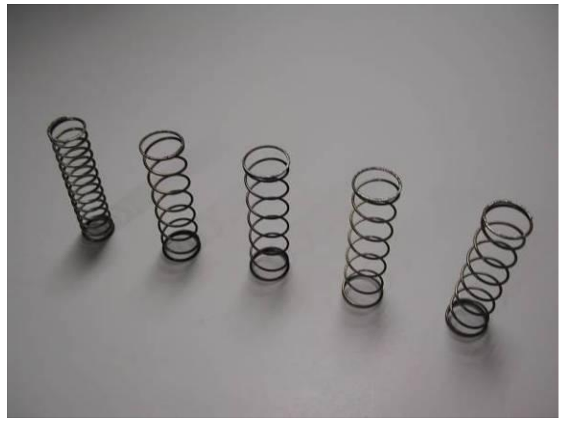


Figure 13 – Springs

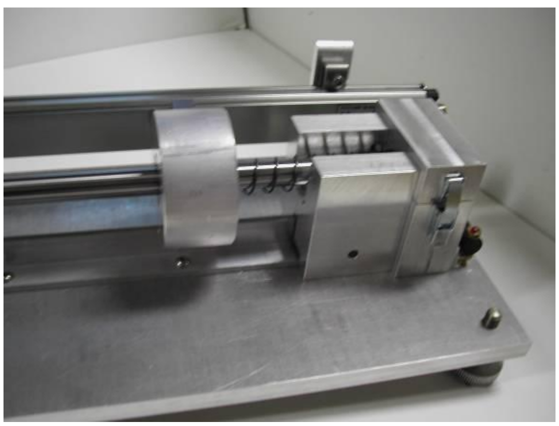


Figure 14 – Detail of Slider, Spring, and Gage Block

Figure 15 – Non-Contact Linear Position Sensor

Figure 16 – Data Acquisition System

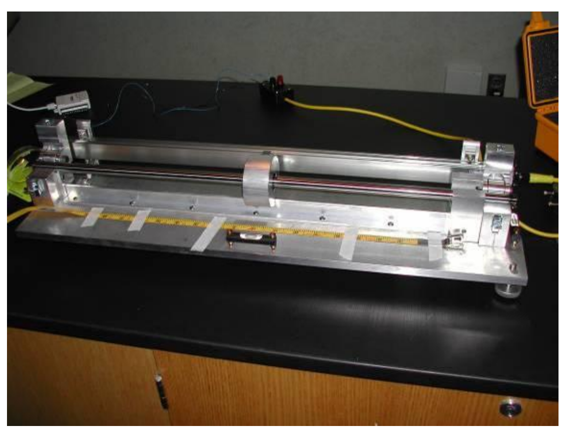


Figure 17 –Testing

9. FEATURES

There are many features of this apparatus that make it ideal for the lab component for Oakland University's ME321 Dynamics and Vibrations course. These features include:

- Portable and compact design
- Vial levels and leveling feet
- Interchangeable springs
- Interchangeable collars
- Interchangeable gage blocks
- Non-contact linear position sensor
- USB port LabView Data acquisition system

The overall dimensions of the apparatus are roughly 8.0 x 30.0 x 5.5 inches with a weight of less than 32 pounds. In addition, the shaft, along with the sliders, springs, and gage blocks, are all removable making transport of the entire apparatus quite manageable. The leveling feet allow the apparatus to be set up on practically any solid surface while the vial levels ensure that the apparatus is properly leveled. These features help to reduce error from uneven surfaces. Being able to interchange springs allows springs with different spring rates to be used, allowing for multiple setups for one apparatus. Interchangeable collars with different masses and gage blocks allow for an even greater number of variations to be employed.

In order to reduce the possibility of human error due to inaccurate reading of a scale, a non-contact linear position sensor was chosen to measure the displacement of the slider. This component is capable of monitoring the position of the slider at any point in time during the experiment. This sensor outputs a voltage linearly proportional to the placement of the slider which can then be converted into a distance measurement. The voltage from the linear position sensor is recorded using a LabView data acquisition system connected to a standard PC via USB 2.0 interface. The data acquisition system also allows the user to get real-time feedback. This data is automatically saved to a Microsoft Excel spreadsheet to be used for further analysis.
A sample experiment was run following the steps outlined in the supplied laboratory handout. For the first part of this experiment, the coefficient of friction can be calculated using a slider of known mass and a spring with a known spring constant compressed a known distance. For the second portion, the slider compressed a certain distance of one spring at one end, was released and traveled on the horizontal shaft, compressed the other spring at the other end, rebounded and then stopped by friction. The theoretical distance traveled by the slider can be calculated and compared to the slider's actual displacement measurement according to the mass of the slider and the springs selected for this experiment.

10. CONCLUSIONS

When designing the laboratory experiment for Oakland University's ME321 Dynamics and Vibrations course, the initial objectives were to research, design, and create a repeatable and reliable laboratory experiment that would give future students hands on experience and would promote greater understanding of essential concepts taught in class. Early in the design process it was decided to use a practice problem demonstrated in class as inspiration for the project. This simple step helped to insure that the laboratory would be directly related to material presented in class and that the students would have some level of familiarity with the concepts the lab is meant to reinforce.

Further research was conducted to determine the materials and components that would allow size and weight restrictions to be met. Preliminary sketches as well as a mockup and prototype were produced in order to facilitate the completion of a final design using *AutoCAD*. Major considerations taken into account during the design process include ease of use, user safety, durability, and portability.

Since cost was one of the factors taken into consideration, it was determined that monies could be saved if all fabrication was performed by students as opposed to hiring a machinist. Having students conduct fabrication afforded them invaluable experience with both the Bridgeport CNC mill and CNC lathe that they had not gained from their previous studies and would not have gained in other endeavors.

Having done over 100 trials, it was approved that the instrument consistently gives reliable results. With proper care and maintenance, the instrument should be able to withstand many years of use.

11. ACKNOWLEDGEMENT

The author would like to acknowledge three students, Mr. Aaron R. Eastman, Frederick A. Gibb and Bradley D. Tracy who have participated in this particular design project in winter and spring 2005 semesters at Oakland University. Their enthusiasm, creative thinking, and inquiring questions during their attempts to synthesize better designs, continually fuels the enthusiasm as teachers to discover and develop new ideas and methods to enhance our effectiveness as engineering educators.

Author's Brief Biographical and Contact Information

Yin-ping (Daniel) Chang, Ph.D., he received his Ph.D. degree in 2002 and continues his research as an assistant professor at Oakland University, Rochester, Michigan. His current research interests include vehicle/tire dynamics, FEA computational solid mechanics, biomechanics, machine dynamics, machine design, and classical mechanism synthesis and analysis. E-mail address: ychang@oakland.edu, website: www.oakland.edu/~ychang.

ME 321 : Dynamics and Vibrations

Laboratory Experiment #4 Assignment : Lab Handout

Particles Kinetics – Work/Energy Approach:

Sliding Collar on Horizontal Steel Shaft

Note: *1. You need a flash drive (jump drive, memory stick) to record the measured data.*
2. You need to make an appointment with TA to do this lab.

Objective:

The purpose of this experiment is to measure the spring compression and travel of a slider of known mass sliding on a horizontal shaft and compare to theoretically calculations. The following image shows the laboratory setup, consisting of a slider of known mass and two springs, each retained at either end of the shaft. The assembly is outfitted with a non-contact linear position sensor used to measure the location of the slider. Using this apparatus and the supplied instrumentation, perform the following tests.

Figure 1 - Laboratory Apparatus

Procedure:

Part 1 – Finding Coefficient of Friction Setup and Operation

1) Select one of the gage blocks and install that gage block on the right side of the apparatus by guiding the slot on the block onto the guide rail. Press against right end clamp and gently tighten set screw.

*(**Note:** Do not over tighten set screw.)*

2) Install the aluminum or steel slider on the shaft, install the selected springs on the right side of the apparatus.

3) Gently lower shaft into shaft supports, making sure that the slot on the slider aligns with the guide rail, the sensor magnet is towards the linear position sensor, and the spring(s) engage its(their) locking tab(s).

4) Roughly center the main shaft in the support blocks. Close support blocks and fasten both latches.

5) Open LabView Data Acquisition software.
(Start>All Programs>National Instruments>NI-LabView Base>NI Data Logger, or JUST double click the "NI Data Logger" icon on the desktop.)

6) Once open the *NI Data Logger*, locate the following features shown in *Figure 2*.

7) Set the following:
   a. Physical Channel – *Dev1/ai0*
   b. Acquisition Type – *Voltage*
   c. Input Terminal Configuration – *RSE*
   d. Samples per Channel – *1*
   e. Sample Rate (Hz) – *100*
   f. Logging Directory – *C:\ME321_Lab*
   g. Prefix for data filenames – *Group_Number_*(your group number)
   *(**Note**: The software will save the acquisition file using the above prefix and a suffix consisting of the acquisition date and time.)*

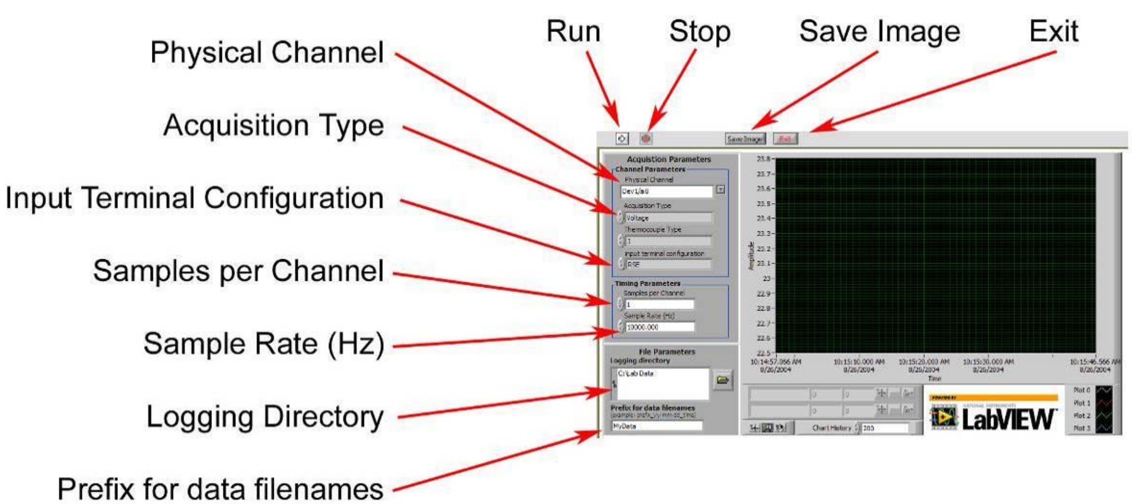


Figure 2 – LabView Data Acquisition Display

8) Once the options are set, the experiment can be performed.

9) With one group member operating the software and another in charge of the apparatus, start the acquisition by pressing the 'Run' button.

10) Pull the slider firmly against the gage block to compress the spring. Quickly release the slider. During this process the voltage output from the linear position sensor is displayed in the LabView Data Acquisition display. Allow the slider to come to a complete stop. The slider needs to completely stop before it reaches the end of the shaft. If the slider does hit the end of the shaft, you need to use another gage block or spring.

11) Repeat the previous test procedure five times.

12) Press the 'Stop' button on the display when all trials are complete. Once the 'Stop' button is pressed, the collected data is stored in a file which is automatically generated using the entered directory and prefix.
*(**Note:** The data recorded by the LabView Data Acquisition software is in volts. This data must be converted to a unit of length before manipulation using the conversion factor of 0.4 V/in.)*

Part 2 – Finding Spring Stiffness Setup and Operation

1) Install another gage block on the right side of the apparatus.

2) Use the same slider, install the selected springs on the left and the right side of the apparatus.

3) Repeat Part 1 test procedures. But this time the slider needs to hit the left side spring and bounce back. If the slider does not hit the left side spring, you need to use another gage block or stronger right side spring.

4) Repeat five times.

Masses of the Sliders:

- Steel: 2.631 lb.
- Aluminum: 1.044 lb.

Report & Discussion:

Using the measured data to:

- Graph the data "displacement vs. time" based on measured data.

- Calculate Maximum velocity from measured data and compare your maximum velocity calculated from theory. Are there any differences between the two? Why?

- Calculate the kinetic energy from Maximum velocity calculated from experiment and theory.

- Calculate the coefficient of friction between the collar (slider) and the shaft from experiment 1.

- Calculate the Spring Stiffness k of the left side spring from experiment 2.

- Discussions.

ME 321 : Dynamics and Vibrations

Laboratory Experiment #4 Assignment: Example Lab Report

Particles Kinetics – Work/Energy Approach:

Sliding Collar on Horizontal Steel Shaft

Submitted to: Prof. Yin-ping Chang

Prepared by:

Aaron R. Eastman
Frederick A. Gibb
Bradley D. Tracy

Abstract

This lab illustrated the work energy approach in modeling a displacement of a mass on a horizontal shaft due to a series of compressed springs. The lab apparatus consisted of a horizontal bar clamped at both ends. Springs with known spring constants was attached to one end of the rod. A magnetic non-contact linear position sensor was employed to experimentally give the distance traveled by the slider. Using the work/energy approach, the theoretical distances traveled differed from the experimental distances traveled by 3.28 inches or 7.28% with experimental uncertainty of 7.757%.

1. Introduction

The purpose of this experiment was to use the work/energy approach to study a slider on a horizontal bar as it was being propelled by springs of differing constants. The apparatus employed a magnetic linear position sensor to monitor the position of the slider. As stated by the manufacturer, the sensor had an accuracy of 1/100 in. A slider with a mass of 1.04 lb was used.

2. Procedure

The coefficient of friction was found using the aluminum slider and a spring with a known spring constant. This was done by compressing the spring a known distance and releasing it five times. With this set-up, the slider never reached the other end of the shaft. An average was taken of the five distances traveled and this distance was used to calculate the coefficient of friction.

The second half of the experiment was performed using the same slider with a different spring set-up. A spring with a higher spring constant was used requiring a second spring at the other end of the rod. The slider was manually pulled back against spring 1 using a gage block with a length of 2.25 in. As before, when finding the coefficient of friction, once the slider was released the position sensor continually relayed its voltage output to a data acquisition system which placed the data into an Excel file.

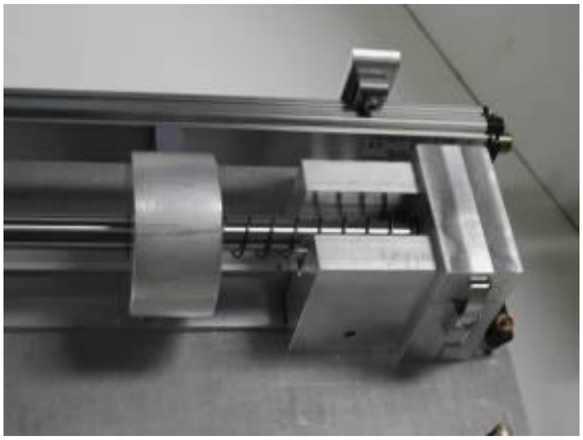


Figure 1 – Gage Block, Spring, and Slider

3. Theory

The action of a collar sliding on a shaft relies on three main concepts, potential energy, kinetic energy, and friction. By definition, the potential energy of a compressed spring is:

$$U = \frac{1}{2}k\delta^2 \qquad (1)$$

Kinetic energy for the slider is denoted as:

$$T = \frac{1}{2}mv^2 \qquad (2)$$

Knowing the velocity is not necessary to calculate distance traveled or spring constants. Using the principle of work and energy:

$$T_1 + U_{1\rightarrow 2} = T_2 \qquad (3)$$

Where:

T_1 = Kinetic energy before slider is released

T_2 = Kinetic energy of slider after it comes to rest

For a collar initially at rest, its kinetic energy is zero. Likewise, when the collar travels to the opposite spring and compresses it to its maximum possible compression, its kinetic energy becomes zero as well. Since the collar's velocity becomes zero before release and after it comes to rest, both T_1 and T_2 are zero. After eliminating T_1 and T_2 from equation 3, it can be seen that $U_{1\rightarrow 2}$ is equal to zero. Where $U_{1\rightarrow 2}$ is:

$$U_{1\rightarrow 2} = U_{spring} - U_{friction} \qquad (4)$$

Where:

$$U_{friction} = F_f \times d$$

From the above equations, the work/energy relationship can be established as:

$$\frac{1}{2}k_1\delta_1^2 = \left(F_f \times d\right) + \frac{1}{2}k_2\delta_2^2 \qquad (5)$$

Where $F_f = \mu_k N$ *(6)*

k = spring constant
δ = spring displacement
m = slider mass
v = slider velocity
F_f = friction force
d = displacement of slider
μ_k = friction coefficient
N = normal reaction force of slider

The work energy approach was used to predict the displacement the slider would undergo given specific spring constants, friction coefficient, mass, and spring compression distance.

Equations (5) and (6) allowed predictions for displacement to be made for any combination of springs after experimentally determining the coefficient of friction. The left side of equation (5) is the potential energy stored in spring 1 once it has been compressed by the slider. Since the energy can neither be created nor destroyed, all of the energy must be balanced by the terms on the right side of the equation. The first term represents the amount of energy consumed due to friction between the slider and the horizontal bar. The second term on the right side of the equation represents the amount of energy stored by spring 2 when the slider compresses it.

These two equations need to be used more than once if the second spring displaces the slider back to the first spring with enough force to compress the first spring a second time. These equations can be used as many times as needed.

4. Results

After the data acquisition system recorded the experimental data into an Excel file, it needed to be converted so that it reflected displacement distance instead of voltage. This was accomplished by using the given conversion factor of 0.4 V/in. Once this was accomplished, a graph showing the first five trials performed in order to determine the coefficient of friction was created (See Figure 2). Each of the peaks in the graph represents the position on the horizontal bar where the slider came to rest. These distances were averaged and that average was used to determine the coefficient of friction.

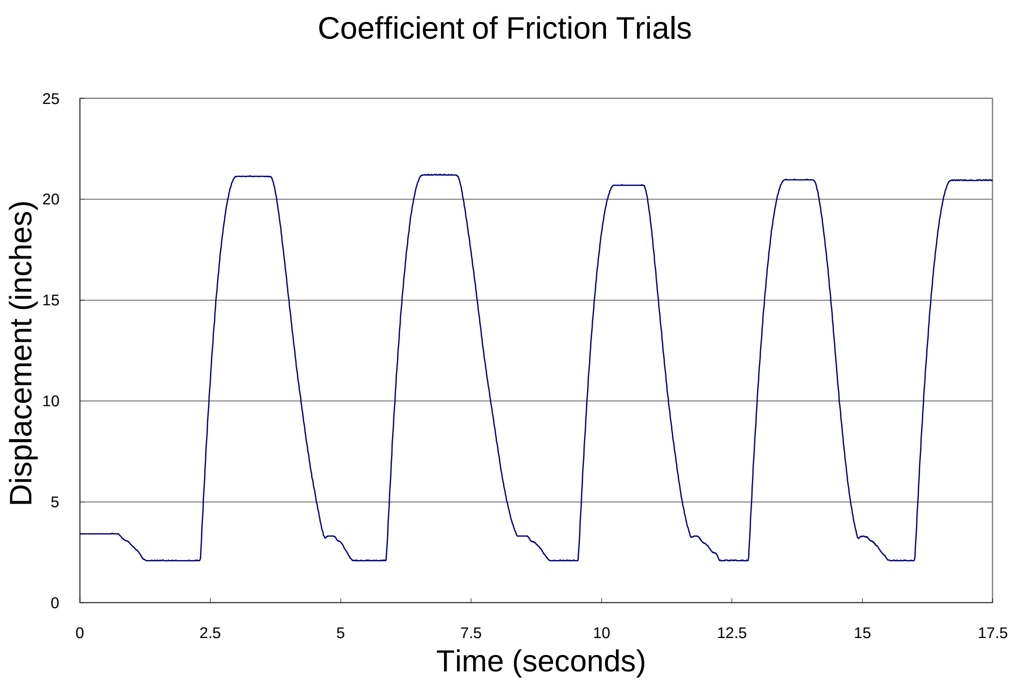


Figure 2- Experimental Results

This resulted in a coefficient of friction between the slider and the bar of 0.14 with an uncertainty of 1.597%.

After obtaining the coefficient of friction, similar calculations were performed to obtain a theoretical displacement for a specific spring setup. With the aluminum slider installed, the configuration of slider mass and spring rates allowed for the spring to travel from its initial position, to the second spring, and return to the first spring to be displaced again as shown in Figure 3. The theoretical displacement was determined to be 45.04 inches. The experimental displacement was 41.76 inches for a difference of 3.28 inches or 7.28% with an uncertainty of 7.757%. The theoretical and actual spring displacements for spring 2 were calculated to be

1.7952 and 1.65 in. respectively. This is a difference of 0.14519 in. or 8.088% with an uncertainty of 8.253%.

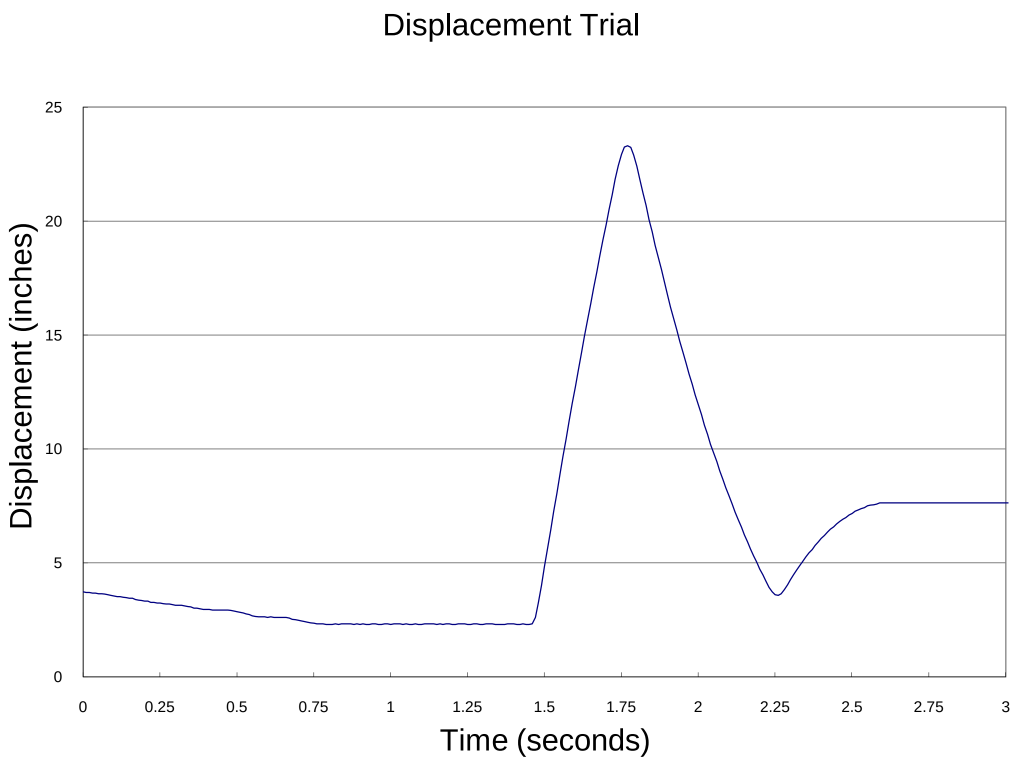


Figure 3 – Experimental Displacement

5. Conclusion

The use of a non-contact magnetic linear position sensor holds a distinct advantage over the use of a scale given that the uncertainty of the linear position sensor was 0.005 in. and a scale can have an uncertainty of as large as 0.0625 in. Having the theoretical and mathematical displacements match so closely also supports the advantage of the linear position sensor over a scale. The discrepancies between theoretical and experimental displacement may be due to the fact that the trials were done at separate times and the coefficient of friction may have changed from when it was calculated due to residue or oils from human contact left on the shaft due to repeated handling.