AC 2011-2653: INTEGRATED HANDS-ON MECHANICAL SYSTEMS LABORATORIES

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Integrated Hands-On Mechanical Systems Laboratories

Abstract

Hands on learning and experimentation are very important aspects of mechanical engineering education. Unfortunately, the integration of kinematic system demonstrations, laboratory activities, and relevant assignments into engineering coursework is not always easily accomplished or cost effective. This educational initiative is based on a concept of developing laboratory kits that would allow multiple levels of mechanical engineering courses to utilize the same system for numerous laboratory sessions.

Introduction

There are indications that engineers are active learners and therefore hands-on experiences are an important part of their education[1]. In order to facilitate hands-on learning in the engineering programs at Robert Morris University, basic mechanisms have already become an integrated part of the introductory courses of ENGR 1010 - Introduction to Engineering and ENGR 2160 - Engineering Graphics. Freshman engineering students become familiar with the motion of mechanical systems. The students have been asked to construct a crank mechanism, such as an oscillating lever with a connecting rod. Three of the many mechanisms that were constructed in the Introduction to Engineering course are shown in Figure 1.

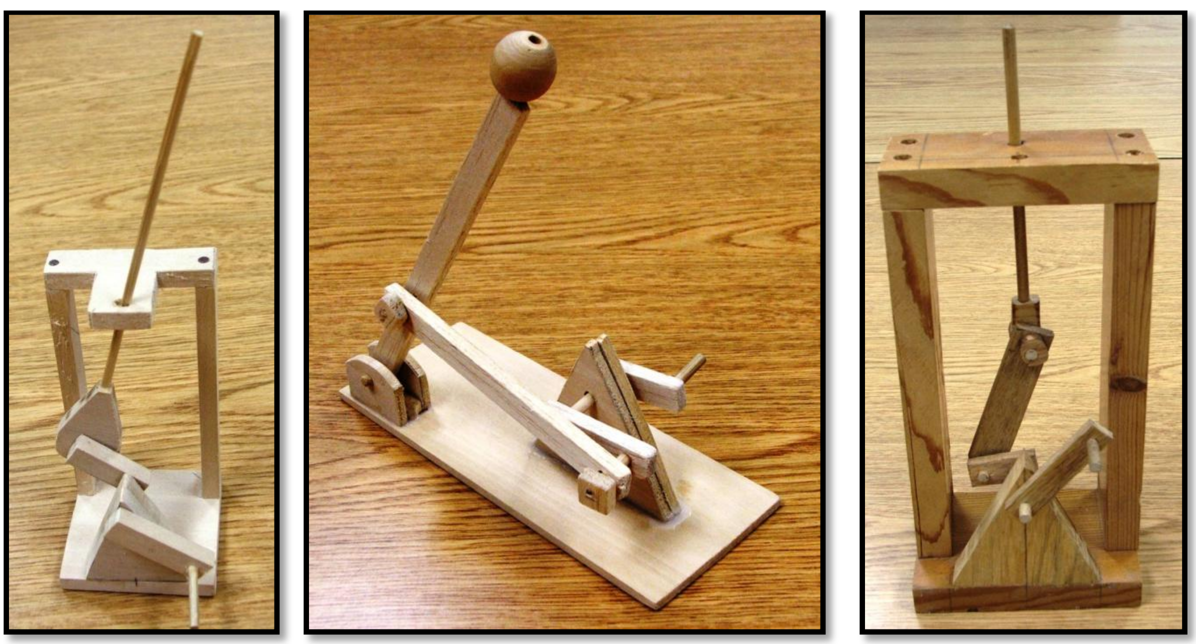


Figure 1: Student built wooden mechanical systems

After the engineering students have a grasp on the construction and assembly motion elements of a kinematic mechanism, they are then asked to create a Computer Aided Design (CAD) model of mechanical system in the Engineering Graphics course. They begin by reviewing their wooden models from the Introduction to Engineering course and then they design a simple mechanism such as a 4-bar linkage, oscillating lever with quick return, ordinary crank, or crank slider. Their designs were to be drawn using a CAD program, such as SolidWorks, and the students were instructed on how to perform a motion study. Figure 2 depicts a 3D CAD image of the mechanism along with a screenshot of the motion study that was conducted. The motion study incorporates a rotary motor that is attached to the crank handle allowing the mechanism to be automatically driven. When the mechanism was put into motion, the students were able to verify their mechanism design, including the critical clearance and tolerance values for the appropriate operation of the mechanism.

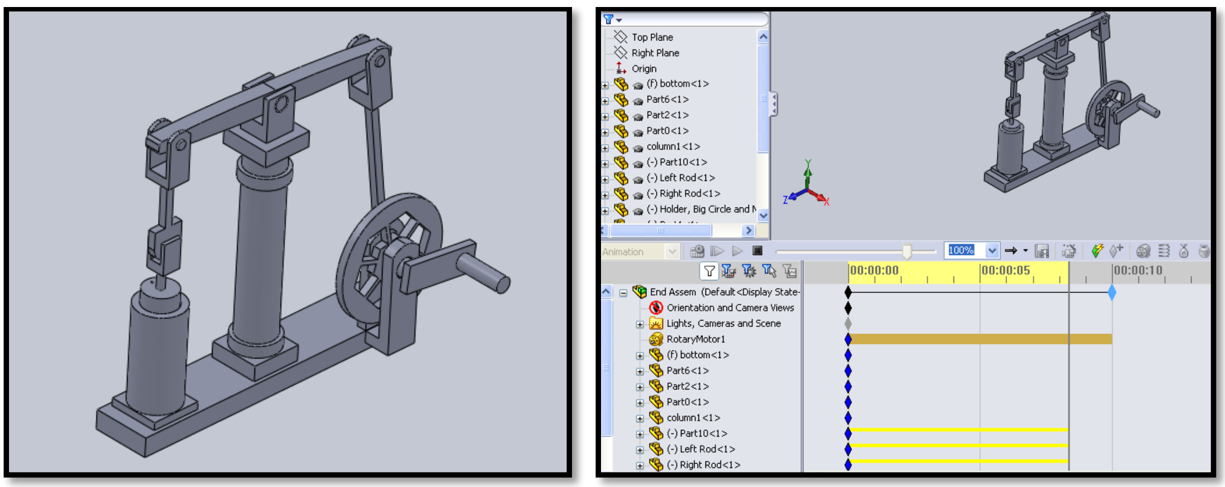


Figure 2: (left) SolidWorks drawing of a mechanical system, (right) Motion study of the mechanical system

The use of simple wooden mechanisms is sufficient for introductory level engineering courses, but it would be advantageous for higher level engineering laboratories to incorporate systems that are capable of more precise motion. The motion of such systems would allow for experimental evaluation and comparison to CAD based analysis systems, Computer Aided Engineering (CAE) tools. In order to accomplish this goal, this initiative will introduce a mechanical systems kit that would provide the necessary building components and precision sensing equipment to provide accurate motion and data acquisition for intermediate and advanced engineering courses. The kits will be capable of providing dynamic classroom support for the construction, demonstration, experimental evaluation, and design of numerous mechanical systems.

Mechanical Systems Laboratory in Intermediate Engineering Courses

To further the active learning environment of engineering students throughout the intermediate engineering courses, it is important to allow students to formulate their own ideas about the subject matter using hands-on experiences[2]. In order to provide engineering students these much needed experiences, this initiative will employ the use of mechanical systems laboratory kits. The kits will make use of the VEX Robotics Development System[3], as well as some custom made parts, in the construction of numerous mechanisms such as a crank slider, ordinary crank, 4-bar linkage, and Geneva wheel.

The use of the laboratory kits in intermediate and advanced courses, such as ENGR 2100 - Dynamics, would provide the students with hands-on experiments that would be focused on the kinematics and dynamic motion of the systems. For these students, the laboratories would guide them through experiments, including the construction of the simple mechanisms, the testing of the mechanisms using sensors that are synced to the data acquisition and controls software, and the analysis of their experimental findings. The intermediate level laboratories will be focused on concepts that include position, velocity, and acceleration as well as velocity ratios, stresses, torques and deflections.

The laboratory kits will include all of the necessary mechanism parts along with the associated data acquisition system and laboratory manuals. The laboratory manuals will provide experimental setups and related question sets. To demonstrate one of the experimental setups, a prototype has been built using the VEX Robotics Development System. Figure 3 shows an image of a slider mechanism, where a student can visualize and calculate the relationship between the linear displacement of the slider and the angular displacement of both links.

A setup, like the one shown in Figure 3, would be useful in the demonstration and experimentation of a simple slider mechanism for use in an intermediate level engineering course such as a Dynamic Systems laboratory. In such a laboratory session, the students will be asked to use the slider mechanism to experimentally determine system parameters such as the angular velocity and angular displacement of the two links, as well as the speed of the slider. Given the necessary dimensions of the setup, the students will then be asked to analyze the slider speed and angular velocity of the two links using the experimental angular velocity at an instant in time. They can then compare their analysis to the experimental data at an instant in time.

Similar setups will be also used in advanced engineering courses with greater demands towards functionality of the mechanical systems and the design and development processes. The next section will detail the content for the advanced level courses.

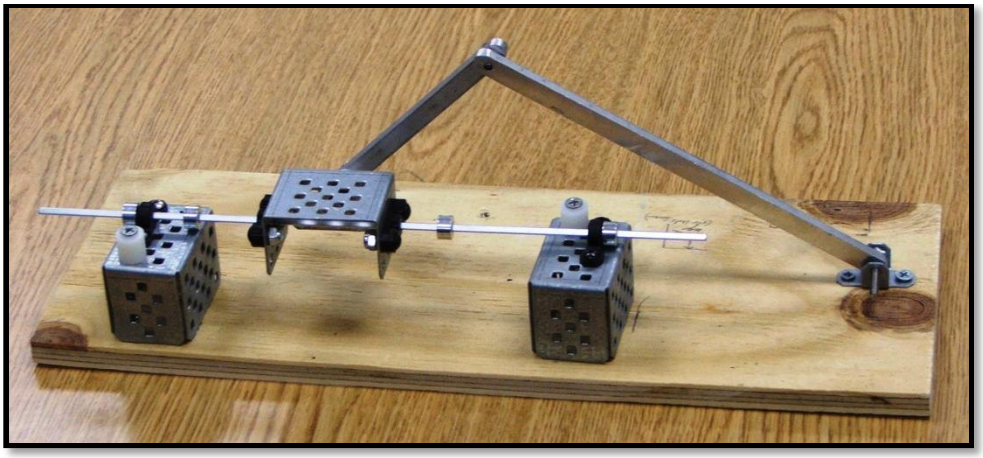


Figure 3: Pre-Built crank slider used for demonstration and experimentation with dimensions based on the Dynamic Systems adopted course textbook[4]

Mechanical Systems Laboratory in Advanced Engineering Courses

Figure 4 shows an image of slider crank mechanism in which an angular motion sensor and two limit switches are incorporated to provide digital feedback. An electric motor connected to a crank mechanism that runs the gear shown in Figure 4 will be used to maintain a constant periodicity of the link which drives the slider. The VEX optical shaft encoder will be used to acquire angular position data and velocity of the link connected to the crank along a time continuum during the experiment. The limit switches will give the times at which the slider reaches maximum displacement. By automating the slider crank mechanism through the use of an electric motor (not shown in Figure 4) and sensors, advanced mechanical system concepts can be demonstrated. An example laboratory for a Dynamic Systems course can be viewed in Appendix 1.

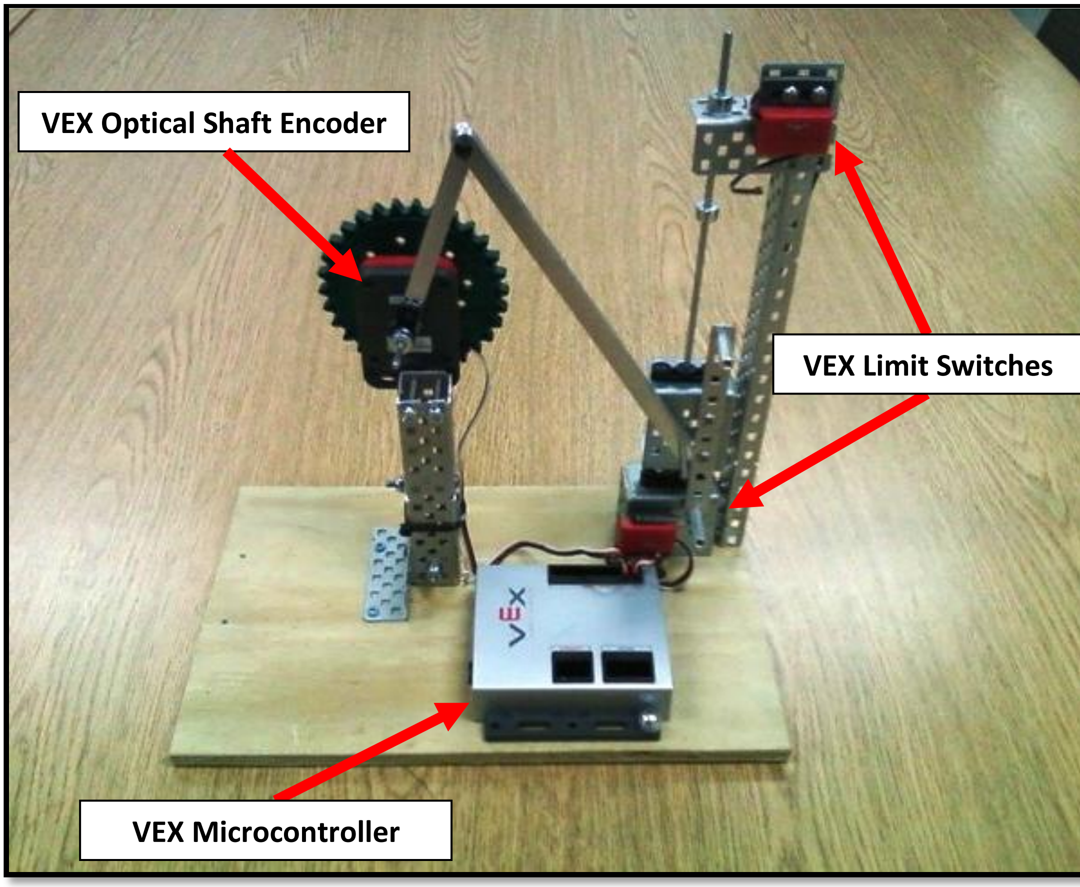


Figure 4: VEX slider crank setup with an angular motion sensor and two limit switches connected to a VEX microcontroller unit

A similar setup to that of the one shown in Figure 4 can be used in combination with machine components such as gear trains, flywheels, and belts to demonstrate and analyze sophisticated machine component systems. The students will be required to construct a gear train with a velocity ratio of their choosing, and install it in line with the motor and crank. After acquiring the velocity data of the system with and without the gear train, the students will be asked to compare the data sets and will see firsthand the effect of the gear train on the mechanism's change in velocity. The students will then be asked to remove the gear train and attach a flywheel to the motor shaft. After allowing the flywheel to reach a maximum speed, the students will remove the motor from the flywheel shaft and allow the flywheel to continue driving the slider crank mechanism. Students will be instructed to calculate the inertial potential energy in the flywheel and compare this energy to the amount of movement achieved by the slider crank mechanism after the motor was disengaged.

Experimentation exercises the use of analysis, but to accommodate higher levels of understanding, the laboratory kit must also allow for the synthesis and evaluation of a mechanical system, as defined by Bloom's Taxonomy[5]. To facilitate these higher level aspects of the learning process, kit provides the necessary mechanical parts in which a student has the capability to design and construct a mechanical system to perform a task or solve a problem. Advanced engineering courses such as ENGR 4100 – Machine Design could utilize the flexibility of the kits to accommodate for design projects. The VEX Robotics Development System also provides pre-drawn SolidWorks VEX parts that would allow for the CAD design of a mechanical system such as the robot vehicle shown in 6 by assembly of the parts.

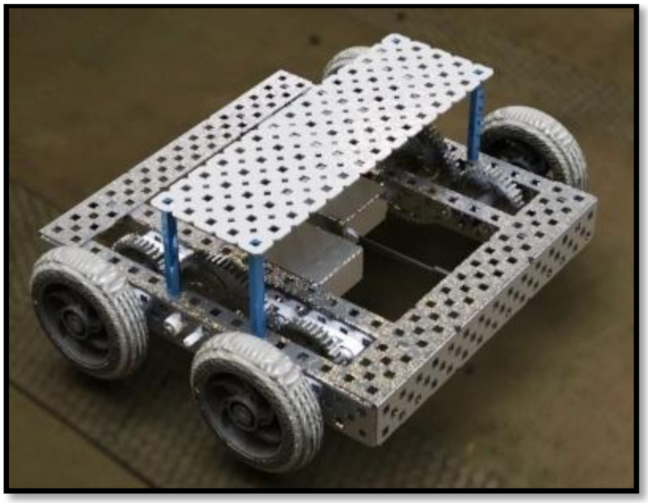


Figure 6: DDS SolidWorks Assembly of a Robot Vehicle Using Pre-Drawn VEX parts (DDS Photo Works rendered)

Conclusions

To further develop classroom understanding and course laboratories across the introductory, intermediate, and advanced levels of engineering, an initiative to introduce mechanical systems kits has been developed. The initiative incorporates the modularity and integrated software capabilities of the VEX Robotics Development System as well as the SolidWorks CAD and CAE features. The flexibility of the mechanical systems kit allows for almost infinite possibilities in the construction, experimentation and design of mechanisms. The future goals of this initiative are to develop the mechanical systems kits, laboratory exercises and to introduce the kits to the Dynamic Systems classroom for initial testing. Results from the initial testing will be provided in future publications.

References

1) Dunn, R., & Carbo, M. (1981). Modalities: An Open Letter to Walter Barbem Michael Milone and Raymond Swassing. *Educational Leadership* , 381-382.

2) Kolb, D. A. (1984). *Experiential Learning: Experience as the Source of Learning and Development.* Englewood Cliffs, New Jersey, U.S.A.: Prentice Hall.

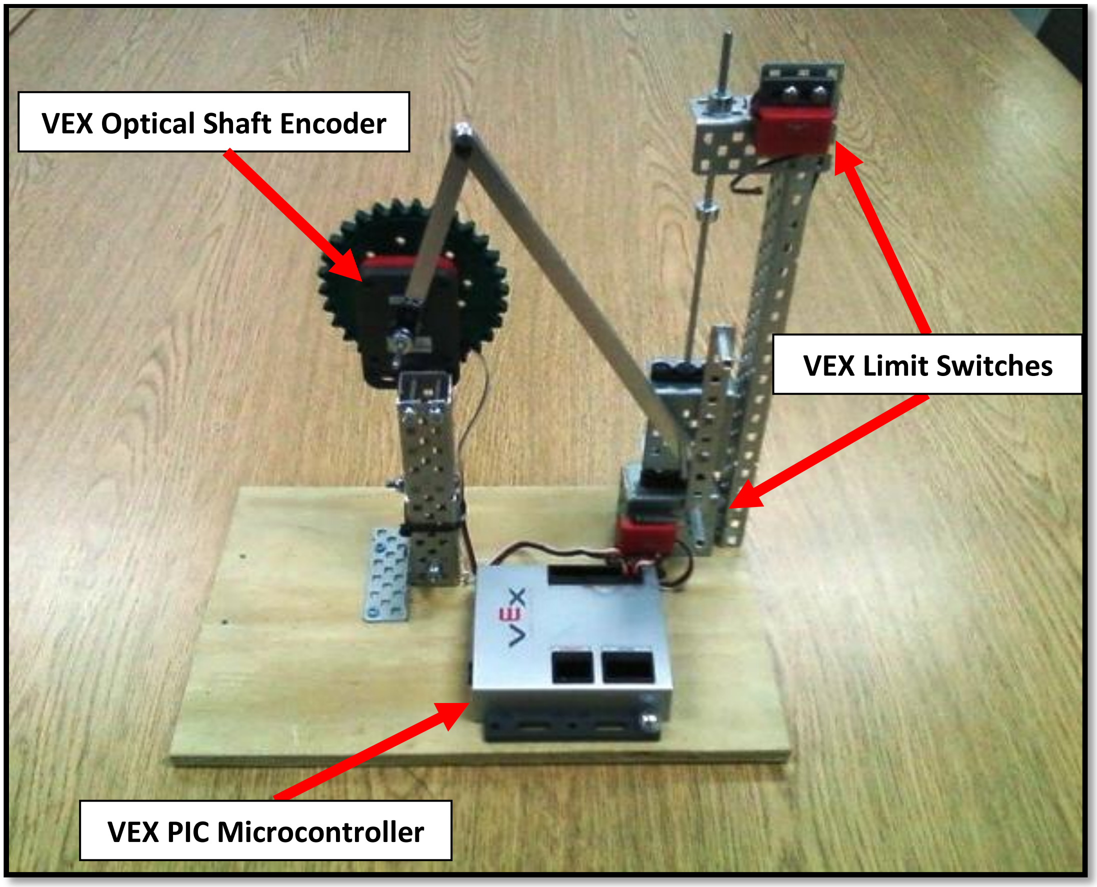
3) http://www.vexrobotics.com/

4) Hibbeler, R. C. (2010). *Engineering Mechanics Dynamics, Twelfth Edition.* Upper Saddle River, New Jersey, U.S.A.: Prentice Hall.

5) Bloom, B. S., & Krathwohl, D. R. (1956). *Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain.* New York, NY, U.S.A.: David McKay Co. Inc.

Appendix 1: Dynamic Systems Example Laboratory

Slider Crank Laboratory



Laboratory Objectives:

1) Experimentally determine the angular velocity of the crank linkage and connecting link, as well as the linear velocity of the slider at motor speeds of 30, 60, and 120 rpm.
2) Calculate the angular velocity of the crank linkage and connecting link, as well as the linear velocity of the slider at the set motor speeds.
3) Compare the experimental results to the analytical results.

Experimental Setup:

1) Connect the VEX Motor to the gear and then to the VEX Motor Controller
2) Connect the VEX Motor Controller, VEX Optical Shaft Encoder, and the VEX Limit Switches to the VEX PIC Microcontroller.
3) Connect the RJ cable to the VEX PIC Microcontroller and then to the USB adapter
4) Connect the USB cable to the computer and open the EasyC V2 program
5) Open the Data Acquisition Easy C program titled, "Slider Crank Laboratory"
6) Run the program

Data Acquisition:

1) After the program has concluded, a table of displacement and velocity versus time data will be visible.
2) Export the data into Excel and save the file
3) Using your Excel data, create an angular displacement versus time chart for both links and do the same for the linear displacement of the slider
4) Repeat these steps for each motor speed

Velocity Calculation:

1) Choose an instant in time to analyze the slider crank
2) Calculate the following for each different motor speed at that instant in time:
    a. Angular velocity of the crank linkage
    b. Angular velocity of the connecting link
    c. Linear velocity of the slider

Discussion Questions:

1) What was the percent error between the experimental data and the analytical solutions?
2) Name 3 reasons that may have caused this error?
3) How is the angular acceleration of the crank linkage affected when you increase or decrease the speed?
4) At which locations does the crank linkage experience the highest angular acceleration?
5) At which locations does the slider experience the highest acceleration?