AC 2012-4137: INTEGRATED HANDS-ON DYNAMICS LABORATORIES IN THE CLASSROOM

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Integrated Hands-On Dynamics Laboratories in the Classroom

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.

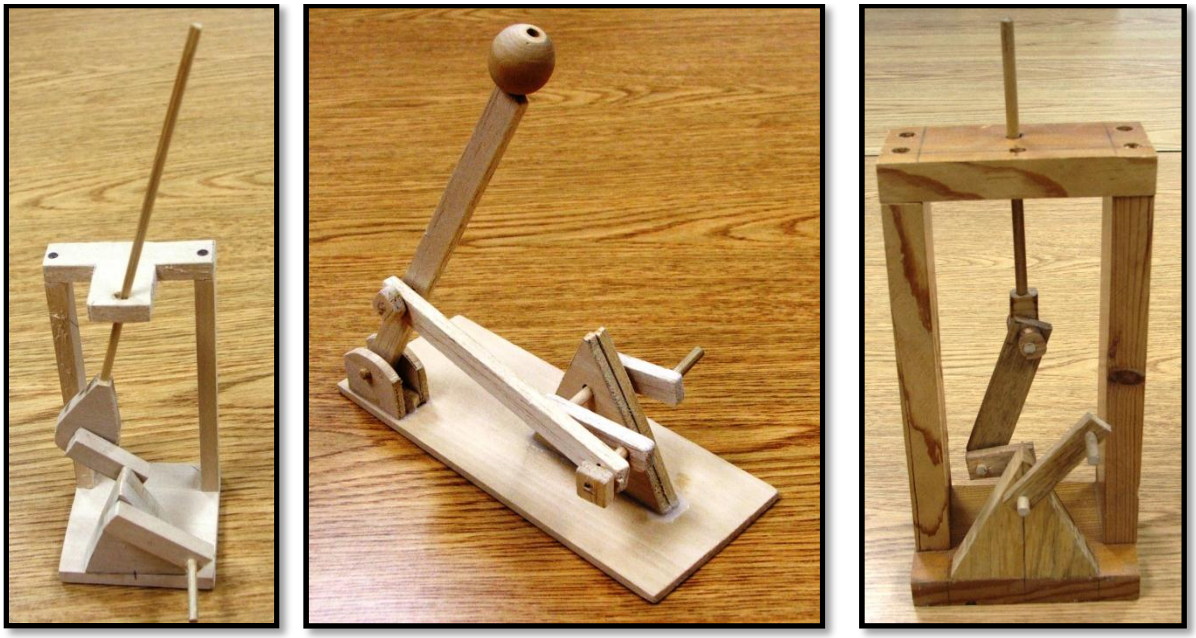


Figure 1: Student built wooden mechanical systems

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 the mechanical system in the Engineering Graphics course. They begin by reviewing their wooden models from the Introduction of 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 a mechanism along with a screenshot of the motion study that was conducted by a student in the Engineering Graphics course. 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 use CAD software to verify their mechanism design, including the critical clearance and tolerance values for the appropriate operation of the mechanism.

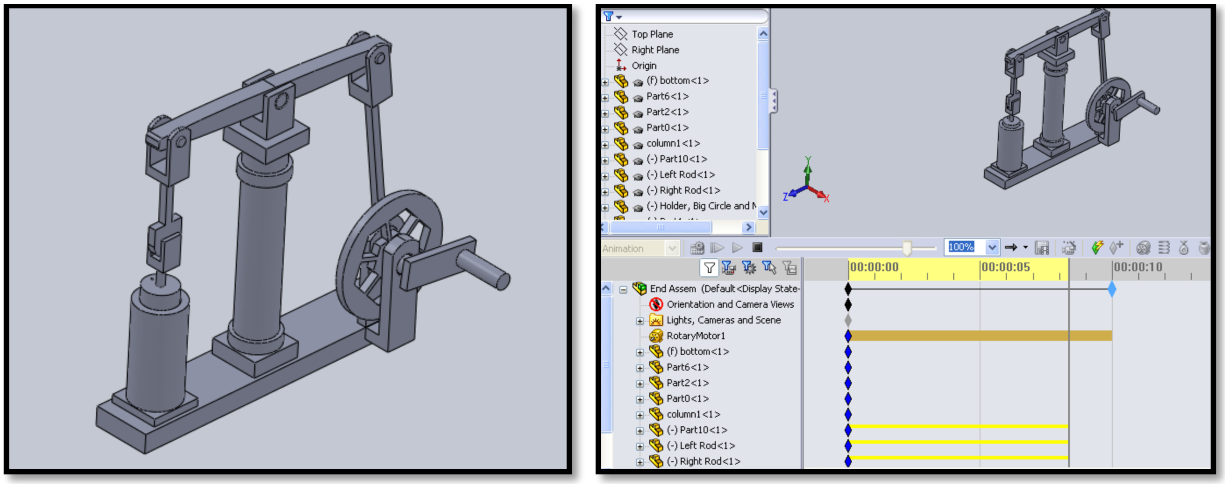


Figure 2: (left) SolidWorks drawing of a mechanical system, (right) Motion study of the mechanical system

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 Computer Aided Engineering (CAE) tools. In order to accomplish this goal, this initiative will introduce the concept of lower cost mechanical systems kits 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 and can be employed in various subjects including Kinematics, Dynamics, and Machine Design and Dynamics of Machinery.

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 has employed the use of mechanical systems laboratory kits. The process for designing these kits are still in progress. The kits will make use of the VEX Robotics Development System, 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 the experiments, including the construction of the simple mechanisms, the testing of the mechanisms using sensors that are synced to 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. Development and implementation of one of the experimental setups has been accomplished in a Dynamics course at Robert Morris University in the fall semester of 2011. This laboratory can be seen in Appendix 1 and was conducted by a total of twenty nine students who were divided up into six groups.

The laboratory has a hands-on analytical portion and a simulation portion that makes use of the Working Model software. **Figure 3** shows the setup and a labeled drawing of the analytical laboratory. In this laboratory, the students were asked to arrange the slider crank system so that link AB is exactly vertical. They then had to measure angles using a digital protractor and also measure the lengths of the links. After they collected the necessary geometric data, they were to make a sketch of the system and determine the Instantaneous Center of Rotation (ICR). The laboratory assignment gives the students the velocity of point B at an instant in time and the students were then asked to find the velocity at point C using the ICR. The purpose of this laboratory was to present a real-world system that uses some theoretical concepts such as determining an Instantaneous Center of Rotation, Rigid Body Motion, Relative Velocity Calculation and Angular Velocity Calculation. The students seemed to enjoy this laboratory and worked very well in their groups to determine the solutions to the questions. The fact that the system was sitting in front of them and they were able to use it in any way they wanted in order to solve the questions, increased the difficulty level of calculations because of the large number of conceivable variables. This laboratory exercise made the students think about how to approach a physical system as opposed to a dimensioned drawing from a textbook.

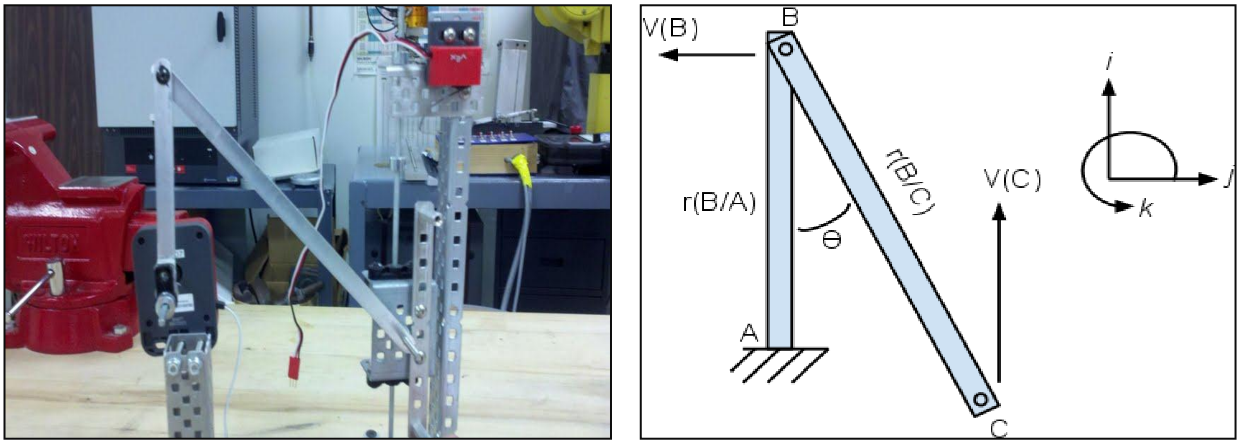


Figure 3: (left) Setup of Slider Crank System, (right) Labeled Drawing of Slider Crank System Including Velocities at an Instant in Time.

The same slider crank setup that is shown in Figure 3 was evaluated by the students using Working Model motion simulation software. The students were simply asked to find the instantaneous velocity at point C given the velocity at point B using nothing more than the Working Model software and the geometric measurements that they made in the previous laboratory class. The students have to use their measurements to draw the setup in Working Model and then have to figure out a way to use the software to analyze the system. There are numerous ways to approach this problem using Working Model and it was up to the students to determine their approach. **Figure 4** shows an image of a Working Model simulation where a motor causes link AB to rotate counterclockwise so that the velocity of Point B is the same as what is given in the laboratory assignment. After the system properties are set correctly, the simulation is run and the links are set into motion. The system can then be analyzed using the charting functions available in Working Model. The top graph shows the angle of rotation of link AB with respect to time and the bottom graph displays the velocity of point C with respect to time. When link AB is exactly vertical (360° in this simulation) the velocity of point B is 5 ft/s in the negative *i*-direction. The students can then look on the velocity chart to determine the velocity of point C at the instant in time that AB is exactly vertical. This laboratory gave the students an interesting example of how to solve a real world problem using simple motion software. The students had to develop a logical methodology to arrive at an answer. There were multiple ways to solve this problem and the students had to understand the problem as well as the Working Model capabilities to arrive at the correct solution.

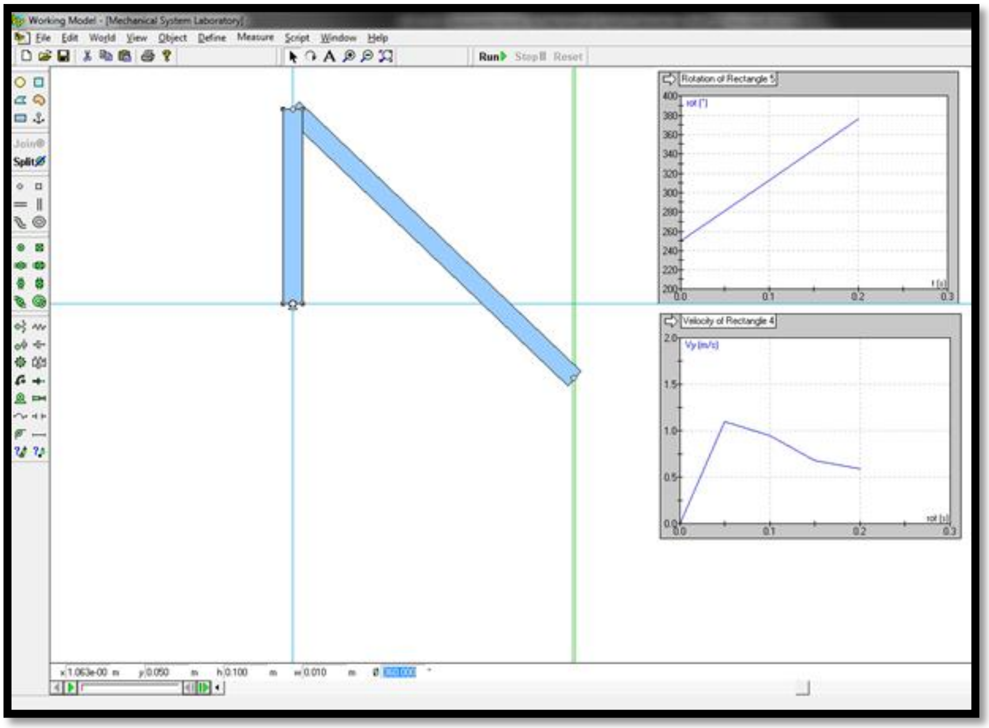


Figure 4: Working Model Simulation of the Crank Slider Setup

Mechanical Systems Laboratory in Advanced Engineering Courses

Figure 5 shows an image of a 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 5, 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 5) and sensors, advanced mechanical system concepts can be demonstrated. An example laboratory for a Dynamic Systems course can be viewed in Appendix 3 while the ROBOT C program utilized in data acquisition is given in Appendix 4.

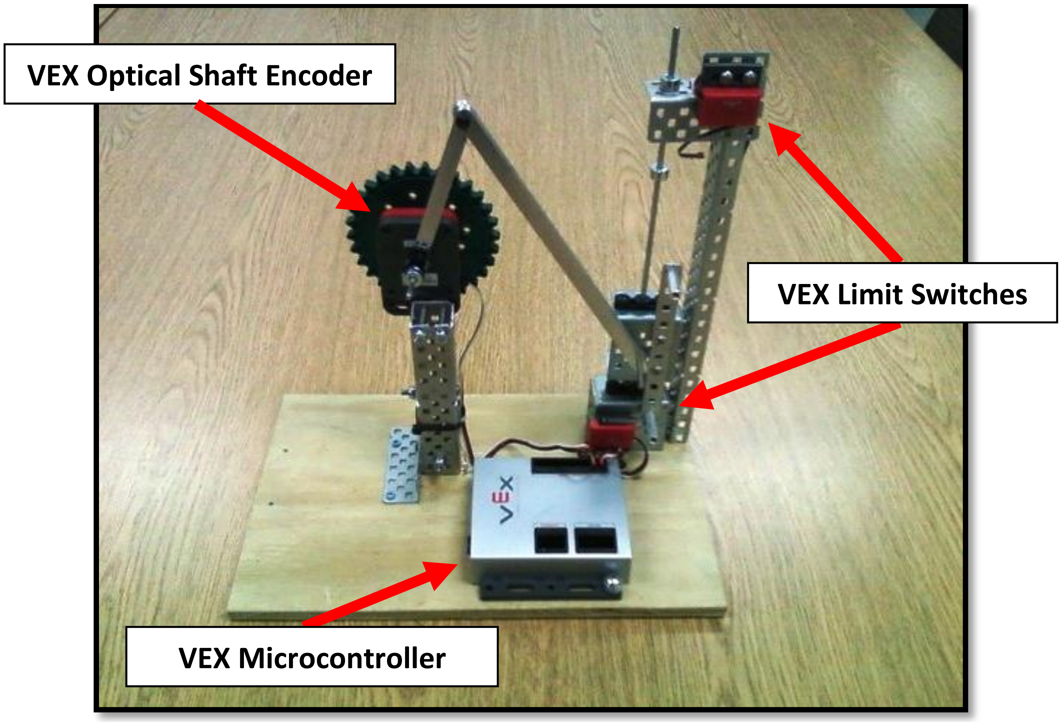


Figure 5: VEX slider crank setup with an angular motion sensor and two limit switches connected to a VEX microcontroller unit

A similar setup to that of the one shown in Figure 5 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 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. The 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 laboratories utilize analysis concepts, but to accommodate higher levels of understanding, the proposed laboratory kits must also allow for the synthesis and evaluation of a mechanical system, as defined by Bloom’s Taxonomy[4]. To facilitate these higher level aspects of the learning process, these kits 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 individualized 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 Figure 6, through CAD assembly of the VEX parts.

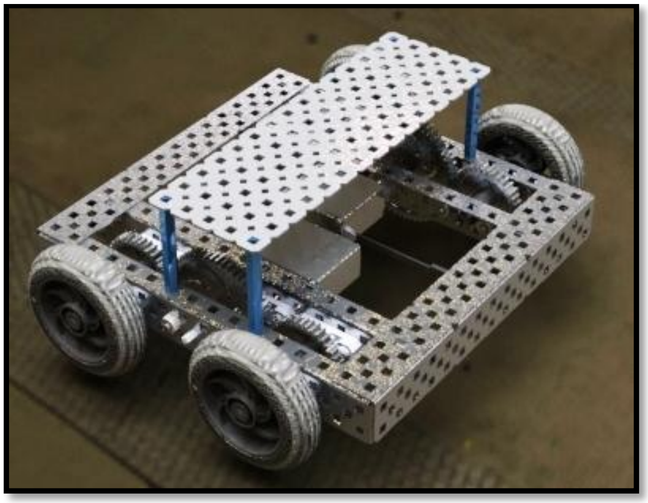


Figure 6: SolidWorks Assembly of a Robot Vehicle Using Pre-Drawn VEX parts (Photo Works rendered)

Conclusions

To further develop classroom understanding and course laboratories across the introductory, intermediate, and advanced levels of mechanical 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, Working Model motion software and SolidWorks CAD and CAE features. The flexibility of the mechanical systems kit allows for numerous possibilities in the construction, experimentation and design of mechanisms. Development and implementation of two Dynamics course laboratories have proven to be successful due to student performances within the course, and course student evaluations in the other courses. The future goals of this initiative are to further develop the mechanical systems kits as well as create more laboratory exercises for introductory, intermediate and advanced engineering students.

References

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

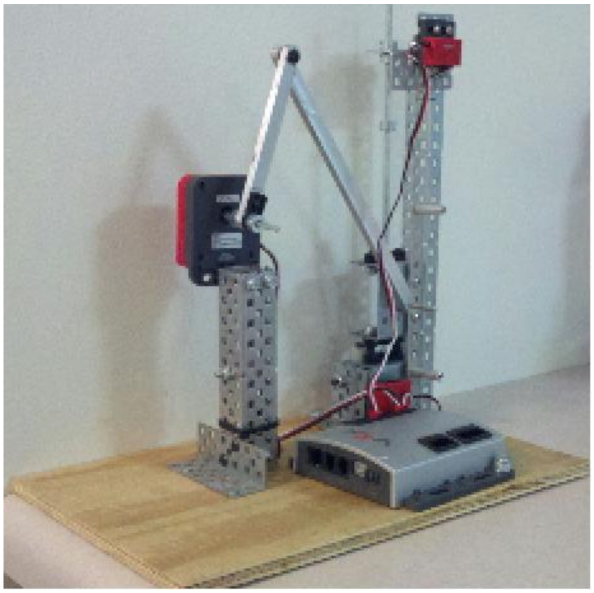
2) Kolb, D. A. (1984). *Experiential Learning: Experience as the Source of Learning and Development.* Englewood Cliffs, New Jersey, U.S.A.: Prentice Hall.

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

4) 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 Analytical Laboratory

Angular Velocity and Instantaneous Center of Rotation

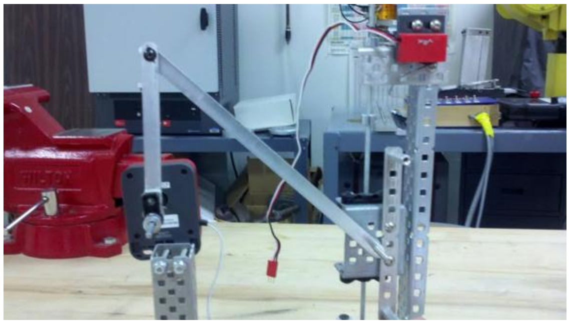


Introduction:

In the class lecture we found the Instantaneous Center of Rotation (ICR) and the angular momentum for a rigid body. We are going to apply this concept to a real life problem. In this lab, you will be given the VEX model shown above. With this model, you will measure the beams and find the angle of the 2 beams when beam AB is exactly vertical. You will then answer the questions assuming that the velocity of point B at an instant in time is 5 ft/s in the negative *i*-direction.

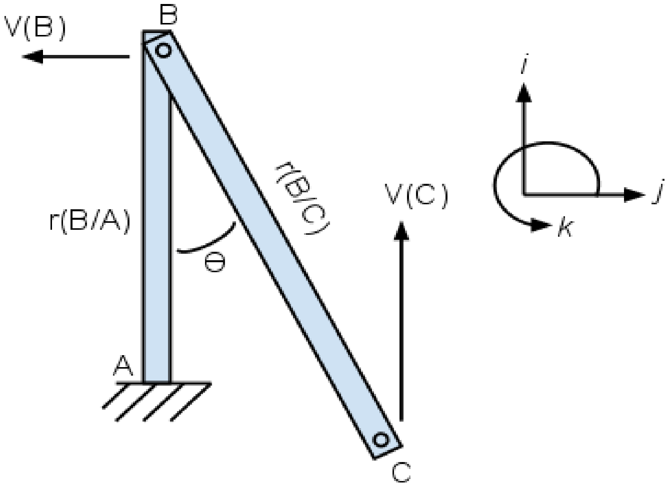
List of Experiment Materials:

1. Vex model →
2. Ruler
3. Protractor
4. Calculator



Experimental Procedure:

1. Measure the beams AB and BC using the ruler
2. Measure the angle between AB and BC using the protractor
3. Find the Instantaneous Center of Rotation (ICR)
4. Answer the laboratory questions



Experimental Results Table:

Variable	**Value**
Given:	
V_B	-5 ft/s $\vec{i}$
r_{AB}	
r_{BC}	
Θ	
Find:	
$r_{A/ICR}$	
$r_{B/ICR}$	
$r_{C/ICR}$	
ω_{AB}	
ω_{BC}	

Calculations/Questions:

1. Sketch a drawing of the setup.

2. Determine the location of the Instantaneous Center of Rotation (ICR) on the sketch.

3. Using the angle and the lengths of the arms, find:
(a) The distance from point B to the ICR ($r_{B/ICR}$)

(b) The distance from point A to the ICR ($r_{A/ICR}$)

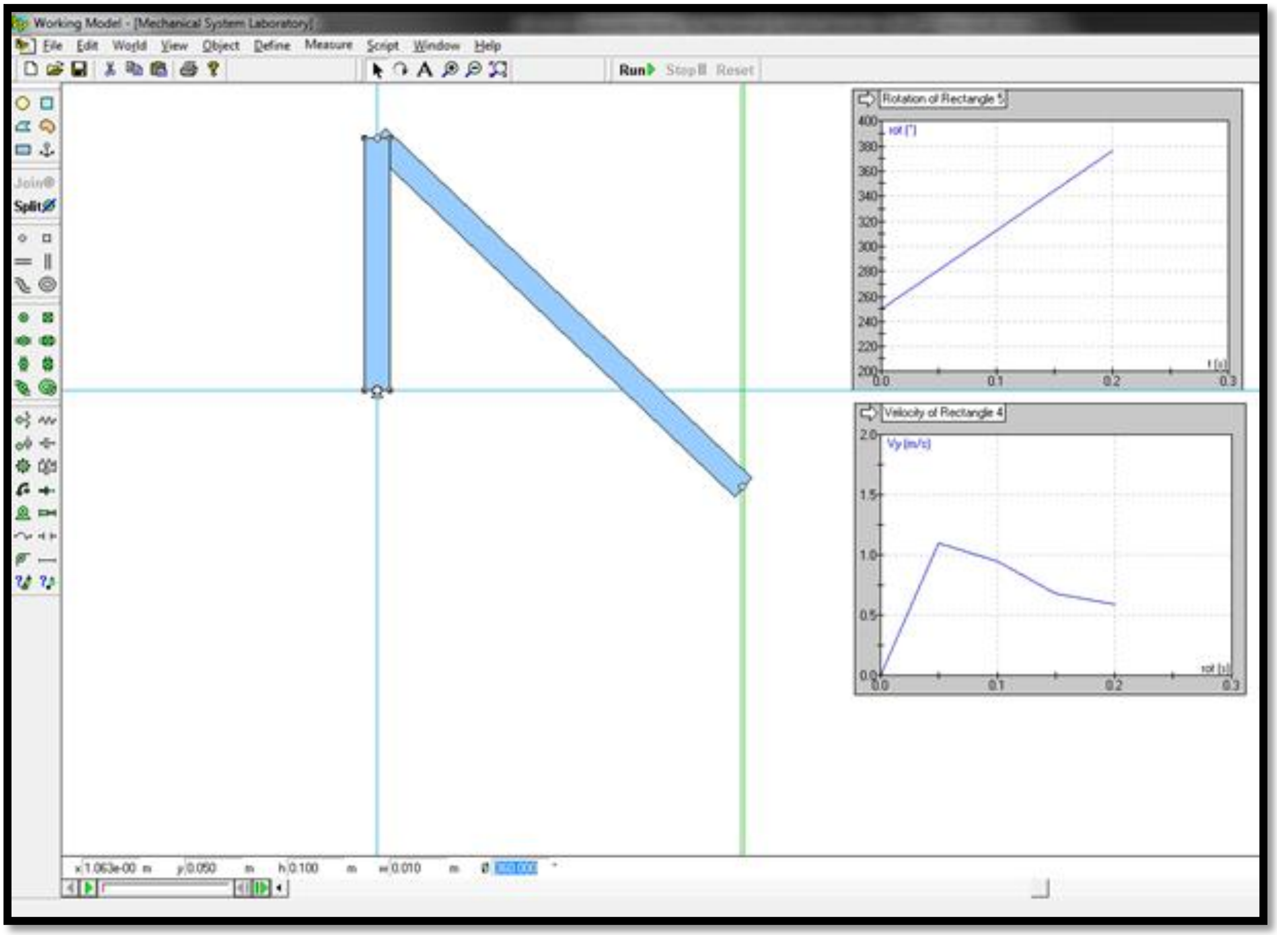
(c) The distance from point C to the ICR ($r_{C/ICR}$)

4. Find:
(a) Angular velocity of link AB (ω_{AB})

(b) Angular velocity of link BC(ω_{BC})

6. Find V_c

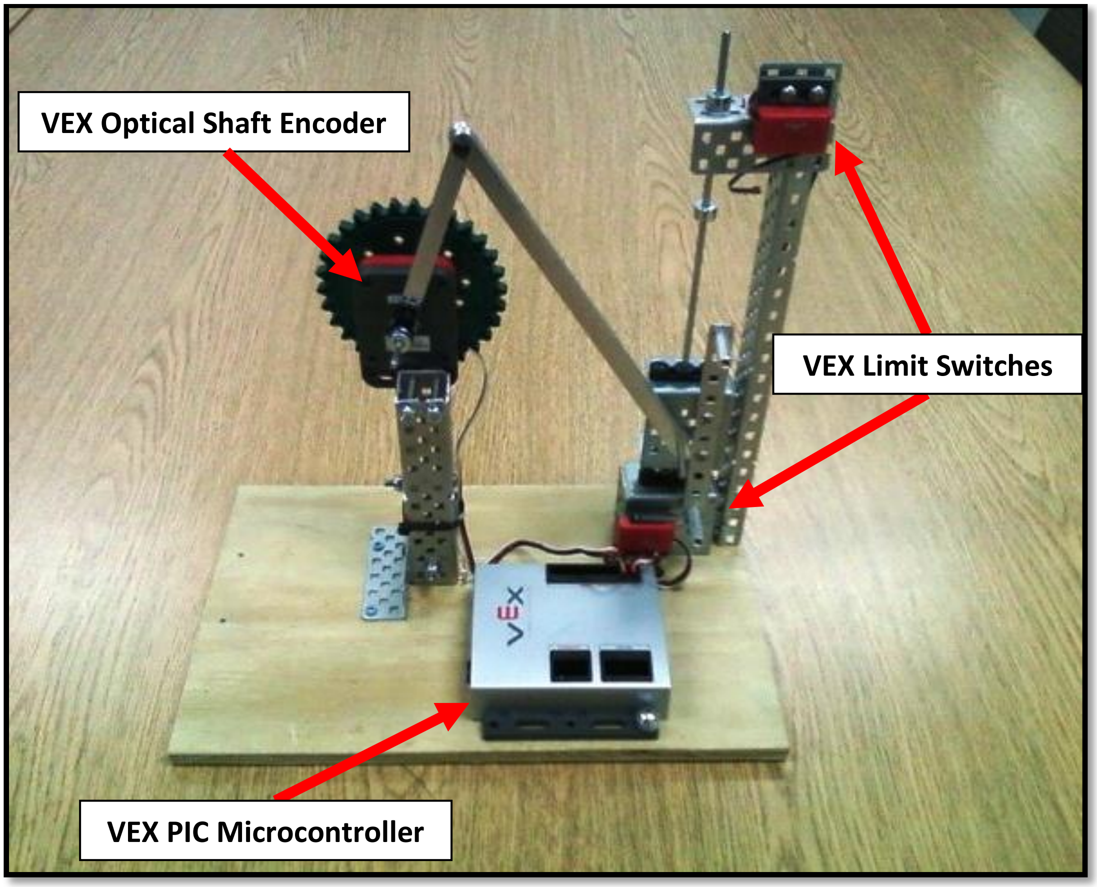
Appendix 2: Dynamic Systems Numerical Laboratory (Working Model)



x 1.063e-00 m
y 0.050 m
h 0.100 m
w 0.010 m

Appendix 3: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

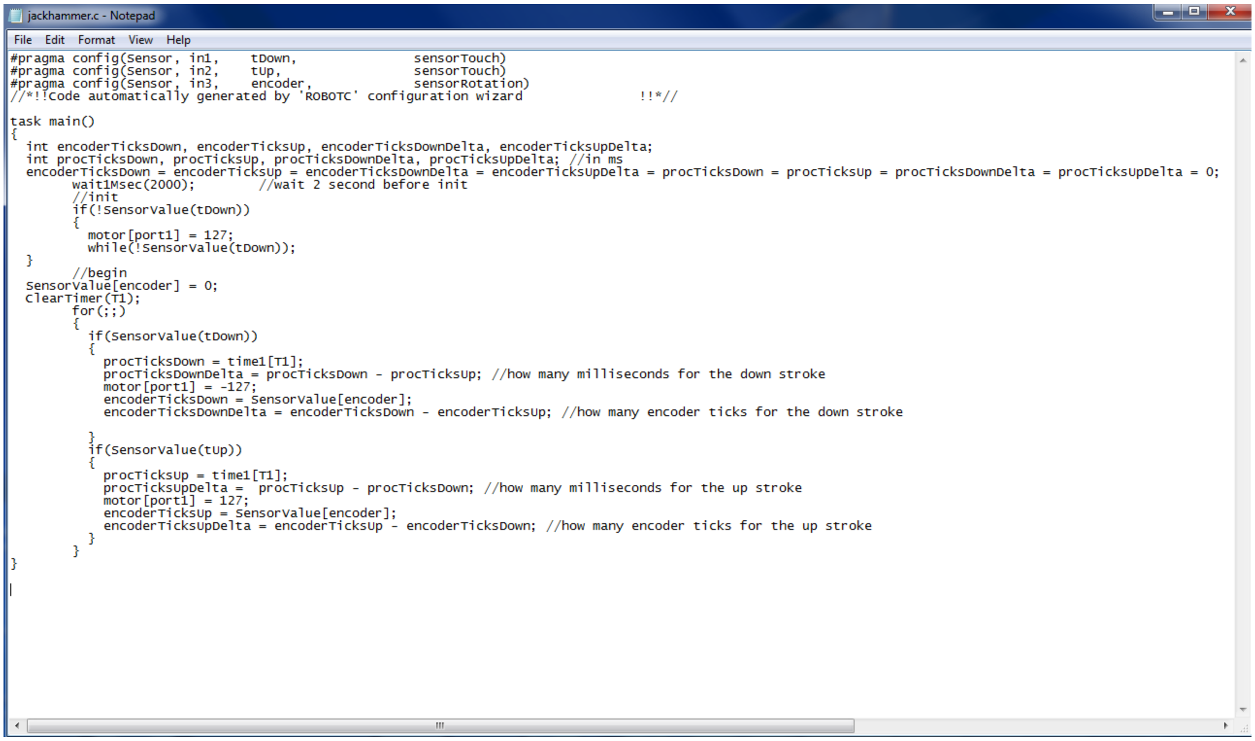
Velocity Calculation:

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?

Appendix 4: Sample Robot C program used in measuring number of encoder pulses for rotational and translational motion



```
#pragma config(Sensor, in1,    tDown,               sensorTouch)
#pragma config(Sensor, in2,    tUp,                 sensorTouch)
#pragma config(Sensor, in3,    encoder,             sensorRotation)
//*!!Code automatically generated by 'ROBOTC' configuration wizard               !!*//

task main()
{
  int encoderTicksDown, encoderTicksUp, encoderTicksDownDelta, encoderTicksUpDelta;
  int procTicksDown, procTicksUp, procTicksDownDelta, procTicksUpDelta; //in ms
  encoderTicksDown = encoderTicksUp = encoderTicksDownDelta = encoderTicksUpDelta = procTicksDown = procTicksUp = procTicksDownDelta = procTicksUpDelta = 0;
        wait1Msec(2000);        //wait 2 second before init
        //init
        if(!SensorValue(tDown))
        {
          motor[port1] = 127;
          while(!SensorValue(tDown));
  }
        //begin
  SensorValue[encoder] = 0;
  ClearTimer(T1);
        for(;;)
        {
          if(SensorValue(tDown))
          {
            procTicksDown = time1[T1];
            procTicksDownDelta = procTicksDown - procTicksUp; //how many milliseconds for the down stroke
            motor[port1] = -127;
            encoderTicksDown = SensorValue[encoder];
            encoderTicksDownDelta = encoderTicksDown - encoderTicksUp; //how many encoder ticks for the down stroke

          }
          if(SensorValue(tUp))
          {
            procTicksUp = time1[T1];
            procTicksUpDelta =  procTicksUp - procTicksDown; //how many milliseconds for the up stroke
            motor[port1] = 127;
            encoderTicksUp = SensorValue[encoder];
            encoderTicksUpDelta = encoderTicksUp - encoderTicksDown; //how many encoder ticks for the up stroke
          }
        }
}
```