Rigid-Body Kinematics
Dynamics Laboratory, Spring 2003

This laboratory involves comparison of measurements and theoretical calculations of the kinematics of a four-cylinder Mazda car engine.

EXPERIMENT

Measure system dimensions as depicted in Figure 1:

- Length of connecting rod, L: The piston in the fourth cylinder has been removed along with its connecting rod, so this dimension can be measured directly.
- Radius of crank, r: The crank is enclosed inside the engine, so the crank radius cannot be measured directly. To determine the crank radius, measure the total travel distance of the piston between the top and bottom of its stroke, and use this distance to determine the crank radius from this kinematics of the assembly. Be sure to record this distance, as it will also be used to determine the calibration factor for the displacement transducer. Since the travel distance is the same for all four cylinders, measure the travel distance in the second cylinder of the engine, where there is no instrumentation to interfere with your measurements. Advance the piston manually from the top to the bottom of its stroke by using the screwdriver to rotate the gear attached to the drive shaft. As the drive shaft is manually rotated, the rotation of the crank can be observed by looking down the fourth cylinder, where the piston has been removed. (*To avoid being hit by rapidly moving parts, do not look down the cylinder while the engine is in operation.*)

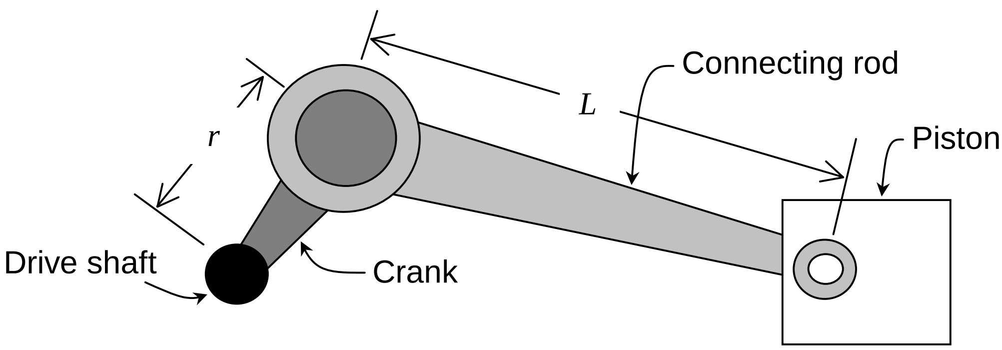

Figure 1. Schematic Diagram of Crank-Piston Assembly

Operation of the engine: The drive shaft of the engine is being driven by an electric motor. To operate the engine, press and hold the switch for the motor; to stop the engine, release the switch. *Be sure to keep a safe distance from the engine while it is in operation.*

Take measurements of the engine in motion:

- Use the optical tachometer to measure the angular velocity of the drive shaft. The optical tachometer emits a light beam and counts the number of reflections per minute; two reflector strips are mounted to the flywheel on the drive shaft, so the number of reflections per minute is equal to twice the number of revolutions per minute.
  - The tachometer switch should be set to position 1 (100 – 6,000 RPM)
  - The tachometer output is read from the voltmeter, which should be set to DC mode, 20V range. *Be sure to switch the voltmeter back to the off position after taking measurements.*
  - To operate the tachometer, press the red button turn on the light, and point the light beam at the rotating flywheel. When the measured reflection rate stabilizes, the green light on the tachometer will glow steadily; then record the voltage indicated by the voltmeter. For consistency, the angular velocity should be measured by the tachometer at the same time as the time history traces are recorded by the oscilloscope, as discussed below.
  - The calibration factor for the tachometer will be provided.
- Use the dual-channel oscilloscope to record the traces of displacement and acceleration of the two instrumented pistons. Channel 1 is displacement of piston one and channel 2 is acceleration of piston 3. Adjust the sensitivity for both channels to 2.00 V/div by adjusting the knob labeled "VOLTS/DIV" for each channel. The current value of sensitivity for each channel is displayed at the bottom of the screen (e.g., CH1 2.00V CH2 2.00V), and this value gives the scale on the vertical axis (the voltage difference between two horizontal gridlines). Adjust the time scale to 50.0 ms/div by adjusting the knob labeled "SEC/DIV". The current value of the time scale is displayed at the bottom of the screen (e.g., M 50.0 ms). When the oscilloscope is not recording, "Stop" will be displayed at the top of the screen; to begin recording, press the "RUN/STOP" button. When the time traces have reached a steady-state sinusoidal appearance, press the "RUN/STOP" button to freeze the traces on the oscilloscope, and print the display by pressing "HARDCOPY".
  - The amplification for the acceleration channel should be set to a gain of 30X; verify that this is the case. This means that the voltage recorded by the oscilloscope is 30 times larger than the voltage output by the instrument, so be sure to account for this factor in interpreting your results. The amplification for the displacement channel should be 1X; verify that this is the case as well.
  - The calibration factor for the accelerometer (without amplification) is 50 *g* /V
  - Record the peak-to-peak voltage difference for both the acceleration and displacement time traces. These values can be determined using the cursors on the oscilloscope. To activate the cursors, press "CURSOR". At the right edge of the display the word "Type" will appear to indicate the current type of cursor (options are "Voltage", "Time", or "Off"). Press the button to the right of "Type" to select "Voltage", and the cursors will become horizontal lines. The

"POSITION" knobs for channels 1 and 2 can be used to adjust the vertical position of cursors 1 and 2, respectively. The positions of the cursors are indicated at the right edge of the screen along with the difference ("Delta") between the two cursors. For both the displacement and acceleration traces, align one of the cursors with the top of the trace and the other cursor with the bottom of the trace, and record the indicated value of "Delta" for the peak-to-peak voltage for each trace.

- Find the frequency of oscillation from the time trace of displacement (and/or acceleration) by determining the time difference between two adjacent peaks in the trace. This time difference can be determined using the cursors on the oscilloscope. Activate the cursors by pressing "CURSOR", and select "Time" by pressing the button to the right of the word "Type" on the display. When "Time" is selected for the cursor type, the cursors will become vertical lines. The "POSITION" knobs for channels 1 and 2 can be used to adjust the horizontal position of cursors 1 and 2, respectively. The positions of the cursors are indicated at the right edge of the screen along with the difference ("Delta") between the two cursors. The frequency corresponding to the inverse of this time difference is also indicated (e.g., Delta, 110.0 ms, 9.091 Hz). Align the two cursors with the two adjacent peaks in the time trace, and record the indicated value of the time difference and the corresponding frequency.

LABORATORY REPORT REQUIREMENTS

1. The laboratory report should have a cover page listing the names of each group member, along with the signature of each member. Each group member must contribute to the preparation of the report, so you should decide how to divide the work or agree on a time to meet together to work on the report.
2. Derive an expression for the position of the piston as a function of time, $x_c(t)$, if the crank angle is given by $\theta = \omega_o t$, where ω_o is the angular velocity of the drive shaft (in rad/s), as indicated in the following figure. Do not substitute numerical values for *r* and *L*.

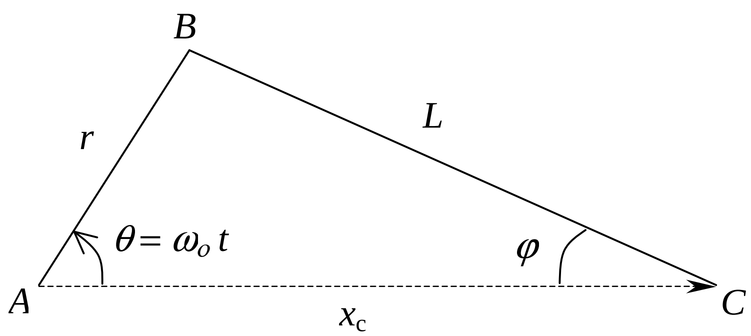

Figure 2. Geometry of Crank-Piston Assembly

3. Derive an expression for the acceleration of the piston as a function of time, $a_c(t)$, using the geometry in Figure 2, and determine the peak acceleration of the piston. Do not substitute numerical values for *r* and *L*.
4. Compare the frequency determined by the optical tachometer with the frequency determined from the time trace on the oscilloscope, and discuss potential reasons for any discrepancy. Which value do you consider more accurate?
5. Compute the calibration factor for the displacement transducer (in/V) from your measurements of the total travel distance of the piston and the measured peak-to-peak voltage difference for the displacement time trace.
6. Using Matlab, plot the theoretical displacement and acceleration against time, using the values of *r*, *L*, and ω_o determined from your measurements. Which appears more sinusoidal, the displacement or the acceleration? Compare these theoretical plots with the experimentally measured plots.
7. Explain why the recorded displacement and acceleration time traces take on maximum values near the same time and minimum values near the same time, even though pistons 1 and 3 are out-of-phase (i.e., piston 1 reaches its maximum displacement when piston 2 reaches its minimum displacement).
8. Compute the theoretically predicted peak acceleration of the piston using the values of *r*, *L*, and ω_o determined from your measurements, and compare this value with the experimentally measured peak acceleration. Discuss potential reasons for any discrepancy.
9. The speed at which we are running the engine in the lab is much slower than speeds at which the engine would run in a car. Compute the theoretically predicted peak piston acceleration for an engine speed of 5,000 RPM.