Motoring of a Flexible Resonant Engine to Estimate Associated Damping Losses

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Introduction

The performance of internal combustion engines is limited by heat losses, friction losses, throttling, and combustion losses. These issues become more prevalent as the size of the engine is scaled down, causing small scale engines to have poorer performance than larger engines.

There has been considerable interest in the past decade in developing even smaller engines, microscale engines, for a variety of applications.

One new concept is the development of a resonant heat engine, where combustion happens in a sealed elastic cavity. This design has many advantages including reduced friction losses as well as lower manufacturing and maintenance costs due to fewer moving parts. Finally, the design of an elastic engine allows for variable compression ratios and fuel mixtures, allowing performance to be optimized for different functions.

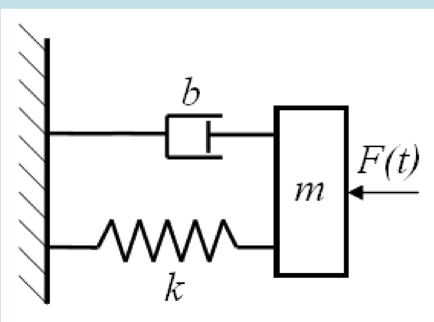
Objectives

- Motor a resonant heat engine to simulate four strokes: intake, compression, combustion, and exhaust
- Calculate engine's friction damping losses and pump work

The long term goal of this experiment is to pair it with research examining the mechanical and thermodynamic properties in order to evaluate overall performance and efficiency.

Methodology

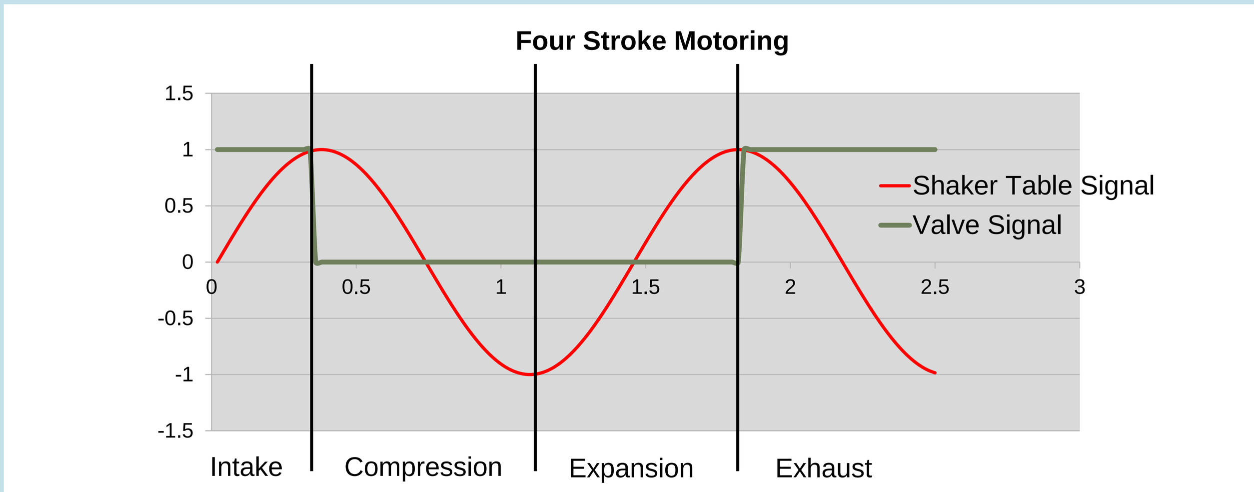
The engine is made of an enclosed bellows with an attached mass, or piston, at one end and is modeled by a spring mass damper system illustrated bellow:

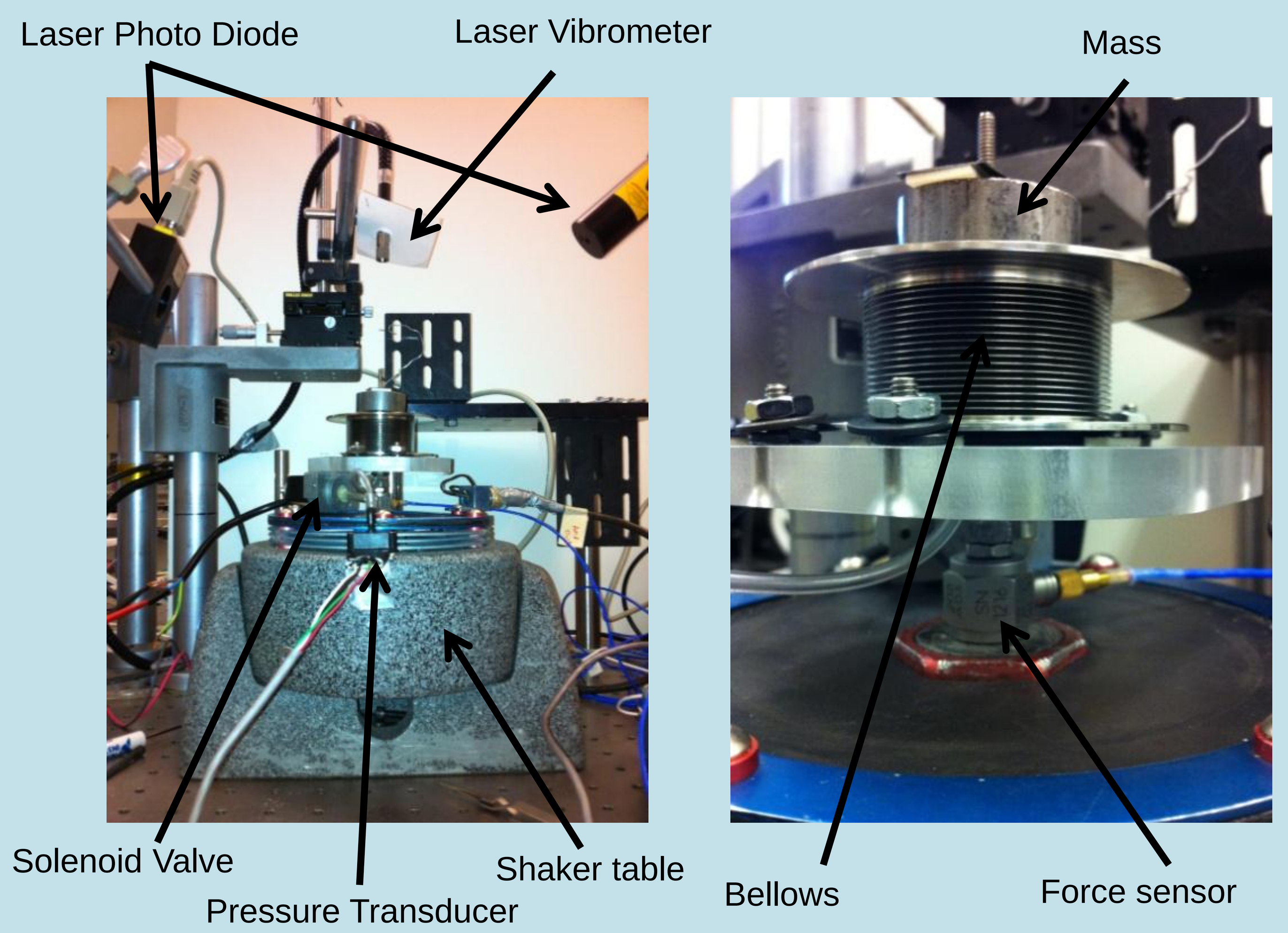


The enclosed air and mechanical damping of the bellows contribute to an overall damping coefficient that can be used to determine how much energy is lost during expansion of the bellows.

Instead of using an electric motor to actuate the piston as in a reciprocating engine, a vibration shaker table is used to drive the engine vertically.

The system has four strokes which are timed by the shaking of the table and the opening and closing of the valve to the atmosphere. Below is a diagram showing the synchronization of the shaker table and valve signals necessary to create the four strokes.





An energy balance is used to compare input work from the shaker to the sum of pump work and mechanical damping work occurring through one cycle of the engine.

$$\Sigma F\bullet dX = \Sigma bV^2\bullet\Delta t + \Sigma P\bullet\Delta V$$

(Input work) (Damping work) (Pump work)

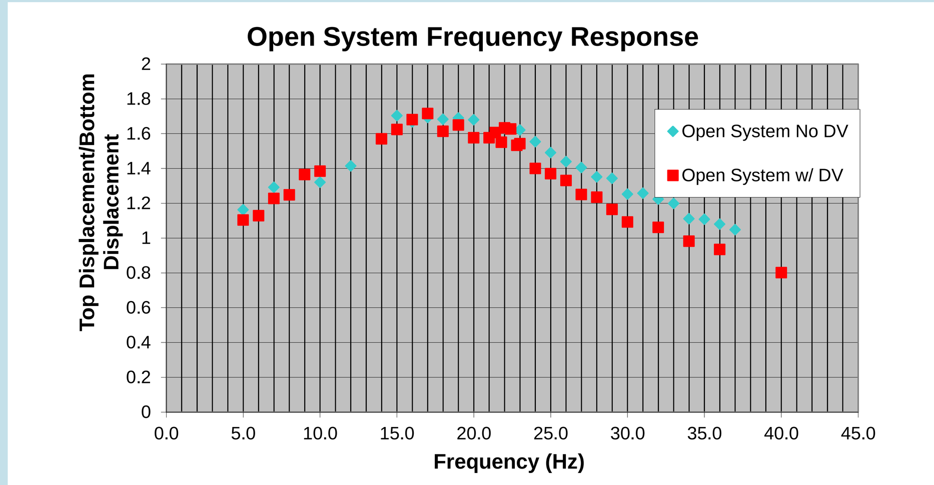
The pump work is calculated by the volume enclosed on a pressure volume plot and is the difference of input work and damping work

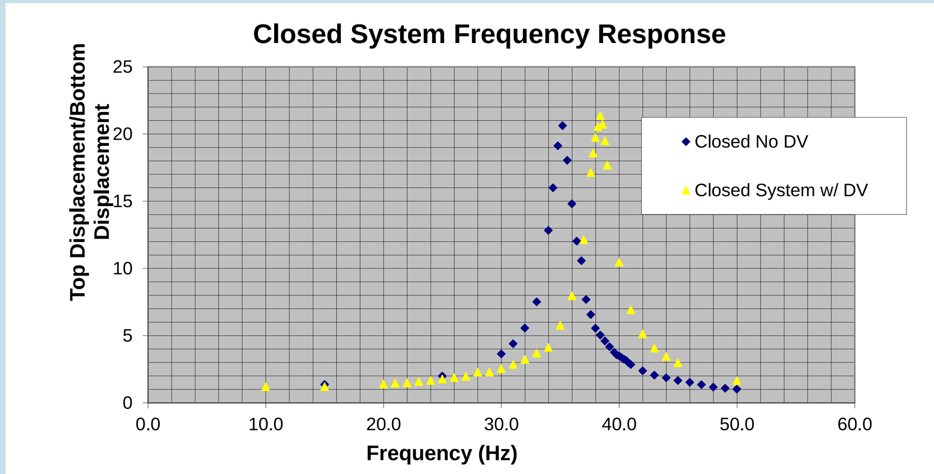
The resonant frequency and damping coefficient of the system are found by frequency response.

With each piece of the energy balance in place, the losses can be quantified.

Results

The frequency response plots of open system and closed system are shown bellow:



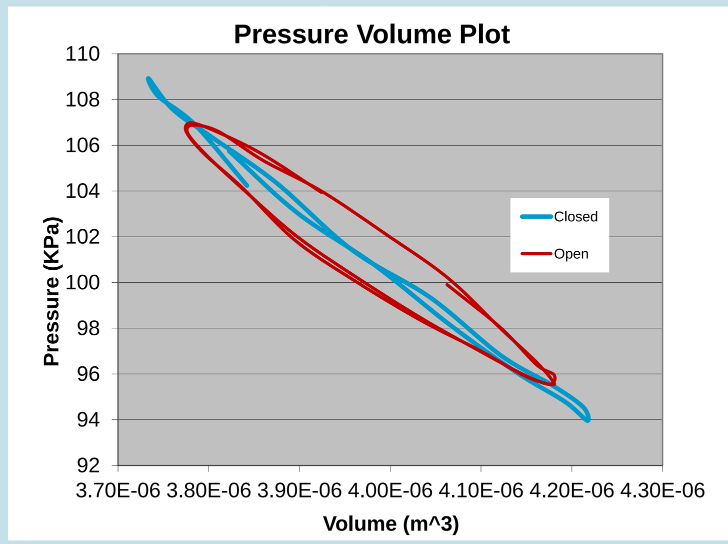


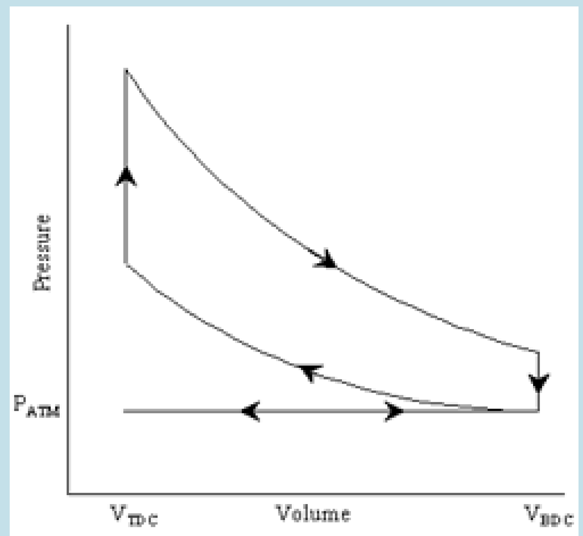
These plots yielded damping coefficients of:

1.888 N-s/m - Closed system without dead volume
0.839 N-s/m - Closed system with dead volume
28.330 N-s/m - Open system without dead volume
23.609 N-s/m - Open system with dead volume

A dead volume was inserted in the bellows to determine its effects on the engine characteristics

The pressure volume plots for an open and closed system is shown on the left compared to an ideal air standard Otto Cycle on the right:





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Summary

A laboratory model of a resonant heat engine in which the piston assembly is replaced by a sealed elastic cavity was constructed and tested. The elastic cavity consisted of a bellows structure with intake and exhaust ports. The engine was motored using a shaker table to assess friction damping losses and pump work. The resonant behavior of the engine was characterized for both open and closed port conditions.

The damping coefficients of both closed and open port conditions were determined from frequency response plots. An energy balance was used to compare input work from the shaker to the sum of pump work and mechanical damping work occurring through one cycle of the engine.

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