Heat Engine Lab
Lab #10
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PHYS 4C

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Introduction & Purpose

The purpose of this lab is to observe the cycles of a heat engine and measure the work it does in one cycle.

Equipment

- Pasco heat engine apparatus
- Low pressure sensor
- Temperature sensor
- Rotary motion sensor
- Science workshop 750 interface
- PC with data studio installed
- 50g and 2x 100g weights
- Hot water
- Ice water
- Two gallon buckets
- Metal cylinder

Procedure

1. Tie a string to the piston of the heat engine, ensuring that its counterweight has clearance.
2. Place a 50 gram weight on the piston
3. Draw the piston to about half volume
4. Connect the metal cylinder (sealed with piston intake)
5. Connect the sensors to the science workshop 750 interface
6. Connect the science workshop 750 interface to the PC and initialize the sensors in the Pasco software
7. Fill one bucket with hot water and one bucket with ice water
8. Mix the ice water with the temperature sensor until it reads 0 (or close to zero)
9. Place the temperature sensor in the hot water
10. Place the metal cylinder in the cold water
11. Start recording pressure and displacement data
12. Place 2x 100g weights on the piston
13. Place the metal cylinder in the hot water
14. Remove 2x 100g weights from the piston
15. Place metal cylinder in the cold water
16. Repeat 11-15 3x

Figure 1: *General lab setup.*

Data & Analysis

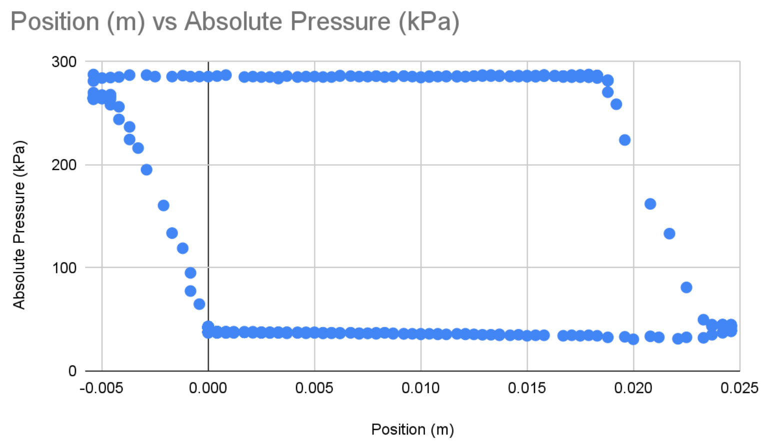

Figure 2: *Trial 1 raw data (PD diagram)*

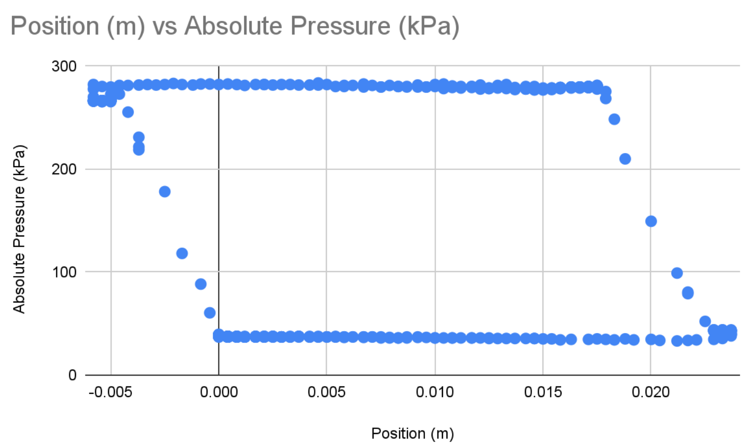

Figure 3: *Trial 2 raw data (PD diagram)*

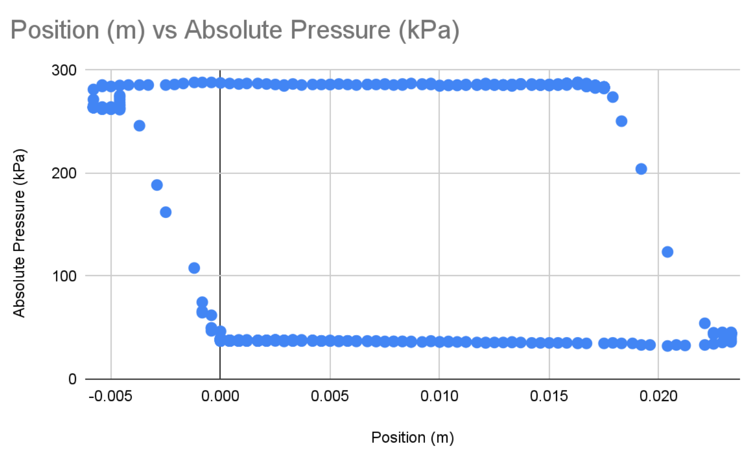

Figure 4: *Trial 3 raw data (PD diagram)*

Total work done by the heat engine is the absolute value of the difference of the integrals of the two isobaric phases (equivalent to the area enclosed inside the PV diagram). The following Jupyter notebook converts the PD diagrams in figures 2-4 into PV diagrams in SI units and finds the area enclosed inside.

Work Jupyter Notebook

```
import pandas as pd
import matplotlib as plt

AREA = 8.32131E-4
```

```
setCoordinates converts pandas dataframes to correctly formatted arrays, and to
convert entry units to SI
polygonArea uses the shoelace algorithm to compute the area of the polygon (finds
the work)
```

```
def setCoordinates(trial):
 poly = []
 x = trial["Position (m)"]
 y = trial["Absolute Pressure (kPa)"]

 for i in range(len(x)):
   #i = len(x) - i - 1
   poly.append([x[i]*1E3,y[i]*AREA])
  return poly

def polygonArea(vertices):
 #A function to apply the Shoelace algorithm
 numberOfVertices = len(vertices)

 sum1 = 0
 sum2 = 0
  for i in range(0,numberOfVertices-1):
   sum1 = sum1 + vertices[i][0] *  vertices[i+1][1]
   sum2 = sum2 + vertices[i][1] *  vertices[i+1][0]
  #Add xn.y1
 sum1 = sum1 + vertices[numberOfVertices-1][0]*vertices[0][1]
 #Add x1.yn
 sum2 = sum2 + vertices[0][0]*vertices[numberOfVertices-1][1]
```

```
  area = abs(sum1 - sum2) / 2
 return area
```

```
Main program body (functions above used to generate desired output)
```

```
trial1 = pd.read_csv("trial1.csv")
trial2 = pd.read_csv("trial2.csv")
trial3 = pd.read_csv("trial3.csv")

poly1 = setCoordinates(trial1)
poly2 = setCoordinates(trial2)
poly3 = setCoordinates(trial3)

work1 = polygonArea(poly1)
work2 = polygonArea(poly2)
work3 = polygonArea(poly3)

print("Trial 1: ",round(work1*100)/100.,"J")
print("Trial 2: ",round(work2*100)/100.,"J")
print("Trial 3: ",round(work3*100)/100.,"J")
```

```
Trial 1:  4.87 J
Trial 2:  4.56 J
Trial 3:  4.67 J
```

The shoelace algorithm in the program is essentially an integration. The average work done in the three trials was 4.7 joules.

The efficiency can be calculated after finding the net heat transfer given the temperatures of the hot and cold water, the minimum and maximum pressures, and the initial volume of air inside the system;

$$1)\qquad V_d = \frac{T_H}{T_C} V_a$$

$$2)\qquad V_c = \frac{P_d V_d}{P_c}$$

$$3)\qquad Q_H = P_d V_d \left(\ln\left(\frac{V_d}{V_c}\right) + \frac{7}{2}\left(1 - \frac{T_C}{T_H}\right)\right)$$

Equation 3 evaluates to about 20.33 joules for trial 1. Given the heat transfer, efficiency can be calculated using equation 4:

$$4) \quad e = \frac{W}{Q_H}$$

Given the solution to equation 3 and the work derived programmatically for trial 1, the efficiency is about 24%. The theoretical maximum efficiency can be calculated using equation 5:

$$5) \quad e = \left(1 - \frac{T_C}{T_H}\right)$$

For trial 1, this evaluates to 13% efficiency.

Additionally, the work done lifting the 200g masses is significantly less than the work calculated from the PV diagram (about 100 times less).

Conclusion

This lab had severe errors that are difficult to explain. The measured efficiency of the heat engine is double the theoretical maximum and the work done by the heat engine is 100 times greater than the work used to lift the 200g mass. The latter issue can be partially explained by the fact that the piston had a mass that was unaccounted for, and that the pulley system and seals introduced friction, but the discrepancy is unlikely to be due to those factors alone. Additionally, the efficiency values are too high.

The common denominators in both these issues are either the pressure or volume measurement-there must have been a major mistake in measuring them, and unfortunately it was not possible to retake these measurements at the time of analysis. However, the programmatically calculated work value was purely computer generated-from data collection to calculations-so that presents a perplexing twist to the problem (position, pressure, and temperature measurements were automatically logged into csv files by the pasco software).