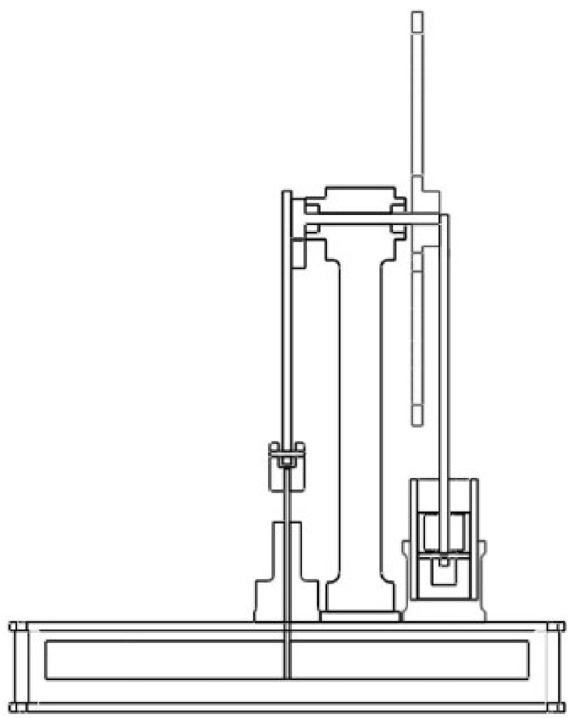
University of Colorado
Boulder

ASEN 3113: Stirling Engine Prelab

Department of Aerospace Engineering



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ASEN 3113: Thermodynamics and Heat Transfer

Contents

1 General Theory

1.1 Gamma-type Stirling Engine

A gamma-type Stirling engine is where the power piston is placed in a separate cylinder alongside the displacer piston cylinder while still being connected to the same flywheel. When the working fluid (air) is being pushed to the hot end of the cylinder, it results in expansion and pushing of the power piston. As the power piston is pushed to the cold end of the cylinder, the machine with the aid of the flywheel helping build momentum pushes the power piston in the other direction resulting in compression of the fluid. The fluid in the two cylinders is able to travel around the displacer from the hot to cold side and cycles through this process over and over again. The displacement in which the working fluid generates convective heat transfer results in pressure gradients through the diplacer piston cylinder which drives the power piston.

1.2 Alpha-type and Beta-type Stirling Engines

An alpha-type Stirling engine consists of two power pistons which are within two separate cylinders. One cylinder being hot and one being cold. The working fluid in the hot cylinder is in contact with more heat, therefore heating the fluid results in pressure increasing and the fluid expanding. When the hot cylinder is at its maximum volume, and the power piston in the cold cylinder has reached mid stroke, the volume of the overall system is increased by fluid expansion in the cold cylinder. When the system is at maximum volume and more fluid is in contact with the cold cylinder, the fluid starts to cool therefore the pressure lowers and the hot cylinder starts to upstroke reducing the overall volume of the system. Once the cold cylinder is at maximum volume and the hot cylinder is at the minimum volume, the overall volume of the system is reduced as the cold cylinder starts compressing. After the system is at minimum volume, then fluid is in contact with the hot cylinder therefore starting the cycle over again.

A beta-type Stirling engine is very similar to the gamma-type Stirling engine but the difference is the power piston is placed within the same cylinder on the shaft as the displacer piston while also producing a slightly lower power output at lower thermal efficiency when compared to a gamma-type Stirling engine.

1.3 Key Differences

The alpha-type Stirling engine consists of two power pistons which are within two separate cylinders connected to a flywheel. The beta-type Stirling engine is where the power piston is placed within the same cylinder on the shaft as the displacer piston. The gamma-type Stirling engine is similar to the beta-type Stirling engine but the power piston is placed in a separate cylinder alongside the displacer piston cylinder while still being connected to a flywheel. Overall the gamma-type Stirling engine when compared to alpha and beta-type Stirling engines produce a higher power output at better thermal efficiency.

1.4 Four Stirling Thermodynamic Processes

Reversible Isothermal Expansion: Fluid in the system at the hot end of the cylinder starts to heat up and expand resulting in the power piston to start moving up. Here the temperature T_H stays constant.

Reversible Adiabatic Expansion: After the gas has expanded, with the aid of the flywheel momentum, it moves the crankshaft which allows the fluid to travel/transfer around the displacer to the cool side of the cylinder. Here the temperature T_H drops to T_L.

Reversible Isothermal Compression: When the majority of the fluid has shifted to the cool end of the cylinder, the fluid starts to cool down and contract resulting in the power piston to start moving down. Here the temperature T_L stays constant.

Reversible Adiabatic Compression: The fluid contracts and the with the aid of the flywheel momentum, the crankshaft starts to move displacer transferring the fluid to the hot end of the cylinder (where the fluid starts to heat up and expand again repeating the Expansion-Transfer-Contraction-Transfer process). Here the temperature T_L rises to T_H.

1.5 Internal Volume of System vs. Change with time

As time increases, heat increases therefore pressure increases and the internal volume of the cylinder increases as well reulting the power piston to start moving. At maximum volume the crankshaft is at the top of the flywheel. As the crankshaft moves to the bottom of the flywheel, the internal volume of the system decreases as the fluid is being compressed. As heat decreases, the overall system is cooler. But this process occurs concurrently therefore as this process keeps repeating over time, the overall internal volume of the system still stays constant.

1.6 Labeled Wideframe of the Engine

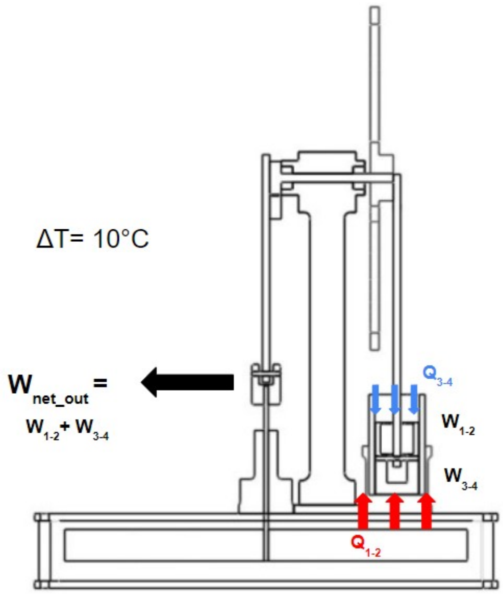

Figure 1: Stirling Engine Mesh Outline Diagram

2 Ideal Stirling Cycle

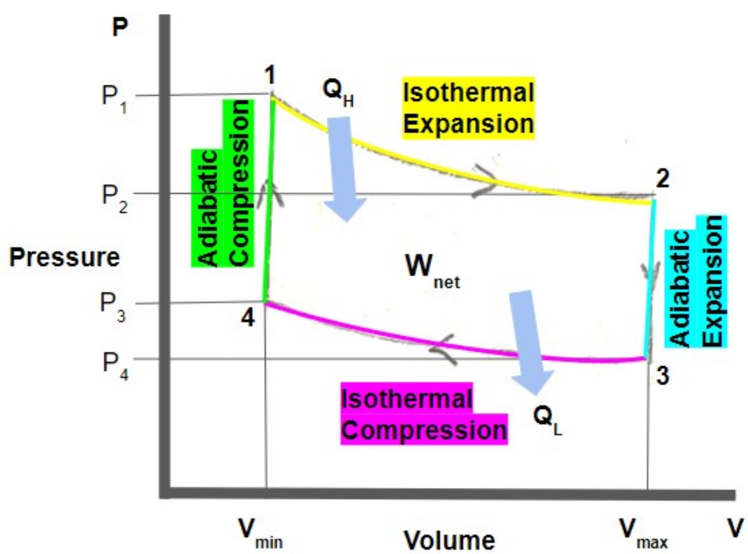

Figure 2: **Ideal Cycle P-V Diagram**

In the cycle, work input occurs during the Isothermal Expansion step while work output of the engine occurs during Adiabatic Expansion and Compression steps. To compute the net work produced in the Ideal Stirling cycle P-V diagram, you have to calculate the area inside the cycle. To do so we set $W_{net} = W_{1-2} + W_{3-4}$ where W_{3-4} is work being done on the system.

3 Experimental Stirling Cycle

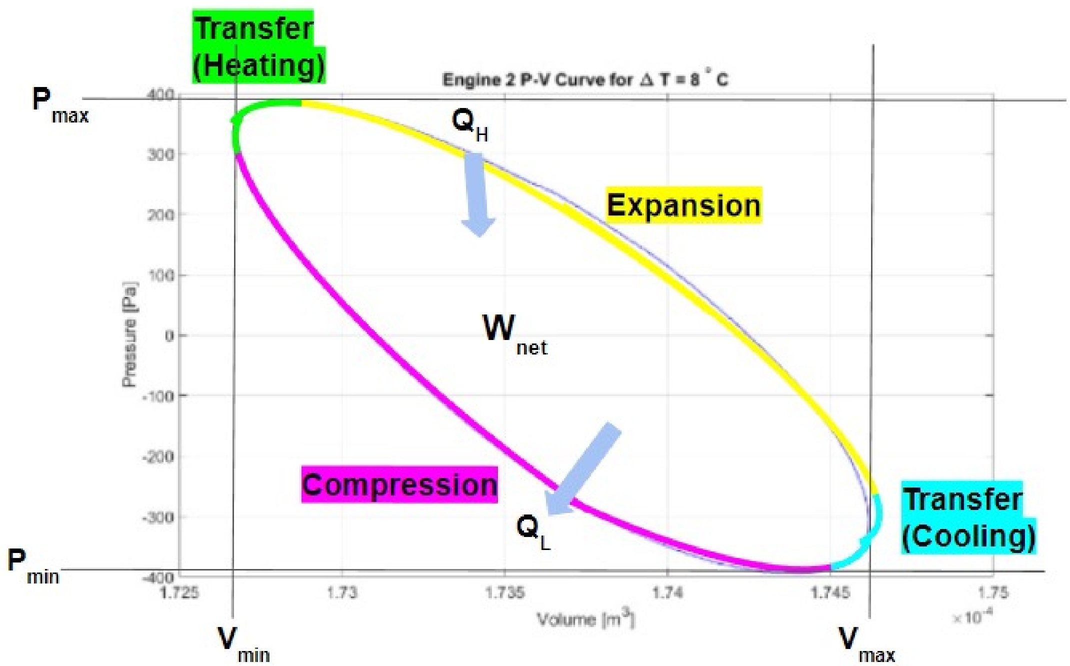

Figure 3: Real/Experimental Cycle P-V Diagram

3.1 Ideal vs. Real Cycle P-V

The Ideal Cycle P-V diagram outlines the thermodynamic process much better when compared to the Real Cycle P-V diagram. We can see the clear break down of the four Stirling Thermodynamic processes, Expansion, Transfer Cooling, Compression, and Transfer Heating in the Ideal Cycle P-V diagram. The main difference is that the net area of the Ideal Cycle is more than the Real Cycle P-V diagram because the work done during Expansion and Compression is Isentropic(constant entropy), meaning the entropy of the system is constant and is reversible. Due to there being losses of different forms of energy, the net work outputted in the Real Cycle is less than the Ideal Cycle P-V diagram.

3.2 Method A

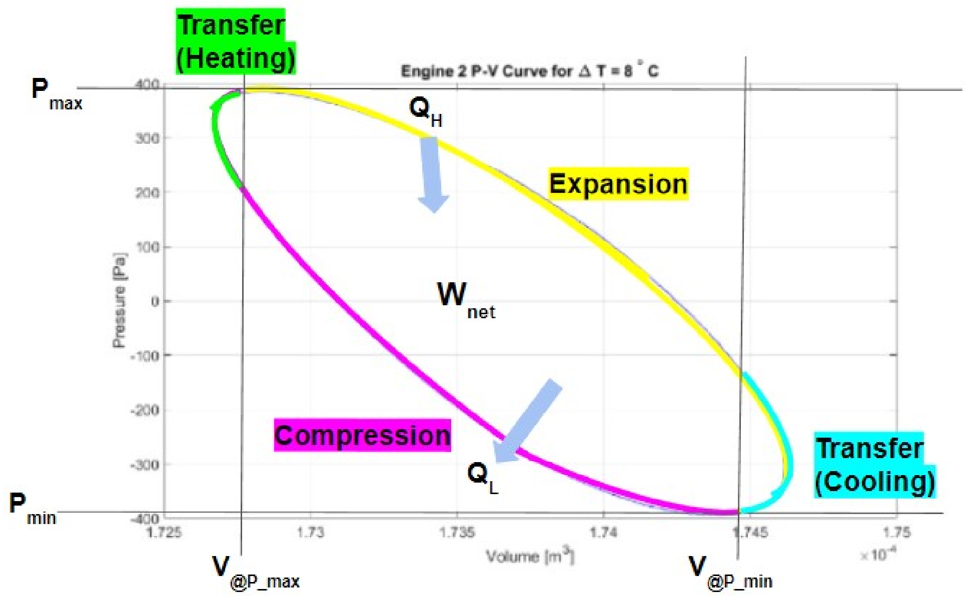

Figure 4: Real/Experimental Cycle P-V Diagram (Pressure Limits)

3.3 Method B

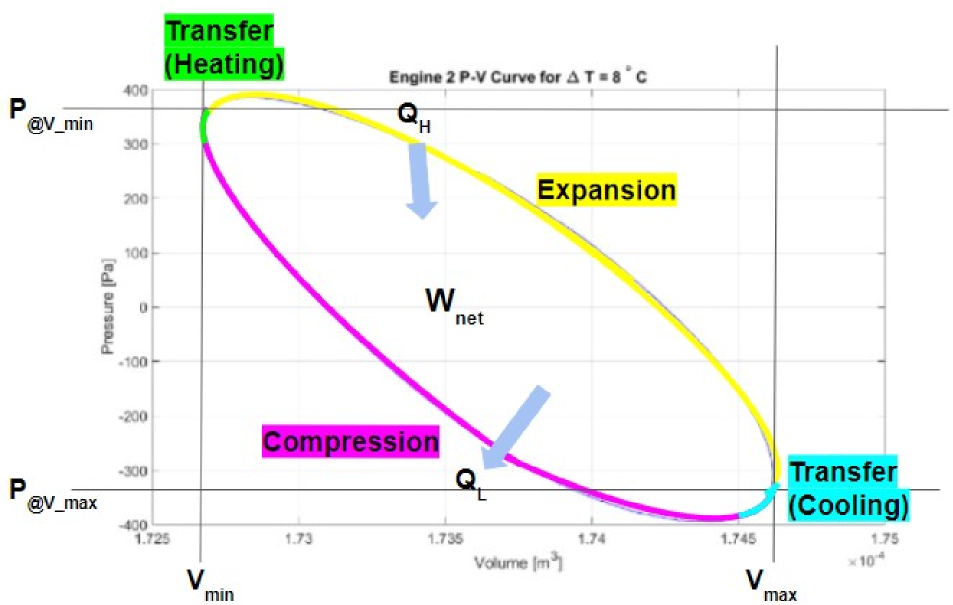

Figure 5: Real/Experimental Cycle P-V Diagram (Volume Limits)

3.4 Method C

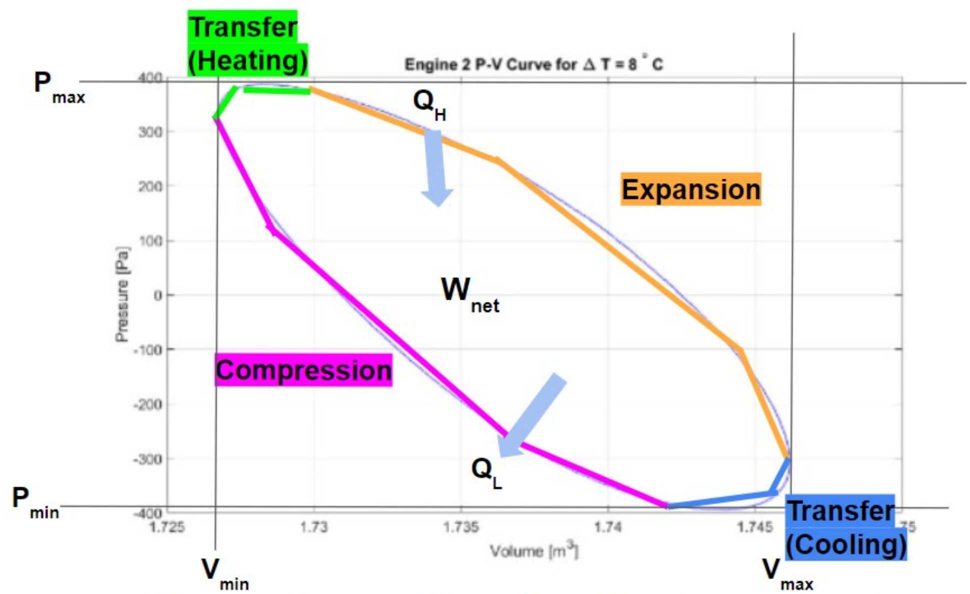

Figure 6: Real/Experimental Cycle P-V Diagram (Largest Extremities)

3.5 Best Method

Method C of splitting up curves by its largest extremities seemed the most appropriate when compared to the labeled experimental cycle diagram seen in Figures 3. Similar to the Ideal Cycle P-V diagram, you can see the four processes in the Stirling Thermodynamic Cycle being outlined much better as the Transfer Heating process starts at minimum volume and Transfer Cooling starts at maximum volume (which coincidentally is very similar to Method B which involves splitting up curves by its volume limits). The Expansion and Compression cycles occur between the two respective Transfer Heating and Cooling cycles. When compared to Method B, the difference here is that the Transfer Heating process ends at minimum volume and Transfer Cooling starts at maximum volume. Method A also does a great job when exemplifying the differences clearly between the four processes in the Stirling Thermodynamic Cycle but overall Method C is able to concurrently include Method A and Method B by using the biggest relative linear trends in the curves while systematizing the Stirling Thermodynamic Cycle.

4 References

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