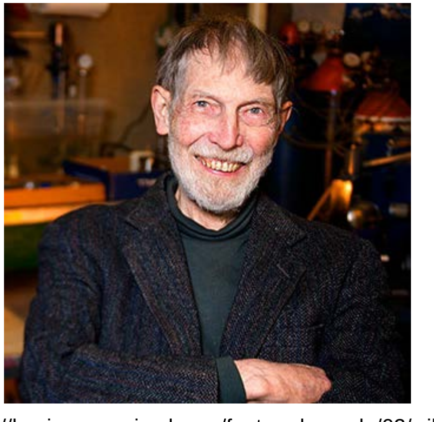
Free Piston Stirling Engines

Introduction

- Heat engine
  - Converts heat energy into mechanical energy
  - Pressure variation
- Robert Stirling (1816)
  - Kinematically linked engine
- William T. Beale (1964)
  - Free piston Stirling engine (FPSE)

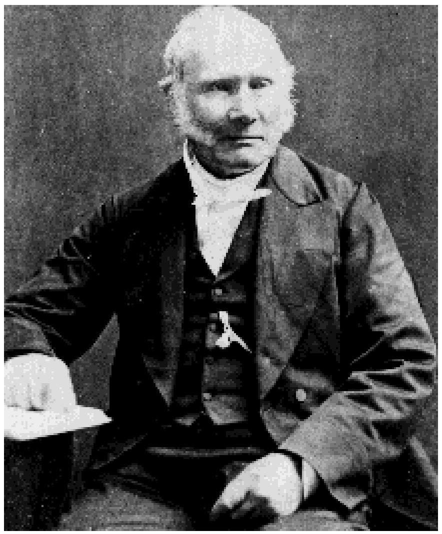
http://en.wikipedia.org/wiki/File:Robert_Stirling.jpg



http://businessremixed.com/featured-people/02/william-beale-engineering-sustainability/

Stirling Engine

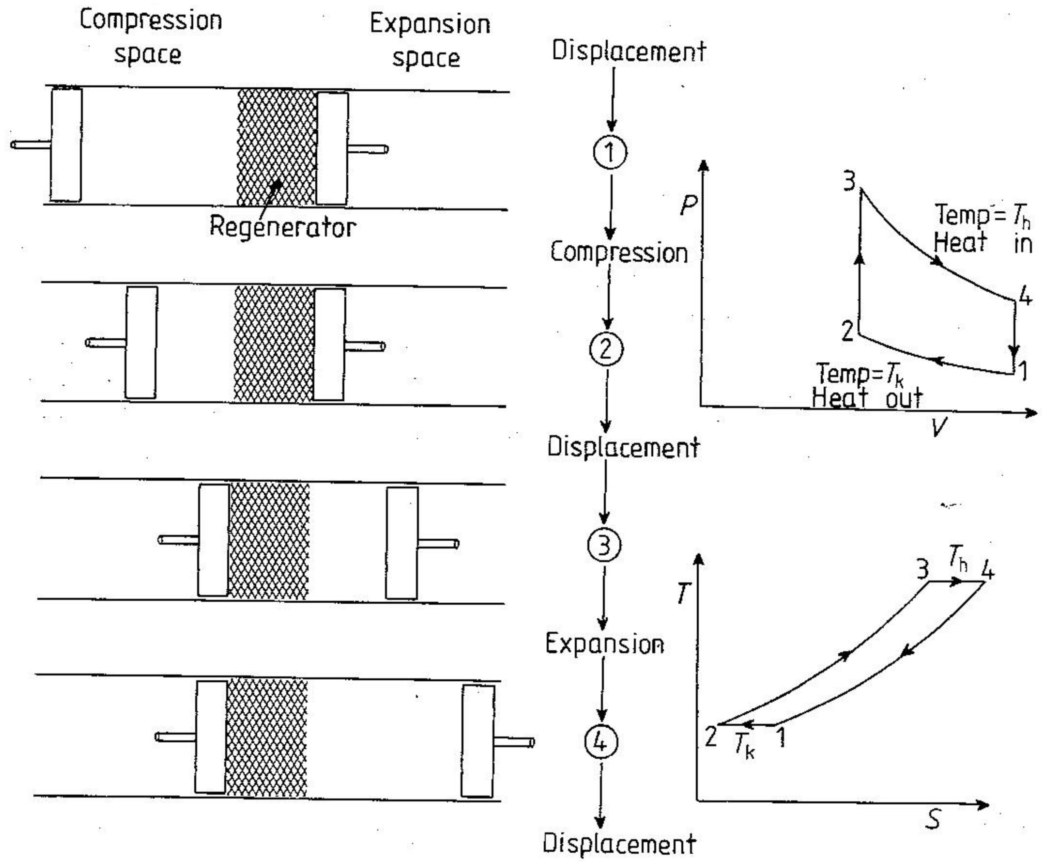
Rev. Dr. Robert Stirling (1790-1878)



http://www.cse.iitk.ac.in/~amit/courses/371/abhishe/main.html

A closed regenerative cycle engine invented by Robert Stirling in 1812.

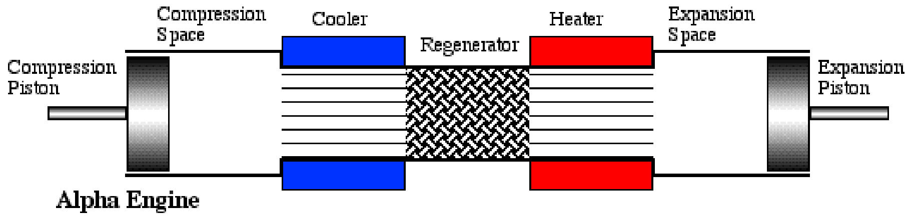
Ideal Stirling Cycle



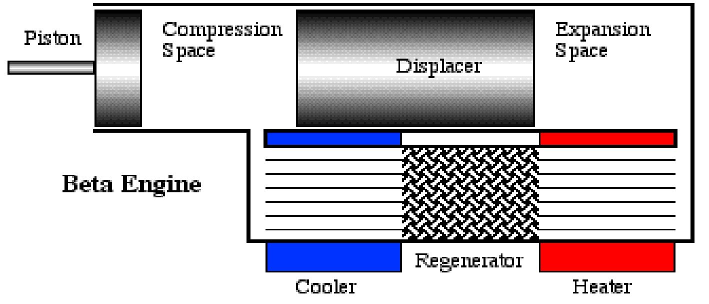
Adapted from Urieli, I., and Berchowitz, D. M., 1984, *Stirling Cycle Engine Analysis,* Adam Hilger LTD., Bristol, NY.

Introduction: Stirling Engine Configurations

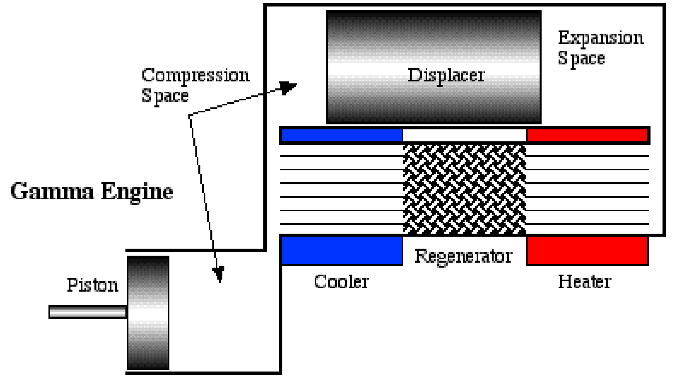
- Alpha: Pistons in separate cylinders connected in series



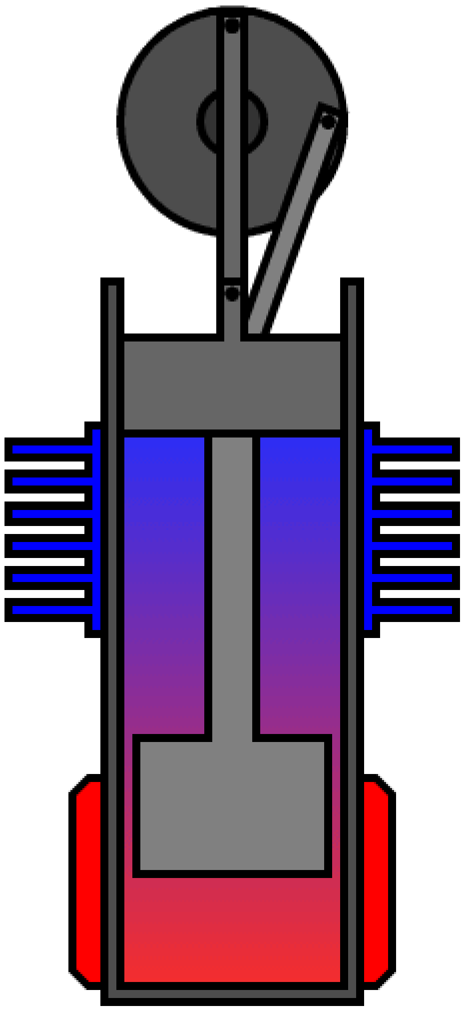
- Beta: Displacer and power pistons in same cylinder



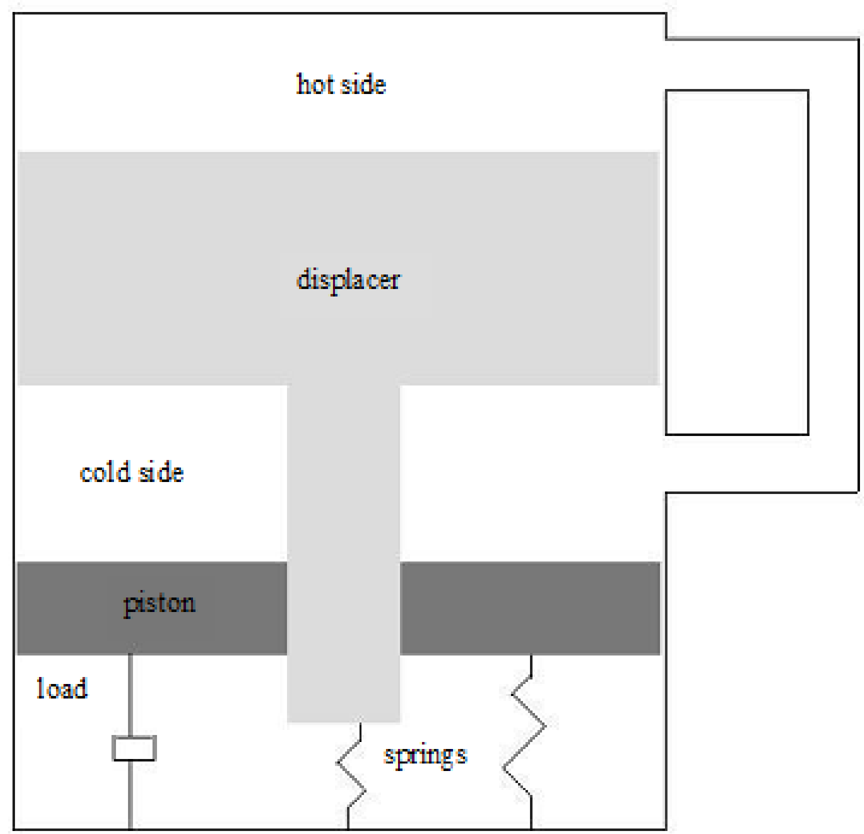
- Gamma: Displacer and power piston in different cylinders



Stirling Engine



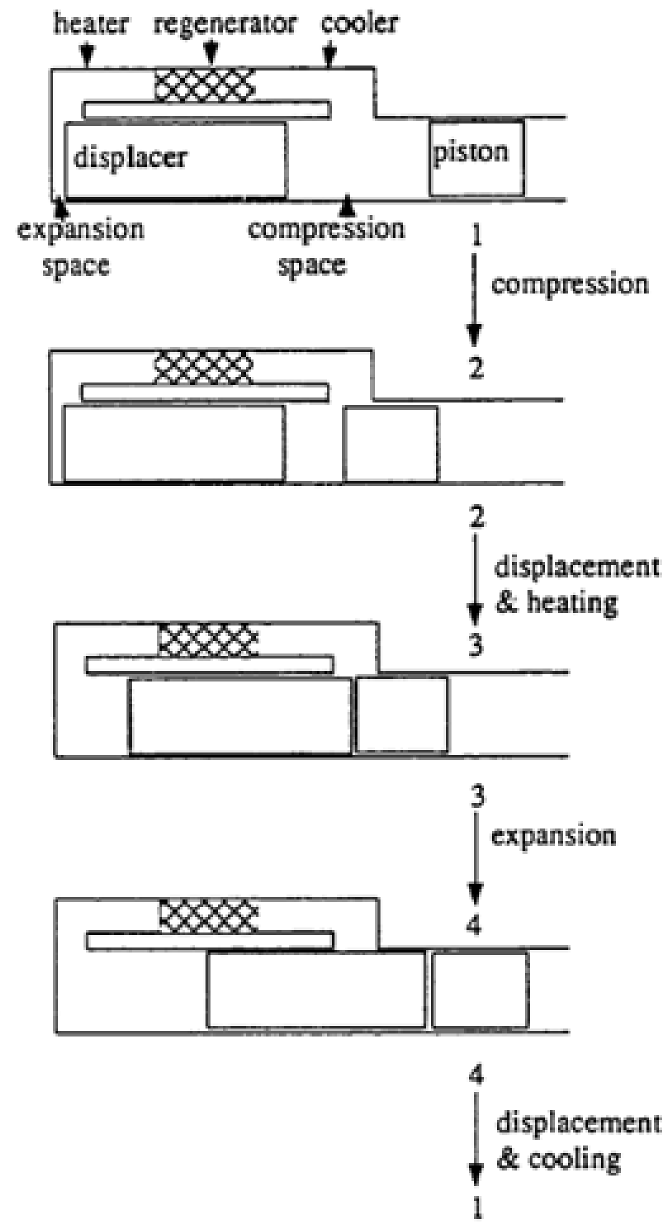
Free Piston Stirling Engine



http://wpcontent.answers.com/wikipedia/commons/4/4e/Stirling_Animation.gif

Introduction: FPSE

- ❖ Expansion (Step 1)
- ❖ Pressure decrease in compression space
- ❖ Compression (Step 1 and 2)
- ❖ Pressure increase in compression space
- ❖ Expansion (3 and 4)



Introduction: Stirling Engine Applications

- Electricity generation
  - Photovoltaic cells
- Domestic cogeneration
  - House water heater
- Potential Applications
  - Space
  - Small portable FPSE (100 Watts and less)

Equations of Motion: General System

❖ Volumes

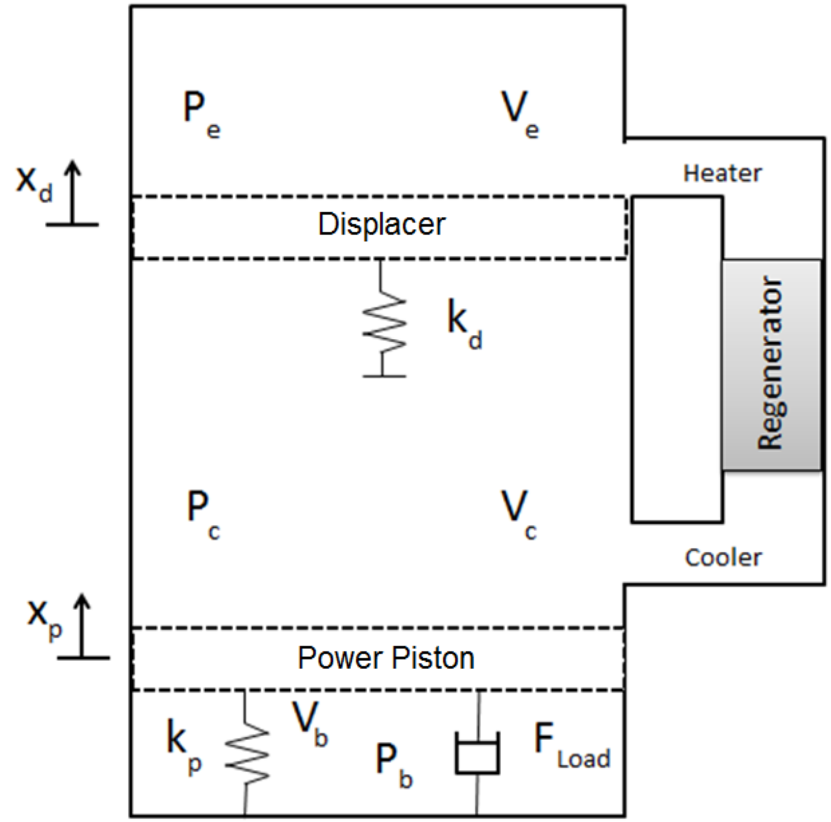
$$V_c = V_{cm} - A_p x_p + A_d x_d$$

$$V_e = V_{em} - A_d x_d$$

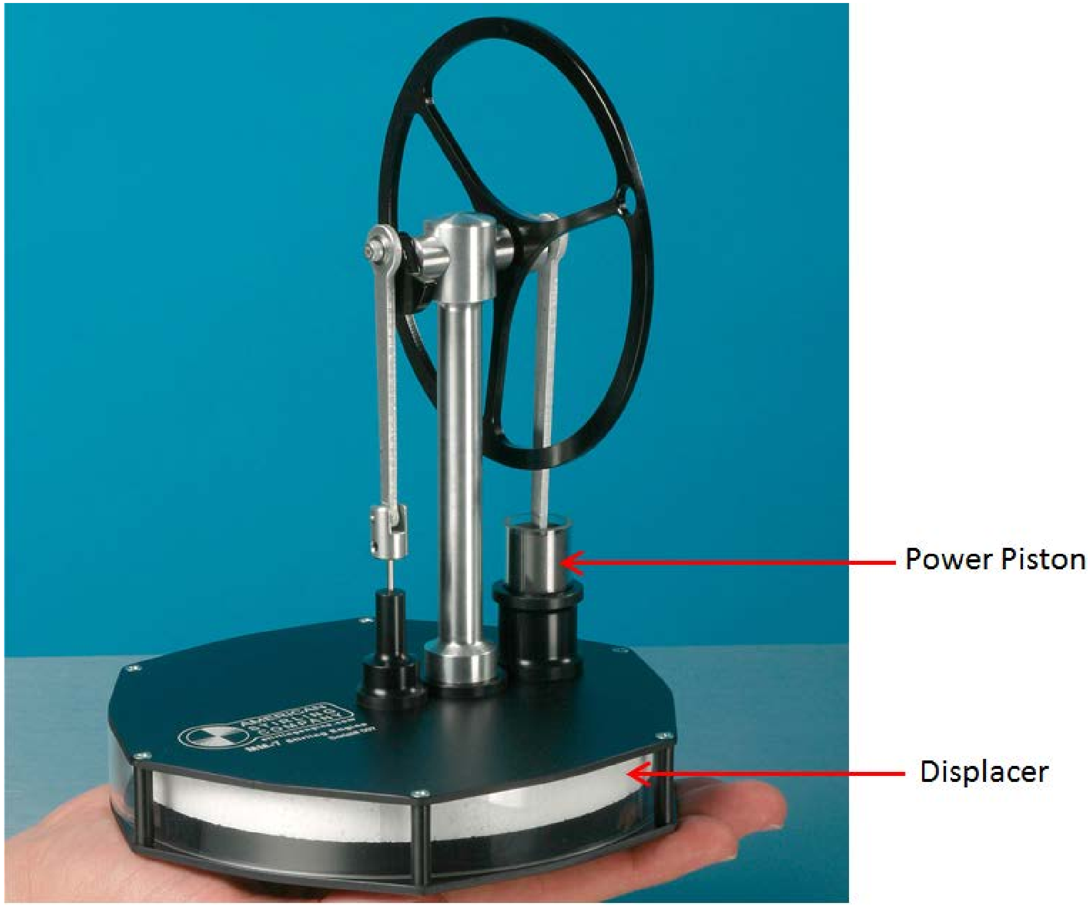
❖ Force balance

$$m_d \ddot{x}_d = A_d(P_c - P_e) - F_{spring_1}$$

$$m_p \ddot{x}_p = A_p(P_b - P_c) + F_{load} \dot{x}_p - F_{spring_2}$$



Experimental Studies: Configurations



Kinematically linked Stirling engine

Diameter (mm)

Displacer: 145.00

Power piston: 15.50

Area (mm^2)

Displacer: 16513.00

Power piston: 188.69

Cooler: 17671.50

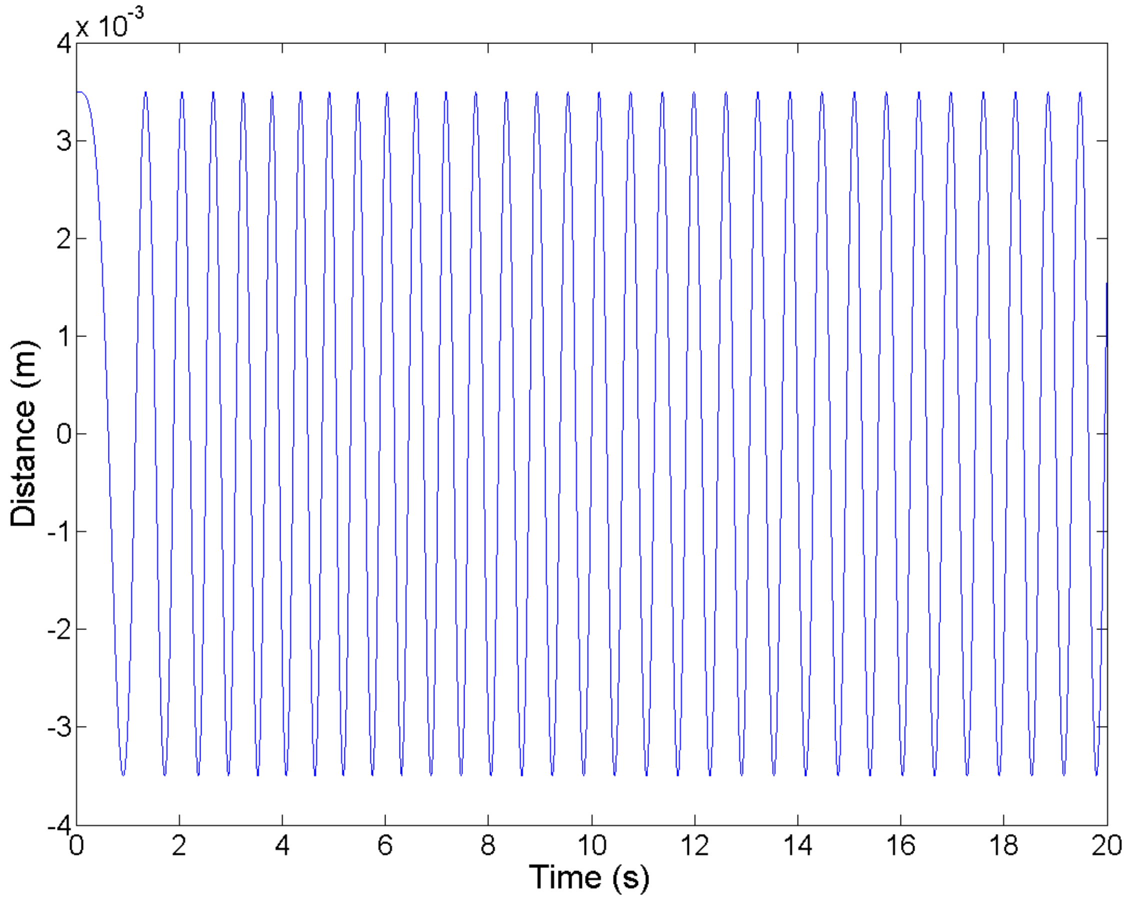
Heater: 17671.50

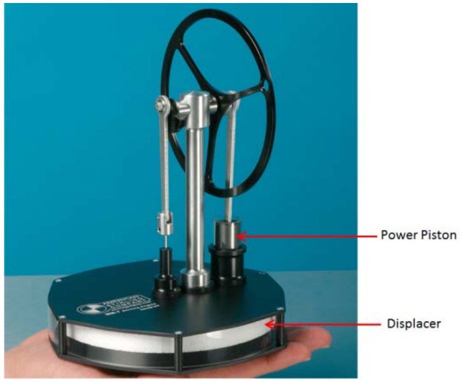
Volume (mm^3)

Expansion: 176715.00

Compression: 180489.00

Experimental Studies: Results





- Hot side: 315.00 C
- Cold side: 25.00 C
- 1.50 Hz

Kinematically linked Stirling engine

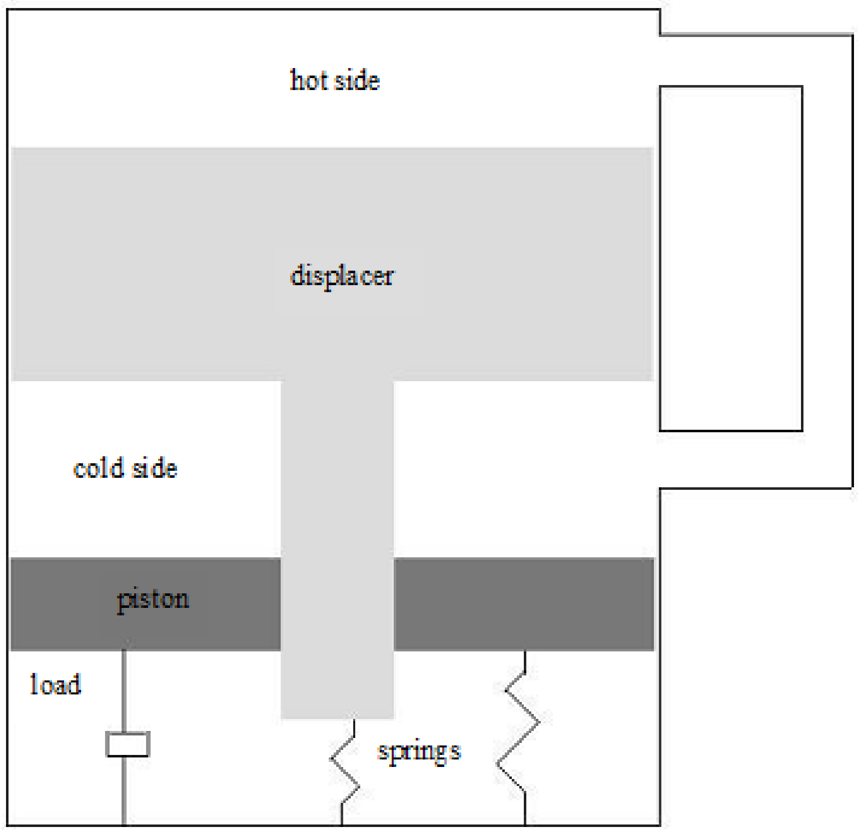
Free Piston Stirling Engines Related Thesis Work

- Choudhury, F., Dynamics of Free Piston Stirling Engines, MS Thesis, Department of Mechanical Engineering, University of Maryland, Spring 2009.
  - Choudhary, F. and Balachandran, B., Hopf Instabilities in Free Piston Stirling Engines," ASME Journal of Computational and Nonlinear Dynamics, Vol. 9 (No. 2), pp. 021003-1-021003-11, 2014.

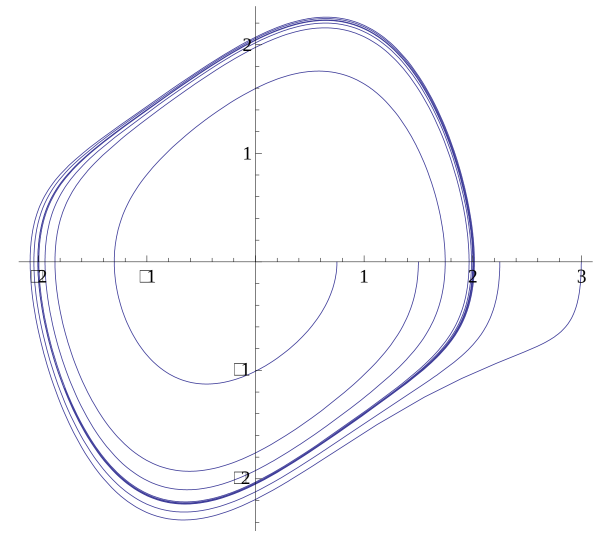
- Shrestha, D., Numerical and Experimental Studies on Free Piston Stirling Engines, MS Thesis, Department of Mechanical Engineering, University of Maryland, Spring 2012.

Thesis Work: Meeting between Hopf and Stirling

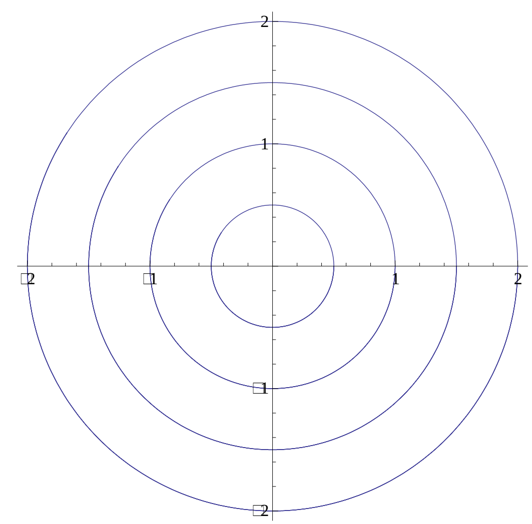
Free Piston Stirling Engine



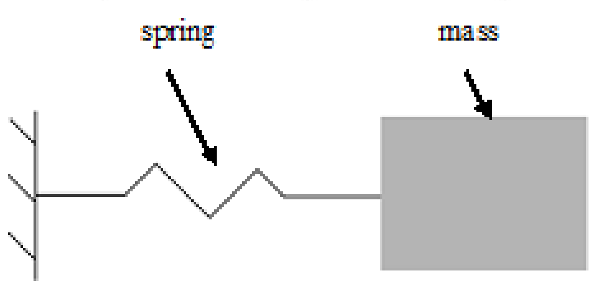
Nonlinear Model



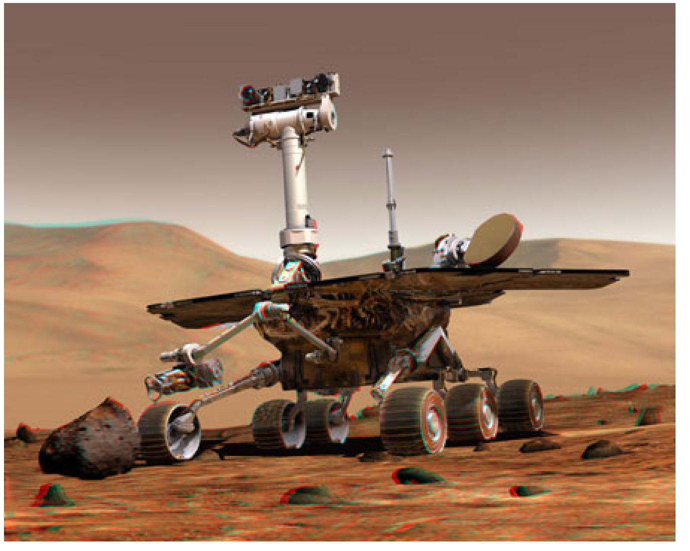
Linear Model



Simple Harmonic Oscillator



Stirling Engine Applications



Question

Can we engineer a Hopf bifurcation in a Free Piston Stirling Engine to have a unique, stable periodic operating condition?