Power Cycles: Stirling Cycles

→ Get a volunteer, have them hold Stirling engine on Palm

Spin lightly this way. Engine will spin other way.

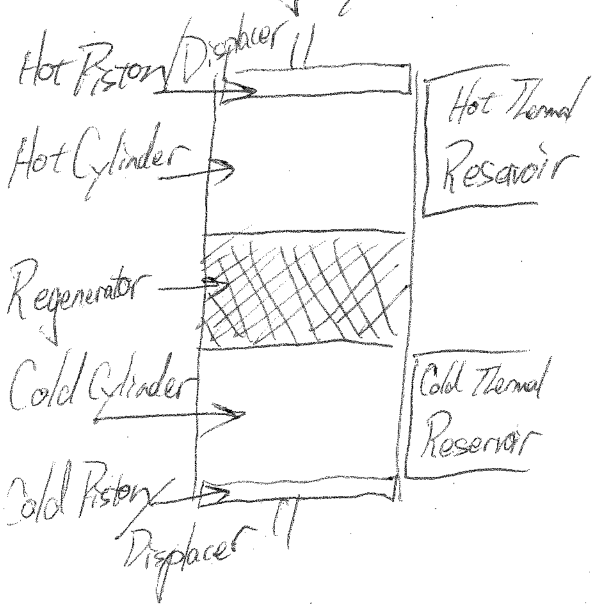
→ Last time we discussed internal combustion engines, ICE's. Specifically we analyzed the Otto & Diesel cycles. To do this we used an air standard cycle --- assumed that the entire system was closed & no enthalpy was required to push air into the system. Many of you pointed out that this was not realistic & over simplistic. Any real heat engine would require air intake & expulsion.

→ Spin Engine → So how does this work? → No batteries. → Completely Sealed

→ This is a Stirling Engine. It is using our volunteer to produce useful work. As we'll find out, it is using our volunteer quite efficiently.

→ Thank volunteer.

→ Stirling Cycles consist of the following components



→ Dual opposed pistons to create flow

→ Regenerator/Stack: Porous matrix of solid material with high heat capacity. BB's, stacked wire screens, etc.

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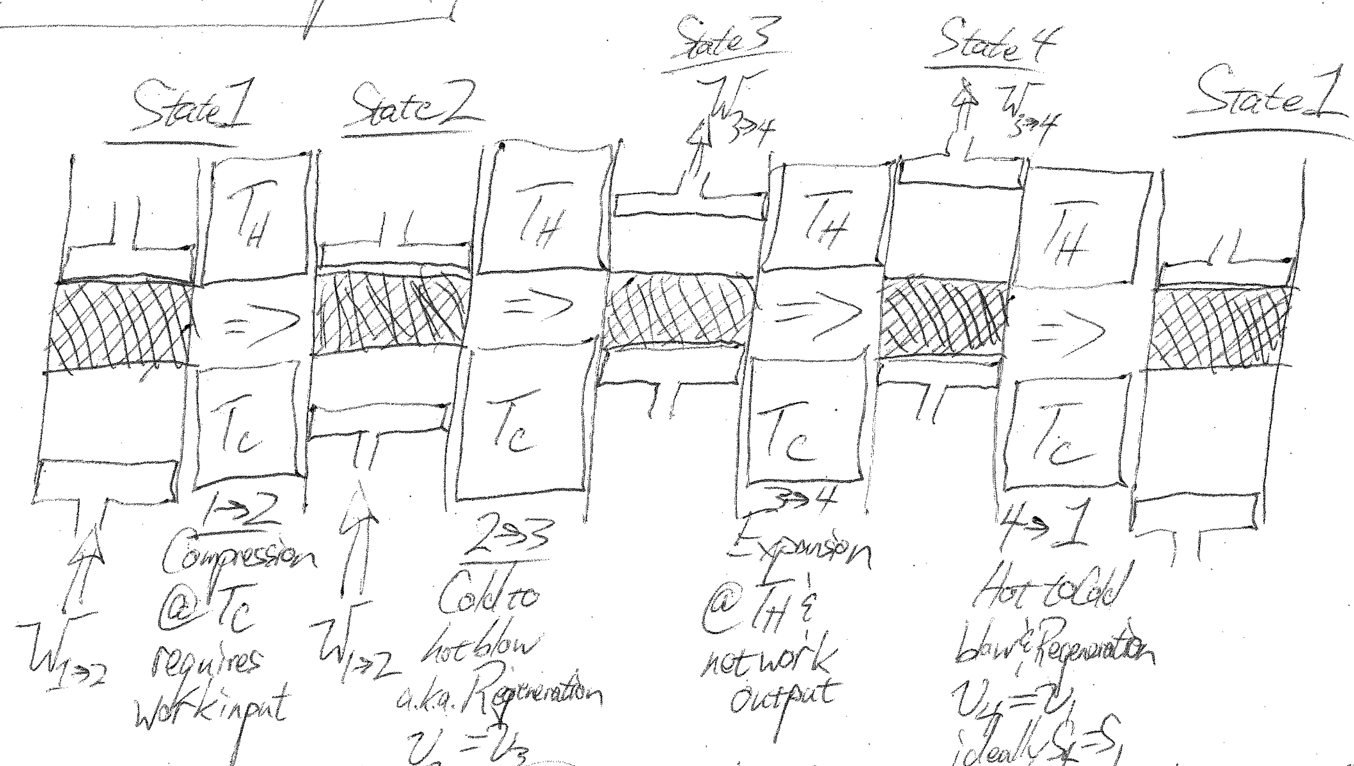
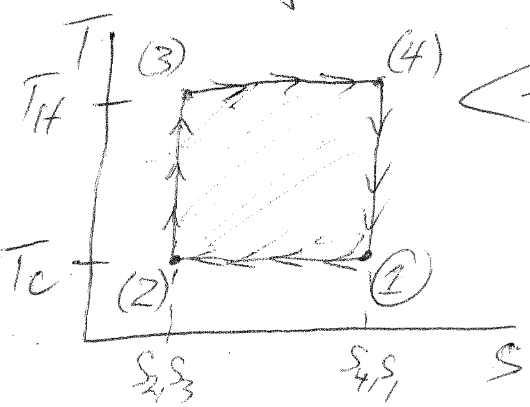


ideally $s_2 = s_3$ ⟶ how? ideally no irreversibilities if all ΔT's are small differentially small & all heat transfer occurs within the regenerator

On T-s diagram



⟸ Look familiar? It's the same as a Carnot cycle! The ideal Stirling Cycle has the same efficiency as a Carnot cycle! → One reason why they are soooo popular!

→ So why don't we see Stirling engines everywhere??

1) Not very practical because these processes have to occur very slowly for maximum efficiency → heat transfer takes a long time

2) (Good) Regenerator materials are usually expensive & heavy

3) Flow losses in Regenerator

4) Friction, & not a lot of power, relatively speaking.

Example: Stirling powered hand-held flashlight or thermo-electric?

$T_{Hot} = 90°F$, $T_C = 68°F$, $\dot{Q}_{Hand} = 13W$, 1W LED Bulb

1st: Thermoelectric:

$$\eta_{electric} = \eta_{Carnot}\left[\frac{\sqrt{1+ZT}-1}{\sqrt{1+ZT}+\frac{T_C}{T_H}}\right]$$

$ZT \approx 0.3$
We'll assume 3.0

$$\eta_{carnot} = \frac{T_H - T_C}{T_H}$$

$\eta_{electric} = ?$

2nd: Stirling Engine: Ideal & Helium filled, $CR = 5$, $P_{Charge} = 1MPa$, $V_{max} = 100 cm^3$

		T	P	v	u	s	m	V
Compression	1	$=T_C$	$=P_{charge}$	✓	✓	✓	=const	V_{max}
Cold to Hot Blow	2	$=T_C$	✓	$=\frac{V_{min}}{m}$	✓	✓	=const	V_{min}
Expansion	3	$=T_H$	✓	$=v_2$	✓	✓	=const	V_{min}
Hot to Cold Blow	4	$=T_H$	✓	$=\frac{V_{max}}{m}$	✓		=const	V_{max}

2→3 & 4→1 average V doesn't change so no work is done

Balances

Process 1→2: Energy Balance

$E_{in} = E_{out} + \Delta E_{stored}$

$W_{C,1\to2} = Q_{out,1\to2} + m(u_2 - u_1)$

Entropy Balance

$S_{in} + S_{Gen} = S_{out} + \Delta S_{stored}$ (ideal)

$0 = \frac{Q_{out,1\to2}}{T_C} + m(s_2 - s_1)$

Process 3→4

Energy: $E_{in} = E_{out} + \Delta E_{stored} \Rightarrow Q_{H,3\to4} = W_{out,3\to4} + m(u_4 - u_3)$

Entropy: $S_{in} + S_{Gen} = S_{out} + \Delta S_{stored} \Rightarrow \frac{Q_{H,3\to4}}{T_H} = m(s_4 - s_3)$

Cycle

$W_{net} = W_{in,3\to4} - W_{out,1\to2}$ $\quad \eta_{cycle} = \frac{W_{net}}{Q_{H,3\to4}}$ = Carnot for ideal Cycle

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→ Go to EES comparison

$\eta_{elect} = 1.35\%$, $\eta_{ideal\ stirling} = 4\%$

RPM = 4.1 $\dot{W}_{elect} = 0.17W$, $\dot{W}_{stirling} = 0.5203W$

→ Probably not possible @ room temperature ⇒ maybe possible if cold outside ⇒ then your hand would get cold.