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Numerical Study of an LTD Stirling engine with a porous regenerator

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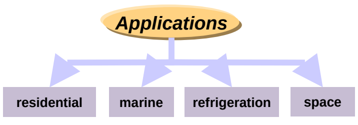
✓Objective :

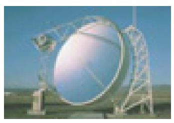
optimization of a Low Temperature Differential (LTD) Stirling engine operation by choice of the porous regenerator material.

✓ Modeling method :

- numerical simulation of energy conversion processes using a multiphysics software with a moving grid , e.g. COMSOL Multiphysics.
- mass, momentum and energy conservation of media in this engine with a porous regenerator, so as to obtain the instantaneous values of the local state variables in pre-defined application modes : pressure, temperature, density, velocity and volume.
- using a systematic and rational variation of the geometrical parameters and physical properties of the regenerator, one deduces the optimal characteristics of the regenerator (porosity, specific heat...) from the balance of the exchanged energy fluxes and other outputs.

Stirling engine :





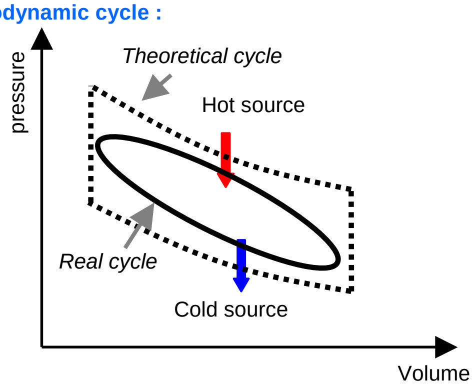
Operation :

An encapsulated working gas (e.g. air), being moved from hot to cold volume, and conversely, by reciprocating movements of the power and regenerator pistons, passes through a regenerator and is submitted to alternate heating and cooling ; that gives out-of-phase pressure and volume changes inducing work generation (Carnot cycle)

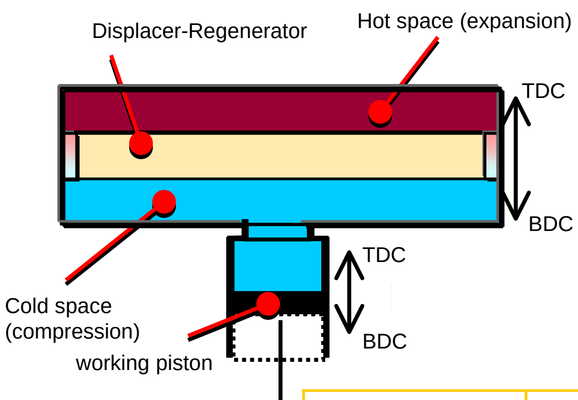
Advantages of this engine :

- Many sources commonly available (solar, biomass, waste heat, …)
- Excellent efficiency (theoretical : Carnot)
- Low noise generation (no internal combustion, no exhaust,…)

Thermodynamic cycle :



The engine is made up of 3 spaces: Hot, Cold & Regeneration



- Two-dimensional
- Axisymmetric
- Conjugate heat transfer
- Compressible
- Moving boundaries(pistons)
- Gas-solid interface
- Porous media

Parameters	Values
Hot wall temperature , K	301
Cold wall temperature , K	291
Initial pressure, Pa	101325
Speed, rev/mn	24
Porosity, -	0.5

Equation system :

- Heat Conservation :

In gas :

$$\left(\rho.c_p\right)_g.\frac{\partial T}{\partial t}+\nabla\left(-k_g.\nabla T+\left(\rho.c_p\right)_g.u.T\right)=\frac{Dp}{Dt}-\tau:\nabla u$$

In solid wall :

$$\left(\rho c_p\right)_w.\frac{\partial T}{\partial t}+\nabla\left(-k_w.\nabla T\right)=Q$$

In regenerator :

$$\left(\rho.c_p\right)_t.\frac{\partial T}{\partial t}+\nabla\left(-k_{eq}.\nabla T+\left(\rho.c_p\right)_g.u.T\right)=\frac{Dp}{Dt}-\tau:\nabla u$$

- Navier Stokes equations:

In gas :

$$\rho_g\frac{\partial u}{\partial t}+\rho_g u.\nabla u=\nabla\left[-pI+\eta\left(\nabla u+(\nabla u)^T\right)-\left(\frac{2\eta}{3}-k\right)(\nabla u)I\right]+F$$

$$\frac{\partial\rho_g}{\partial t}+\nabla\left(\rho_g u\right)=0$$

In regenerator :

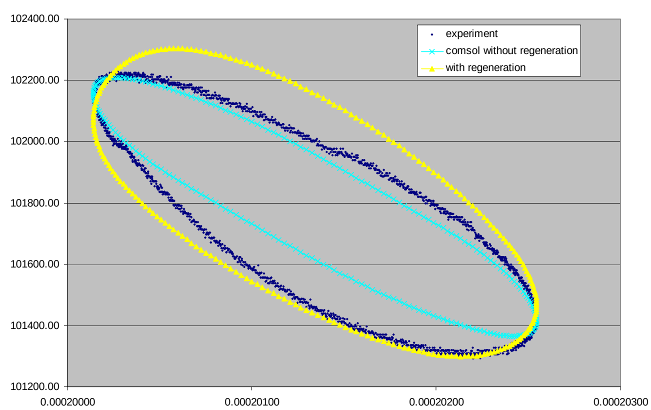
$$\left(\frac{\rho_g}{\varepsilon_g}\right)\frac{\partial u}{\partial t}+\left(\frac{\eta}{k1}\right)\rho_g u.\nabla u=\nabla\left[-pI+\eta\left(\frac{1}{\varepsilon_g}\right)\left(\nabla u+(\nabla u)^T\right)-\left(\frac{2\eta}{3}-k\right)(\nabla u)I\right]+F$$

$$\frac{\partial\left(\varepsilon_g\rho_g\right)}{\partial t}+\nabla\left(\rho_g u\right)=0$$

- Equation of state (ideal gas) :

$$p=\rho_g\ r\ T$$

Results :



Conclusion :

- by replacing the displacer by a moving porous media, we simplify the engine geometry and construction and we improve its operation.
- With regeneration, one approaches the theoretical reversible Stirling engine cycle (work, efficiency).

Perspectives :

- further optimization of the engine operation is possible by modifying the geometrical parameters and the physical properties of the whole engine and working fluid.