project update

Optimising regenerator of Stirling-motor for micro-CHP

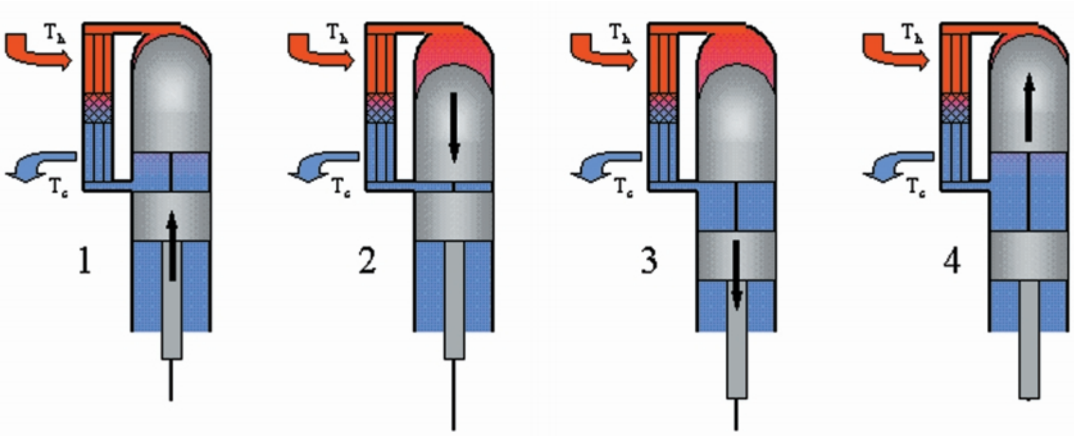
Challenge

Stirling based technology holds high promises for the economic realisation of domestic Combined Heat and Power (CHP) systems for combined generation of electricity and heat. With their typical electric power output of 1 kW, such systems are named micro-CHP systems. Already Robert Stirling realised the importance of the regenerator for the efficiency of a closed cycle Stirling engine. The design of the regenerator is vital to the design of an efficient and thus economic Stirling engine.

Equipment

The free-piston vibrator generator is a modern type of Stirling engine, in which helium gas is compressed and expanded by an oscillating system of masses and springs. The heart of the engine is a closed helium-filled vessel with two moving parts, the displacer and the power piston. The head of the vessel is heated from the outside by combustion gases from a natural gas burner. This yields a typical wall temperature of 600°C of the hot chamber, the gas space enclosed by the head of the vessel and the displacer. The cold chamber, enclosed by the displacer and the piston, is water-cooled at a temperature of typically 50°C. The power strike is provided by the force enacted by the expanding helium gas in the hot chamber on the displacer, which is coupled to the power piston by a gas spring. The displacer resonates virtually frictionless at 50 Hz and serves to transfer expanded hot helium gas from the hot chamber to the cold chamber and compressed cold helium back.

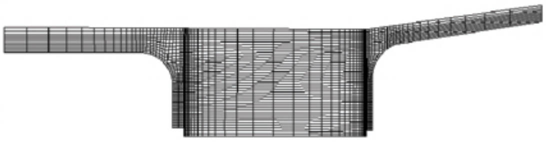
Nearly the whole of the temperature difference between the hot space and the cold space appears over the regenerator. To avoid wasting heat, the heat leak across the regenerator must be small, in spite of this large temperature difference. The regenerator also must have a large heat capacity, for it must absorb as much heat as possible when the hot helium passes downwards toward the cold space. And on the way back, it must yield up as much heat as possible to the helium. The typical helium cooling (heating) rate in the regenerator is about 20,000 degrees per second. Furthermore, the pressure drop across the regenerator and the gas volume of the regenerator must be low. Regenerators are made of metal wire meshes or other high-porosity materials.



Artist impression of modern Stirling engine for micro CHP

Approach

The processes in the Stirling regenerator are rather complicated, due to the combination of transient nature of the flow and the anisotropy of flow and heat transport. CFD modelling techniques are able to capture both aspects and to provide the necessary information on successful possible ways to improve the design.

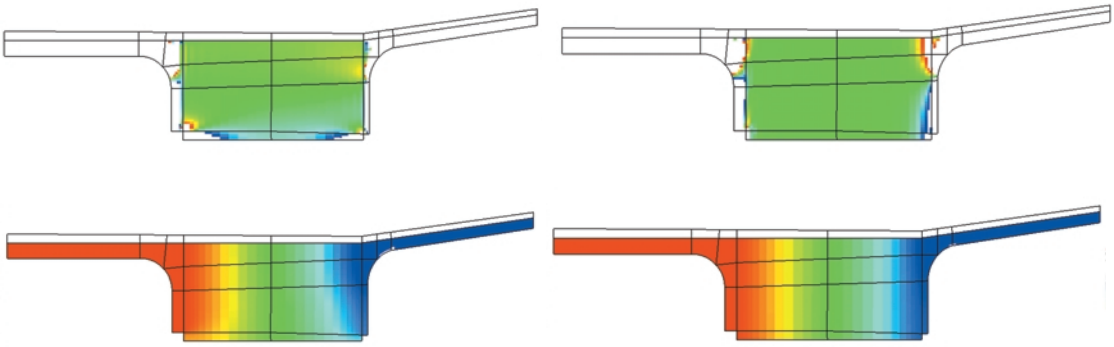


Computational mesh, with expansion side on the left

A two-dimensional model suffices for representing the regenerator geometry (see figure.) Concerning modelling of the physics, a stepwise approach was followed with increasing complexity, starting with stationary, isothermal calculations and progressing to time dependent, non-isothermal calculations. The latter comprises modelling of many complete cycles, before the stationary operational situation is approached. The effect of the conduction in the wall was determined by modelling adiabatic walls and conductive walls.

Solution

The first calculations already gave insight into the dead zones of the regenerator, thus providing a straightforward insight in how to reduce the volume without the penalty of efficiency loss (see top figure, the gas velocity is zero in the white zones.) Subsequently, the effect of anisotropic matrix material was investigated. The figures show the horizontal gas velocity (top) and the pressure drop (bottom) in the regenerator for two different radial flow resistances. This shows that the effect of anisotropy and porosity can be large. The project team was able to decide on the basis of these results in which direction further material development was desired. In addition, the project provided justifications for the approximations to be made in engineering models.



Horizontal gas velocity (top) and pressure drop (bottom) for two radial flow resistance cases (left, right)

About the author:

Michiel Houkema has been working with NRG for five years. After working on modelling of species transport in porous media, he shifted his attention to CFD modelling of coal combustion and design of systems for sustainable energy generation and energy efficiency. He is presently involved in design of thermal acoustic cooling and Stirling engines. Michiel holds an M.Sc. in Applied Physics.

About NRG CAE's group:

NRG's Computer Aided Engineering (CAE) group has successfully applied CAE technology for customers in the power, offshore, petrochemical and machinery industries. The core competencies of the group are Structures-FEM, Processes-CFD and Design-CAD. The expertise of the Processes-CFD team includes combustion technology for gas turbines and coal burners, separation and filtration processes, aerodynamic and hydrodynamic design for valves and other components, reactive systems, two phase systems. The Structures-FEM team has proven expertise in design and analysis of mechanical structures, simulation of metal forming processes, pressure vessels, crash analyses and drop tests and many other processes. NRG is a member of the KEMA–ECN group of companies.

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Call Victor Wichers, telephone +31 224 564656 or +31 6 511 523 84 (cellular); or send us an email at wichers@nrg-nl.com. For more information visit http://www.nrg-nl.com/product/ppt/cae.