

The Stirling Cycle

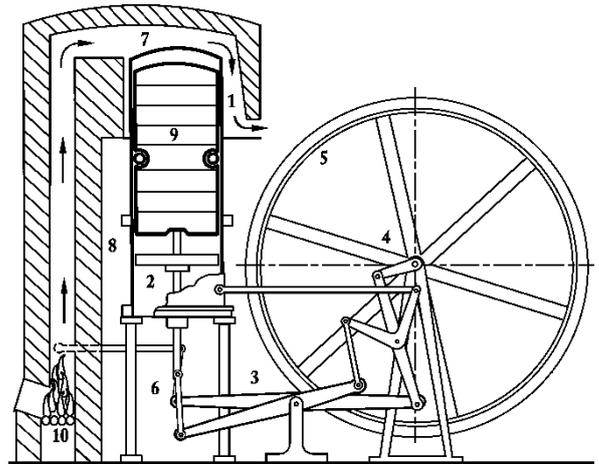
The ultimate way to generate cooling power

History

The Stirling cycle is a thermodynamic closed cycle invented in 1816 by the Scottish minister Robert Stirling. It was used as an engine and was considered at the time to be capable of replacing the steam engine since their steam boilers were prone to life-threatening explosions. The counterpart of the Stirling engine, the refrigerator, was first recognized in 1832. Both machines experienced high and low points during the nineteenth century. The principle behind the machines was almost condemned to obscurity after the invention of the internal combustion engine (gas-, petrol-, and diesel motors) and compressor refrigerators with external evaporation.

In 1938 the famous Dutch Philips Research Laboratory was looking for a means to power electricity generators for short wave communication systems in remote areas without electricity supply. The practically-forgotten Stirling engine attracted their attention.

In 1946 Philips started optimizing the Stirling cycle to be used for cryogenic cooling. The result was the development of the world conquering Stirling Cryogenerator, marking the start of significant cryogenic activities at Philips. Though the Stirling engine itself never became a commercial success, the Stirling Cryogenerator has been selling by thousands worldwide and has been incorporated in equipment and projects used from Antarctica to the North Pole.



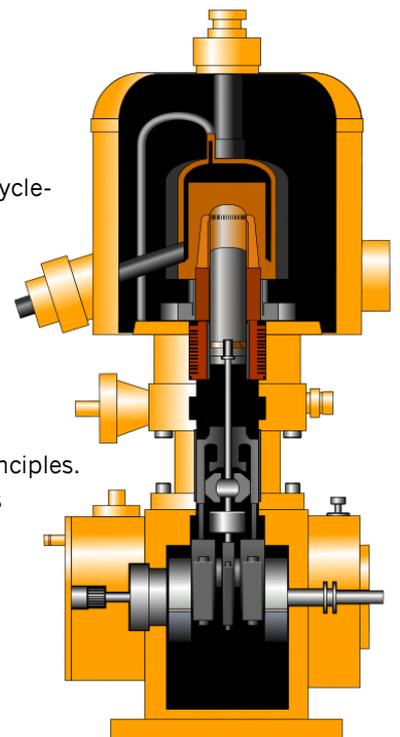
Today

In the beginning of the 90's the Philips Cryogenic Division became independent and continued its worldwide activities under the name of Stirling Cryogenics B.V.

Stirling Cryogenics is the only company in the world that successfully produces Stirling cycle-based cryogenerators with cooling powers of 1,000-4,000 watt (at 77K) per unit. Thanks to continuous innovation and considerable investment in R&D, the Stirling Cryogenerator is now used in a wide range of applications, including the production of liquid gases such as LN₂, LOX, LNG, LAr and the cooling of research applications and industrial processes between 20 and 200K.

Stirling efficiency

The Stirling Cryogenerator is extremely efficient compared to other cryogenic cooling principles. Carnot efficiency is 30% at 77K, resulting in a high practical over-all efficiency defined as Watts of cooling power available to the application divided by kW of electric input power. Depending the application's temperature, the over-all efficiency of the Stirling Cryogenerator varies between 10% for LN₂ applications to over 20% for LNG systems.



The Stirling Cycle

The central element in all equipment of the Stirling Cryogenics brand is the Stirling Cycle Cryogenerator. The Stirling Cycle is remarkable because it is a closed cycle in which the Cryogenerator's internal working gas (He) never comes into contact with the fluid to be cooled; they connect only by flow of heat through the heat-exchanger wall. This concept eliminates contamination of the customers process as well as of the Stirling Cycle working gas, resulting in long continuous operating periods and longevity.

The Stirling Cycle alternately compresses and expands a fixed quantity of helium in a closed cycle. The compression takes place at room temperature to facilitate the discharge of heat caused by compression, whereas the expansion is performed at the cryogenic temperature required by the application

For the purpose of explanation, the process may be split up into four distinct piston positions illustrated in Figure 1. In position I, all helium is at room temperature in space D. Going to position II, this gas is compressed by piston B increasing the gas temperature to about 80°C, refer to figure 2, column 1. When the displacer C moves down from position II to III, the gas is displaced from space D to space E, forcing it first through the cooler H where the compression heat is dissipated into the cooling water, reducing the gas temperature to about 15°C (column 2). Next, the helium flows through regenerator G. Using the cold which was stored in the regenerator by the previous cycle, the helium gas is cooled to almost the final liquefaction temperature when arriving in space E (column 3). The final and main action is the displacer and piston moving down to position IV, expanding the helium gas. This expansion creates the actual cooling power in the cold heat exchanger J (column 3), cooling the customers process.

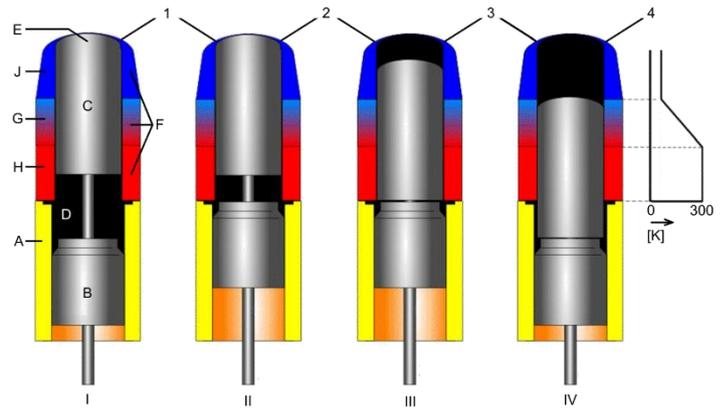


Figure 1: The Four stages of the Stirling cooling cycle

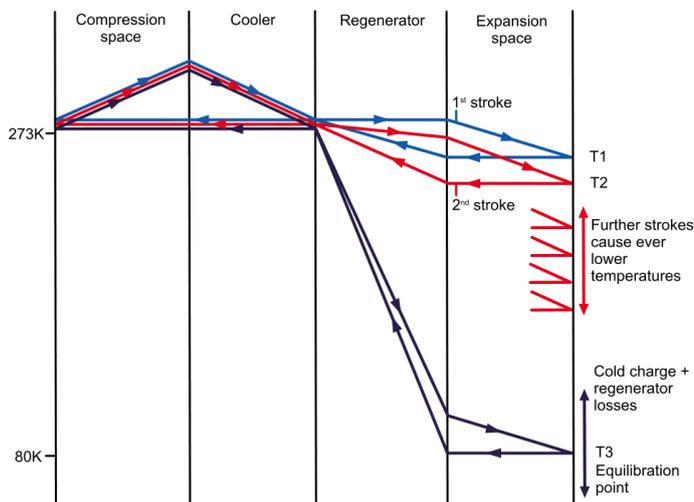


Figure 2: Temperature gradient in a single stage cycle

Further strokes cause ever lower temperatures

For a new cycle to begin, the displacer moves up to position I, displacing the helium to space D again. The regenerator is cooled by the passing helium, storing cold to be used in the next cycle. The helium is reheated to nearly room temperature so the initial situation of the cycle has now been restored for the cycle to repeat. This cycle is typically repeated at 25 Hz, providing a continuous extraction of heat.

When starting warm, the Cryogenerator will initially first cool down itself, building up a cold buffer in the regenerator (column 3). This cool-down requires about 10 minutes only, allowing a fast start-up of the total process.

Process integration

Integration of the Stirling Cryogenerator into the process is straight-forward. Since the cycle to produce cooling power is completely separate, there is only need for in and outlet lines to be connected, supplying the flow of gas to be liquefied, or a gas or liquid to be cooled.