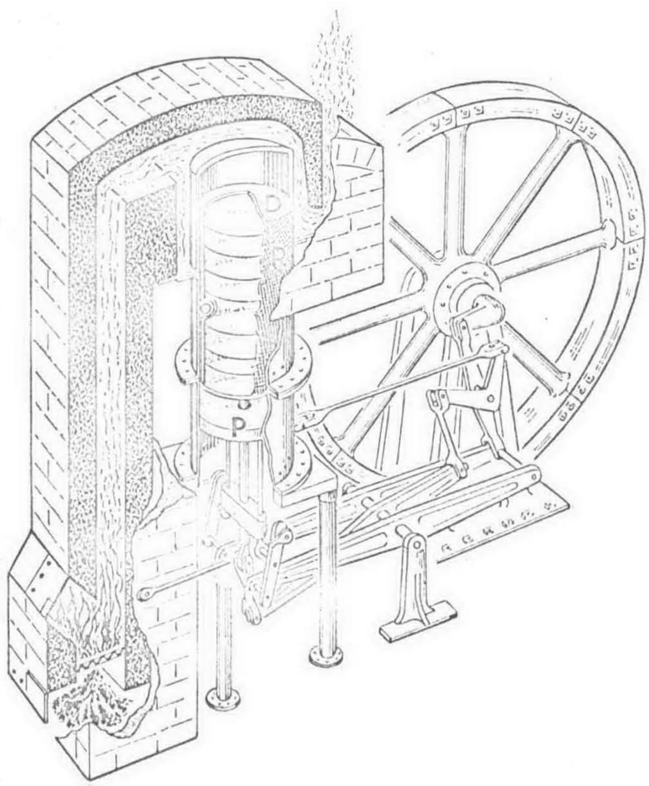

Stirling's original 2-horsepower engine, from the drawing in his patent application. This model was used in 1818 to pump water from a quarry. The displacer (D), regenerator (R), and piston (P) are identified.

tical machines. Up to now, research has been confined to a narrow range in a broad subject, and the main purpose of this article is to supply some background information in a field which may provide the answers to several problems of energy utilization and conversion.

Working Principles

For a better understanding of the working principles, a few notes on general cyclic processes used in thermal machines are given here. To thermodynamicists, a "cycle" simply means that a compressible fluid such as a gas or a vapor (the "working fluid") is repeatedly subjected to variations in volume, temperature, and pressure with a conversion of heat energy to mechanical work or vice versa. Ideally the state of the working fluid at the end of each cycle should be the same as that at the beginning. Typical examples of the two main kinds of machines using thermodynamic cycles are internal-combustion engines and refrigerators.

An important law of thermodynamics states that any cycle has the highest possible efficiency if heat transfer from or to an external source always takes place at the two extreme temperature limits of the cycle. For example, in an engine or a prime mover, heat must be supplied only at the highest temperature and heat must be rejected only at the lowest temperature. Similarly, for a refrigerating or heat-pumping cycle, heat must be supplied only at the lowest temperature and heat rejected only at the highest temperature.

It is usually thought that the only cycle which fulfills this requirement is based exclusively on isothermal and adiabatic processes.° For many years this hypothetical reference cycle has been called the Carnot cycle and, as such, has been widely used in textbooks, although it is rather different from the one described in 1824 by Sadi Carnot in his classic paper, "Reflexions sur la Puissance Motrice du Feu". This concept is an abstraction which involves idealized components as, for example, an enclosure with infinite heat conduction at one stage, and perfect thermal insulation at another. Since large ranges of pressure and volume ratios are also involved, there is no practical mechanism which even remotely resembles this cyle.

Actually the Carnot cycle is only one special case of an infinite number of reference cycles with the same high efficiency, where the adiabatic operations are replaced by polytropic phases. In such processes, the heat removed during compression is equal to the heat absorbed during expansion. If the heat rejected can be stored and reabsorbed later, no external heat exchange is involved during the polytropic phases, and the cycle therefore has the same efficiency as the Carnot cycle. The term "regenerative cycles" used for this process refers to the periodic recovery of thermal energy associated with polytropic processes, and a regenerative thermal machine is an apparatus which attempts to realize such a cycle.

The device which stores the heat during one part of the cycle for use later is a "regenerator". In this application, it is usually a simple component, merely thin wire stuffed into the duct through which the gas flows. Such a regenerator separates two working spaces maintained at different temperatures. A temperature gradient between these is established in the regenerator matrix so that whenever the working fluid is transferred from one space to the other, heat transfer within the regenerator will cause the temperature of the working

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°Glossary of terms commonly used by thermodynamicists:

Adiabatic process: Expansion or compression of a substance during which there is no heat supplied to or rejected by the substance; follows the law PV^{γ} = constant.

Isothermal process: Expansion or compression of a substance during which the rate of heat exchange is sufficient to keep the temperature constant; follows the law PV = constant.

Polytropic process: Expansion or compression of a substance with arbitrary heat transfer; follows the law PV^{n} = constant.