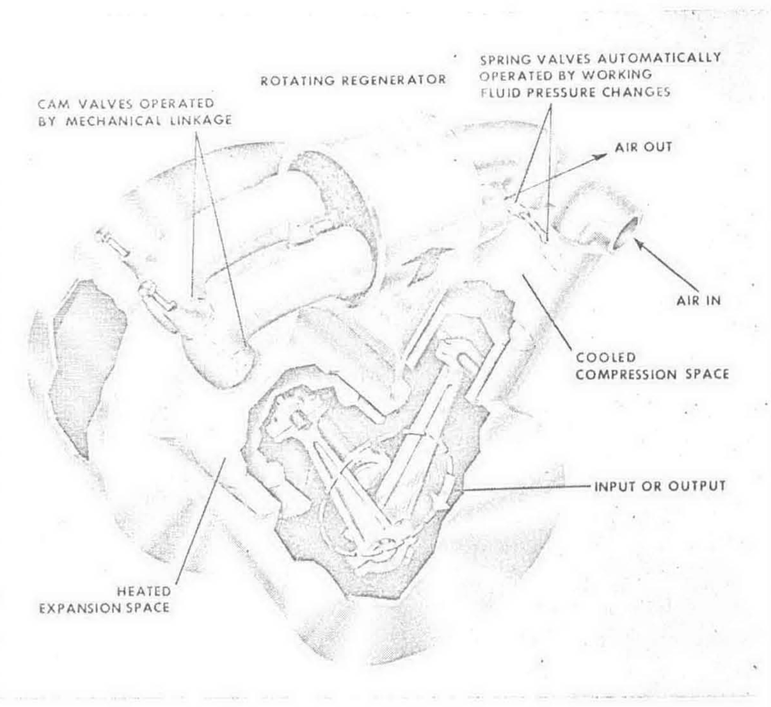
hot end of the cylinder would continue to absorb heat. As a consequence, the temperature dropped to below atmospheric conditions and ice formed on it by condensation from the atmosphere. Eventually, the temperature became so low that air liquefied on it. These two experiments correspond to operation as "prime mover" and "refrigerator", respectively. With the power disconnected at this stage, the temperature differential between atmosphere and the very cold cylinder head would cause heat to be absorbed at the lower temperature and the mechanism functioned as a "cold prime mover". The machine then rotated in the opposite direction and generated electricity until the temperature between the two cylinders was equalized. If the motor were then again supplied with electrical energy to continue to drive it in the same direction, heat was elevated to a higher level. The cylinder head could again be made red-hot by the mechanical energy supplied to it by the electric motor instead of heat energy supplied by the burner, and the same device now functioned as a heat pump.

Different Designs

The two basic arrangements with either two cylinder-piston assemblies, or with a piston and a displacer in one cylinder, are only the two simplest configurations out of many possible alternatives. In more sophisticated machines, oscillating or rotary cylinders, vane-type assemblies, or free-piston devices could replace the moving pistons in stationary cylinders. It is also possible to use totally sealed systems with bellows or diaphragms for the volume variations. All these designs have been applied to regenerative thermal machines on paper, and some are extremely promising.

Even the more elementary mechanism with reciprocating pistons in stationary cylinders can be made much more efficient with a double-acting design. By using both sides of each piston in a multicycle machine for producing the volume variations in two different constituent cycles, only one major moving element is used per cycle instead of two. The efficiency could be greater since there are fewer working parts and because net forces are more equalized. This is particularly important in machines where the working fluid is a highly compressed gas, such as hydrogen.

The preceding discussion of thermal machines was based mainly on so-called "closed" thermodynamic cycles. This term indicates that, apart from incidental leakage past the piston, no inlet or exhaust process is involved, and an identical mass of gas is used again and again. In contrast, open-cycle machines replace at least a substantial portion of the working fluid during each cycle but, in all other respects, the thermodynamic cycle is the same as in closed-cycle machines. The only significant difference is that one or more phases are now performed outside the mechanism, for example, in the atmosphere. An example of a typical open-cycle machine is shown above. While closed-cycle machines usually have no valves, all open-cycle machines need them to regulate the flow process. In the design shown here, the valves in the compression space are automatic, and those in the expansion space link operated. A rotary regenerator is used where the matrix can change position between the two gas streams.



This open-cycle regenerative thermal machine differs from a closed-cycle machine in that it has a rotary regenerator and an intake and exhaust to the atmosphere.

Two "caloric" engines with 14-foot-diameter cylinders of this type powered the famous "Ericsson", a 2200-ton vessel built in 1853; however, power production is apparently not a good application for open cycles, as specific output is low. There are, nevertheless, other promising possibilities. Since a continuous stream of heated or cooled gas is delivered by the machines, they can function as cooling, warming, or dehumidifying devices or even as air compressors, and some attractive designs have been proposed.

The main object in enumerating all of these various possible systems is to demonstrate that only a narrow range in a vast field has been explored. Out of dozens of different technically feasible alternative configura-