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"Solar Stirling Engine"

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These are preliminary lecture notes, intended only for distribution to participants.

SOLAR STIRLING ENGINE

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ABSTRACT

Stirling engine is an external combustion engine that can use almost any fuel. Solar energy would be an appropriate candidate here. A great deal of interest on solar stirling engine has been revived in recent years. It has shown great promise as a decentralized power system, which would be a boon to developing countries. The 50 kW solar Stirling engine established at the Solar Village near Riyadh is an excellent example of a very potential solar energy conversion system, which could be a forerunner to new developments in this field.

INTRODUCTION

Environmental Damage

The developing nations are currently facing several crucial problems. One of them is the degrading environment and serious health hazards to the entire population. If these nations have to survive, they must adopt tha path of sustainable development with a serious concern for the protection of our environment. Stirling engine is a potential engine which is versatile and efficient, and can run on solar energy. This would reduce the problem of air pollution.

Excellent Heat Converter

In 1817 the Reverend Robert Stirling invented a practical engine, which theoretically would give an efficiency as high as that of the Carnot engine. This engine,named after the inventor, is an external heat engine (the heat is supplied from an external source). The fact that almost any fuel can be used allows for an efficient utilization of local energy sources. Stirling engines that are heated directly can also run on solid fuels like mill, forest and crop residues. Solar energy could be an excellent external heat source. Stirling engine is particularly well suited to solar electric power systems because of its high efficiency, which is of critical importance in solar power systems.

United Stirling, a research and development company, was founded in 1968 as a licensee of N V Philips in Holland, a company engaged in research in Stirling engine since 1938. The development of Stirling engine has benefited from dramatic technological advances since then. Several double-acting Stirling engines have been installed both in passenger cars and distribution trucks by the United Stirling company. Tests on a Stirling engine,with its 11 m diameter parabolic dish concentrator, at the Edwards Air Force Base in

California, USA, in 1982 have shown excellent performance with a conversion efficiency of 33 percent - thermal input to engine to electric output to grid[1].

PRINCIPLE OF STIRLING ENGINE

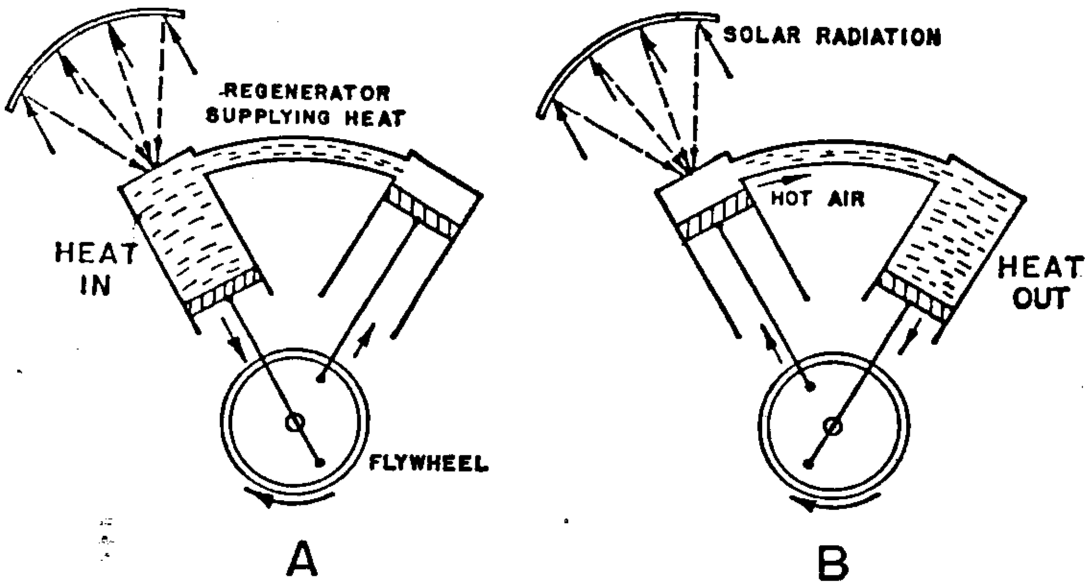

Figure 1. **Principle of Stirling hot-air engine.**
Source: F. Daniels

The principle of Stirling engine,using hot-air as the working medium, is shown in Figure 1. Focused sunlight heats the air contained in the cylinder at the left. Heat is absorbed in the left cylinder and discharged in the right cylinder, either into water-cooled jacket or an air-cooled wall with metal fins. The regenerator, which is packed with metal wool or other material, stores the heat, which is then available on the next half-cyle for preheating the incoming air. Air is expanded in the left cylinder, while hot, and compressed while cold,in the right cylinder. The net difference is made available for converting heat into mechanical work [2].

Most Stirling engines of today work on the double-acting principle, which means that the pistons have two functions; they move the gas back and forth between the hot and cold sides. The pistons are thermodynamically coordinated, and each one operates simultaneously in two cycles; the hot upper surface of one piston is coordinated with the cold undersurface of the next piston, and so on. Optimal efficiency for a Stirling engine module is achieved by using 4 - 6 cylinders, arranged either in line or coaxially [3].

Internal Combustion Engine

In an I.C.engine,the fuel inside the cylinder must be burned in order to heat the working gas, which is always air. In the gasoline engine, a mixture of air and gasoline is sucked into the cylinder and compressed by the piston. The mixture is ignited by an electric spark. 'Knocking' occurs in these engines due to self ignition. To prevent knocking, the compression should not be too high and the gasoline should not be easy to ignite. In the diesel engine, only air is compressed, and a fine spray of diesel fuel is injected into the

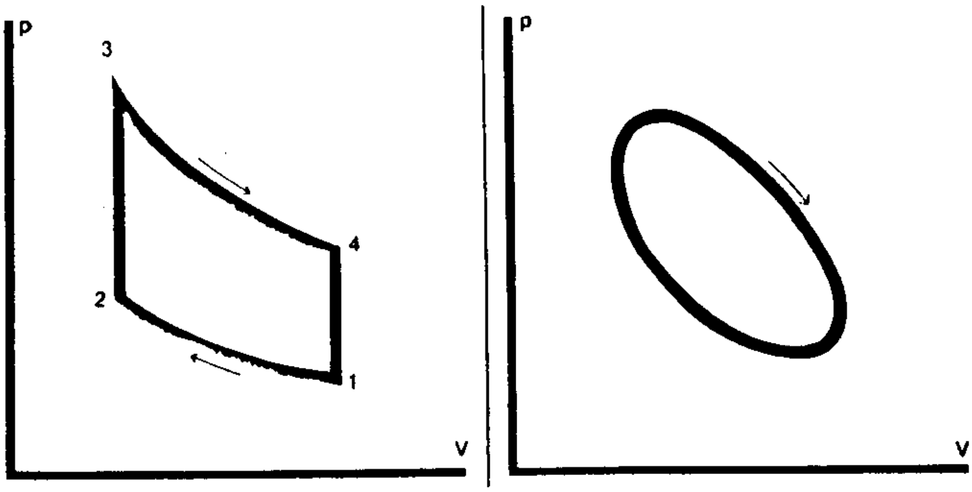

Figure 3. Theoretical and actual pressure-volume diagrams; 1-2:Compression of the working gas on the cold side,2-3:Displacement from the cold to the hot side at constant volume,3-4:Expansion of the gas on the hot side,4-1: Displacement from the hot to the cold side at constant volume. The actual curve has a somewhat different shape because the process entails continous piston movements and continous heating and cooling

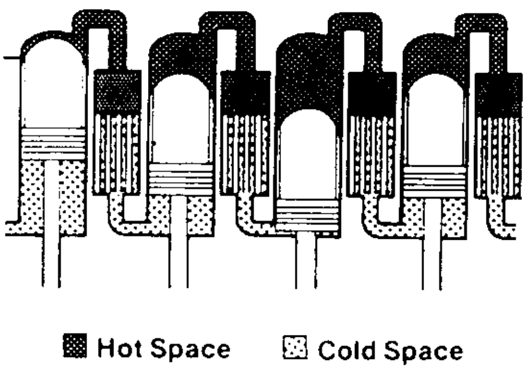

Figure 4. Coordination of pistons in a double-acting Stirling engine

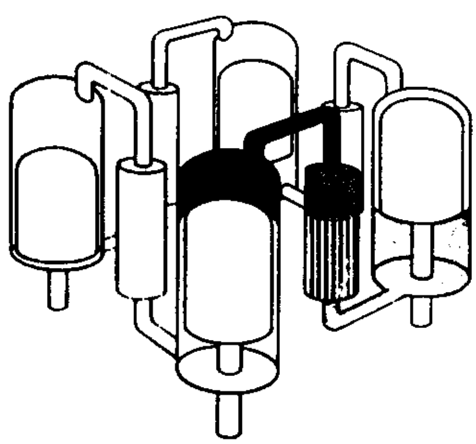

Figure 5. Working gas in one of the cycles of a 4-cylinder Stirling engine module

cylinder. The heated air ignites the fuel without resorting to a spark. The intermittent ignition in the cylinders of I.C.engines prevents complete combustion of the fuel, and this decreases the efficiency of the engine and results in air pollution which in addition to noise pollution limits the usefulness of the I.C.engine.

In the Stirling engine, heat is supplied continously and externally, and the working gas which is usually hydrogen or helium operates in a completely closed system. Continous operation in a closed working cycle, with a pressure curve that is almost sinusoidal, and the absence of valves reduce both noise and vibration. If the Stirling engine uses solar heat, it is also pollution free.

SOLAR VILLAGE PROJECT

The solar energy conversion system, comprising of a 50 KW Stirling engine and a 17 m diameter concentrator, was established in 1985 under the German-Saudi Arabiantechnical cooperation program. With a keen desire for solar energy development, the two countries are working on some advanced solar technologies, which have a very high potential for an efficient and versatile use of solar energy. One of the projects described here is the solar energy conversion system

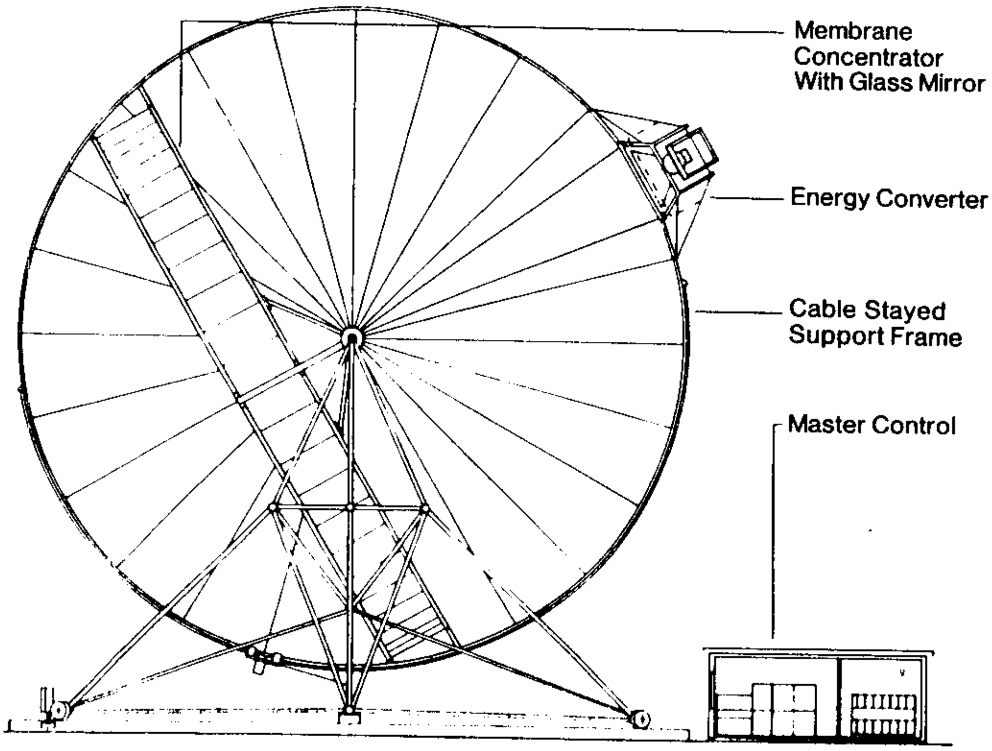

Figure 2. A Schematic Diagram of the Energy Conversion System

The structure shown in the diagram is an unique and a very compact one, which houses the Stirling engine and a large membrane dish. The membrane dish is a hollow reflector, which is suspended and supported on rails in such a way that it can track the sun. The energy converter, which is a Stirling engine coupled directly to a generator, is located at the focal point of the reflector.

The special feature of this power plant is the construction method, which permits the fabrication of a large membrane dish in a simple and a very effective manner. The membrane is made of individual sheet-metal strips welded together. Mirror glass is bonded to the sheet metal to form the reflecting surface. The membrane is plastically deformed to the desired paraboloid shape by air pressure. When the concentrator is in operation, the shape of the membrane is kept constant by partial vacuum in the interior of the concentrator.

The reflected solar rays hit the receiver of the engine and heat the working gas, which is hydrogen. A central control system controls tracking, monitors the Stirling engine control system, processes wind data and indicates malfunctions. The system can be operated in grid connection mode or 'stand-alone' mode with battery storage[4].

Development and management of this project is done by Schlaich and Partner of Germany.

Technical Data:

Concentrator diameter	17 m
Concentrator area	227 m^2
Usable mirror area	95%
Reflectivity (cleaned)	92%
Concentration factor (average).. ..	600
Focal length	13.6 m
Interception factor of receiver ..	90%
Power reflected on to receiver ..	178.6 kW
Concentrator efficiency	78.7%
Receiver loss	36 kW
Available thermal power	142.6 kW
Efficiency of the engine	42%
Generator efficiency	91%
Power output	54.5 kWe
System consumtion	2 kWe
Net power input to grid	52.5 kWe
Efficiency (overall)	23.1%
Permissible wind velocity while the concentrator is moving ..	80 km/h

CONCLUSION

The author was privileged to work with the scientific group at the Solar Village and was very much impressed by the performance of the solar power plant. While concluding it must be mentioned here that Stirling engine has some disadvantages. High manufacturing costs result principally from the complexity of the machinery and the heat exchanger elements. The necessity for construction of s gas-tight system presents additional manufacturing problems. But technical advances have reduced these problems to a great extent. The merits of the engine far outweigh the disadvantages, and the practical possibilities of the engine have increased during the past few years. The Stirling engine has been considered for use in space using energy from the Sun. Its most important applications have been as air engines and as a refrigerator.

With the Stirling cycle reversed, it is capable of reaching the low temperatures of the cryogenic regions. Machines have been built and used for the liquefaction of gases, and since 1958 the General Motors Corporation of America has built and tested Stirling engines for automotive purposes and a considerable assessment experience has been obtained. With the knowledge and experience gained so far, and with the increasing awareness of environmental damage due to fossil fuel burning, and of the importance of solar energy as a viable alternative to fossil fuels, solar energy conversion systems employing Stirling engine as the prime mover, will soon establish itself as a potential power plant for many applications.

REFERENCES

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2. F. Daniels, Direct Use of the Sun's Energy, Yale University Press, New Haven and London, 1964
3. United Stirling company brochure
4. Brochure prepared by Lipp GmbH, D-7097, Tannhausen, Germany