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SECTION I: PRODUCTION OF THERMIC AND ELECTRIC ENERGY

KINEMATIC STIRLING MOTOR-DRIVEN COMPRESSORS

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Abstract: The paper analyzes the possibility of building monoblock kinematic Stirling motor-driven compressors. Such an engine is a combination between a compressor and a kinematic Stirling engine. In the equivalent schematic diagram the power piston of the Stirling engine also performs the function of the compressor piston.
The advantages and the disadvantages of these machines are analyzed.

Key words: kinematic Stirling engine, motor-driven compressor

1. INTRODUCTION

The Stirling engines are piston heat engines in which the working substance (a gas - air, helium or hydrogen) evolves in a closed thermodynamic cycle [1], [2], [3], [4], [5]. The Stirling thermodynamic cycle, shown in fig. 1-a, is a combination between two isothermal (for heating and for cooling the gas) and two isochoric processes.

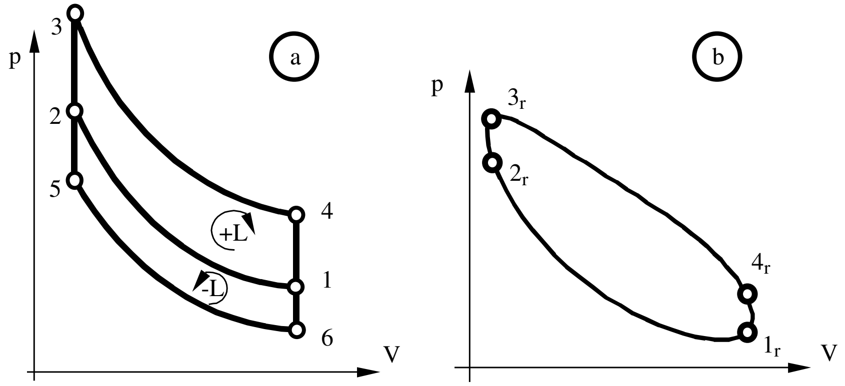

Fig. 1. Stirling cycle (a) and an indicator diagram (b)

If in the Stirling cycle the processes take place clockwise, the engine is a motor. The gas is heated at constant high temperature (isothermal process 3-4) and is cooled at a constant low temperature (process 2-1), delivering a work proportional with the area 12341 (fig. 1, a). The work is used outside the engine. If a Stirling engine receives work from an external motor, the gas evolves in a reversed cycle, receiving heat from the low temperature heat source (in the isothermal process 5-6) and yielding heat to the high temperature heat source (in the isothermal process 1-2). As a result, the Stirling engine operates as a heat pump or a refrigerator.

The Stirling cycle can be obtained in a functional unit (equivalent to an internal combustion single cylinder motor) with two pistons. The pistons can be placed inside two cylinders (fig. 2, α and γ) or into a single cylinder (fig. 2, β). At β and γ arrangements the power piston 7 is used to modify the total volume occupied by the gas inside the machine. For the α arrangement the displacer 2 is also a power piston. In the Stirling engine schematic diagram (fig. 2) the expansion chamber 1, the compression chamber 6 and three heat exchangers, the heater 3, the cooler 5 and the regenerator 4 can be seen. The displacer 2 moves the gas from one chamber to another. The regenerator accumulates the heat removed from the cycle during one isochoric process and returns it back to the gas during the other constant volume process. At γ arrangement the compression chamber is divided between the two cylinders of the functional unit..

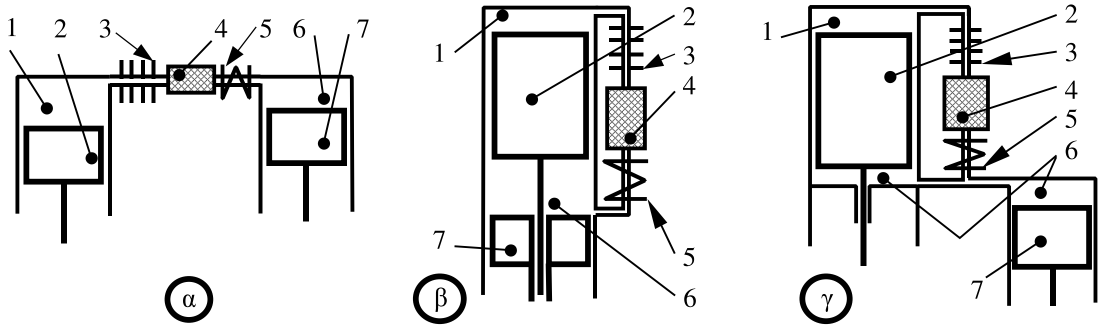

Fig. 2. Stirling engine arrangements: 1 - expansion chamber; 2 - displacer; 3 - heater; 4 - regenerator; 5 - cooler; 6 - compression chamber; 7 - power piston

In order to obtain the Stirling cycle previously described, the pistons must move intermittently [2], [3], [4]. The temporary stops are compulsory, because the gas must evolve in two isochoric processes. In order to obtain the isothermal processes the gas must be either inside the compression chamber or inside the expansion chamber, so the heat exchangers volumes must be neglected [2].

In the actual Stirling engines the synchronous movement of the pistons and the work exchanged can be performed with a mechanism (e. g. a slider-crank mechanism) or dynamic (at free-pistons machines). Inside the kinematic Stirling engines the movements of the pistons are correlated with a mechanism. Inside such a kinematic Stirling engine the indicator diagram, calculated with an isothermal physico-mathematical model [1], takes the shape shown in fig. 1, b.

2. STIRLING MOTOR-DRIVEN COMPRESSORS

The presence of a stem-equipped, single-acting piston in each possible Stirling engine arrangement brings on the idea of completing the construction with a cylinder head and with valves which, in association with the piston, form a compressor functional space.

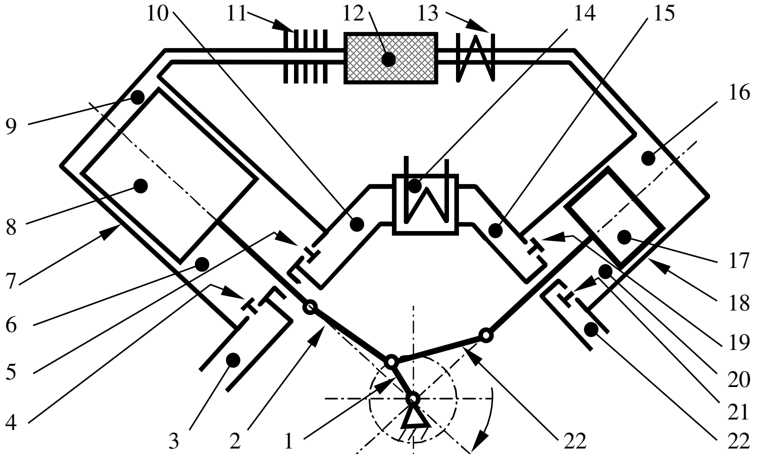

Fig. 3. SMDC based on α arrangement: 1 - crankshaft; 2, 22 - rod; 3 - stage I intake manifold; 4 - stage I inlet valve; 5 - stage I outlet valve; 6 - stage I compressor space; 7, 18 - cylinder; 8 - displacer; 9 - expansion chamber; 10 - stage I discharge manifold; 11 - heater; 12 - regenerator; 13 - cooler; 14 - intermediate cooler; 15 - stage II intake manifold; 16 - compression chamber; 17 - power piston; 19 - stage II inlet valve; 20 - stage II compressor space; 21 - stage II outlet valve; 22 - stage II discharge manifold

The second possibility to obtain a Stirling motor-driven compressor (SMDC) requires the transformation of the power piston into a differential double-acting piston. Now the engine has two compression spaces, each with its own suction and discharging valves.

In the fig. 3, fig. 4 and fig. 5 some schematic diagrams of single-stage or two-stage SMDC are presented. All the schematic diagrams are based on a Stirling engine functional unit. The schemes become more intricate if more than one Stirling functional unit is used.

The Stirling engines working with the reversed cycle can be also completed with cylinder heads and valves, in order to obtain compression spaces. In such a case the refrigerator motor provides the work needed to compress the gas.

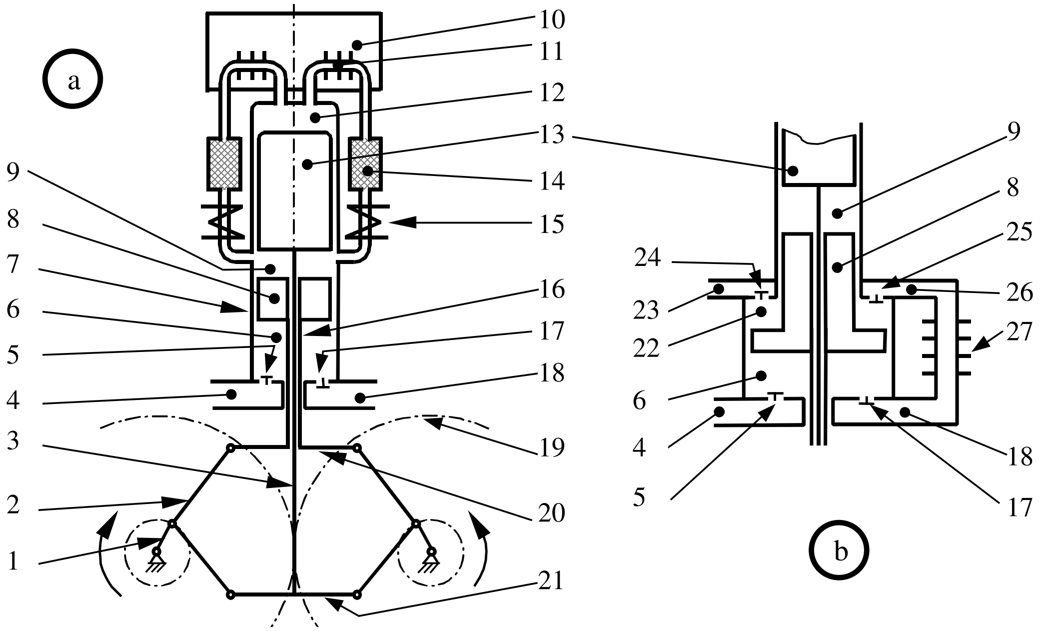

Fig. 4. SMDC based on β arrangement: a - one-stage SMDC; b - two-stage SMDC;
1 - crankshaft; 2 - rod; 3, 16 - stem; 4, 26 - intake manifold; 5, 25 - inlet valve; 6, 22 - compressor space; 7 - cylinder; 8 - power piston; 9 - compression chamber; 10 - burning chamber; 11 - heater; 12 -expansion chamber; 13 - displacer; 14 - regenerator; 15 - cooler; 17, 24 - outlet valve; 18, 23 - discharge manifold; 19 - gear weel; 20, 21 - yoke; 27 - intermediate cooler

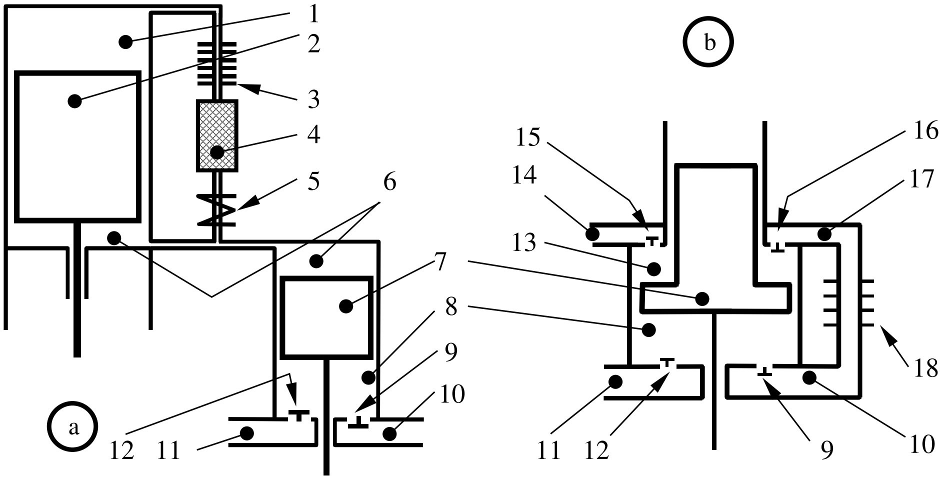

Fig. 5. SMDC based on γ arrangement: a - one-stage SMDC; b - two-stage SMDC;
1 - expansion chamber; 2 - displacer; 3 - heater; 4 - regenerator; 5 - cooler; 6 - compression chamber; 7 - power piston; 8, 13 - compressor space; 9, 15 - outlet valve; 10, 14 - discharge manifold; 11, 17 - intake manifold; 12, 16 - inlet valve; 17 - intermediate cooler

3. ADVANTAGES AND DISADVANTAGES

The major advantage of the kinematic SMDC lays in combining a Stirling heat engine and a reciprocating compressor into a single machine. The engine structure is more compact than in the case of an independent reciprocating compressor driven by a Stirling motor. A metal economy and a reduction of the overall weight are also obtained.

A notable disadvantage of the SMDC is the more intricate construction.

In comparison to the classical reciprocating compressors, the SMDC are more efficient. The piston of the classical reciprocating engine is driven by its own slider-crank mechanism, the work needed for the compression process being taken from a crankshaft of an electric motor or from a heat engine. The compression spaces of the SMDC can be placed in such a way that the work needed for the compression process is taken (totally or partially) directly from the Stirling engine, in the time interval when the expansion process takes place. As result, the energy flow within the driving mechanism (e. g. the crankshaft) diminishes. In the SMDC the friction of the compressor driving mechanism is annulled. The energy saving will become more and more significant over time, as the energy price raises continuously.

SMDC's are also very attractive because the Stirling engines can operate with heat from virtually any heat source: fossil fuels, various biomass fuels like sawdust or agricultural residues, hot exhaust gases from various sources or even solar energy [4], [5].

Preventing the gas leakage from the Stirling engine (inside which the pressure is high) toward the functional space of the compressor is a difficult task. For the seal between the piston and the cylinder the constructive solution with piston rings (widely spread at the contemporary Stirling machines [4]) can be used.

Based on the schematic diagrams of SMDC, reciprocating pumps can also be realized. A possibility to use a SMDC (or a reciprocating Stirling motor-driven pump) is inside a plant with a solar energy motor. During daytime the compressed air (or the pumped water) can be stored for later use.

3. CONCLUSIONS

The kinematic Stirling motor-driven compressors and pumps (SMDC and SMDP) are very promising constructive solutions, with a great potential for development and diversification.

Using SMDC may lead to important energy savings.

The SMDC high temperature heater can use almost every possible fuel or heat source. This advantage allows SMDC usage even in remote areas.

Properly designed, the SMDC and SMDP can be more efficient than the classical compressors and pumps.

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