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Feasibility Study of the Wave Disk Micro-Engine Operation

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Abstract

Development of micro turbine engines in recent years was strongly intensified. Since turbo-component efficiency becomes very low due to the downsizing effect, the micro wave rotor is expected to be applied for the improvement of the performance of ultra micro gas turbines, increasing the cycle pressure ratio. Applying only a combustion chamber and using oblique blades to form the rotor cells, net power can be taken from the rotor. In that way the use of an inefficient turbo unit can be omitted. Conventional construction in form of wave rotor can not be realized in MEMS technology. The new idea of a wave disk gives the possibility of easy implementation of a wave engine in MEMS technology. In the proposed solution the wave disk plays the role of an active compression-decompression unit and torque generator. Paper presents some preliminary results of simulation of the MEMS wave disk engine.

Key words: unsteady flows, MEMS wave engine

1 INTRODUCTION

Many groups of researchers have focused on the design of micro turbine engines in recent years [1,3]. Since turbo-component efficiency becomes very low due to the downsizing effect, an important problem arises of how to obtain thermal efficiency high enough to produce the positive power required. One of possible solution can be use of unsteady compression processes instead of commonly used steady state solutions. In that way the use of an inefficient turbo units in a micro scale, can be omitted. Such solution in form of wave engine was developed and practically realised by Pearson [5] in centimetre scale 50 years ago. Unfortunately conventional construction of wave engines in form of wave rotor can not be directly realized in MEMS technology. The new idea of a wave disk developed by Piechna, Akbari, Iancu,and Mueller [6] and independently by Nagashima and Okamoto [4] gives the possibility of easy implementation of a wave engine idea in MEMS technology.

2 WAVE DISK ENGINE IDEA

In the proposed solution the wave disk plays the role of an active compression-decompression unit and torque generator. Appropriate port geometry with oblique blades forming the disk channels generates torque. The engine disk rotates with speed much lower than the conventional turbo-unit that simplifies the bearing problem and construction of electric generator.

The idea of wave discs is relatively young and is not commonly known [2,6]. There are not known solutions of wave engines in radial geometry.

In present work has been proposed solution on the basis of the wave disc geometrical configuration with porting system realising one and two stage compression-decompression processes to increase the total efficiency. Middle pressure by-pass was prepared for generating the torque and consequently net power.

Probably up to now, radial wave rotors were omitted because of negative influence of centrifugal forces on the compression process. Papers [6,7] show methods suitable for the control of these forces. The main problem of conventional constructions of the wave rotors are a bad scavenging properties. However, the compression process is realised without special problems, purifying of the wave rotor cells are problematic when the back-pressure is too high. Proposed solution in form of radial rotor having curved channels can overcome this problem adding in controllable way additional force (being the component of centrifugal forces) improving the scavenging process.

According to Epstain [1] and Frechette [3] the motor-generator can be integrated within the engine.

In Fig.1 a schematic thermodynamic cycle of wave engine is presented. At the same compression pressure ratio the increase of top wave-engine cycle temperature is evident. Due to the self cooling phenomena characteristic to the wave processes, the top cycle temperature in the wave-engine can by higher than in the turbo-engine.

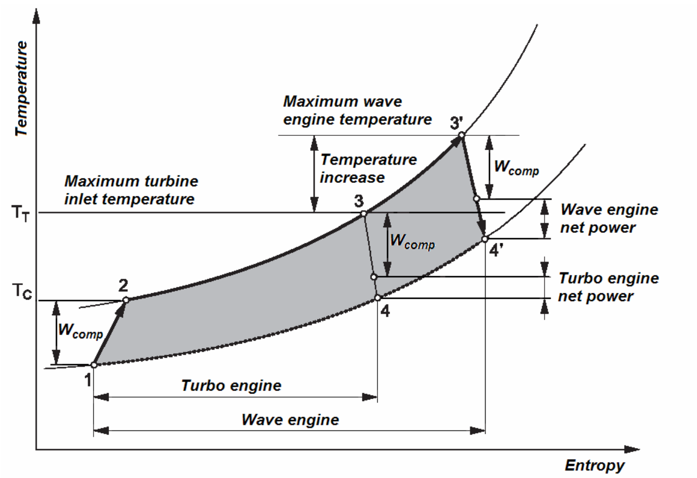

Fig.1 Schematic Temperature-Entropy diagram for turbo-engine and wave-engine.

Air compression power W_{comp} must be compensated by the part of the turbine power in conventional solution or hot gas expansion power in wave engine. In the turbo-engine the compression power must be transferred by the shaft from the turbine. Wave engine exchange compression energy directly between hot exhaust gases and fresh cold air, and due to that only the net power had to be extracted from the flow. The net turbo-engine power and net wave-engine power are shown on the scheme.

The flow scheme of a wave engine can be based on single o multi-step compression principle. Actually have been considered one and two-step compression configurations.

In Fig. 2 an exemplary construction of one step compression micro-engine in MEMS technology was visualized. In presented construction a double port set with two parallel operating combustion chambers was applied. Arrows in the figure explains the used flow field scheme.

The engine case can be prepared as a three part set. The most complicated part contains the basic plate with all port arrangements. The second part forms the combustion chambers and outflow mufflers. The third part it is only the cover with air inlets and exhaust gases outlets. Wave disk can be formed as two parts etched together.

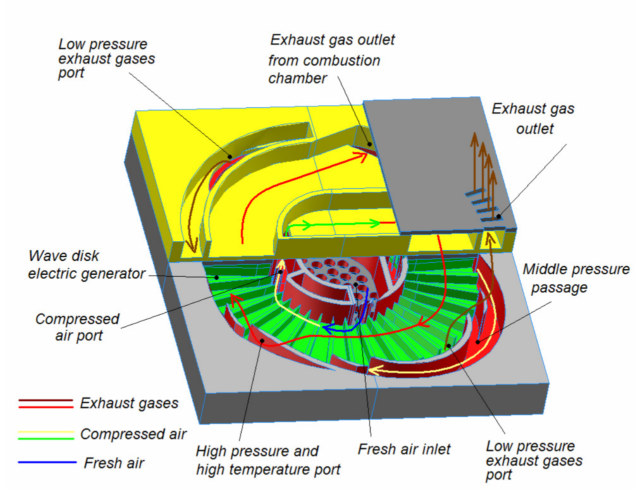

Fig. 2 Details of the one step compression wave engine construction

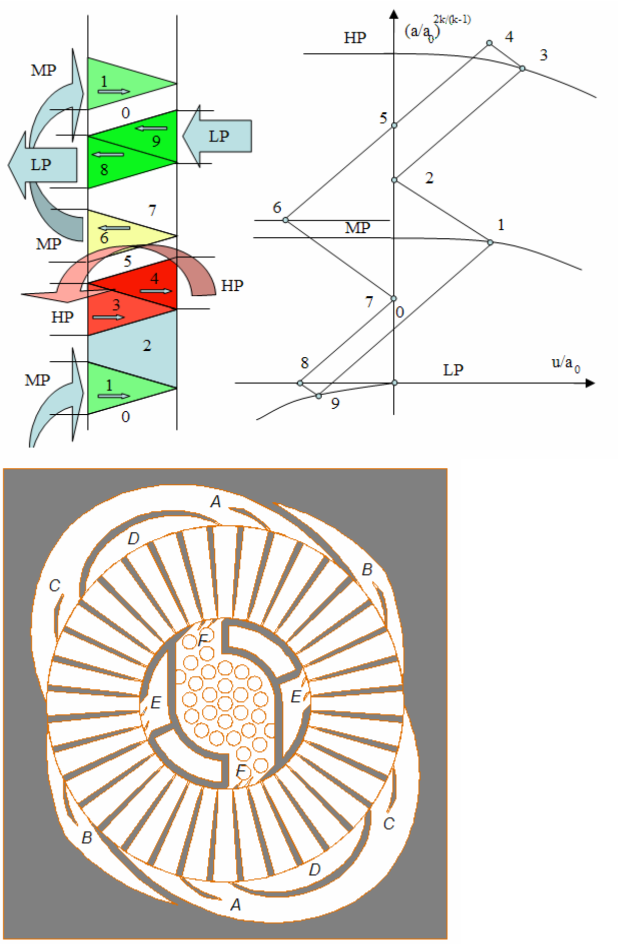

Fig. 3 Two step compression micro-engine wave diagram, corresponding state plane and double set of ports geometry (see Fig. 4).

The electric motor-generator can be imprinted in the case part containing ports and in one of parts forming a wave disk.

In proposed micro-engine construction also two-step gas compression-decompression idea was adopted. In Fig.3 the micro-engine proposed porting scheme, simplified wave diagram and state plane are presented. In the left side of the drawing schematic wave diagram with position of all ports is presented with corresponding state plane on the right side. Flow parameters in areas on the wave diagram separated by waves, compression and expansion, are constant and are described by the corresponding points on the state plane. Numbers in wave diagram areas have equivalents on the state plane.

In proposed solution at the outer side of the wave disk the high pressure gas port (port B), two middle pressure gas ports (inlet (port A) and outlet (port C)) connected by passage, and low pressure gas outflow port (port D) are located. The high pressure air port (port E) and low pressure fresh air port (port F) are located at the inner side of the wave disk. Generally this flow arrangement can be classified as the reversed flow configuration. Proposed flow scheme is different than used by Pearson [5]. The flow scheme was matched to the radial wave rotor geometry used in proposed solution. It was assumed that centrifugal forces can improve the flow during the scavenging and slightly disturb the compression process. During the compression process enough energy exists to overcome negative influence of centrifugal forces. During the end of scavenging process always exists a lack of energy to completely remove exhaust gases from cells. Centrifugal forces act in a way improving the scavenging process in proposed configuration.

The numerical code, written in Fortran on the basis of 1-D Euler equation and proper boundary conditions [7], has been developed and used for simulation of the micro-engine operation. Several simulations have been performed for predefining a proper micro-engine geometry, rotational speed and heat released in combustion chamber for a stable wave engine operation.

3 RESULTS OF NUMERICAL SIMULATION

However, one-step compression simulations were performed, more attention was concentrated on the two-step compression version of the wave-engine. All the presented below results correspond to the case of heat release stream equal 800 W and disc rotational speed equal 176 500 rpm.

Has been found by the simulation that exist a relatively narrow range of parameters in which the engine works stable.

In Fig. 4 pressure distribution inside the wave disk strait cells is presented.

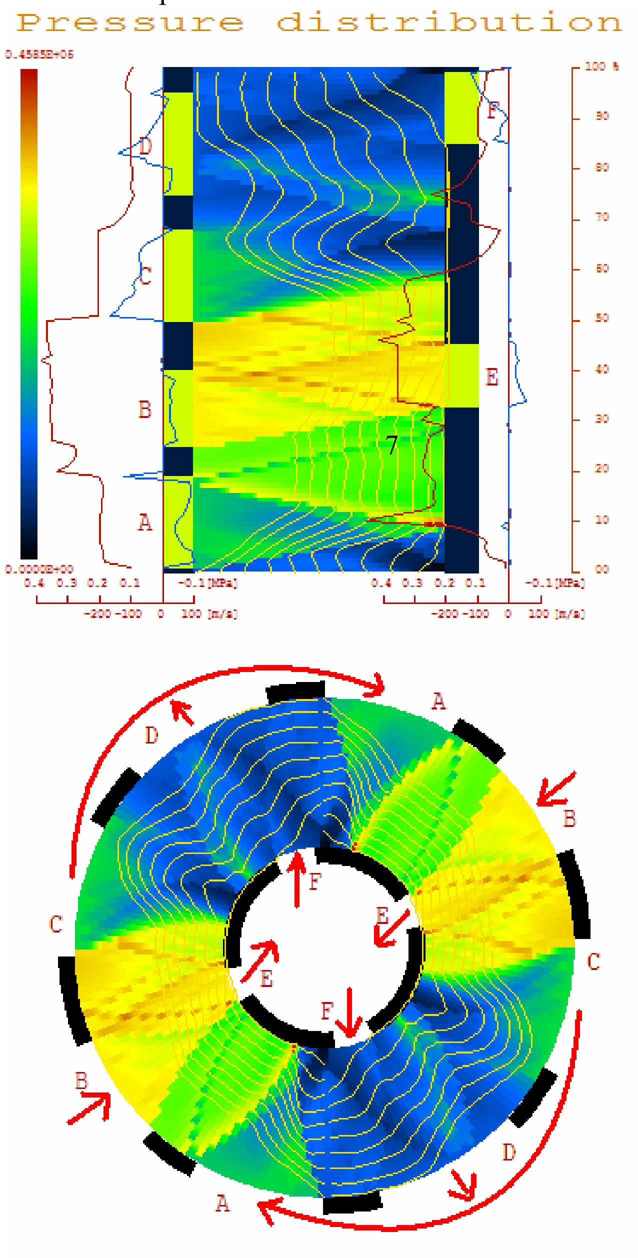

Fig. 4 Pressure distribution inside the wave disc of the two step compression wave engine.

Analysing Fig. 4 a wave propagation can be easily recognised and track. One can notice a lot of reflections and additional waves mainly generated at almost all port edges. Three basic pressure levels expected in considered configuration are clearly visible. As expected, the highest pressure level is observed near the port B (high pressure exhaust gases port) and port E (high pressure compressed air port) representing the second and final compression step. Medium pressure is observed near the port C (partial expansion of exhaust gases port) and near the port A (first step of air compression). From the path line shape the first step of the air compression can be easily identified in vicinity of the port A. Compression process is confirmed by the pressure level on the right closed side of the cell. Also two steps of exhaust gas decompression can be identified.

Many simulations have been performed showing, in analysed port geometry, rather very narrow range of rotational speeds and accepted heat streams. Outside operational regime very oscillatory and unsteady flows have been observed.
Predicted two-step compression micro-engine efficiency is 13-16% in stable operational area. In the case of single compression step wave engine estimated efficiency was about 6%. Presented results show potential strength of proposed micro-engine construction. Actual micro-engine geometry is not optimal and need a strong and wide investigation.

4 CONCLUSIONS

Paper presents the proposition of the micro-engine construction utilizing the unsteady phenomena to reach the higher micro-engine efficiency in comparison with conventional steady state flow machinery. The proposed idea is confirmed by the numerical simulation showing the potential range of operational parameters and predicted engine efficiency. The Pearson's wave engine [5] has had the efficiency about 10% at the operational point. . However used mathematical micro-engine model is not taking into account all physical phenomena (heat transfer from the gas to disk walls is neglected, leakage in the disk case gap is omitted, gradual cell opening process is not taken into account) the numerical simulation results achieved, suggest that the micro-engine of proposed construction can deliver a net power in micro-scale with reasonable efficiency. Presented work concentrated on the unsteady flow phenomena consideration omitting problem of bearing construction, heat transfer problems and construction thermal stresses. It seems that this work can be a good basis for the building more sophisticated 2-D and 3-D models using commercial codes like Fluent.

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