TWO-DIMENSIONAL NUMERICAL ANALYSIS OF THE WAVE JET MICRO-ENGINE OPERATION

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Abstract: This Paper presents results of a numerical, two-dimensional analysis of the wave jet micro-engine operation. A full model of the complicated, looped flow field was built, combining heat addition and unsteady processes in the set of compression-decompression wave rotor channels, and with it the jet engine operation numerically was simulated. Parameters of the flow (pressure, velocities, temperatures) are presented in graphical form. The results of the numerical simulation confirmed the expectation of the engine stable work in some temperature regime. The wave jet micro-engine can work stable reaching the compression ratio about 4.0.

Key Words: Wave engine, unsteady flows, gas dynamics

1. INTRODUCTION

Due to the scale effect, the operation of conventional steady state, micro jet devices that are based on the radial compressor and turbine, are characterized by very low efficiency [1]. Application of unsteady effects seems to be the cure which could increase the efficiency of micro engine devices [4],[6].

The idea of the wave engine has been known for many years [2],[3],[7] but in classical form can not be applied in MEMS technology. In 2003 [4], a new geometry of the wave machine was proposed, based on the radial cell configuration. It was expected that the use of the radial configuration could resolve the problem of the insufficient scavenging that is typical for wave machines in classic axial geometry.

In the analyzed jet engine construction, a radial wave rotor plays the role of the compression – decompression device, and a gas generator delivers hot gases to the jet nozzles (see Fig. 1). The wave disk assures the direct transfer of energy accumulated in the hot gases to jet nozzles. The main compression process is realized in an unsteady way, while decompression is done in two parallel ways. The first one is the steady generation of thrust by the help of two nozzles. The second way of decompression is realized in an unsteady process. The scavenging process, being the main problem of the unsteady devices, is mainly realized due to the action of centrifugal forces generated through rotation of the radial wave disk and partially by the gas inertia. The wave disk directly transfers the energy accumulated in the hot gases to the fresh cold air.

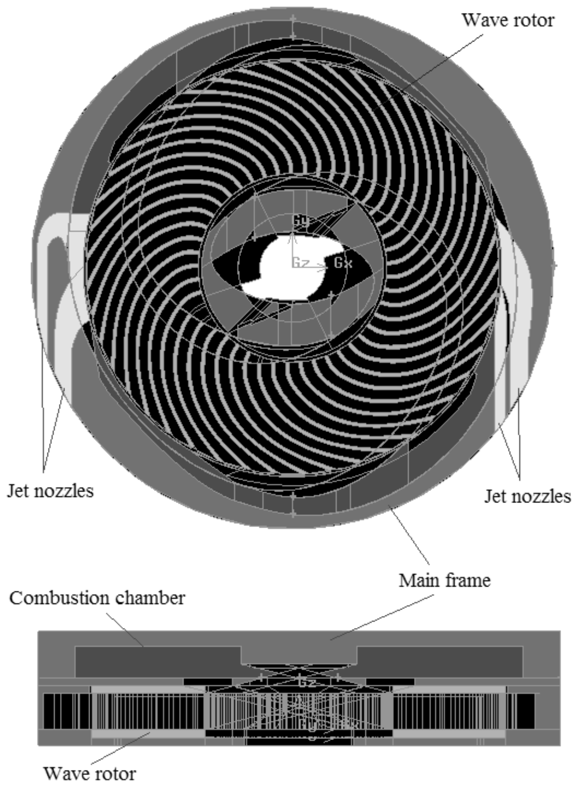

Fig. 1 Basic components of the wave jet micro - engine.

The fresh air is compressed to the combustion chamber pressure by the moving shock waves generated in the disk compression-decompression channels. In the considered jet micro-engine construction, the rotating disk is the only moving part.

Due to the geometry of the jet micro-engine that has the form of the thin disk (Fig.1), an engine body can be located inside the wing profile of the micro plane. The main rotor is self-driven assuring the totally autonomous action of the jet engine.

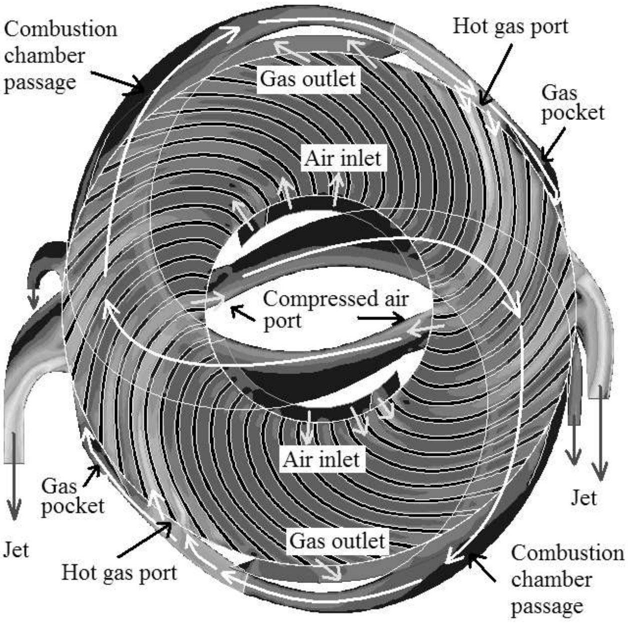

Fig. 2. Flow scheme inside the wave jet engine.

The application of the radial cell configuration in the construction of the wave jet engine enables its fabrication in silicon wafer technology (Fig.1).

The typical thermodynamic process based on the air compression, heating at constant pressure and expansion to ambient conditions, is realized in the proposed wave engine.

The fresh air, aspirated from the ambient, is compressed in the set of radially distributed cells by shock waves that are generated by the expanding hot gas. Compressed air is then delivered to the combustion chamber, heated, and expanded to the rotating cells. During the expansion process, expanding hot gas plays the role of a fast piston that moves in the cell and generates in front of it shock waves. These propagate into the fresh air that fills the cells. To repeat the cycle, the hot expanded gas has to be removed from the cells. By the proper combination of the disk's rotational speed and the position of the fresh air inlet ports and expanded gas outlet ports with the proper phase shift, the initial phase of the scavenging process is realized. The generated unsteady processes that are responsible for the scavenging are of very short duration and therefore the hot gas is not fully extracted from the cells. Due to the disk rotation and radial position of the cells, the centrifugal forces improve the processes of filling the cell with fresh air and of the outflow of the expanded hot gas.

In the proposed technical realization of the wave engine, two sets of ports have been used in order to reduce the rotational speed of the rotor and to realize a symmetric thermal load of the engine case. Additionally the spiral channels located in the rotor have been used to elongate the cell's length and prolong the duration of the wave processes in the cells. The scheme of the flow pattern inside the wave jet engine is presented in Fig. 2. Due to the principle of operation, the compression process takes place in only 10% of the disk plane. Decompression is realized on 10% and scavenging occupies 40% of the disk plane. Due to such distribution of the thermodynamic cycle phases and their durations, a relatively low volume density of energy transfer in comparison to typical radial compressor and turbine can be achieved.

2. NUMERICAL MODEL OF THE WAVE JET MICRO-ENGINE

The present investigation differs from the author's previous works [5],[6]. Up to now only the assumed boundary conditions were used in such configuration. In the recent two-dimensional simulation a direct connection between compressed air port and hot gas port was simulated. Such a model guaranties the total mass conservation.

A two-dimensional model of the flow field is modeled in stator part of the engine and in rotating disk. Most importantly, all flow streams have been combined in a single flow system fulfilling conservation of mass and energy inside the engine channels and passages. Due to that, it was possible to fully simulate the operation of the engine as a closed and autonomous system. Chemical processes taking place in the combustion chamber were not simulated. Instead, a heating process of the air passing through the combustion chamber area was modeled. Such a model corresponds to heating of air by external heat sources.

3. RESULTS OF NUMERICAL SIMULATION

Numerical test of two-dimensional models of the wave jet micro-engine operation with FLUENT, confirmed the basic expectation and showed the potential of the proposed solution. Fig. 3. shows the temporary pressure distribution inside the casing and the rotor. The unsteady compression process is clearly seen in disk channels connecting hot gas port and compressed air port. The corresponding temperature distribution is shown in Fig. 4.

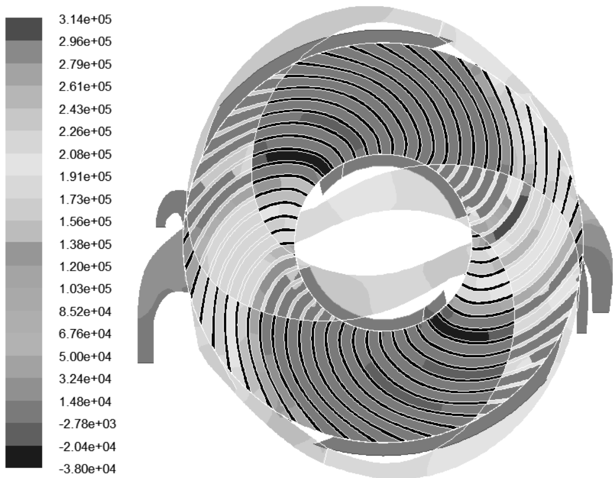

Fig. 3 Temporary pressure distribution inside wave rotor cells and case passages.

The inflow of the hot gas into the set of disk channels in the disk compression area can be seen as well. After the unsteady expansion, the temperature of the hot gas is reduced. The area of the fresh air inlet can be identified by the very low temperature of values close to the ambient temperature.

4. POSSIBLE ENGINE CONSTRUCTION

In Fig. 5, basic elements of the proposed wave engine are presented in the form of an expanded view of the engine.

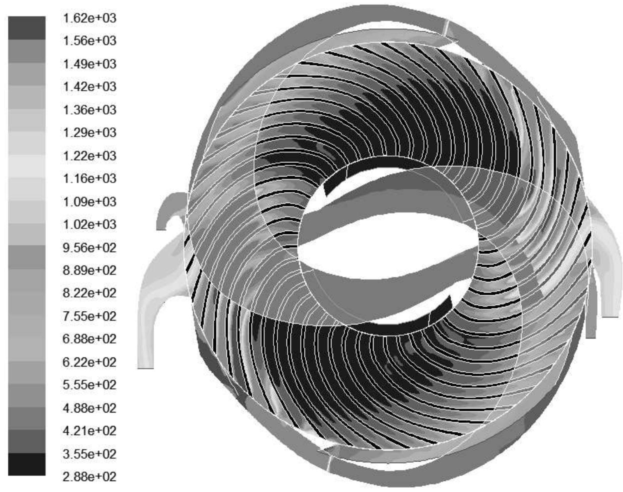

Fig. 4 Temporary temperature distribution inside wave rotor cells and case passages.

The main frame of the engine consisting of the external ring and internal core can be etched as a single part with the bottom case disk. The wave rotor etched in two parts and bonded together is rotating inside the main frame. The disk position is stabilized by the axial and radial air bearings. The main frame with rotor is covered on the top by the combustion chamber etched in two parts. These parts contain passages, mixing space and combustion space.

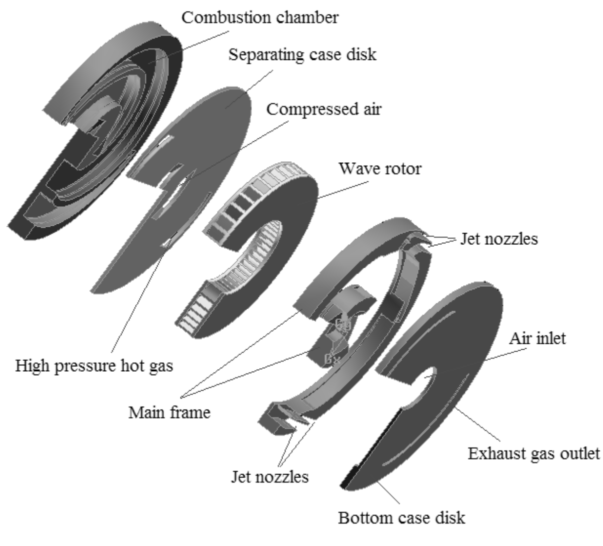

Fig. 5 Exploded view of the engine components

Generally, to start the wave engine, the rotor has to rotate with the proper speed for wave synchronization. The pressure in the combustion chamber should be high enough to generate (after expansion) shock waves in disk channels. Than the heat transfer to the compressed air should be realized by burning fuel or by high temperature heat exchanger. The engine operates at constant rotational speed. The thrust can be controlled in some small range by the variation of the heat stream transferred to the air. For the engine operation, it is important that the heat transfer rate is above a critical value. If it is below, the engine cannot compress the fresh air.

The temperature of the hot gas in the considered wave engine ranges between 1300 K and 2000 K. Such high temperatures have been considered due to the self-cooling feature of the wave disk. Each cell wall was loaded by the high temperature gas for only very short period of time and then immediately cooled by the fresh air. The highest temperatures were recorded in the case passages. Since the high gas temperature in the casing is limited to very small area, special temperature resistant materials may be used only in these places. Reduction of the heat transfer from the combustion chamber can be realized by the back-to-back configuration of two engines as presented in Fig.6.

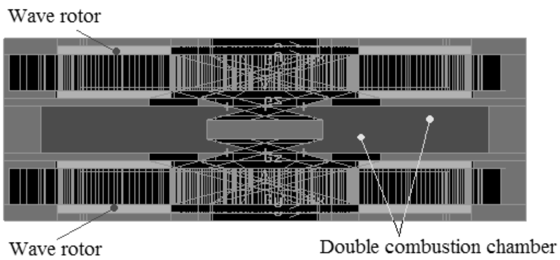

Fig.6 Double engine configuration

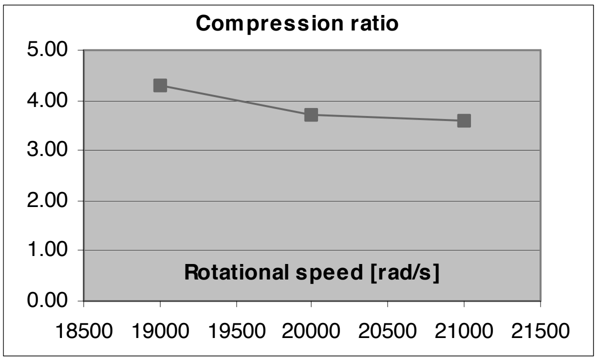

Fig. 7 Engine compression ratio versus disk rotational speed.

4. CONCLUSION

For the first time, the stable operation of the wave jet micro-engine was confirmed through the results of a two-dimensional numerical simulations of the full flow structure inside the engine. Therefore it appears that this engine of uncommon construction can work in a stable mode. For this, it was found that the provided heat rate needs to be strong enough to increase the compressed air temperature to the minimum value of about 1300 K. In the radial disk configuration, a compression ratio of about 4 can be reached, dependent on the provided heat rate and rotational speed (Fig.7). A wave engine of 15 mm diameter and of 3 mm thickness, with estimated weight of 0.6 grams can generate an average thrust of 0.7 grams.

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