NUMERICAL SIMULATION THE PERIODIC OPERATING REGIME OF HRE WITH MHD – CONTROL

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Nowadays both in Russia and abroad active research has been conducted on developing perspective hypersonic aerospace aircraft. The developing of such aircraft would allow to essentially expand aircraft possibilities and to reduce delivery cost of goods to the near-earth orbit.

In many countries of the world there are programs of creation of hypersonic aircraft such as: HOTOL in Great Britain, NASP in USA, HERMES in France.

One of key while conducting these projects is the creation of a hypersonic ramjet engine having necessary propulsive, mass and dimensional characteristics with all altitude range and flight velocities of an aircraft.

The basic difficulties, in development of such engine types are caused by substantial of deterioration of quality of fuel mixture with an oxidant under supersonic flow velocities in the combustion chamber, which results in decrease of an engine efficiency and deterioration of its propulsion.

To increase the efficiency of HRE with the supersonic flow velocity in the combustion chamber the authors offered MHD control of gas flow in the channel HRE based on creation in a stream of local plasma areas with temperature 10^4 K interacting with an external magnetic field [1], [2].

The work presents investigation results for the structure of non-stationary gas-dynamic flow in the channel HRE with MHD – control. It also describes the calculation of propulsion performance characteristics of the given engine on the basis of mathematical simulation of processes, which take place in the channel of an engine.

Thee work objective was the research of non-stationary periodic flow with heat application in the tract HRE with MHD - control on the basis of mathematical modeling of processes which take place in the channel of an engine and the calculation of propulsion performance characteristics of an engine.

In the work the model HRE including the air intake, MHD - channel and nozzle was considered. The MHD - channel is made of two flat electrodes and sidewalls from a dielectric. The local constant flow heat permitting to create periodical local plasma areas (T- layer) is provided with the systems of initiation the constant magnetic field in the volume of the channel is ensured with an external magnetic system.

Let's consider processes taking place in the tract HRE with MHD - generator with T- layer integrated in it (fig.1).

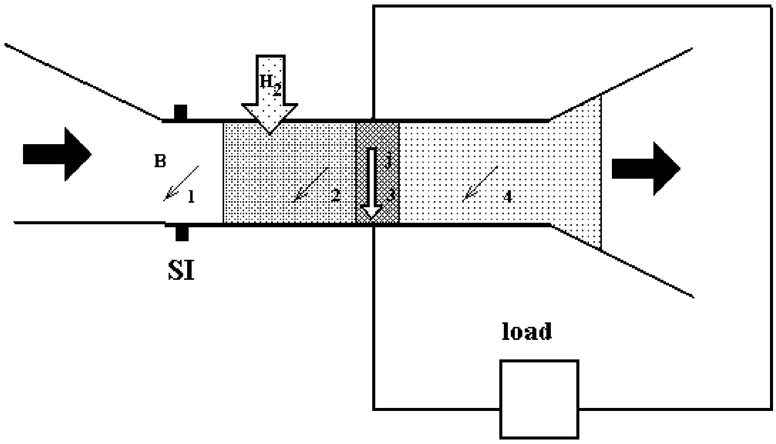

Fig.1. The scheme of HRE with MGD – control.

The filling stream is braked and contracted in the air intake whereupon proceeds to the entry of the combustion chamber, which is structurally combined with MHD - channel. Here the system of initiation by a high-voltage break-down of gas periodically creates high-temperature current layers. T - layer in a flow of gas is the peculiar plasma's piston to which the braking electromagnetic force rebuilding a structure of current in the combustion chamber is applied. The mode of MHD interaction is installed so, that Joule dissipation should compensate power losses on a radiation with the mode of self- sustaining T- layer being installed. At the same time with T - layer being braked under electromagnetic force in the tract of an engine, the non-stationary flow structure consisting of the following zones is formed: 1-non-disturbed flow, 2 - shock compressed gas, 3 - T- layer, 4 - area of a wave of exhaustion.

The area of shock compressed gas is characterized by higher pressure, and the flow velocity here is much lower than that at the input which promotes more effective burning of fuel. Depending on this, it is expected the fuel will be combusted in this area. With T – layer entering the nozzle, the gas temperature in it drops, but at that the acceleration of this mass of gas happens, which allows to increase propulsion performance characteristics of an engine.

The authors used the system of non-stationary equations of hydrodynamics in Ailers coordinates while modeling the processes, which take place in the tract of an engine. The current displacement and induced magnetic fields were not taken into account, owing to their smallness. For the full description of processes in MHDE the set of equations was supplemented by the members describing the interaction of magnetic field and T - layers initiation. The approximation of a volumetric emitter was used in modeling radiation. The magnitude of current flowing in T- layer volume at the time of its interaction with an external magnetic field was determined from the differential law of Om. In the end the supplemented set of equations is as follows:

$$\begin{cases} \dfrac{\partial \rho F}{\partial x} + \dfrac{\partial \rho \upsilon F}{\partial x} = 0 \\ \dfrac{\partial \rho \upsilon F}{\partial x} + \dfrac{\partial \rho \upsilon^2 F}{\partial x} + \dfrac{\partial p F}{\partial x} = jBF + \dfrac{\partial F}{\partial x} \\ \dfrac{\partial \rho F\left(e + \dfrac{\upsilon^2}{2}\right)}{\partial x} + \dfrac{\partial \rho \upsilon F\left(e + \dfrac{\upsilon^2}{2}\right)}{\partial x} + \dfrac{\partial p \upsilon F}{\partial x} = \left(jE + q_{in} + q_f + q_r\right)F \\ j = \sigma E \\ E = (1-k)\upsilon B \\ p = \rho R T \\ E = c_v T \end{cases}$$

where j - current density, F(x)) cuts of the channel, t- time, E - electric field strength, e - internal energy, q_{in} - potency of heat output at the time of initiation, q_R - radiation energy losses, q_f - specific heat of combustion of fuel, σ - electroconductivity, T - temperature, p - pressure, ρ - density.

For a numerical solution of the system the obvious method of MacCormack of the second exactitude order [3] was used. Boundary conditions at the in to MHD - channel were the parameters of a flow at the exit from the air intake for the given flight number of Mach. The boundary condition of the exit from the nozzle corresponded to free departure, it mines the equality of derivatives to zero was set. The entry condition is the supersonic undisturbed flow of gas.

Due to areas with large gradients of parameters in the flow such as T- layers and shock waves for averaging oscillations and increase of the fidelity of calculations the method of the correction of streams FCT [4] was used.

Values of conductivity and emissitivity factors were calculated with the help of software package MONSTR and were entered into the program in tabular form.

In the course of numerical experiment the evolution of originally created perturbation was investigated, and the conditions of T- layer formation under given initial stream were determined.

The non-stationary process begins at the moment of initiation of the first T- layer, which is simulated by the representation of a power of thermal flux as sinusoidal impulse with duration of 10^{-4} seconds at the entrance in the channel. The powers of thermal flux such that for these time the temperature in a local area of a stream achieves 10^4 K, which is accompanied by recompression. At the same time the conducting gas begins to interact with a magnetic field at the same time the conducting gas begins to interact with a magnetic field, at the same time the wave of compression gas up the stream while the wave of under pressure gas down (Fig. 2).

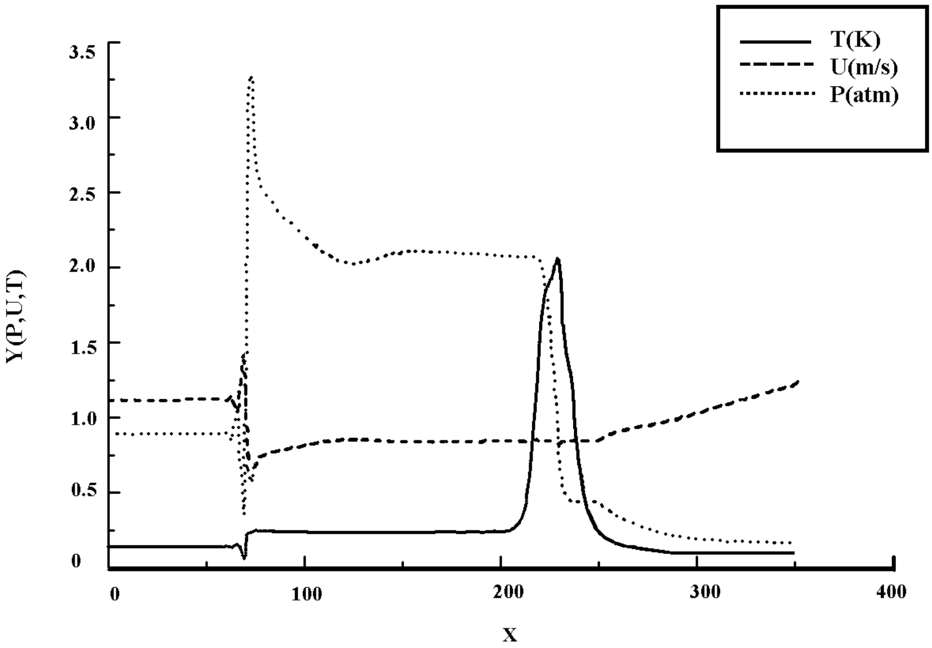

Fig.2. Distribution of temperature (scale 10^4 K), pressure (scale 10^5 Pa) and velocity (scale of 10^4 m/s) in the tract at the moment t = $0.8*10^{-3}$ s. K = 0.8.

At the expense of an induced magnetic field current starts flowing, compensates radiation losses of power and provides a mode of self-sustaining. The firing of fuel is simulated by the heat evolution in area of shock compressed gas.

To the moment of 10^{-3}seconds T- layer is formed in the stabilized structure, i.a., its parameters remain constant up to an exit in to the nozzle part. When T – layer enters the nozzle, gas temperature drops, which results in electroconductivity loss and T – layer disintegration. It courses the acceleration of gas mass behind T – layer permitting to increase specific characteristics of an engine.

While simulating the periodic operating regime of an engine it is impotent to choose an optimal frequency value for T – layer initialization. The frequency of initialization is to meet following conditions: it is necessary for the shock-compressed gas following from T - layer have time go out from the combustion chamber as, if reinitiated T – layer overtakes the wave of compression in combustion chamber then the pressure differential at the T – layer disappears, velocity and thermal flux drop which results in finishing MHD- interaction. In too time, the periodic power setting should be effective, that the interaction.

value of required significance's of specific characteristics of an engine should be reached.

As a result of numerical experiments values of T- layers initialization period and parameters of MHD - interaction have been determined depending on initial stream parameters. Figure 4 shows the dependence of engine specific impulse on Mach flight number.

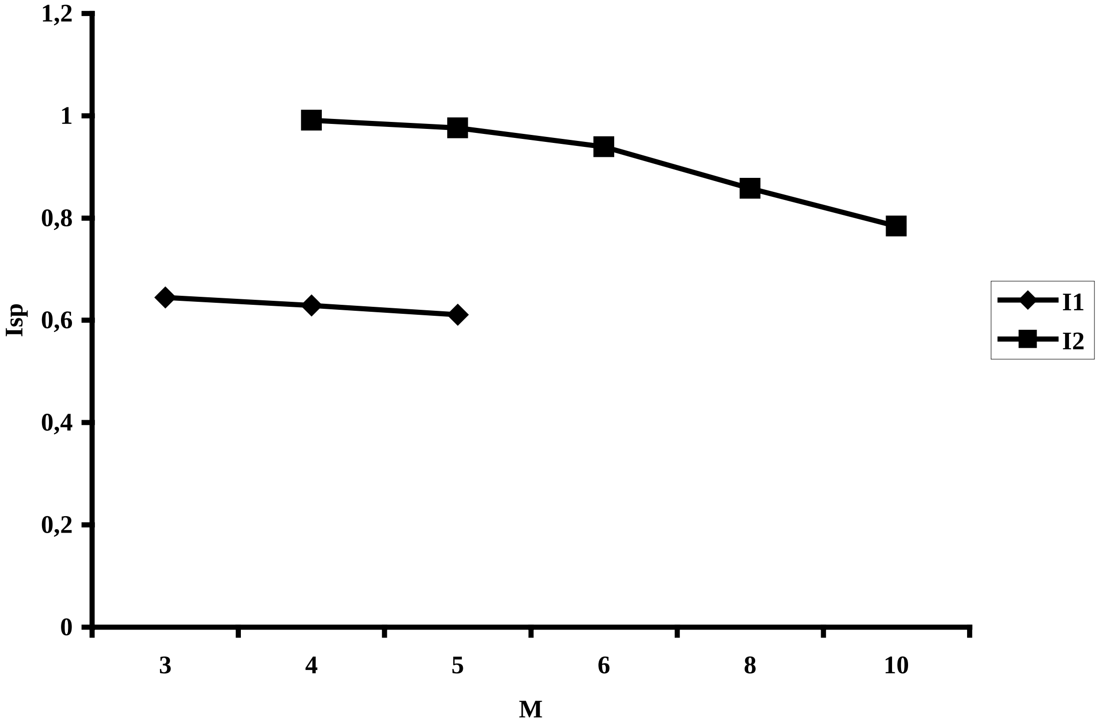

Fig.4. I1 is specific propulsive impulse for ramjet, I2 is specific propulsive impulse for HRE with MGD - control. $\Delta t = 5.5*10^{-3}$c.

At the same time best values of period of initialization T- layer for data's of initial parameters of a stream of gas are indicated.

The conducted research of gas dynamics of current has shown, that the considered model HRE with MHD - control allows considerably to improve propulsion performance characteristics of an engine with Mach flight numbers 4-10 in comparison with traditional schemes of a ramjet.

Literature

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