69. EXPERIMENTAL STUDY OF ENERGETIC PERFORMANCES OF ADVANCED SOLID PLASMA-GENERATING PROPELLANTS FOR PULSED MHD GENERATORS

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Abstract. Results of experimental study of advanced solid plasma-generating propellants of double-based (BP-15C) and composite (CPP) types in the pulsed self-exciting MHD power system "Pamir-1" are presented. The power generated by Faraday MHD channel was obtained of 10.15MW to 10.83MW for the BP-15C propellant, and of 11.31MW to 14.64MW for the composite propellant application. Thus, an increase of the output power of the MHD generator by 10-60% was obtained only by application of the novel plasma-generating propellants without modification of main components of the MHD power system (MHD channel and magnet system). An application of these propellants for the pulsed MHD power systems will provide an increase of their power performances and efficiency for solving different problems of science and engineering.

Introduction

The self-contained, self-exciting pulsed MHD power systems should provide the high level of power density, which depends on the power complex $\sigma u^2$. In addition, the maximal energetic performances (electric power, current, and voltage) of the solid-propellant pulsed MHD generators of "Pamir" type are obtained in the flow mode with strong MHD interaction (St $\sim$ 0.2) \[1\]. These modes are accompanied by an occurrence of perturbations of the supersonic flow at the outlet of the conversion area of the MHD channel. These perturbations move upstream under further increase of magnetic field that results in stabilization of electric current, voltage, and power. An alternative of the process noted from the point of view of raising the power generated is the pressure increase in the plasma generator at the moment of the crisis occurrence of the supersonic flow.

The study presented is purposed to assist the development of new compositions of the plasma-generating propellants providing increased power parameters of the MHD generator. The double-based propellant BP-15C \[2\] differs from the standard plasma-generating propellant BP-10F by increased content of ionized seed CsNO$_3$ (15%), that provides a growth of electrical conductivity $\sigma$ of combustion products at the inlet of MHD channel up to 100S/m (for BP-10F propellant $\sigma$=80S/m). The composite propellant is based on the advanced oxidizer KDNA (potassium salt of dinitramide) \[3\] providing the raised temperature in combustor (4100K) and increased electrical conductivity of combustion products at the inlet of MHD channel up to 140S/m. These advanced propellants were test-fired in the plasma generators GP-81 and GP-83L having the combustor pressure increase during operation.

Pulsed MHD power system "Pamir-1"

The experimental MHD facility consists of the following components:

- Plasma generator (GP-77, GP-81, or GP-83L);
- Standard Faraday type MHD channel IM-112-5 \[1\] with volume of conversion zone of 0.033m$^3$ and Mach number of 2.4 at the inlet of this zone;
- Air-core magnet system consisting of four standard sections IM-114-1 \[1\] with total inductance $L_m=9$mH, resistance $R_M=10.2$mOhm and the magnet constant $\alpha=0.105$T/kA; the magnet system in the series of firings discussed was used simultaneously as a load of the MHD channel;
- Initial excitation system consisting of capacitor bank of capacity $C=0.2$F;
- Commutating, protective, and control devices;
- Multi-purpose test bench equipment;
- Control, measurement, and recording system.

The electrical circuit diagram of the experimental MHD facility is given in Fig.1.

The study of the advanced double-based propellant BP-15C was performed with application of the plasma generator GP-81. The plasma generator case design and shape of the propellant grain provide a growth of the combustor pressure from 3.0 to 5.0MPa. The standard plasma generator GP-77 for geophysical MHD power systems of "Pamir" type with a charge of the solid plasma-generating propellant BP-10F provides the constant
pressure in the combustor on a level of 4.0–4.5MPa and mass flow rate of combustion products of about 25kg/s. In the firing testing of the composite propellant the special-designed plasma generator GP-83L was used with a growth of the combustor pressure during operation from 4.0 to 6.0MPa. Typical curves of the pressure for the three types of the plasma-generating propellants are shown in Fig.2.

To exclude an influence of declining of performances of the MHD channels and plasma generators after multi-run operation only new MHD channels IM-112-5 and cases of the plasma generators.

The experiments for all three types of the propellants were performed with application of the same timing diagram. The pre-charged capacitor bank is discharged to the magnet about 1.5 s after ignition of the plasma generator creating an initial magnetic field of about 1 T for starting the self-excitation process. The typical variations of the electric power, current, and voltage generated by Faraday MHD channel versus operation duration for the propellants above mentioned are shown in Figs. 3, 4, 5, relatively.

Fig.1. Electrical circuit diagram of the experimental MHD facility. $R_C$—resistance of the capacitor bank; $R_B=11\,\text{mOhm}$—ballast resistance; $I_C, I_B, I_M$—currents of the capacitor bank, MHD channel, and magnet, relatively; $V_C$—the capacitor bank voltage; $B_1, B_2$—diode units; $K_1, K_2, K_3$—commutating switches.

Fig. 3
As shown in Fig.3, the maximal level of the power of 13.0MW is obtained faster in the firing of composite propellant, then 10.1MWe in the firing of BP-15C double-based propellant, and 9.3MW in the firing of BP-10F double-based propellant. After occurrence and development of the crisis of the supersonic flow the power generated by MHD channel dropped significantly (approximately by 33%). After that the power generated is at the quasi-stable level in the firings of propellants BP-10F and BP-15C, whereas in the firings of the composite propellant the power rises to the end of the plasma generator operation approximately by 46% in spite of the flow crisis.

Main output parameters obtained by application of the plasma-generating propellant BP-15C and composite propellant CPP, as well as standard propellant BP-10F are given in the table below.
Parameters of MHD generator "Pamir-1"

<table>
<thead>
<tr>
<th>Plasma-generating propellant</th>
<th>BP-10F</th>
<th>BP-15C</th>
<th>CPP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustor pressure, MPa</td>
<td>4.6</td>
<td>5.1–6.0</td>
<td>5.7–6.5</td>
</tr>
<tr>
<td>Electric current of Faraday MHD channel, kA</td>
<td>24.1</td>
<td>31.3–32.2</td>
<td>27.12–33.0</td>
</tr>
<tr>
<td>Voltage of Faraday MHD channel, V</td>
<td>384.4</td>
<td>324.2–342.8</td>
<td>342.8–539.9</td>
</tr>
<tr>
<td>Maximal power of MHD generator, MW</td>
<td>9.3</td>
<td>10.15–10.83</td>
<td>11.31–14.64</td>
</tr>
</tbody>
</table>

Thus, only by application of advanced plasma-generating propellant without modification of another main components of the MHD generator (MHD channel and magnet system) an increase of the maximal output power of the pulsed MHD generator by 10 – 60% was obtained.

Conclusion

1. The advanced plasma-generating propellants BP-15C of double-based type and CPP of composite type were successfully tested in the series of firings of the pulsed MHD power system "Pamir-1".
2. The power generated by MHD facility fired by BP-15C propellant varied from 10.15 to 10.83 MW, and from 11.31 to 14.64 MW when the facility was fired by composite propellant that exceeds the maximal power obtained with standard propellant BP-10F by 10 – 60%.
3. An application of the advanced composite and double-based propellants will provide the growth of their power performances and efficiency for solving the problems of science and engineering.

References