A hydrogen plasmator of 1 MW power

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A plasmator design is analyzed for producing hydrogen plasma at a mean-mass temperature above 4000 K with a rather high efficiency.

Plasmators operating on hydrogen can be classified into those for industrial, electric rocket propulsion, and plasma research applications. From the practical viewpoint, of considerable interest would be industrial plasmators operating at a mean-mass temperature of $T_{m,m} = 4000-4500$ K and a pressure of 1-5 atm abs for about 300 h. Such devices are desirable for use in plasma chemistry applications. Meanwhile there are available industrial hydrogen plasmators of various designs.

The three-phase plasmator [1] with wearing carbon electrodes 70 mm in diameter was used for producing acetylene. Its basic parameters, along with those of other plasmators, are listed in Table 1.

For heating methane, the plasmator in [2] was used with face-type copper electrodes and magnetic arc stabilization. The feasibility of operating this device on pure hydrogen has not been proved experimentally.

The arc of the plasmator in [3], with a lanthanum-plated tungsten cathode pressed flush into an externally cooled copper housing and with a tubular copper anode (10 or 20 mm in diameter, 100 or 200 mm long), was gas stabilized. The results of 12 min tests at an arc current $I_a = 900$ A, erosion rates $G = 3.4 \times 10^{-7}$ g/C for the copper anode and $\bar{G} = 6.2 \times 10^{-8}$ g/C for the tungsten cathode are presented.

A plasmator with bilateral gas discharge was studied in [4]. This one had copper electrodes protected by graphite retainers. Arc stabilization was achieved by means of two metallic diaphragms (8 mm in diameter) and a whirled gas stream.

For heating hydrogen, a plasmator was developed in [5] with a lanthanum-plated tungsten rod cathode (10 mm in diameter, 70 mm long) and a copper anode (30, 40, or 50 mm in diameter). A magnetic field of up to 1 kG was produced by a solenoid. At an arc current $I_a = 400$ A the cathode eroded at a rate $\bar{G} = 3 \times 10^{-7}$ g/C. Increasing the anode diameter from 30 to 50 mm raised the plasmator voltage at $I_a = 600$ A from 280 to 420 V. Increasing the external magnetic field from 0.4 to 1.0 kG reduced the efficiency from 70 to 40%.

Of all designs considered here for the achievement of a high-power hydrogen plasmator, most promising is the one with a long tungsten thermocathode, a copper anode, and a whirled arc.

In this study the authors have tested a plasmator of such a design with a copper capability of 1 MW.

### TABLE 1. Parameters of Hydrogen Plasmators

<table>
<thead>
<tr>
<th>Arc current, A</th>
<th>Arc voltage, V</th>
<th>Plasmator power, kW</th>
<th>Gasflow rate, g/sec</th>
<th>Pressure, atm</th>
<th>Mean mass gas temperature, $10^3$ K</th>
<th>Arc stabilization</th>
<th>Thermal efficiency</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>250-900</td>
<td>2.5-3.5 \times 10^6</td>
<td>16-19</td>
<td>1</td>
<td>3-4</td>
<td>Gas</td>
<td>-</td>
<td>0.8</td>
<td>[4]</td>
</tr>
<tr>
<td>200-700</td>
<td>2.3 \times 10^6</td>
<td>100 (CH₄)</td>
<td>0.3-1.5</td>
<td>3-4</td>
<td>Gas</td>
<td>-</td>
<td>0.6-0.8</td>
<td>[3]</td>
</tr>
<tr>
<td>300-800</td>
<td>~350</td>
<td>0.5-1.5</td>
<td>5-15</td>
<td>3-4</td>
<td>Gas</td>
<td>-</td>
<td>0.8-0.8</td>
<td>[5]</td>
</tr>
<tr>
<td>400-1400</td>
<td>~1.10^3</td>
<td>3-62.9-5.5</td>
<td>Magnetic</td>
<td>0.4-0.8</td>
<td>Magnetic</td>
<td>This study</td>
<td>0.8-0.88</td>
<td></td>
</tr>
</tbody>
</table>


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Structurally, the plasmatron consists of a cathode, an electrically insulated intermediate segment, and an anode (Fig. 1). The thermocathode 22 (grade VL-10 lanthanum-plated tungsten, 10 mm in diameter and 70-80 mm long) was soldered into a copper bushing 11 and fastened into a steel housing 17. The position of the thermocathode relative to the anode can be smoothly adjusted by means of a threaded coupling between the housing 17 and the collar 14.

The electrically insulated intermediate segment includes a housing 15, a tail spindle 13, a flange fitting for gas supply 12, and spacers. These cooled spacers are made up of a steel body 5, 6 and an interchangeable copper sleeve 4 by means of which the duct section for the gas flow can be varied. By changing the number of spacers, it is possible to vary the length of the thermocathode 22.

The anode consists of a steel housing 2 and a copper sleeve 1 with an inside diameter 38 mm and a 5 mm thickness. The cooling gap is 2 mm wide. A cooler was connected to the anode, and a supercritical nozzle behind for maintaining the excess pressure in the chamber and for measuring the gas flow rate.

For shifting the arcing spot on the anode, a solenoid 3 has been wound around the latter with a magnetic field as shown in Fig. 2.

All plasmatron components are held together, through an electrically insulating seal 7, by means of three pins 8 also electrically insulated from the rest by Textolite sleeves 9.

The plasmatron is water-cooled, the cathode and the intermediate spacers cooled sequentially.

An arc discharge between the center thermocathode and the anode is initiated by means of a fuse wire. The anode and the solenoid are supplied from separate direct-current sources [6].

During the experiment we measured the flow rate and the temperature rise of the water, the gas flow rate, the solenoid current, and the plasmatron voltage and current. The mean-mass gas temperature was determined from the heat balance.

The plasmatron was tested over the following range of parameter values: arc current $I_a = 0.4$ to $1.4$ kA, hydrogen flow rate $G = 5$ to $15$ g/sec, solenoid current $I_s = 20$ to $30$ A, pressure in the discharge chamber $P = 3$ to $6$ atm·abs.

The plasmatron performance parameters are shown in Fig. 3 as functions of the arc current. For comparison, the volt·ampere characteristic of the plasmatron in [5] ($d = 40$ mm, $P = 1$ atm·abs, $G = 1.5$