

PHENOMENOLOGY OF PLASMA ENGINE CATHODES
AT HIGH CURRENT RATES AND LOW PRESSURES

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16. Abstract The effects of low surrounding pressures on cathodes of arc jet engines with electromagnetic acceleration are investigated for pressure and current energies of 20 to 100 Torr. and 400 to 1000 A. Experiments with 50 mm long and 8 mm diameter tungsten-thorium cathode in a coaxial gas flow show that pre-heating of the cathode reduces the duration of the instable arc discharge and thus material loss. The use of lighter gases also reduces instability effects, as well as the use of increased pressures and a massive gas influx.			
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PHENOMENOLOGY OF PLASMA ENGINE CATHODES AT HIGH CURRENT
RATES AND LOW PRESSURES

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1. Introduction

In arc jet engines with electromagnetic acceleration, the ambient pressure of the cathode is kept within a range of 40-100 Torr for engineering reasons. Various observations made it possible to speculate that, on account of this low pressure, a functional cathode mode could be expected, which differs from the well-known normal or high pressure modes. Since no data exist for the pressure and flow range of 20-100 Torr, or 400-1000 A, a thorough experimental investigation of the cathode phenomena appeared to be of great interest.

2. Experimental Setup

The principle of the experimental arrangement is illustrated in Figure 1. A cathode of 50 mm length and 8 mm diameter, made of thoriated tungsten, is coaxially exposed to the flow of the working gas. A water-cooled copper ring serves as anode; when operating with nitrogen or hydrogen, this must be replaced by three tungsten rods.

The whole apparatus is located in a vacuum tank which is fitted out with two windows opposite each other. Through one of these the pyrometric measurement of the temperature sequence takes place, /159 while simultaneously the physical appearance of the cathode projection is photographed through the other.

* Numbers in margin indicate foreign pagination.

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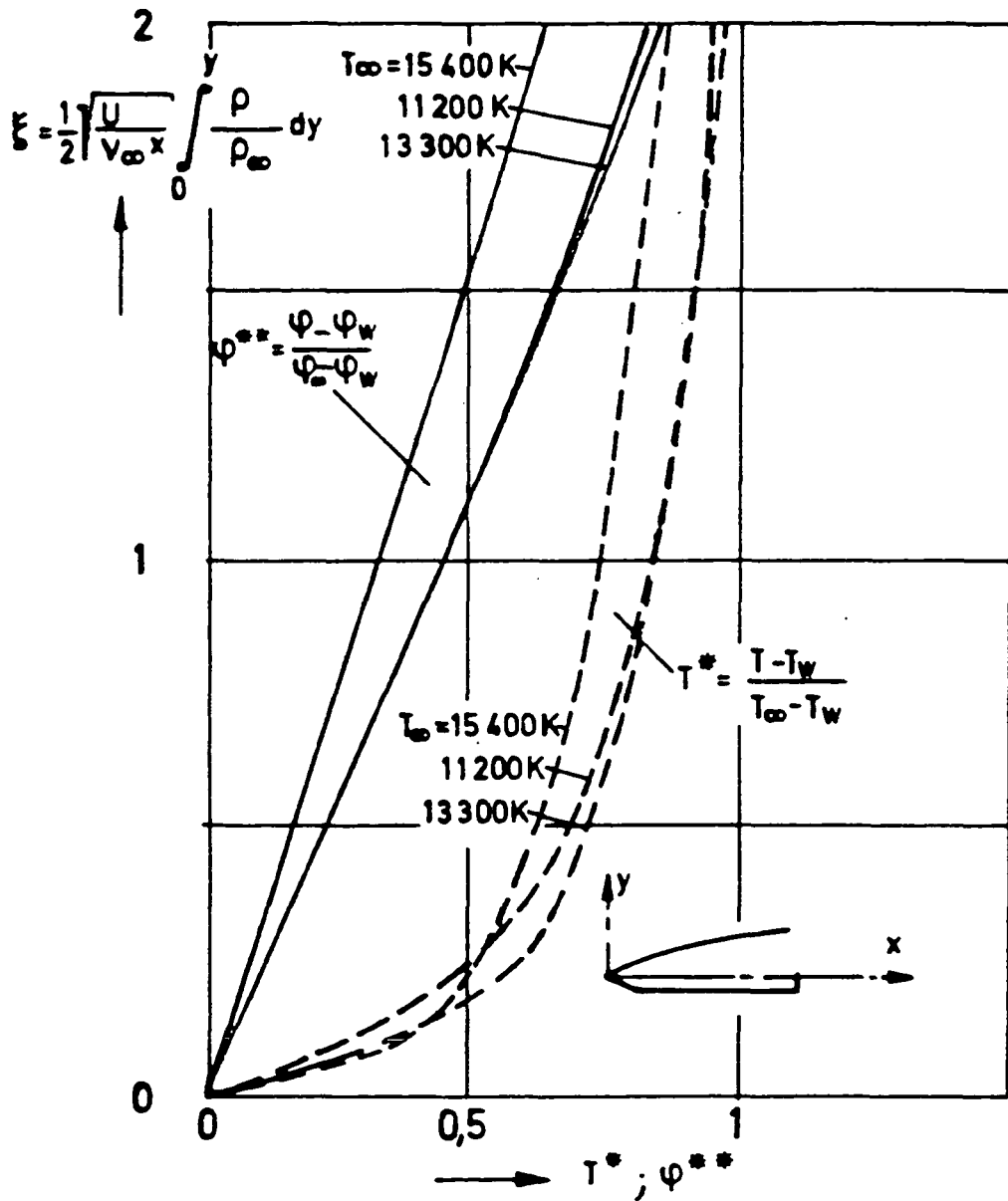


Figure 6*. Flat plate exposed to longitudinal flow.

* NOTE: There are two Figure 6's in this MS.

3. Experimental Investigations and Findings

3.1. Intermittent Processes after Activation of the Arc

Intermittent processes occurring during the first phase of the arc discharge are studied using Fastax photos (up to 5500 frames/sec).

Several moving arc focal points appear in which in the cathode projection the melting point of the cathode material can be attained. This leads to violent localized melting (cathode scintillation). As a result of the bombardment of the surface in the contracted arcs, the cathode temperature increases. When it attains a certain value, there occurs a changeover into an arc shape with a completely stable projection.

By appropriate preheating of the cathode, the duration of the unstable arc discharge can be considerably reduced and the loss material diminished.

3.2. Stable Cathode Projection

The influences of the type of gas, current strength, ambient pressure and mass flow on the physical appearance of the stable arc projection, as well as on the temperature sequence of the cathode were all thoroughly researched.

3.2.1. Type of gas

As Figure 2 shows, the form of the cathode projection is very strongly shaped by the type of gas. While in the case of the noble gases it appears diffuse and large in area, with molecular gases /160 it is more sharply demarcated, in which the projection extends only along the ball-shaped tip of the cathode. These characteristic

phenomena are further stressed in Figure 3 where the development of the corresponding (black) cathode temperatures is reproduced. Each of the lighter types of gases lead to lower temperatures.

3.2.2. Current strength

The influence of current strength and of the other two parameters is treated using measurements in argon. With helium, nitrogen and hydrogen the same effects appear but are not so strongly expressed.

Figure 4 makes it possible to distinguish the influence of the current strength on the cathode temperature. With increasing flow, the maximum temperature increases and propagates in the direction of the cooled end; thus the cathode is hotter overall. The corresponding photos show an increase in the surface area of the projection.

3.2.3. Pressure

Increasing pressure causes a minor reduction in the cathode temperature (Figure 5) and the cathode projection becomes smaller.

3.2.4. Mass flow

The cooling influence of the mass flow can be clearly seen in Figure 6. Cathode temperature increases considerably with decreasing gas throughput. The associated photos show a growth in the projection surface with increasing mass flow.

4. Final Remarks

The average flow densities arising on arc engine cathodes (see Figure 7) and the corresponding temperatures can be well controlled.

Physically considered, the cathode projections studied seem to /161 be in a transitional form from a thermal to a focused-type arc.

Comparison of the experimental findings with theoretical ones seems hardly possible since the existing cathode models do not embrace all the participating influences.

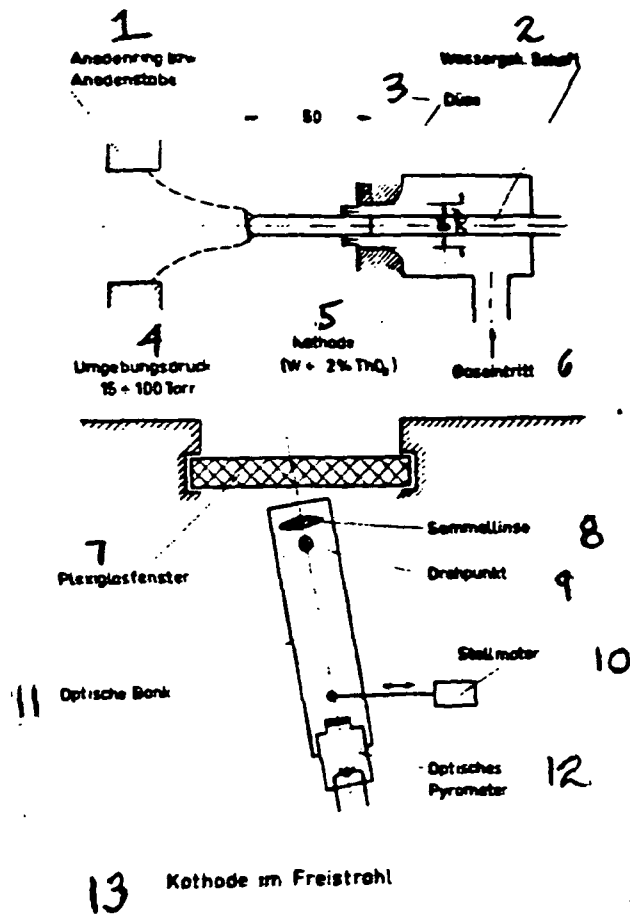


Figure 1. Sketch of principle of the test setup. Using the servomotor the optical bench is swung so that a portion of the cathode about 30 mm longer can be detected by the pyrometer.

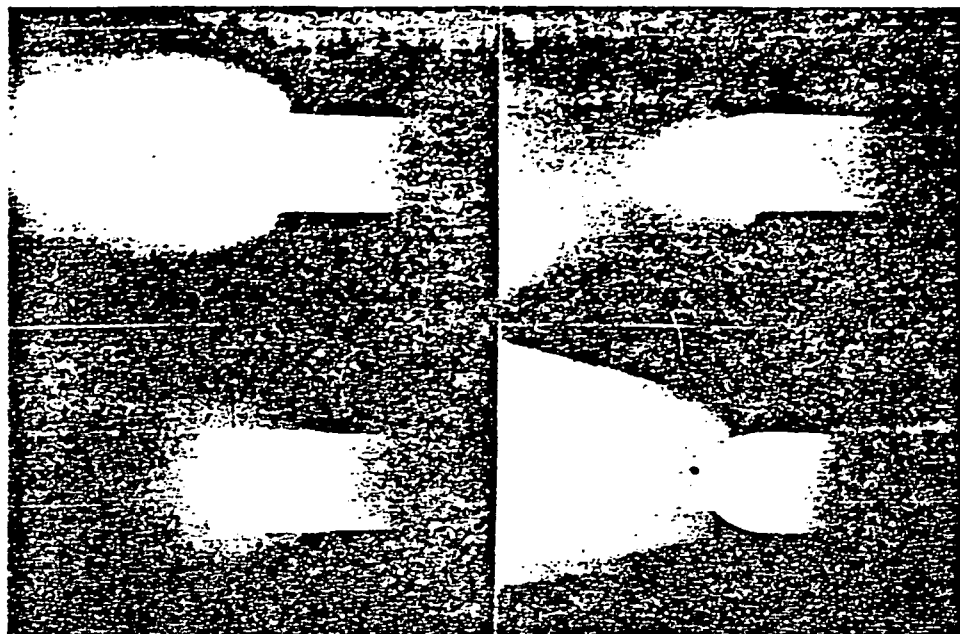
FIGURE 1

- 1-- anode ring or rod
- 2-- water-cooled stem
- 3-- nozzle
- 4-- ambient pressure
- 5-- cathode
- 6-- gas inlet
- 7-- plexiglass window
- 8-- convergent lens
- 9-- axis of rotation
- 10-- servomotor
- 11-- optical bench
- 12-- optical pyrometer
- 13-- cathode in free-jet operation

Ar

N₂

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He

400 A 20mm Hg H₂

Figure 2. Photos of the cathode projection in argon, helium, nitrogen and hydrogen at 400 A and 20 Torr.

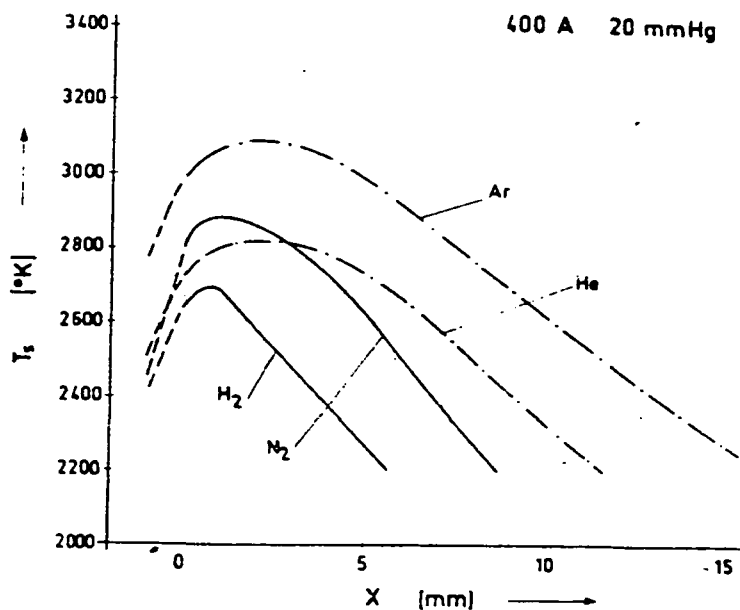


Figure 3. Temperature sequence of the cathode associated with Figure 2. Black temperatures are plotted as a function of the distance from the cathode tip.

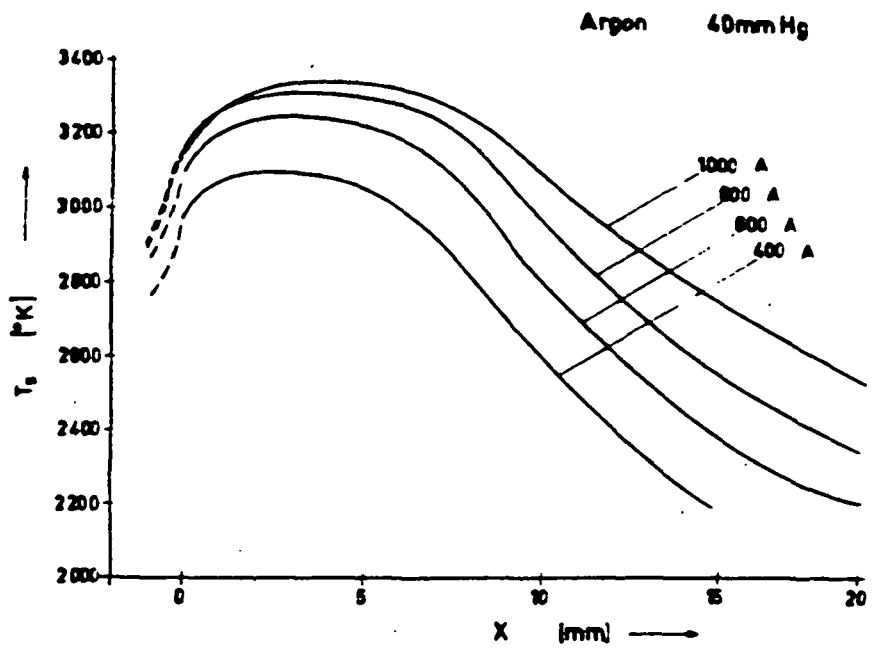


Figure 4. Influence of current strength on the temperature course at an ambient pressure of 40 Torr.

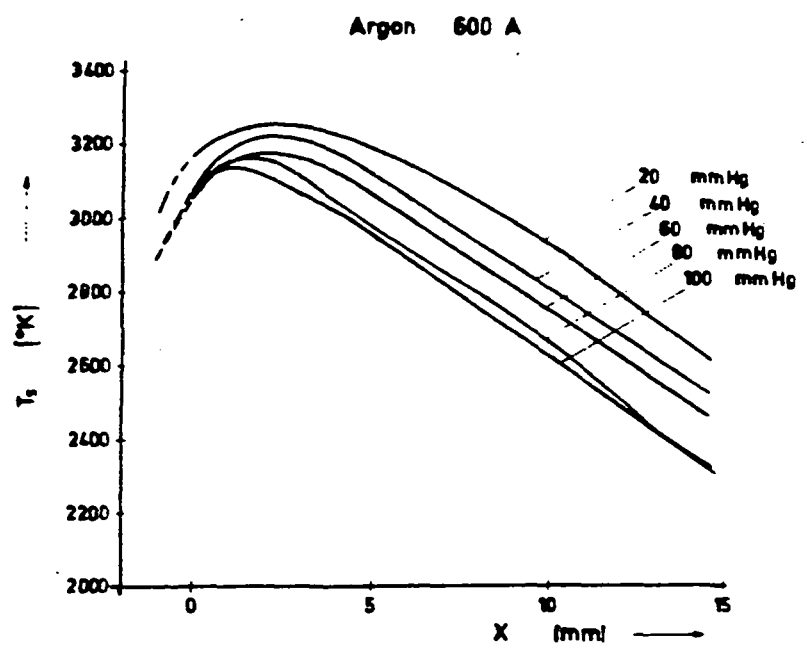


Figure 5. Cathode temperatures as a function of ambient pressure at constant flow and mass throughput.