

Feb. 21, 1967

J. W. POOLE

3,304,774

ELECTRIC ARC TORCH

Filed July 27, 1964

2 Sheets-Sheet 1

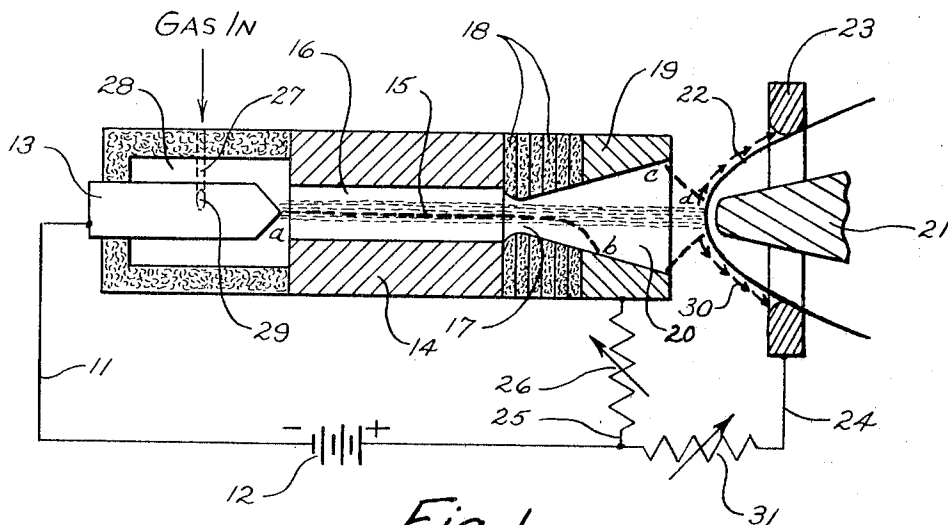


Fig. 1

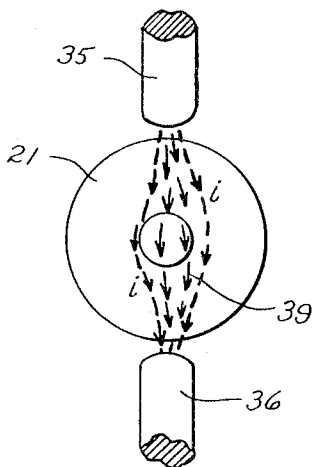


Fig. 2b

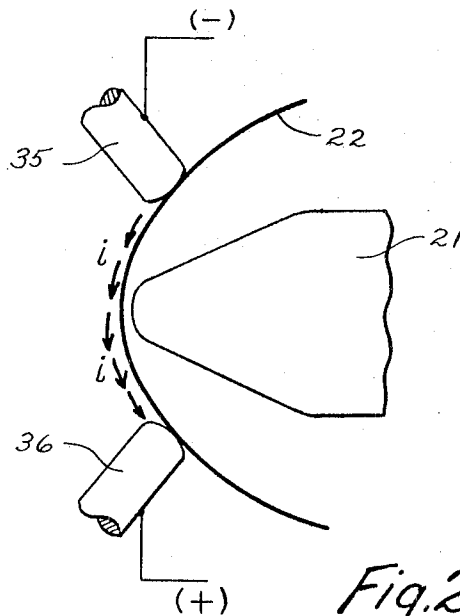


Fig. 2a

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2 Sheets-Sheet 2

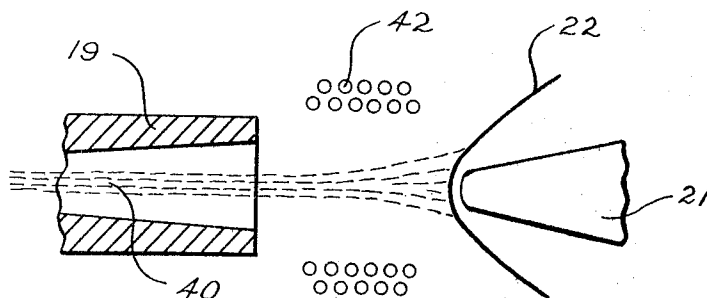


Fig. 3

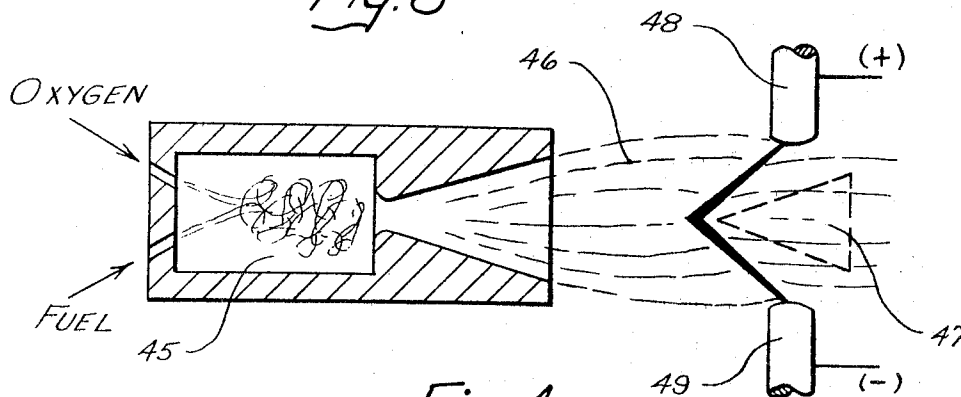


Fig. 4

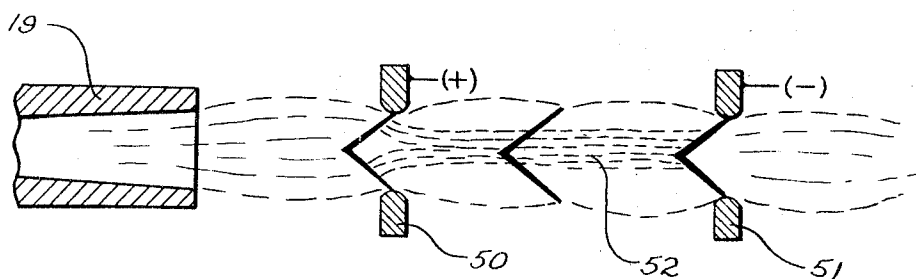


Fig. 5

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ELECTRIC ARC TORCH

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2 Claims. (Cl. 73-147)

My invention relates to high temperature technology and relates more particularly to electric arc torches, plasma flame generators and other devices used to create gaseous jet flows at supersonic speeds.

In the testing of materials and the evaluation of models designed to withstand high velocities in the atmosphere, and in the simulation of space vehicle reentry conditions, it is now the practice to subject such materials and models to high velocity gases in the plasma state. Test specimens are positioned in chambers capable of being evacuated and a variety of conditions can thus be simulated.

In typical reentry studies, a limiting factor is the amount of energy (in terms of temperature and particle velocity) that can be invested in the jet flow which impinges on the test model. In accordance with my invention, novel use of the resulting shock waves permits the attainment of higher energy levels and a more accurate simulation of space and sub-space conditions. Higher power levels are also desired in order to make possible tests on larger models, thereby partially avoiding the risks inherent in the scaling up of data on theoretical bases.

For a more complete understanding of my invention, reference is now made to the following description and accompanying drawings, in which

FIGURE 1 is a longitudinal view, in cross section, of an embodiment of the invention in use to simulate reentry of space vehicles into the atmosphere;

FIGURES 2(a) and 2(b) are end and side views of an alternate means for carrying out the invention;

FIGURE 3 illustrates magnetic means for controlling the arc streams;

FIGURE 4 is a schematic view of a conventional combustion type gas stream generator to which the principles of the invention are applied; and

FIGURE 5 is a further modification of a device to exploit the principles of the invention using multiple electrodes.

Turning now more particularly to FIGURE 1, a plasma generator is shown, having a lead 11 which supplies electric current to an electrode 13 from a suitable power supply 12. Axially aligned with electrode 13 is a nozzle member 14 which defines an arc passageway 16. The member 14 may be electrically neutral, while an anode 19 provides a nozzle exit with a throat at 17 and an expanding region at 20. The anode 19 is electrically separated from the remainder of the plasma generator by insulating members 18. The electrical return to the power supply 12 is established through alternate paths provided by variable resistors 26 and 31 and leads 24 and 25.

A chamber 28 surrounds the electrode 13 and into this chamber plasma forming gas is introduced tangentially through an orifice 29. A strong gas vortex is thus formed, which passes through passageway 16 and becomes a high-velocity, high temperature effluent impinging on a test model 21, representing, for example, the nose cone of a space vehicle. The gas vortex serves also to stabilize an arc column 15 established to run from point (a) to point (b) in the initial stages of operation. At this stage, resistor 26 is set at a low value and resistor 31 is set at a relatively high value. The arc column 15 heats the stabilizing gas, as is now well understood in this art; and the effluent, which may comprise

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gas atoms, ions, electrons, and dissociated atoms, emerges from the plasma generator.

The high velocity stream resulting from the operation of the plasma generator as described impinges on the model 21 and an intense shock wave 22 is created. This shock, as it will hereinafter be referred to, may be described as a thin surface of revolution about the axis of the jet stream. The shock 22 is a region of high ionic density produced by the obstruction to uniform flow because of the presence of the model 21.

I have found that this shock region defines a virtual electrode which can serve as an arc terminus. Accordingly I provide a ring electrode 23 which is coupled to the arc circuit through the medium of the shock 22.

After the shock is well established, resistor 26 is increased in value, (or alternatively lead 25 is opened) and resistor 31 is dropped in value (or alternatively shorted out). The arc column may then constitute a double arc, *ab* and *cd*, or a single arc column may extend directly from the electrode 13 to the apex of the shock 22. The arc electrons then flow in the shock to the electrode 23.

The arc column may be non-transferred and remain wholly within the plasma generator (as arc *ab*). In this mode of operation I provide alternative means to invest additional energy in the system by the arrangement shown in FIGURES 2(a) and 2(b). Here I provide two electrodes, 35 and 36, which may be in the form of conducting rods adjusted to contact the shock surface. By applying an electrical potential to these electrodes, a current *i* flows as shown. The highly ionized shock region affords an effective conducting path, and the current density may assume the pattern shown in FIGURE 2(b). The current *i* preferably derives from a separate or isolated power supply, and serves to further heat the effluent stream passing through the region before striking the model 21.

It may be desirable to produce a more diffuse current pattern than that shown in FIGURE 2(b). This can readily be accomplished in a variety of ways. For example, three electrodes may be placed 120 degrees apart, replacing electrodes 35 and 36. Three phase power may then be applied to produce a pattern covering a substantially higher proportion of the area directly ahead of the model 21. Alternatively, a field coil 42 can be added to establish a magnetic field which interacts with the arc column. The arc column 40 (FIGURE 3) is thus conically expanded such that the arc current is uniformly distributed over the region ahead of the model 21. This latter alternative is applicable where the plasma generator is operated in the transferred mode, with the shock 22 acting as a virtual electrode and arc terminus.

The arrangement just described is equally applicable to cases where the initial generation of hot gases is achieved with oxygen and a suitable fuel. This is shown schematically in FIGURE 4. The supersonic jet 46 produced from a combustion chamber 45 forms a shock as shown. Electrodes 48 and 49 are placed to produce, with the ionized shock, a circuit to a power supply, not shown. Thus additional energy is supplied to increase the enthalpy of the jet.

In some experimental situations, the plasma stream effluent is of sufficient ionic density to support an auxiliary enthalpy boosting current before a shock wave is formed. The arrangement of FIGURE 5 exploits this phenomenon. Here, supplementary electrodes 50 and 51, each in the form of an annulus, are connected to a suitable power supply. The plasma stream 52 establishes a complete electron circuit, and the I^2R energy dissipated between the electrodes is imparted to and adds further to the total jet energy.

When the shock is used as a virtual electrode in accordance with the principles discussed above, distinct advantages are realized. In addition to increasing the radiant energy of the shock, further gas heating is achieved. Thus gas flows are produced at much higher temperatures than heretofore possible. It should be emphasized that the energy so supplied to the shock is added at the precise location best representing an actual reentry condition. An equivalent amount of energy, if added "upstream" in the plasma torch itself, may press the limitations already being experienced in torch design. Furthermore, high energy states in plasma formation often lead to undesirable chemical transformations in the gas. For example, when using air, significant amounts of the oxides of nitrogen and even ozone may be formed. The formation of these compounds is made possible if the dwell time in the plasma generator is relatively long—a condition which occurs when long arc ducts associated with high power levels must be used. Heat added at the shock, on the contrary, permits the attainment of higher energy levels, without the attendant distortion of the actual reentry condition it is desired to simulate.

Although the invention has been described in the context of devices for reentry studies, it should be appreciated that the principle of the virtual electrode may have wide application in the field of high temperature technology and I intend to include in the concepts of my invention devices within the spirit and scope of the following claims.

I claim:

1. The method of operating a plasma forming electric arc torch with an arc terminus external to said torch comprising establishing an electric arc in said torch; stabilizing said arc with a gas to create a heated and at least partially ionized gaseous effluent; impinging said effluent upon an object to create a shock wave; transferring said arc to said shock wave, and employing said shock wave as a conductor to complete the electrical circuit for said arc.

2. The method of testing a model by subjecting it to high velocity plasma arc stream particles comprising directing said stream at said model to create a shock wave, and connecting a plurality of points in said wave to a source of electrical energy, whereby additional energy is invested in said stream after particles thereof impinge on said model.

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