N71-35402
NASA TM X-67931

NASA TECHNICAL MEMORANDUM

NASA TM X-67931

FLOW CHARACTERISTICS IN THE EXHAUST OF A PULSED MEGAWATT GAS FED ARC

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TECHNICAL PAPER proposed for presentation at
Twenty-fourth Annual Gaseous Electronics Conference and
Third Arc Symposium sponsored by the American Physical Society
Gainesville, Florida, October 5-8, 1971

E-6599

FLOW CHARACTERISTICS IN THE EXHAUST OF A PULSED MEGAWATT GAS FED ARC

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ABSTRACT

The transient flow generated by a pulsed, megawatt-level, gas-fed arc with an applied magnetic nozzle has been examined with a new design piezoelectric pressure transducer. Sensor thermal conduction and accelerations have been examined and eliminated in the 500 μsec period of plasma flow. Existence of a large magnitude cold gas pressure front of 20 μsec duration has been reconfirmed and its relationship to the following plasma flow of about 200 μsec duration has been examined for the first time. At a point 30 cm from the arc source, initially near vacuum conditions (typically with an arc current of 11.2 kA and 1 tesla applied magnetic field), a pressure pulse of unionized gas with a magnitude of 10^4 N/m^2 is followed by plasma flows with nearly constant impact pressure of 10^3 N/m^2. Pressure and number density in this plasma region are seen to decrease with applied magnetic field strength. With electron density derived from Thomson scattering measurements (10^{20} m^{-3}) plasma flow velocities on the order of 5×10^4 m/sec are calculated.

INTRODUCTION

The mechanisms involved in megawatt level current conduction in gases, the acceleration of plasma, and the identification of dominant energy transfer mechanisms are not well understood. Earlier works have described the dynamic terminal characteristics of a pulsed, high-power gas fed arc system (ref. 1), and the initial examination of the exhaust flow field characteristics (ref. 2) with Thomson scattering laser diagnosis. A more comprehensive review of the arc/flow problem was presented at a Lewis Research Center conference (ref. 3). More recently, an attempt at defining plasma exhaust flow properties with a momentum sensitive pressure transducer resulted in a description of the early temporal behavior of the discharge which is dominated by a pressure pulse of large amplitude (ref. 4). From reference 4 the sequence of events at a given station in the exhaust for a single shot megawatt-level arc source is:

(a) Exhaust light arrives.

(b) After a few microseconds, a narrow (20 microseconds wide) total pressure pulse of neutral gas passes.

(c) Arc current sheet (plume) arrives tens of microseconds later, and at the same time that plasma is first detected.

(d) A flowing plasma is noted.

Details of the exhaust flow after the passage of the narrow neutral gas pulse (item (b) above) were not measurable because of instrument limitations after about a 50 μsec period. The present work is an extension of the effort described in reference 4 and is aimed at diagnosing the exhaust flow for times comparable to the duration of arc power (~500 μsec). A new probe incorporating a built-in accelerometer and having higher sensitivity was developed (ref. 5) for this research.

In order to deduce other properties of the exhaust, the plasma pressure data of this report is combined with the number density data of reference 6.

In this paper, the results of transient pressure measurements in the exhaust for the time period of the power cycle (~500 μsec) are presented. The time varying pressure at one point in the exhaust is discussed and the earlier data on front behavior is related to the following quasi-steady plasma flow. Attention is focused on exhaust measurements both with and without an applied diverging axial magnetic field.

APPARATUS

Capacitor Bank

The arc was energized by a 10 kilojoule capacitor bank. Details of the capacitor bank are described in reference 2. After the bank switch was closed, arc current was allowed to develop to its peak value. Then (21 μsec after bank firing time) a crowbar switch was closed, forcing current to decay monotonically with time. The L/R decay time ranged from 250 to 350 microseconds depending on arc resistance. This allowed an almost linear decay of arc current for 500 microseconds after crowbarring time. It is during this time that the data was gathered. Typical voltage-current waveshapes for the two-peak current cases investigated (11.2 and 20.0 kA) are shown in figure 1 for the three values of auxiliary magnetic field (0, 1, and 2 T).

Arc Chamber System

A cross-sectional view of the arc chamber is shown in figure 2. A superconducting magnet is used to supply an auxiliary magnetic field at the arc chamber which can be varied from 0 to 2.0 T. An iron filings map of the magnetic field is also shown. The cathode is a tungsten ribbon measuring 1 cm wide, 2 cm long, and 1 mm thick. The anode is a 4.2 cm inside diameter copper ring.

Nitrogen gas was introduced into the arc chamber by a high speed gas valve that was operated by an electromagnetic actuator. All tests were run at a nitrogen flow rate of 7 g/sec. The transient, cold flow, gas pressure in the arc chamber was measured by a commercially available piezoelectric pressure transducer in a previous experiment. That pressure and the orifice equations for steady flow were used to calculate the mass flow rate for all the tests of this report. From the transient pressure records it was found that stable flow occurred after 650 microseconds. The arc was started at that time. Thereafter, the transient plasma flows for a few hundred microseconds into the evacuated glassware section.

A sequence controller actuates gas puff injection, delay for gas distribution, bank switch closure, crowbar switch closure, and then data gathering "start" times. The system can be recycled every four minutes.

Instrumentation

Piezoelectric pressure probe. - Basic considerations relating to the measurement of pressure in a plasma have been previously reported (refs. 7 and 4). A new probing unit was specifically developed (ref. 5) for this research. The geometry of piezoelectric sensing element was designed for the magnitude and duration of the pressure signals anticipated and used a matched sensing unit as a built-in simultaneous accelerometer. Two probing units with 0.75 and 1.25 cm diam sensing surfaces and 2.0, 2.5 cm o.d., respectively, were constructed. Calibration was carried out with a simple shock tube. In both cases, with 6 ft of coaxial cable, an output of 4 volts per atmosphere was achieved; with a pair of matched amplifiers (x10), an output of 40 volts per atm resulted. In order to more precisely define trends in the pressure data, an electronic low-pass filter (Spectrum Analog Electronic Filter Type H-18) was at times used for the 0.3-inch probing unit as it demonstrated an active, well-defined higher frequency stress oscillation after impact of the pressure front. Corrections were made for the slight delay of the filter (~10 μsec).

A rigid mounting of the probe support fitting and subsequent comparison of simultaneous records from the pressure sensing and built-in accelerometer units revealed pressure signals an order of magnitude higher than those due to accelerations. However, extraneous signals due to thermal effects and probe heating proved to be substantial. Experimental evaluation indicated that radiant energy flux from both the source and local plasma radiation produced insignificant effects. However, thermal conduction to the probe from the plasma proved to be substantial. A single layer of vinyl electrical insulating tape (Scotch Brand No. 22, 3M Mfg. Co.) covering the sides and sensing surface of the probe eliminated the thermal drift without degrading pressure sensitivity or linearity of response.

Arc voltage and arc current. - Transient arc voltage was measured with a commercially available resistive-divider probe, and amplifiers. The signal was sent to an oscilloscope in a nearby screen room. Dual-voltage probes were used; one on the cathode and one on the anode, and their signals were electrically subtracted by a difference amplifier and recorded. The dual-probe technique electrically subtracts the unwanted common-mode signal portion from the "read" voltage signal.

Source current was measured by a precision dynamic current transformer, conditioned, and recorded on the other channel of the oscilloscope.

Thomson scattering diagnostics. - The technique of determining number density and electron temperature from 90° Thomson scattering of a probing light pulse from a Q-spoiled ruby laser was employed. It is described in earlier work (ref. 2).

RESULTS AND DISCUSSION

Cold Flow Total Pressure

The 0.3-inch diameter piezo-pressure probe was used to measure "cold" gas flow in the duct. The propellant was injected without starting the arc. At the data gathering times and station used in this report, the cold gas propellant total pressure (fig. 3) is an order of magnitude less than the measured pressures for the powered case. Specifically, at arc initiation time the total pressure on axis at a distance downstream from the anode face of 30 cm is 6.0 N/m^2 (see ref. 3). Supplementary measurements indicate static pressures are approximately one-tenth of the total cold gas pressure.

Typical Total Pressure Traces

Figure 4 shows typical 2-trace overlays of the total pressure signals for two different peak arc current cases, 11.2 and 20.0 kA. Two-trace overlays were used to illustrate the degree of repeatability. For both cases, the pressure probe signals all show one common feature, the total pressure appears as an initial large amplitude pulse (10^4 N/m^2, 20 μsec wide) with lower and varying pressure (10^3 N/m^2) thereafter for about 200 μsec. The two-trace overlays are shown for three auxiliary magnetic field cases (0, 1.0, and 2.0 T). A ringing frequency with a period of 12.5 μsec is noted in all the pressure traces of figure 4. This oscillation is an unwanted crystal oscillation that has not been completely filtered from the probe signal. The pressure history was obtained by fairing curves through these oscillations in the traces. For instance, at $t = 225$ μsec for the $B = 0$ case, the plasma total pressure is about 3000 N/m^2 for 11.2 kA peak current, and 6000 N/m^2 for the corresponding 20 kA peak current case. These averaged values were used in the following section to determine a flow velocity for each case.

Flow effects. - The pressure history at a given axial and radial position in the exhaust flow of a gas fed arc as presented above adds several new pieces of information to present understanding. With both acceleration and thermal effects accounted for in the probe used, the phenomenon of the initial high pressure pulse is reconfirmed. The behavior of the pulse is initially that of a blast wave. A detailed consideration of this flow region is receiving further attention and will not be discussed further here. Previous efforts (refs. 4, 2) have identified luminosity within this region but only weak ionization, which agrees with a blast wave interpretation. After the initial pulse, the varying pressure noted is plasma related as described in reference 6. The average number density during the plasma period is approximately constant and on the order of 10^{20} particles per cubic meter. The occurrence of local current flow in the exhaust field has been identified by Rogovski loops (ref. 4). The onset of substantial currents occurs approximately 50 μsec after the initial pulse passage.

With no applied magnetic field, and using the data presented in figure 4 with the assumption of full ionization and Newtonian impact theory, particle velocities of 3.7×10^4 m/sec for the 11.2 kA peak current case and 5.7×10^4 m/sec for the 20 kA peak current case are calculated at this axial station ($Z = 30$ cm). With applied magnetic field increased to 1 and 2 tesla, the number density from Thomson scattering was seen in reference 2 to decrease almost an order of magnitude. Correspondingly, the impact pressure is also seen to decrease, but only by factors of about 2.0. Thus, the applied field appears to produce a more rarefied yet higher velocity plasma flow.

REFERENCES

1. C. J. Michels, AIAA J. 9, 173 (1971).

2. C. J. Michels and D. R. Sigman, AIAA J. 9, 1144 (1971).

3. Anon., NASA SP-226 (1970), pp. 21-22.

4. C. J. Michels and T. M. York, AIAA Paper 71-196 (1971).

5. T. M. York, Pennsylvania State Univ. Report Aersp. 71-3 (1971).

6. C. J. Michels, J. R. Rose, and D. R. Sigman, to be presented at the AIAA Tenth Aerospace Sciences Meeting (1972).

7. T. M. York, Rev. Sci. Instr. 41, 519 (1970).

E-6599

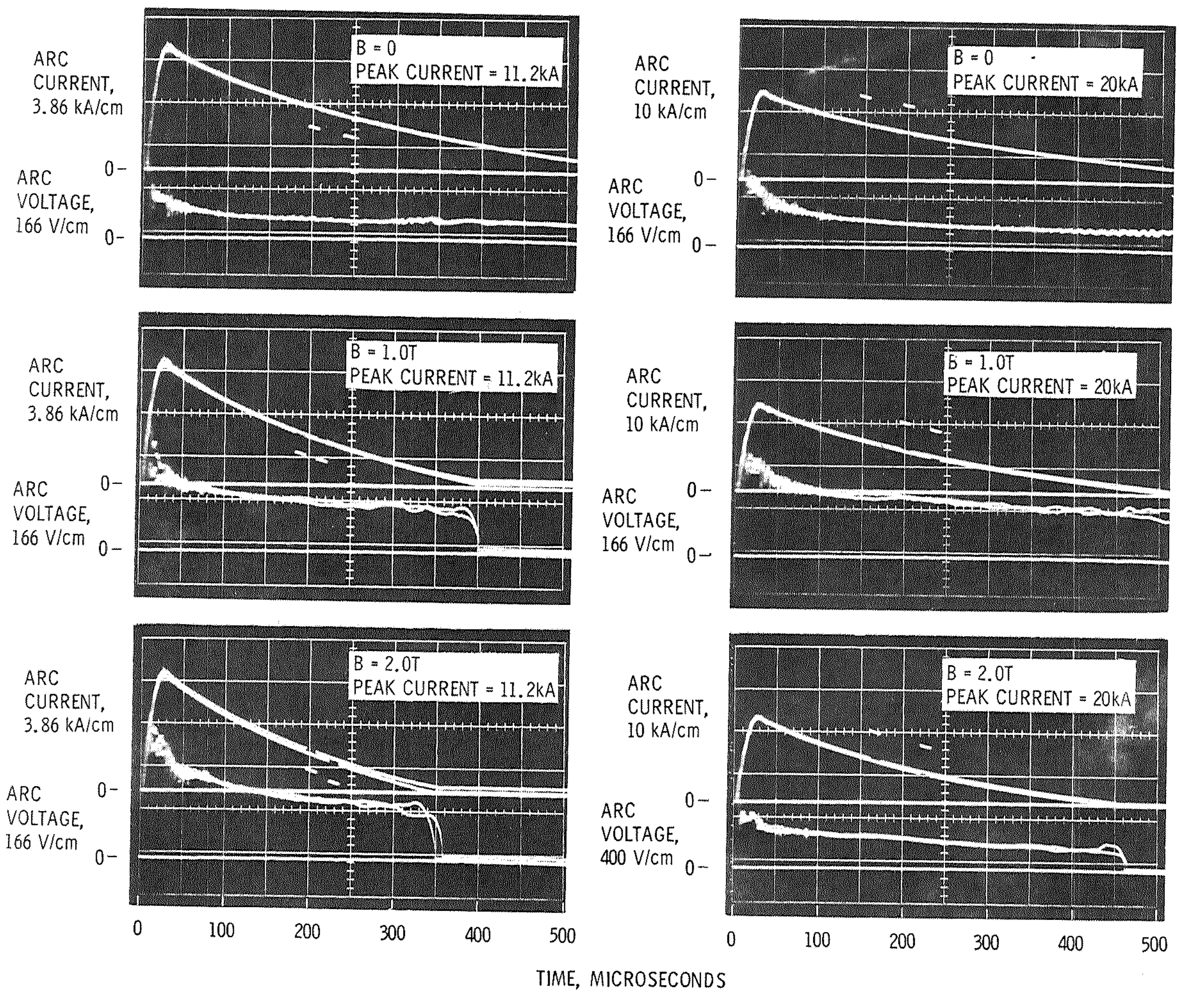

Figure 1. - Current-voltage traces (2-trace overlays).

E-6599

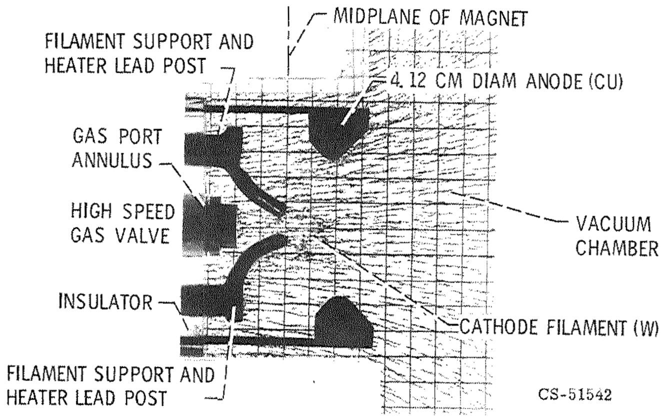

Figure 2. - Arc chamber.

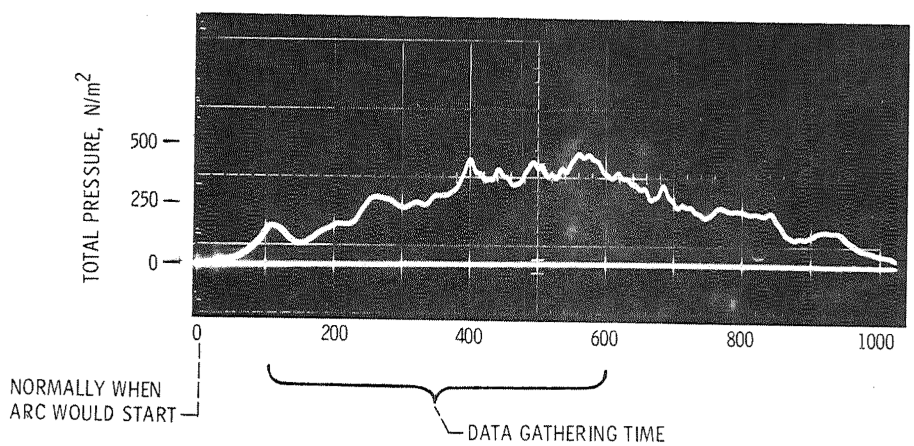

Figure 3. - Cold gas pressure (R = 0, z = 30 cm).

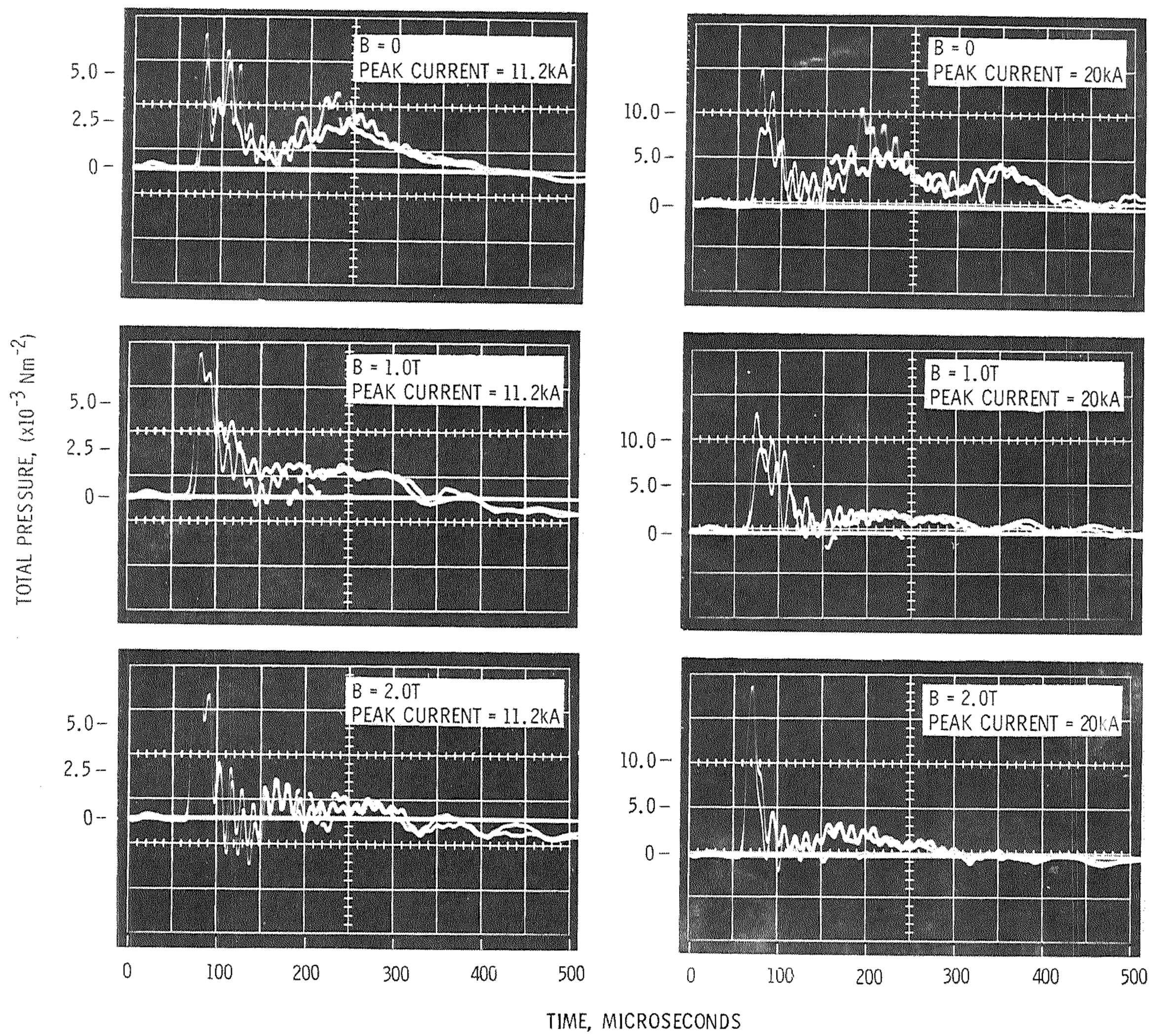

Figure 4. - Total pressure traces (2-trace overlays).