A 12 Mw, 200 atm Arc Heater for Re-Entry Testing

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Theme

THE goal of this work was to develop a 200 atm arc heater capable of high stagnation enthalpies. Performance chacteristics and ground test capabilities of a 12 Mw, continuous-flow arc air heater are presented. A new state-of-the-art stagnation pressure (P_0) of 210 atm was achieved with a stagnation enthalpy (h_0) of 2100 Btu/lb. Model impact pressures to 175 atm and heating rates to 19,000 Btu/ft^2 sec were measured in a Mach 1.7 test stream. Data analyses revealed inherent energy conversion limitations resulting from arc radiation and shunting. Preliminary results of tests on high-pressure, fixed-length arc devices using single and multiple isolated inter-electrode inserts are presented.

Contents

The MDC-200, a high voltage 12 Mw d.c. continuous flow arc air heater, was designed specifically for peak performance at high stagnation pressure levels. During operation, a high-voltage arc is maintained between the electrodes which are separated by a central chamber and main insulator. The arc heater is operated with the front electrode positive or negative using auxiliary magnetic field coils for arc positioning. Cold air is injected into the heater in either a clockwise or counterclockwise tangential direction. The resulting vortex serves to stabilize the arc along the centerline of the electrodes.

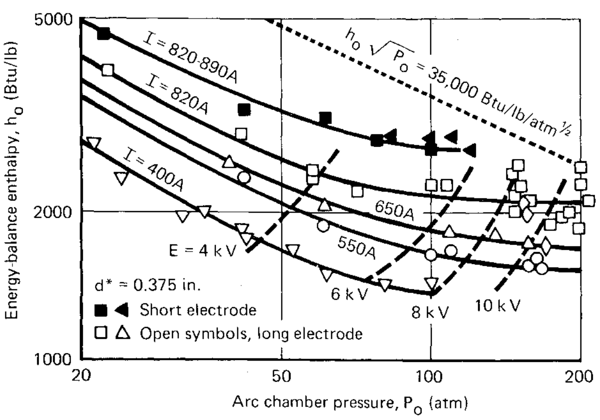

Fig. 1 Operating envelope of MDC-200 arc air heater.

All internal components are water-cooled (using a 1250 psig supply) or shielded from the arc by thermal insulators. The downstream (front) electrode is designed to allow operation with various electrode lengths. A 0.375-in. throat diameter Mach 1.7 contoured nozzle was used in the tests reported here. Test models, calorimeters, and pressure probes are placed downstream of the nozzle exit on a seven-arm rotary model actuator.

Power is supplied by four d.c. modules in series, each containing three-phase, full wave rectifiers with saturable reactor current controls. An open circuit voltage of 24.4 kv is provided with a maximum power capability of 12 Mw for 6 min. Clean, filtered air can be supplied at a flow rate of 2.0 lb/sec for 4 min at an injection pressure of 3240 psig. Continuous flow regulation down to 0.1 lb/sec is permitted. Magnetic tape recording of all data at a maximum scan rate of 11,000 samples per second is provided.

Figure 1 shows the stagnation enthalpy-pressure performance achieved to date. The enthalpy shown is an energy balance value. Data are included for front electrodes with lengths up to 48 in. The highest stagnation enthalpy (4600 Btu/lb at 20 atm) was obtained with the short front electrode which was used at pressures to 120 atm, while the highest pressures (to 210 atm) were reached with a

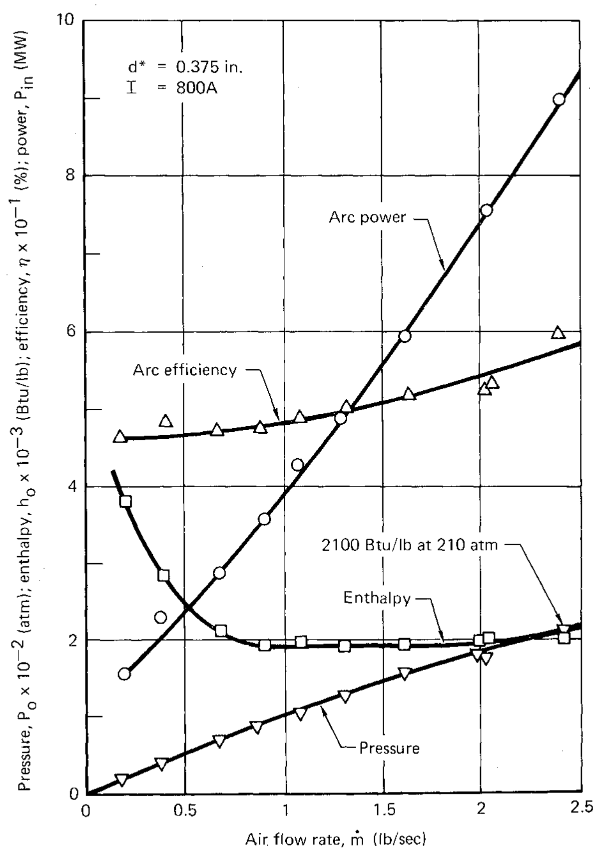

Fig. 2 Typical MDC-200 arc air heater performance characteristics.

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Index categories: Launch Vehicle or Missile System and Component Ground Testing; Spacecraft and Component Ground Testing and Simulation; Research Facilities and Instrumentation.

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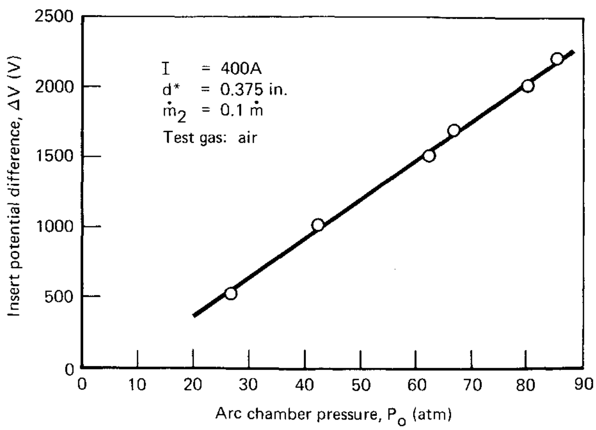

Fig. 3 Single isolated interelectrode insert potential difference.

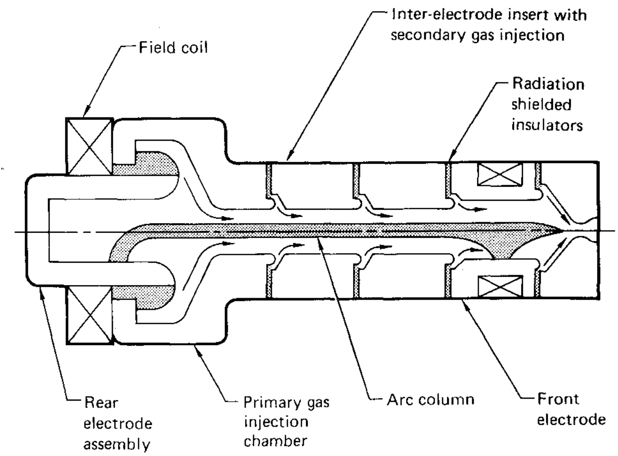

Fig. 4 Suggested high-performance arc heater.

longer front electrode. Figure 2 depicts the general performance characteristics of the MDC-200 arc air heater at 800-amp arc current.

Enthalpy increases with arc current according to $h_0 \propto I^n$, where $0.5 < n < 0.6$. Erosion of the electrodes was minimal at 400 A but quite significant at 900 amp. Higher voltage is less destructive than increased current and results in less contamination in the test stream, higher thermal efficiency, and higher gas pressures for any given power level. Factors influencing the arc voltage were arc length, arc chamber pressure ($V \propto P_0^{0.8}$), arc current ($V \propto I^{-0.4}$), air flow rate ($V \propto \dot{m}^{0.65}$), and electrode surface condition.

The characteristics of the MDC-200 are such that the only means available to increase the enthalpy at a fixed pressure was through an increased arc current. Unless the nozzle size is reduced, a fixed pressure cannot be held with a reduction in air flow rate. Increased power through increased voltage is not accessible without a change in the pressure and/or a reduction in the arc current. Extrapolation of the data shows that an order of magnitude increase in arc current is necessary for a three-fold gain in stagnation enthalpy. At arc pressures above 200 atm, this would result in immediate destruction of the arc heater electrodes. Since electrode life at the highest arc currents used was on the order of minutes, it was concluded that further power increases must be achieved through increased arc voltage. The arc voltage gradient was 200–280 v/in. at high pressure. A high-pressure arc heater that could maintain a fixed length arc, longer than the "natural length" without shunting, would capitalize on this high voltage gradient and provide increased power input to the gas.

Fixed-length arc devices use isolated inter-electrode inserts to reduce the potential difference between the arc column and the constricting wall. Each insert floats at a potential near that of the arc column passing through it; thus, shunting is prevented and a long high-voltage arc can be maintained. The length and design of the insert and its insulator are paramount in importance to achieving successful high-pressure operation.

Structural considerations dictate the use of as few inter-electrode inserts as possible for a given length arc, which requires isolated sections capable of sustaining high potential differences (ΔV) without arc-over. The arc column voltage gradient, insulator length, and insert length determine the ΔV between adjacent inserts. Arc-over occurs between inserts when the ΔV is sufficient to cause breakdown in the insulator gap. The close proximity of the high pressure arc column and resulting radiation increases the relative number of charge carriers in this gap and reduces the potential required for breakdown.

Experiments were made using existing arc heater components, modified for 1) interelectrode section isolation to prevent arc shunting, and 2) secondary gas injection to reduce the number of charge carriers present in the insulator gap. The isolated sections were the same diameter as the front electrode (cathode). The cathode was located downstream of these sections. Primary air was injected between the anode and the first isolated section, and a secondary air flow rate equal to 10% of the primary flow was injected between each of the isolated sections and upstream of the cathode. A 0.375-in.-throat-diameter nozzle constricted the flow to provide the desired high pressure. Although arc-over and insert damage resulted during some of the tests, the resulting data (Fig. 3) indicate that sizeable potential differences can indeed be sustained between adjacent tandem cylindrical inserts with secondary injection. The data supports this approach toward a rugged high-pressure "fixed-length" arc heater design.

Figure 4 depicts a suggested hollow-electrode constricted-arc air heater with multiple isolated inter-electrode inserts and secondary gas injection for operation at 200 atm pressure and significantly higher gas enthalpies. This heater would incorporate modified versions of the recently tested inserts.