Arc Driver Operation for Either Efficient Energy Transfer or High-Current Generation

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Theme

An investigation is made to establish predictable electric arcs along triggered paths for research purposes, the intended application being the heating of the driver gas of a 1 Mjoule electrically driven shock tube. Trigger conductors consisting of wires, open tubes, and tubes pressurized with different gases were either placed on the axis of the arc chamber or spiraled along the chamber walls. Design criteria are presented for successful arc initiation with reproducible voltage-current characteristics. Results are compared with those from other facilities and several applications are discussed.

Content

In the Ames electric-arc driver, helium under several atmospheres of pressure is heated at constant volume by an arc discharge between electrodes located at each end of a cylindrical arc chamber. The chamber walls are electrically insulated, and a 1 Mjoule (40 kV, 1250 μF) capacitor bank is connected directly across the electrodes. The chamber is 10 cm in diameter and its length (electrode spacing) can be adjusted to 76, 137, or 290 cm. Trigger conductors were either positioned "straight" along the chamber axis, or "spiraled" as illustrated in Fig. 1. To initiate an arc discharge, the conductor is drawn toward the electrode until the insulation (gas) breaks down and the conductor explodes. Although all types of conductors could be exploded within the arc chamber, only one class of metals (transition elements) would culminate in an arc discharge. The choice of the conductor (and the arc-chamber load pressure) was found to determine the discharge current waveform. Typical electrical records for different trigger arrangements are shown in Fig. 2. Straight conductors generated very high currents. Peak currents up to 10^6 amp were delivered by tube conductors pressurized with hydrogen or deuterium.

A spiraled conductor with a high chamber load pressure exhibited an easier electrical duty cycle (lower peak current, better damping). Spiraled triggered discharges also substantially improved the conversion of the electrical energy into gas flow energy. The shock generating capability of the 76 cm driver into 1 torr of dry air in the 10 cm diameter driven tube is used to illustrate this point. A shock Mach number of 34 was obtained with a straight trigger wire. With a spiraled trigger wire, the shock Mach number was increased to 45. In both instances, the electrical discharges were 1 Mjoule and the driver records are those shown in Figs. 2a and 2c.

The dwell period noted in Fig. 2, i.e., the interval from the conductor explosion to the start of the rise of the arc current, is a parameter that operating experience has shown to be remarkedly repeatable and systematic.[1] It decreases with increasing field intensity (the ratio of preset voltage to the total length of conductor) and increases with increasing arc-chamber load pressure. The agreement of dwell periods measured for spiraled wires and open tubes with those of the straight conductor (Fig. 3) suggests that the arc follows the original path of the conductor. The results obtained to date substantiate this premise. Furthermore the dwell periods measured in eight other arc-driver facilities of widely different energy ratings and chamber sizes showed similar agreement. For practical purposes, the dwell measurement offers a useful parameter by which the electrical circuit performance of one arc chamber can be applied to another with a high degree of confidence.

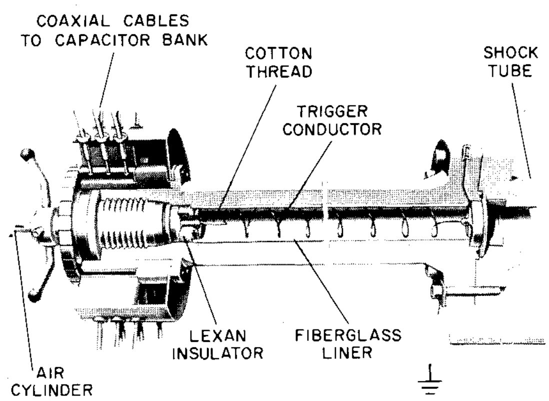

Fig. 1 Spiraled arrangement of trigger conductor in the electric arc driver.

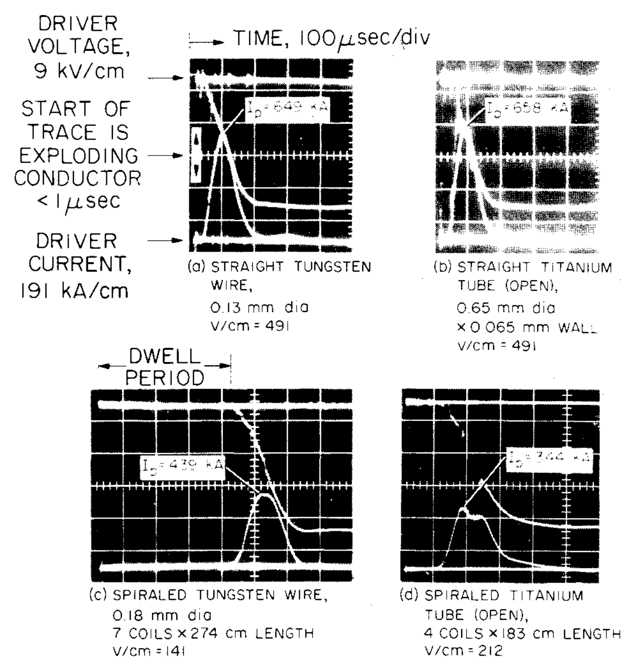

Fig. 2 Electrical characteristics of the 76 cm arc driver with different trigger conductors for a 40kv, 1 Mjoule discharge and load pressure of 30 atm helium, energy density of 150 joule/cm^3.

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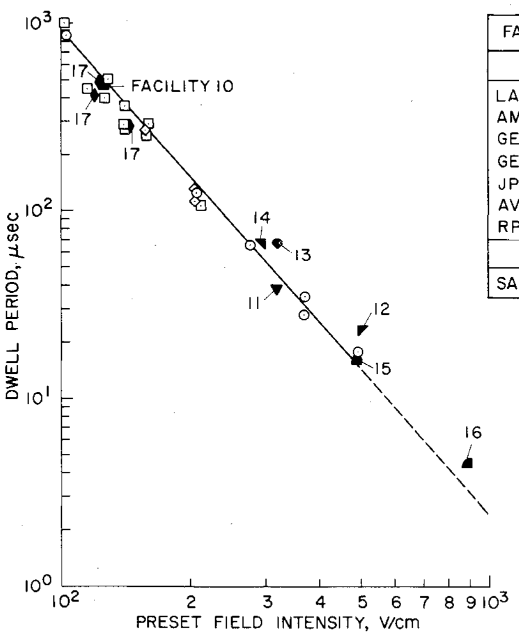

FACILITY		kJ	μF	kV	L_4, cm	D_4, cm
TRIGGER CONDUCTOR: STRAIGHT WIRE						
LAL	10	2,500	34,000	12	61	15
AMES	11	1,000	5,000	20	30	15
GE	12	750	960	40	76	6.4
GE	13	304	380	40	76	7.6
JPL	14	120	610	20	66	3.7
AVCO	15	25	264	13	27	3.3
RPI	16	6.6	58	15	15	1.9
TRIGGER CONDUCTOR: SPIRALED WIRE						
SANDIA	17	500	625	40	76	10

AMES 1MJ, 1250μF, 40 kV SYSTEM

ARC LENGTH, cm	TRIGGER CONDUCTOR
—— 76, 137, 290	STRAIGHT WIRE (REF. 1)
○ 76, 137	STRAIGHT TUBE (OPEN ENDS)
□ 76	SPIRALED WIRE
◇ 76	SPIRALED TUBE (OPEN ENDS)

Fig. 3 Variation of the dwell period of a triggered discharge as a function of the preset field intensity, load pressure of 18.5 atm helium.

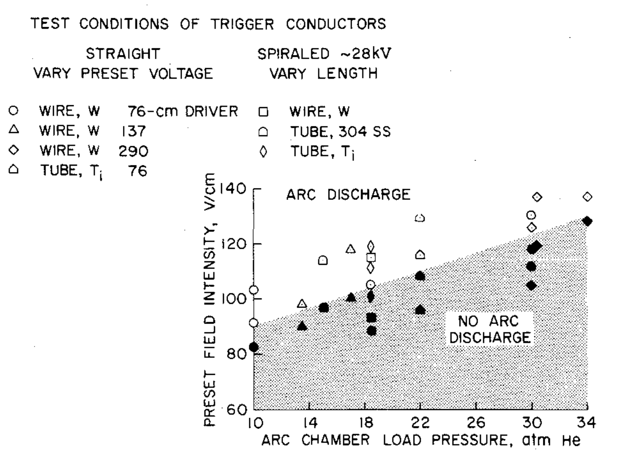

Fig. 4 Threshold of field intensity for an arc discharge along the core path of the exploded conductor.

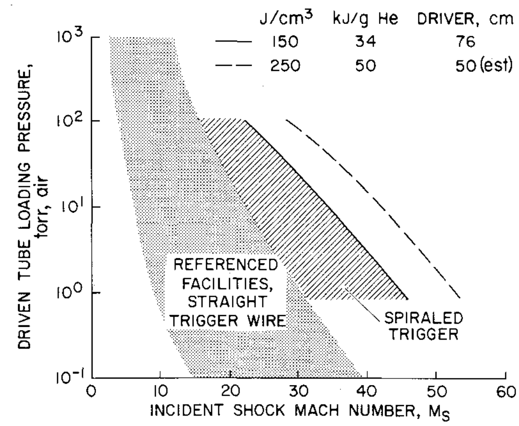

Fig. 5 Shock tube performance, arc-heated helium driver with dry air as the driven gas.

Experimentally, it was found that the minimum voltage required to induce an arc discharge increased with the chamber length and was greater for a spiraled conductor than for a straight conductor. However, the corresponding values of the field intensities were about the same. The results of the present study established that a clearly defined correspondence exists between the gas pressure in the arc chamber and the preset field intensity necessary to induce an arc discharge along the path of the exploded conductor (Fig. 4). The breakdown field intensity is of the order of 100 v/cm and increases slightly with increasing pressure. It is a useful design parameter to establish the voltage requirement for a given triggered arc path.

The shock driving capability of electric-arc drivers is summarized in Fig. 5 for a constant-area shock tube with air as the driven gas. The shaded region shown in the figure represents the demonstrated performance with straight wire triggered discharges. The increase in shock Mach number obtained by means of the spiraled triggered discharges is indicated by the cross-hatched area in Fig. 5. The highest shock speeds achieved thus far (solid line) were obtained using the 76 cm driver. If the energy density of the discharge is below about 100 joule/cm³, the driver performance (in terms of shock speed) is of sufficient quality with a straight conductor that a spiraled installation is not warranted. However, as the energy level is increased, driver performance falls off markedly for straight conductors, and it is for the higher energy densities that spiraled conductors are advantageous. As a point of interest, the maximum shock-tube performance to be expected with a 1 Mjoule discharge is also indicated in Fig. 5 (dash line). The driver and trigger arrangement to generate the projected performance would require a chamber length of 50 cm, with a 5-coil spiraled conductor (217 v/cm), and a chamber load pressure of 30 atm helium to initiate a satisfactory arc discharge. The discharge parameters represent a practical compromise between the maximum allowable pressure in the chamber and diaphragm design, while maintaining a realistic bound of specific energy of 50 kjoule/g of gas for efficient driver/driven operation (> 70%).

Reference

[1] Cheng, D. Y. and Dannenberg, R. E., "Dark-Pause Measurements in a High-Pressure Arc Discharge," *AIAA Journal*, Vol. 9, No. 1, Jan. 1971, pp. 184–186.