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Summary

The spark erosion characteristic of high-purity graphite and CO for 1-kHz gas blown rail-gap applications has been experimentally evaluated. The test configuration simulates a single channel, 1650-A arc discharge per linear inch of electrode length, with a 44-kV self-breakdown voltage and a transverse gas flow of 98 m/s. The dielectric gas was seeded with a small quantity of azulene vapor and a downstream uv preionization spark was used to assist the self-breakdown of the test electrodes. The erosion characteristics of other, more conventional electrode materials and dielectric gases were also examined and the results are presented graphically. Commerically pure tungsten in air was determined to exhibit the least erosion rate (2.1×10^{-6} cc/C) for this duty, as compared to graphite and CO (75×10^{-6} cc/C).

Introduction

Gas blown rail-type spark gaps are reasonable candidates for solution of the fast, high power switching problems inherent in pulsed gas-discharge lasers. The low inductance geometry and the reduced, distributed electrode erosion of multichannel operation are key factors in meeting high di/dt switching requirements and solving electrode wear limitations at repetition rates approaching 1 kHz. The erosion wear characteristic of an electrode material is obviously a result of many complicated and undefined interactions between the electrode material, the dielectric gas and flow parameters, peak current, voltage, coulomb transfer and repetition rate. An optimum material or class

of materials needs to be identified for use in gas blown, high repetition rate rail-gap applications. The most practical approach to this purpose is empirical experimentation with candidate electrode materials and conventional dielectric gases operating at appropriate stress levels.

Experimental Hardware and Operating Parameters

General

An electrode holder/gas-flow configuration was fabricated as shown schematically in Fig. 1. The electrode spacing (0.635 cm), the active electrode length (2.54 cm), the gas flow velocity (98 m/s), and the repetition rate (1 kHz) were held constant. A 12-Ω cable PFN was resonantly charged (Fig. 2) and discharged through the test electrodes electrodes into a low-inductance 12-Ω ohmic load. Self-breakdown was assisted by a low intensity uv preionization spark located 4.4 cm downstream. Gas input temperature of the closed-cycle system was held near room temperature (70-79°F) by a water-cooled heat exchanger. Gas outlet temperature was monitored at the downstream throat of the electrodes by a thermometer; heat generation due to the uv preionization spark was negligible. Electrode weight was measured with a 5-decimal gram balance at various operating intervals and the electrode volume lost was calculated from these weight measurements. Azulene vapor was injected into the dielectric gas from a heated (160°F) flow-cell. The azulene partial pressure was small and appeared to have no affect on the erosion performance of the electrode materials.

Operating parameters of the electrical driver circuit and flow system are listed in Table I.

Graphite and CO/Azulene

A high purity graphite material was machined into two identical electrodes, each with a 0.635-cm radius along the length, and an overall length of 3.8 cm. The ends were machined to a radius of 0.635 cm; the active length of the electrode was 2.54 cm. Full power operation of the test circuit generated an average current density along the electrode length of 650 A/cm, with a peak single-channel current of 1650 A and 44 kV self-breakdown. The PFN voltage risetime was adequately slow (550 ns) that multichanneling of the arc discharge did not occur, so the erosion rates of the electrodes can be scaled to full-size rails operating in multichannel mode with one discharge per inch of rail length. Azulene vapor was injected into the CO dielectric gas and the system was operated for 5.46 million shots (1310 Coulombs). Current and voltage waveforms are shown in Fig. 3. Results of the erosion wear are plotted in Fig. 4.

The seeded azulene vapor creates single-photon electron ionization from the uv preionization spark, reducing temporal jitter in the self-breakdown of the main electrodes by eliminating the statistical electron formation time (1,2,3). In addition, because a copious amount of irradiated azulene vapor actually reduces the self-breakdown potential, the excess electron density effectively increases the E/P ratio in the dielectric gas by increasing E, similar to inserting a small conducting body between the electrodes or reducing the electrode spacing. With CO gas and the experimental configuration used, only a very small effect of the azulene seed in the CO gas could be detected. A more energetic uv preionization source might produce better jitter reduction and enhanced control over the self-breakdown voltage; closer spacing between the uv spark and the main electrodes may also be appropriate.

The main electrode self-breakdown time preferred to lock onto the initialization of the uv spark, not onto the peak uv fluence. (The ohmic transition phase of the uv spark occurs during initialization and maximum energy is dissipated in the spark during this interval, producing more energetic radiation. This may enhance the photoionization processes or create secondaries emitted from the electrode surfaces.) The azulene vapor appeared to "burn out" of the CO gas faster than it could be replaced by the hot flow cell. The uv preionization spark lost effectiveness after several minutes of operation at 1 kHz. Probable cause of seed gas burn-out is the large amount of uv radiation from the main discharge.

Examination of the eroded surfaces of the graphite showed evidence of microscopic pitting probably caused by sublimation or burning. The erosion was probably not caused by localized chipping from mechanical or thermal shock; no evidence of graphite particulate contamination of the gas flow system was observed. The anode evidenced 20-30% more erosion than the cathode, indicating that electron bombardment accounts for significantly more energy deposition than does the cathode-fall effect (4). This was a universal observation for all electrode materials tested, not just for graphite. Because of the extreme erosion rate of graphite at this particular duty, no experimentation with the anisotropic properties of graphite were performed, nor were any attempts made to reduce oxidation erosion by spiking the CO with CO_2. In addition, self-preionization effects due to corona were observed during single-shot trials, which caused prefires at all repetition rates up to 1 kHz. The corona phenomenon was manifest as low intensity, light blue, self-initiated impulse streamers occurring at random at the ends of the electrode gap. Increasing the system pressure was ineffective in preventing their inception

except at extreme pressures where the gap would not break at all. Higher gas flow rates may solve this problem.

Other Electrode Materials and Gases

CO_2 and dry air were used as dielectric gases with commercially pure tungsten (cpW), 90W 6Ni 4Cu, K25 composite (75W 2.5Cu by Plansee), 70/30 brass, and 316 stainless steel. The results of these tests are shown in Figs. 5-8. Operating parameters were maintained as in the previous experiment. Electrode shapes and dimensions were identical to those used in the graphite/ CO test, except for a single SS 316 run where the electrode radius was doubled, creating a radius/spacing ratio = 2. This had no effect on the erosion rate.

The essential metallurgical property affecting erosion at this duty appears to be high temperature strength, hence the best performance by refractories.

Oxygen in the presence of tungsten appears to retard the erosion process, perhaps by the formation of protective oxides (5). The 90%W material in CO_2 was subjectively judged to be the best combination of those tested: erosion rates of the cathode and anode were nearly equal and only slightly higher than cpW/air. The machinability of the 90W 6Ni 4Cu material is substantially better than cpW. Air with 90%W needs to be tested.

CO_2 gas did not exhibit as good a self-breakdown characteristic as air; the extreme temporal jitter with CO_2 and 550-ns charge time was virtually eliminated by adjusting the uv preionization spark initiation to the peak of the PFN charge voltage. This was accomplished both with and without azulene.

Azulene vapor seed in CO_2 produced reasonable results in that the self-break voltage could be shifted about the peak of the PFN voltage approximately ± 10% by adjusting the timing of the uv spark. The magnitude of this effect

is very dependent on the partial pressure of azulene vapor, and as with CO/azulene, the effectiveness was eliminated by burn-out after several minutes of full power operation at 1 kHz.

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TABLE I

Full power operating parameters at 1 kHz.

V_{br} = 44 kV I_{pk} = 1650 A C/shot = 0.24 mC

	CO	CO_2	Air
Gas Pressure	12.4 PSIG	18 PSIG	18 PSIG
SCFM Flow	63	127	131
ΔT rise	25°F	15°F	13°F
Efficiency	78%	67%	77%

Efficiency was determined by ΔT rise of the gas flowing through the electrode gap, using eff. = (1 - energy diss./energy switched) × 100%. Energy dissipated was calculated from the relation,

$$ED = \frac{K\ (SCFM)(\Delta°F)}{pps} ,$$

where,

K(air and CO) = 0.34, and $K(CO_2)$ = 0.43.