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HIGH REPETITION RATE BURST-MODE SPARK GAP*

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SUMMARY

Results will be presented on the design and testing of a pressurized gas blown spark gap switch capable of high repetition rates in a burst mode of operation. The switch parameters which have been achieved are as follows: 220-kV, 42-kA, a five pulse burst at 1-kHz, 12-ns risetime, 2-ns jitter at a pulse width of 50-ns.

Spark Gap Design

The construction of the coaxial spark gap[1] is illustrated in Fig. 1. The spark gap bolts on to the lower end of a $5.2\text{-}\Omega$ coaxial water Blumlein and is designed to switch the mid conductor to ground. The Blumlein's mid conductor feeds through a polycarbonate resin insulator which interfaces between the water

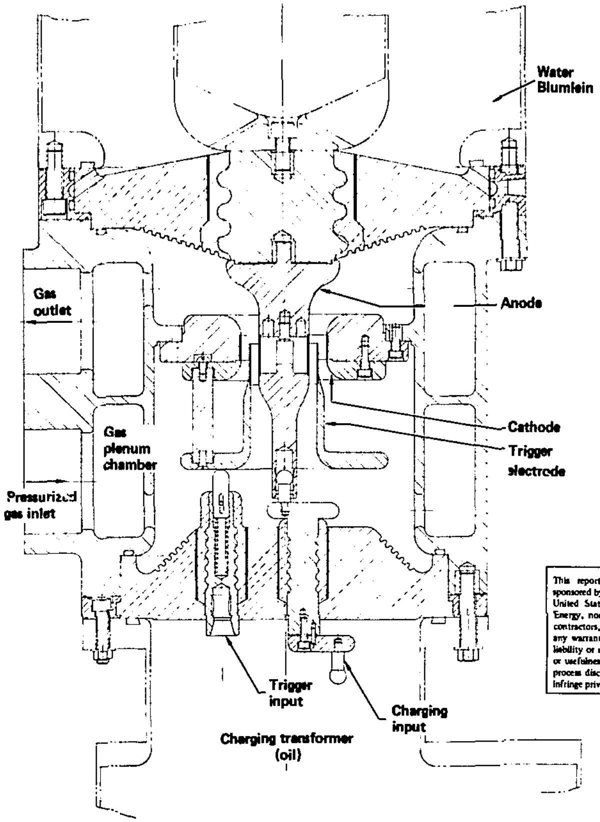

FIG. 1 SPARK GAP CROSS SECTION

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and high pressure gas and becomes the switch's anode. This electrode continues through a second lexan insulator separating the high pressure from the oil filled charging transformer. The center electrode or anode of the switch is 3.81-cm in diameter and is made of stainless steel with a .76 mm thick, 3.18-cm long tantalum insert where the actual arc is to occur. The trigger electrode is a concentric cylinder 30 mils thick and 3.18-cm long, also made of tantalum. The ground electrode or cathode is stainless steel with a .76 mm thick cylindrical tantalum insert 1.91-cm long and 6.76-cm in diameter. The tantalum cylindrical liners are made to give the spark gap long life and to be easily replaceable after wearing out. Concentricity of tantalum inserts is maintained with 5 mils maximum deviation. The coaxial cylindrical geometry was adopted for two main reasons: long life and high rep-rate. The trigger electrode is expected to wear uniformly in the axial direction with no change in the spark gap electrical characteristics. The 30 mil tantalum cylinder can then wear for 2-cm axially before replacement should be necessary.

Secondly, since we chose to achieve the 1-kHz rate by blowing gas through the spark gap, the coaxial geometry assures high gas velocity and low pressure drop. The chamber on the outside of the spark gap reduces the pressure drop and provides uniform gas flow through trigger to ground and trigger to anode.

The interface insulators were made of polycarbonate resin because of their strength and resistance to high voltage tracking. Some cold flow problems were encountered when we tried to use cast epoxy for those insulators.

Charging System

In order to obtain high rep-rates, careful attention must be given to the charging system. Fig. 2 shows the charging pulse to the Blumlein and spark gap being triggered at the peak of this wave form. A resonant transformer coupling coefficient of .525 was chosen because this gives current non-reversal in the

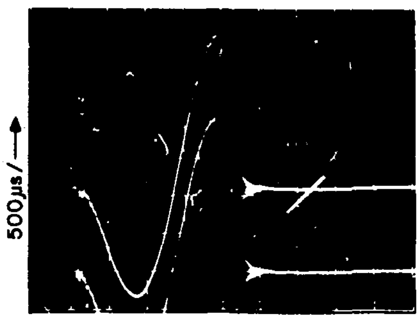

FIG. 2 BLUMLEIN CHARGING VOLTAGE

primary or thyratron switch. The current in the primary switch at peak output voltage is nearly zero and most of the energy is switched out of the Blumlein by the spark gap. These are nearly optimum conditions for arc snap-out in the switch. If, for example, a coupling coefficient of .8 is used, steps must be taken to dissipate the energy still remaining in the transformer which acts to maintain the spark gap arc with only amperes flowing. To insure quick arc snap-out and recovery times short with respect to 1-ms, we installed some linear resistance and some non-linear resistance (varistors). Although these resistors are not necessary in an ideal energy transfer system, in the practical case, they provide damping (<50-μs) of the residual energy.

Gas System

The test setup for the gas flow system consisted of a Roots type blower in a pressure tank closely connected to the plenum chamber of the spark gap. We did not have means for varying the flow rates in the switch but only pressure and gas mixtures. No extensive studies were made of gas mixtures but several were tried and for our rep-rate and voltage requirements it appears that 6-8% (gage) of SF_6 with Nitrogen has given us satisfactory results. The gas flow rate for this mixture was about 4-cm/ms; this is expected to be about 5-cm/ms in the final accelerator system. The pressure drop in the spark gas was about 3 psi at 80 psig gas pressure. It is expected that once in operation the gas mixture will be changed periodically and some of the contaminants may be removed between changes by mechanical and chemical filtration.

Test Results

The test results indicate qualitatively what is expected of the spark gap. Fig. 3 shows the relationship between rep-rate, voltage and pressure. The air flow remained relatively constant as pressure was varied. The graph shows that the closer the switch is run to the self-breakdown mode, the lower is the rep-

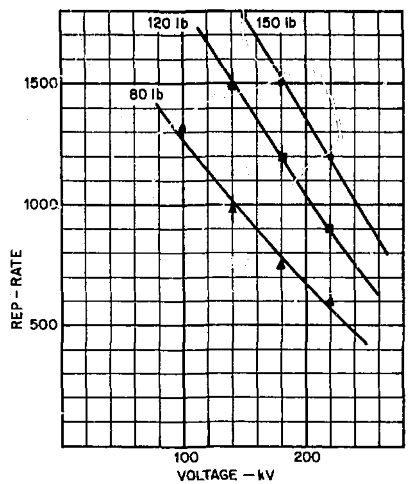

FIG. 3 REP-RATE VS. VOLTAGE AND PRESSURE

rate. As the voltage is lowered, the rep-rate increases and one is limited only by the trigger amplitude on how low in voltage or high in rep-rate it is possible to go. Fig. 4a shows the output pulse into a copper sulfate load connected to the Blumlein by a 1-m water transmission line. The 10-90% rise time is 12-ns and some improvements on this rise time were observed when a trigger pulse with faster rise time was used (Fig. 4b). The decrease in rise time is an indication that multiple arcs are occurring, thus decreasing the arc inductance.

Jitter

The trigger electrode is biased at the natural mid equipotential that it is designed to follow and is pulsed negatively or toward ground, producing a high field at the edge leading to electron emission and breakdown. The trigger pulse for the test was generated by a ferrite loaded transformer with geometry much like an induction accelerator unit. This transformer has a step-up of nine and produces 125-kV, 100-ns pulse with 30-ns rise time. A 50-Ω resistor in series with the trigger electrode terminates the trigger cable once spark gap breakdown has occurred. Before breakdown, the load impedance is high and the pulse voltage doubles.

(a) PULSE INTO $CuSO_4$ LOAD

(b) 10-90 RISETIME

FIG. 4

The final trigger for the spark gap will be generated from a Blumlein with faster rise time. The jitter measurements were made with the trigger transformer and yielded the results shown in Fig. 5. These results

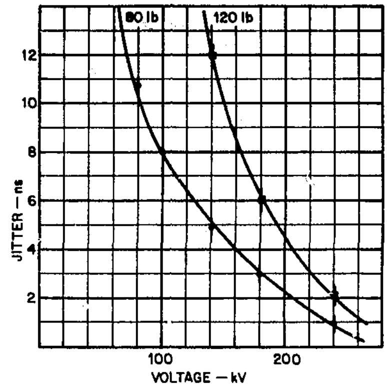

FIG. 5 SPARKGAP JITTER AS A FUNCTION OF PRESSURE AND VOLTAGE

were not unexpected. As the self-breakdown of the spark gap is approached, the jitter becomes less, and conversely as the voltage is reduced, the jitter increases until the gap no longer triggers. Fig. 6 shows the jitter of ten shots superimposed.

FIG. 6 TEN SHOTS SUPERIMPOSED

Spark Gap Wear

The spark gap was tested at full voltage for 10^5 shots at less than maximum rep-rate. The electrodes were then removed and inspected. The anode and cathode tantalum liners showed practically no wear. The majority of the arcing had occurred at the edge of the trigger electrode but a few stray arcs occurred lower down toward the insulator where the electrode is reduced in diameter. The trigger electrode showed uniform wear at the edge except for one spot (Fig. 7). This wear spot occurred because sometime during the test the spot

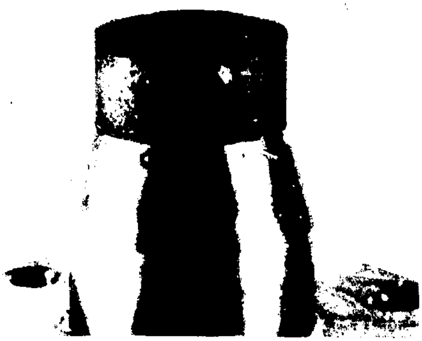

FIG. 7 TRIGGER ELECTRODE AFTER 10^5 SHOTS

welding had come loose and the tantalum electrode became tilted to one side. Even with this shift the spark gap operated normally. If one assumes uniform wear to this electrode for 2-cm, the projected life appears to be greater than 10^7 shots. For the 10^5 shot test the insulators upstream of the air flow showed a small amount of debris deposited on them. These insulators could be shielded, as in the LBL ERA[2] gap, if necessary.

CONCLUSION

We have carried the spark gap development to the point where we feel satisfied that all the requirements of rep-rate, voltage, currents, rise time, jitter and expected lifetime for the ETA have been met.

With further development of the existing technology of gas-blown spark gap, it is likely that rep-rates of a few kilohertz at full voltage will be achieved. It appears that because the blower power requirements are proportional to the cube of the velocity, a few kHz may be the practical limit with this technique. After completion of the ETA, we hope to do further development to find the limits of the existing spark gap.

[1] A disclosure of invention has been made by A. Faltens.
[2] Avery, R., et al., "The ERA 4-MeV Injector, IEEE Transactions in Nuclear Science, Vol. NS18-No. 3.