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DEVELOPMENT OF THE SWITCHING COMPONENTS FOR ZT-40*

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## Summary

Switching of the main capacitor banks for ZT-40 will be accomplished by spark gap switches. Initially, there will be 576 start switches and 288 crowbar switches. A development program is underway to develop three switches; (1) a versatile start switch, which can be used for both the $I_z$ and the $I_\theta$ capacitor banks, with a wide operating voltage range, (2) a crowbar switch which is capable of crowbarring the circuit without the power crowbar bank, and (3) a power crowbar switch, which can handle 50-100 coulombs, so that a large number of crowbar switches will not be required when the power crowbar circuit is added.

The problems with the start switches and the first crowbar switch have been solved, or alleviated. The development of a power crowbar switch has just begun.

## Development of Start Gap

The design adopted as the start gap switch for ZT-40 was a modification of the spark gap which has served as the start gap on the ZT-S machine. Although considerable operating experience had been gained with this gap in the ZT-S system, no detailed investigation of its operating characteristics had been made. It was known, however, that it has a wide range of operating voltage, and this was the primary reason for its selection over the old warhorse four-electrode Scyllac gap. A necessary step was to establish the expected lifetime and the triggering delay and jitter.

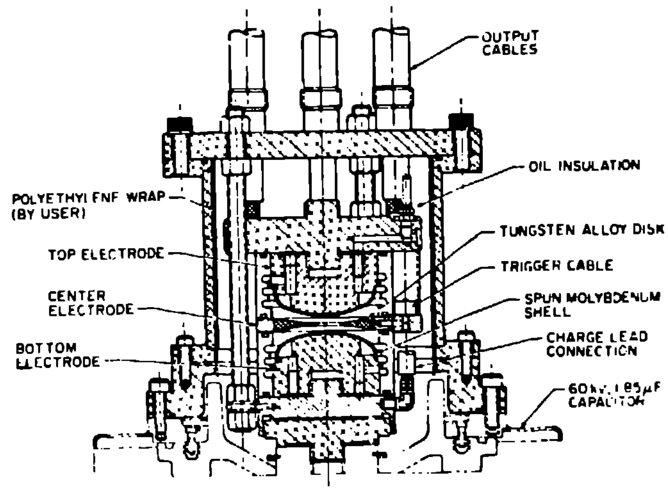
The requirements on the start gap are as follows:

1. It must have an operating voltage up to 50 kV with a low prefire rate.

2. It must conduct a peak current up to 100 kA, with a coulomb load per discharge of about 2 coulombs, for at least 10,000 discharges.

3. It must have wide triggering range, from 12 kV to 50 kV, with less than 40 ns jitter, when the trigger pulse is 100 kV with a risetime of 30-60 ns, and for either polarity of capacitor charge.

A sectional view of this spark gap is shown in Fig. 1. It is a three element gap which is triggered by field distortion. The main electrodes are thin (1 mm) shells of refractory metal (Mo,Ta) which are shrunk-fit onto an aluminum base. The trigger electrode has a heavy-metal insert, in a brass holding ring. It is tapered to a 1-mm edge, and is shaped overall to conform to an equipotential surface. The spark gap mounts directly on the capacitor, and the output is via coaxial cables. The entire gap is of cartridge construction, such that the gap can be assembled separately and then inserted into the housing on the capacitor. This greatly facilitates both initial assembly and replacement of gaps.




FIELD DISTORTION START GAP

Fig. 1.

## Triggering Tests of Start Gap

Extensive measurements were made of the triggering delay and jitter. Parameters which were varied were gap spacing, charge voltage and polarity, pressure, trigger pulse amplitude and polarity, and trigger pulse risetime. It was found that with a gap spacing of 1/4-inch, the gap could indeed be triggered over the full range 10-50 kV with a jitter of less than 40 ns. A gap spacing of 1/2-inch was found to be triggerable with acceptable jitter only over the range 20-50 kV. (The upper limit of 50 kV does not represent a limit of operation; rather, it was the upper limit of the investigation.) A gap spacing of 1/8-inch yielded satisfactory operation, but it was not adopted because it was felt that the tolerances on the parts and the assembly would have to be too close and the necessary air pressure in the gap (80 psi) would be undesirably high. Therefore, a gap spacing of 1/4-inch will be used in the ZT-40 start gaps.

The overall qualitative results from the entire triggering test series are that this spark gap can be operated over the desired range of voltage, with either charge polarity, and it can be satisfactorily triggered with a 100 kV trigger pulse with a 30-60 ns risetime. Therefore, both capacitor banks in ZT-40 can use the same start gap and identical gap spacing.

## Lifetesting of Start Gaps

A series of life tests were performed on the start gaps to establish whether they would survive for 10,000 shots under the most severe conditions they would experience in the ZT-40 operations. In the initial tests, the gaps failed after only 1,000 shots. As various corrections and modifications were made, the lifetime was extended to 5,000, then to 10,000, and finally to 25,000 shots. Changes were made, both in the materials used, and in the basic geometry.

The earliest failures occurred when the trigger electrodes developed radial stress cracks and subsequent chipping. This occurred after only 1,000 shots, and caused the spark gaps to prefire. It was found to be due to a materials problem. Both Elkonite (75% W, 25% Cu) and another popular electrode material (50% Mo, 50% Cu) were susceptible to cracking. A third alloy, with a higher percentage of refractory metal, (90% W, 6% Ni, 4% Cu) has survived for up to 25,000 shots with only "normal" erosion. It should be noted, however, that in a single test out of about twenty total, chipping did occur at about 10,000 shots. The chipping was noticed during a scheduled inspection at 10,000 shots and did not affect the performance of the gap. It was subsequently reassembled and tested in excess of 20,000 shots with no further chipping.

During a normal test, the hole in the center of the trigger electrode erodes from 1-inch at the start, to 1-3/16-inch at 10,000 shots, to 1-5/16 inch at 20,000 shots. If the hole is made 1-1/4 inch at the beginning, the erosion is negligible up to 10,000 shots. Trigger electrodes of brass have also been tested. While no thermal stress cracks developed, the erosion rate was so great (about 1-3/8 inch at 10,000 shots) that the added material and machining expense of heavy metal alloys is thought to be justified.

When the problem with the trigger electrode had been solved, allowing testing to continue beyond 1,000 shots, the main electrodes began failing at 5,000 shots. The failure was due to delamination of the thin shell of refractory metal which forms the electrode surface.

The thin shell electrode surface is one of the unique, and most economical, features of this spark gap. Both spun tantalum and spun molybdenum have been tested successfully to 10,000 shots. Tantalum is an expensive electrode material, but using a thin shell holds the cost in line. Molybdenum is a less expensive material than tantalum, but the increased difficulty of the spinning operation makes the overall cost about the same. In an effort to produce more economical molybdenum electrodes, we decided to use drawn, or pressed, molybdenum shells.

We discovered, however, that drawn molybdenum shells were subject to delamination. Microscopic examination of the subsurface structure revealed no difference between spun moly and drawn moly, so it was reasoned that the difference is in the surface condition. This was verified by working several drawn electrodes on a lathe, to condition the surface by spinning. The reconditioned electrodes survived for 20,000 shots, at which time failure occurred due to recrystalization, rather than delamination. Also, since the structure of the shells formed by drawing and by spinning is similar, differing only in the surface condition, even spun moly shells could delaminate if the surface is breached.

Having found electrode materials which would survive for the desired 10,000 shots, it was then discovered that the insulators began to fail at 10,000 shots. Failure was visable as surface tracking paths. This was probably caused by the gradual deposition of conducting metal vapor on the insulator surface.

To remedy this insulator failure and to reduce the prefire rate, the geometry of the gap was modified, to increase the space between the electrodes and the insulators. This change is shown in Fig. 3.

A test model was built in this configuration, using brass electrodes. This model was tested to 25,000 shots, when an aluminum current joint failed. During the test the prefire rate was less than 0.1%. The electrodes and insulators were still usable, but the current joint failure prevented reassembly of the gap.

Development of the start gap is essentially completed, and the gaps are presently being installed in ZT-40. Further investigations are planned, however, to determine its limits of operation; such as, whether it can operate successfully at 75 kV. Since it is the most economical gap that we have in its performance range, it is anticipated that it will find future use in other machines.

## Development of the Crowbar Spark Gap (Phase I)

ZT-40 will be operated initially in a standard crowbar mode, without the power crowbar bank. There will be one crowbar gap for each two capacitors in the system, and the coulomb load per gap will be 6-12 coulombs. Since this is within the capability of the crowbar gap used on the Scyllac system, it was decided to use that gap in the ZT-40 system, suitably modified to accommodate two capacitors instead of one. The modified gap is shown in Fig. 4.

This spark gap is a ferrite-isolated crowbar gap. The spark plug provides irradiation of the main gap; in addition it provides a fireball which effectively shortens the gap spacing. In service in the Scyllac system, it was found that these spark plugs would wear out after about 3,000 shots, thus limiting the lifetime of the gap, even though the main electrodes and insulators are usable for over 50,000 shots.

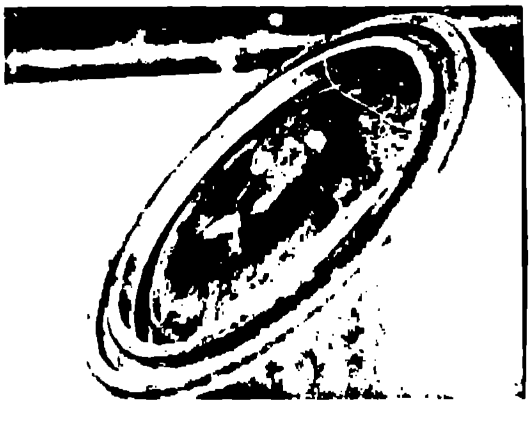
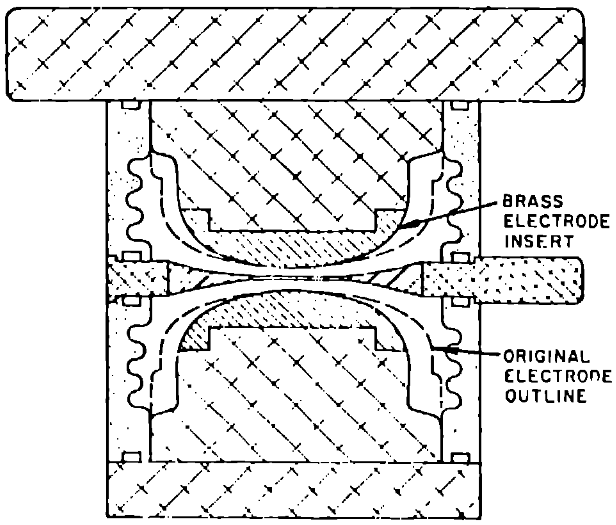
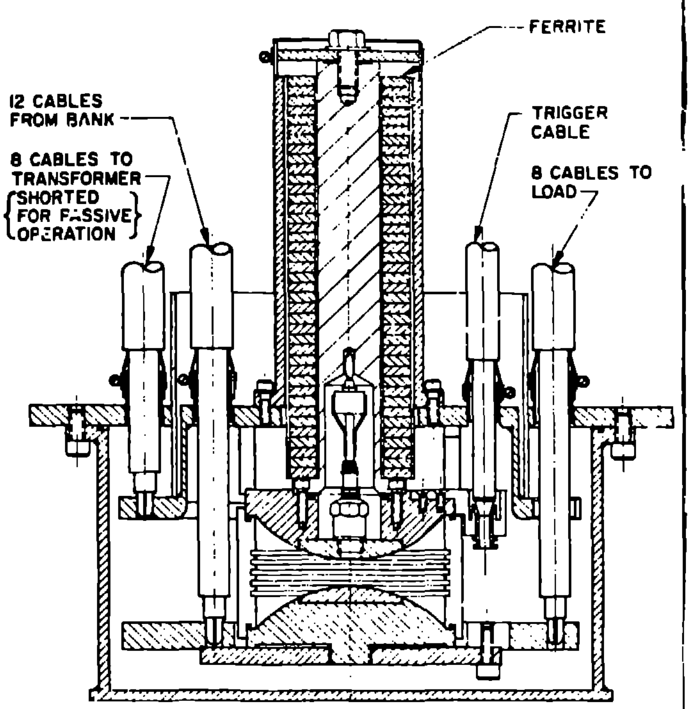


Fig. 2.
Start gap electrode, after 5,000 shots showing delamination of surface.




FIELD DISTORTION START GAP
MODIFIED GEOMETRY

Fig. 3.



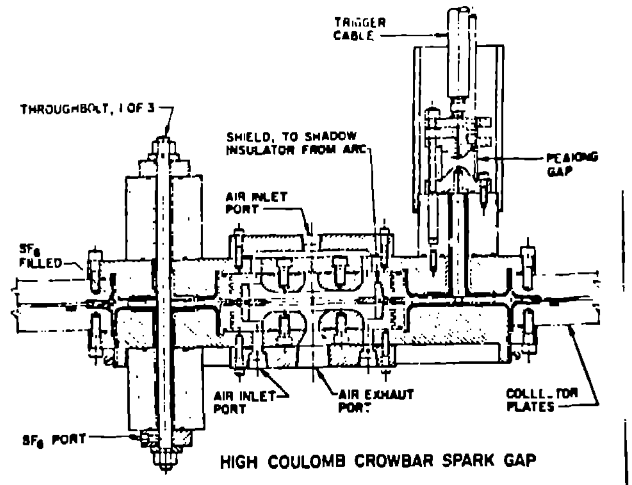

ZT-40 PASSIVE CROWBAR GAP

Fig. 4.

In testing these gaps for their application in ZT-40, it was found that the spark plugs could fail as early as 1,000 shots. The earlier failure is attributed to higher current levels. Fortunately, a simple circuit modification was found which extends the lifetime.

It has been found that the spark plugs fail in two ways; by erosion of the trigger pin and by cracking of the ceramic insulation. It has also been found that only about 10% of the wear is caused by the trigger system; that most of the wear is caused by that fraction of the crowbarred load current which passes through the spark plug. We found that the load current can be successfully shunted away from the spark plug by placing a small inductance (about 300 nh) in parallel with the spark plug.

With this modification, the lifetime has been extended to about 5,000 shots, and hopefully beyond. It is difficult to predict at this time an expected lifetime because of wide variations in the quality of the spark plugs supplied by the manufacturer.




HIGH COULOMB CROWBAR SPARK GAP

Fig. 5.

Development of Power Crowbar Spark Gap

In phase II of ZT-40 construction a power crowbar circuit will be added to sustain the magnetic field for 250 $\mu$s. This will greatly increase the coulomb load on the crowbar gaps. To avoid paralleling a large number of crowbar gaps, we are developing a high coulomb spark gap which hopefully will be able to conduct 50-100 coulombs per discharge.

The initial design of this gap is shown in Fig. 5. It has several features included specifically to increase the coulomb capability and to extend the lifetime. To minimize electrode erosion, it has a wide gap spacing and thus low operating pressure. The holes for air flushing are large to allow a high air flow rate. After the arc is struck, it should push to the center of the main electrodes. Hence, most of the erosion should occur at the center, and not in the triggering area. The insulators are screened from the main area of arc activity in order to minimize coating and damage from the arc. The trigger electrode capacitance is made quite high (800 pf) deliberately, to facilitate triggering at zero voltage.

Conclusion

Development of the start switch and the phase I crowbar switch is completed. These switches are presently being installed on ZT-40. A first version of the power crowbar switch has been designed and built. Testing is due to begin soon. Most of the problems encountered in the development program have been in the selection of proper materials and configurations which will allow the gaps to operate for 10,000 shots.

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