DESIGN AND PERFORMANCE OF THE NEW MULTICHANNEL OIL OUTPUT SWITCH ON THE GAMBLE IIA WATER DIELECTRIC PULSE POWER GENERATOR AT NRL*

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Summary

The six or twelve channel overvolted oil switch at the output of the pulse forming line in the Gamble IIA generator has been replaced with another lower inductance oil switch. The new switch has a floating trigger disc near the center of the switch driven by a self closing axial oil gap. Until the axial trigger gap closes there is relatively low electric field enhancement on the main electrodes and the overall gap length is therefore much shorter than in the original switch. The shorter length plus more channels results in lower inductance and shorter output risetime. The new switch retains the very desirable features of the original oil output switch such as very low prepulse fed through during the charge of the pulse forming line and negligible resistive losses as compared with water switches.

Introduction

Large water dielectric pulse power generators such as the original NRL Gamble II[1] have in general used single or multichannel output switches using water as the breakdown medium. These switches, although very convenient and relatively simple since no dielectric separating diaphragms are required, have two disadvantages. First, due to the high dielectric constant of 80 for water, they capacitively couple through a relatively large prepulse during the charge of the pulse forming line. Second, the series resistance of the Gamble II water output switch never dropped below about 2½ Ohms resulting in a relatively large switch loss. To overcome these disadvantages in the upgraded version of Gamble II, called Gamble IIA[2], multichannel oil output switches are used and the final version is the main subject of this paper.

Self Closing Multichannel Oil Output Switch

When Gamble IIA was first made operational it had a pulse forming line oil output switch with 6 field enhanced electrodes on the positive side. The enhanced electrodes were 1 inch diameter rods with flat ends perpendicular to the rod axes. They protruded about 5 cm from a smooth ring at the output end of the pulse forming line center conductor. At a maximum operating voltage of about 4.5 MV, the gap spacing between the ends of the rods and another smooth ring on the negative side of the switch was 15½ cm. It is believed that the streamers start from the enhanced positive electrodes very early in the 140 ns charge time of the pulse forming line with very little jitter and the overall jitter between channels is mainly due to differences in transit times of the 6 streamers. In any case all six channels closed on every shot and when 12 electrodes were used about 8 to 10 closed, as indicated by open shutter photographic records.

The disadvantages of this switch were its relatively high inductance of about 90 nH and its relatively long resistive phase time of about 8 ns as calculated by the formula of J. C. Martin[3]. Its long gap at the highest voltages also allowed a few streamers to miss the negative electrode ring and damage the polyurethane diaphragm separating the oil and water on that side. The switch did have very low capacitance and negligible energy loss as compared with the water switches originally used.

Multichannel Oil Output Switch with Floating Midplane Trigger Disc

Description of the Switch and the Switch Closing

The latest version of the oil output switch on Gamble IIA is shown in Figure 1. The sketch is a cross section of the switch which is cylindrically symmetric about the axis.

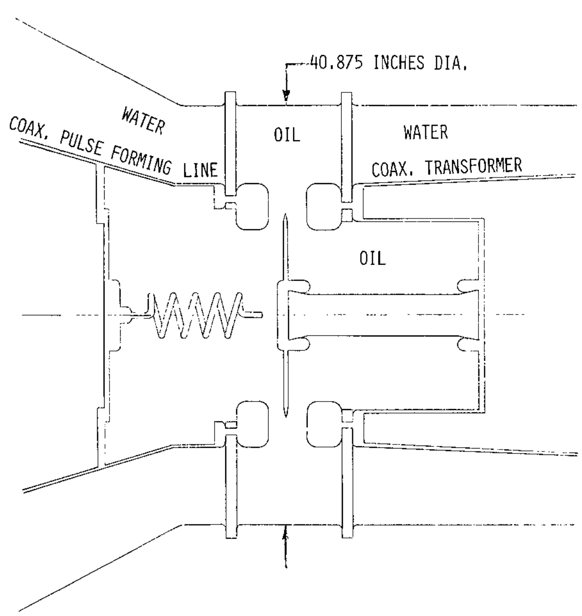

Figure 1. Cross sectional view of the midplane trigger disc oil output switch on Gamble IIA.

The total gap between the main electrode rings is 9.34 cm. The trigger disc is supported by a strong 4 inch diameter polycarbonate rod at a location near the midplane between the main electrode rings on the center conductors of the coaxial pulse forming line and the coaxial impedance transformer. To the left of the trigger disc is the self closing axial gap and solenoid inductor of the trigger circuit. The switch is mechanically designed so that in negative polarity operation the trigger disc can be supported from the pulse forming line side and the solenoid inductor from the transformer side.

The charging of the pulse forming line and the closing of the switch proceeds as follows:

1. As the pulse forming line is charged to 5 MV in about 140 ns from the intermediate store and voltage is applied to the open switch the trigger disc "floats" in potential maintaining a value equal to about 55% of the pulse forming line voltage. Until the axial gap closes, there is no field enhancement at the edge of the trigger disc during the charge as shown in the potential plot

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of Figure 2. The maximum field on the smooth electrode ring on the pulse forming line side is about .75 MV/cm at 5 MV and is about 88% of the self-break value.

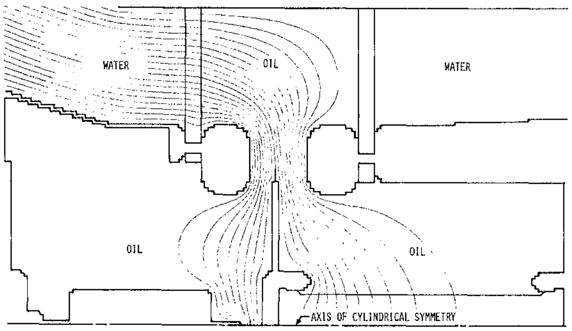

Figure 2. Equipotential surfaces at 5% intervals before the axial gap has closed

2. Switch action starts when the axial oil gap switch reaches its self-break field and closes. The disc is now connected to the pulse forming line through the solenoid inductor and starts to swing in potential in cosinusoidal fashion toward the pulse forming line with a quarter period of about 17 ns. If the disc were to reach the potential of the pulse forming line before streamers formed the potential distribution would be as shown in Figure 3. As shown in this figure, an intense field enhancement at the edge of the trigger disc will launch streamers from this edge toward the smooth electrode ring on the transformer side. Actually, if one calculates the transit time of these streamers, utilizing the mean velocity formula of J. C. Martin[3], the result indicates that the streamers probably close about the time the disc potential is equal to that of the pulse forming line, but this has not been experimentally verified.

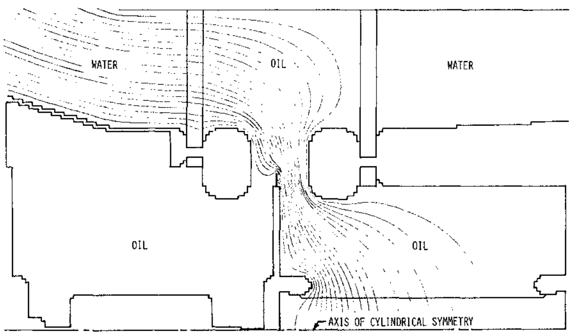

Figure 3. Equipotential surfaces at 5% intervals after the axial gap has closed and the trigger disc has swung in potential to that of the pulse forming line.

3. After the first main gap closes in multichannel fashion the disc will be snapped to the potential of the coaxial transformer ring in 2 to 3 ns, since the inductance of the multichannel gap will be about 30 nH as compared with about 970 nH in the axial gap circuit. The potential distribution will then be as shown in Figure 4 with the intense field enhancement at the disc edge in such a direction as to launch multichannel streamers toward the smooth electrode on the pulse forming line side. The transit time in this case calculates to be about 6 ns. If one assumes that there are 12 channels in the switch the resistive phase time for the overall switch is about 3 ns. The inductance calculates to be about 47 nH and the overall 10% to 90% risetime of the switch calculates to be about 20 to 25 ns.

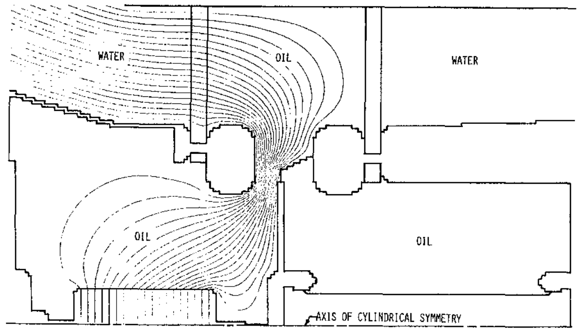

Figure 4. Equipotential surfaces at 5% intervals after the first multichannel gap to the coaxial transformer has closed.

Velocity of Propagation of the Voltage Wave Between Spark Channels

Since water is present outside the diaphragms which contain the oil, the velocity of propagation between spark channels is lower than the velocity of electromagnetic wave propagation in oil alone. The presence of the water increases the shunt capacitance of the circumferential transmission line around the switch rings by a factor of about 16 to 25 thereby reducing the velocity of circumferential propagation by a factor of 4 to 5, enabling the switch to have more parallel spark channels than if only oil were present.

Switch Performance

Figure 5 is an open shutter photograph of the switch in action. J. R. Boller reinvented the pinhole camera in our laboratory to take this very wide angle photograph. It is difficult from the very wide angle and the large number of spark channels to count them but there are probably more than 12.

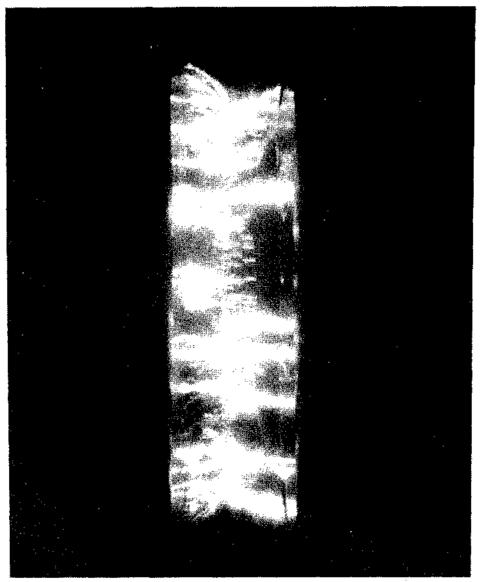

Figure 5. Open shutter photograph of the output switch spark channels during a shot.

Figure 6 is a record of two Gamble IIA current outputs into non-inductive $CuSO_4$ disc type loads of about 2 Ohms. The current pulse from the shot with the positively enhanced self-closing six channel switch has a 10% to 90% risetime of 45 ns and a FWHM of 93 ns. The current pulse from the shot with the trigger disc switch has a risetime of 20 ns and a FWHM of 84 ns.

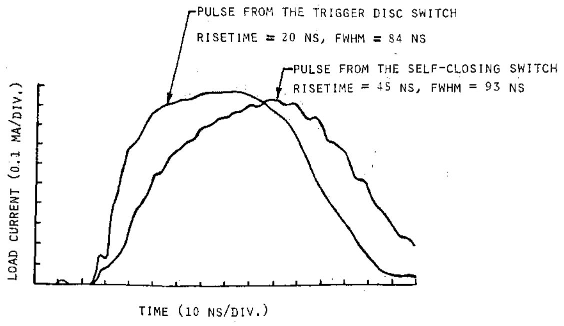

Figure 6. Measured current pulses at the output of the Gamble IIA generator into a non-inductive 2 Ohm load with the two types of multichannel oil output switches used.

The small step (~5 ns long) in the pulse from the trigger disc switch is very consistent from shot to shot and is believed to be fed through the first gap closure during the transit time of the second gap since its length agrees with the calculated transit time of the second gap.

The experimentally measured risetime with the trigger disc switch agrees quite well with the calculated value for 10 to 12 spark channels.

The midplane disc oil switch has a shunt capacitance of about .03 nF and the prepulse into an open circuit load calculates to be about 4 kV. It is experimentally so low that we have been unable to accurately measure it with the noise level present during a shot, but it is lower than about 10 kV.

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