

INVESTIGATION OF A HIGH VOLTAGE VACUUM INSULATOR FOR THE DARHT ACCELERATOR

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ABSTRACT

Tetra has optimized the design of the Microstack vacuum insulator based on previous Microstack results and a specific series of experiments at Tetra's facilities for operation on the DARHT accelerator. Over 30 insulators have been tested with variation in the ratio of insulator to conductor thickness, and various overhangs of the conducting rings relative to the insulator. The insulators were tested on Tetra's MegaMarx generator at electric field levels of greater than 200 kV/cm and pulse-widths of 2 μ s. A series of tests were conducted to quantify the voltage, flashover characteristics and the leakage current characteristics as a function of the ratio of the conductor overhang to insulation thickness.

INTRODUCTION

The purpose of this work is to use the results of previous Microstack tests (Refer to Phase I Report, TR96-005) at Tetra Corporation to optimize the design for the DARHT accelerator. The present DARHT insulator design is shielded by a single bend induction cell design. One issue that has been raised during testing of the ITS accelerator cell is the recurring breakdown in the cell bend when an occasional stray electron from the beam is accelerated into the metal wall of the bend.

Tetra's MicroStack technology resolves one of the basic physical mechanisms responsible for surface flashover: suppression of electron avalanching at intermediate points of the insulator¹. Tetra's Microstack insulators have been successfully tested to over 400 kV/cm for 50 ns pulse widths.

The Microstack insulator design offers several advantages over conventional insulator designs for linear accelerators. Because of the close spacing between the recessed insulators and the conducting grading rings, the MicroStack insulator is self-shielding. The insulator may act to suppress BBU instabilities because of the close spacing between grading rings. The Insulator can be placed even with the inside diameter of the outer wall alleviating the need for the bend used in some designs. Because most of the induction cell is now filled with oil, the design can be simplified and higher field stress can be maintained without breakdown.

A conceptual design was performed for a MicroStack insulator for the DAHRT. Several key parameters were determined from the previous experimental data. The parameters considered were: optimum layer ratio, conductor thickness t , minimum recess of insulator γ , and insulation material. In addition, a 2D electrostatic model of the conceptual insulator design was used to determine the electric field profile across the insulator.

INSULATOR TESTING

The megavolt Marx pulser was used for testing the insulators. It provides a fast (20-30 ns) rise-time. The Marx layout consists of 22 capacitors and 11 switches. The unique features of this Marx (fast rise-time; flat top) are accomplished by the capacitor arrangement and the gas switch construction.

The Microstack Insulator has demonstrated much higher flashover suppression characteristics than other types of insulators (see Phase I Report TR96-005). Optimizing that voltage hold off was the primary item to be determined during testing. Secondly, there is concern about diode emission leakage current across the fins and that was measured and design variations tested to minimized leakage current and to quantify the amount of leakage current present. Thirdly, the vacuum integrity in terms of outgasing and the ability to sustain the vacuum interface was demonstrated.

Table I shows the insulator test matrix that was tested. The first set of measurements were concerned with the insulator thickness ratio. Tetra's data has shown an optimum in the ratio of the insulator to the fin spacing in the range of 8:1 to 16:1 and the primary purpose of testing was to optimize that ratio for the DARHT conditions. As shown, five insulators were fabricated and tested for each of these insulator ratios at the 2 us pulse width. The second area of optimization concerns the overhang of the conducting rings. A series of tests were conducted to quantify the voltage flashover characteristics as a function of the ratio of the conductor overhang to insulation thickness. As shown in **Table I**, three different configurations were tested with five insulators each. Because one configuration is tested in the first series, that is $\gamma = 1$, a total of 25 insulator were tested in all.

Five insulators were selected for these tests as a sufficient number to create a statistical basis for the conclusions but without incurring excessive costs at this stage in the development of the DARHT insulator.

Table I. Test matrix for Phase II testing.

Pulse Width	Layer Ratio					Conductor extension length/thickness	Samples
	8:1	12:1	16:1				
100 ns	-	-	-	-	-	0	5
500 ns	-	-	-	-	-	1	5
1 us	-	-	-	-	-	3	5
2 us	-	5	5	5	-		
ringing	-	-	-	-	-		

In consultation with the DARHT team, it was decided to use a 2 microsecond long pulse that is reasonably square in shape for these tests. This will encompass the envelop of the DARHT operation and should be a conservative test of the capability of the insulator to withstand the DARHT wave-form. The nominal design voltage is for 250 kV, so the design will be capable of 400 kV over 2 cm or 200 kV/cm. Voltage will be imposed across the insulator in the 400 - 450 kV range to simulate the DARHT operating conditions. The insulator will need to operate in the 100 kV/cm electric field range and so will be designed to operated at 200 kV/cm or 400 kV total.

INSULATOR TESTS

A test procedure was designed to provide the best statistical data as possible. However, the jitter in the Marx output, specifically when the crowbar fired, made it difficult to follow the procedure exactly due to conditions when no crowbar occurred allowing for pulses greater than 8 us in duration leading to insulator failures.

The Marx voltage was increased after 3 consecutive shots at one charge voltage. Variations in voltage were due to voltage jitter in the Marx output. It is important to note that there were breakdowns in the insulator well below the maximum voltage that was achieved. The insulator appeared to recover after these breakdowns and continued to increase in voltage. This was most likely due to electrode conditioning.

Twenty three insulators were tested and the results are reported here. Of the total twenty five insulators made, one was damaged during the fabrication process and one was fabricated incorrectly. Of the other twenty three insulators, the highest electric field achieved was 157 kV/cm for a 2 us pulse, and over 170 kV/cm for 400 ns pulses. Many insulators did not show any apparent signs of surface flashover and many insulators may have not reached their flash-over limit.

There was a trend seen in the thickness ratio to breakdown electric field see **Figure 1**. The breakdown electric field is plotted for three different pulse widths, 400 ns, 1 us, and 2 us. The trend would suggest that the larger the thickness ratio, the better the voltage hold-off of the insulator. This is counter intuitive to the theory and previous

data. The variation in electric field is only on the order of 10-15% which is not significant. It should also be noted that this data was based on the average of five breakdowns per series.

It may also be possible that the optimum thickness ratio for the insulator has not been reached. **Figure 2** shows a plot of the breakdown electric field for various thickness ratios including the 133 kV/cm case taken for a solid insulator. The plot in **Figure 2** suggests that an optimum ratio lies between thickness ratios of 12:1 and a solid insulator.

Many of the insulators did not show any signs of breakdown when examined. Many of the breakdowns were obviously between the electrodes and not across the insulator.

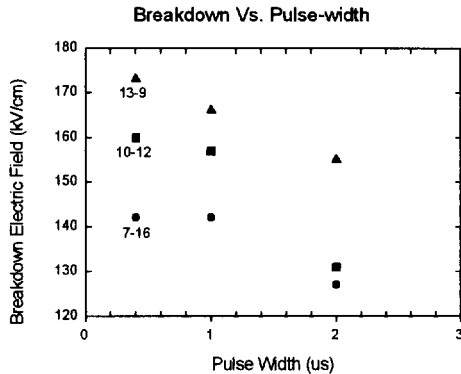


Figure 1. Breakdown electric field for various thickness ratios and pulse widths.

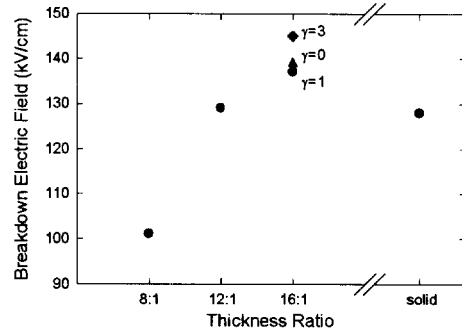


Figure 2. Breakdown field as a function of thickness ratio.

As mentioned earlier, several configurations were tested. The highest electric field level was seen with, which was the base line design with the fins extending out one insulator thickness or $\gamma = 1$. The maximum electric field for a 400 ns pulse width reached 173 kV/cm.

The second setup which showed similar results was with an added piece of stainless steel pressed to the top and bottom of the insulator. This was done in an attempt to reduce any ionization points formed by the gap between the insulator and the electrodes. The tests showed that this had no significant effect on breakdown leading to the conclusion that the insulators were compressed sufficiently. The maximum electric field reached 160 kV/cm.

The third setup was for $\gamma = 0$ or the case when the conducting fins were flush with the insulator. This case showed only a slightly lower breakdown field level. The simplification in cleaning and maintenance is significant and may show promise in many applications. However, there appears to be one major disadvantage in that the insulator is not shielded from stray electrons in the presence of a beam. This was not tested as part of this experiment but will certainly have an impact on accelerator application. The maximum electric field reached 165 kV/cm.

A final design which was tested was for the case when $\gamma = 3$ (the conducting fins extended three insulator thickness past the insulator). This configuration demonstrated favorable results. Two of the insulators in this series show high average electric fields in the range of 133 kV/cm to 145 kV/cm. A visible examination of the other insulators showed that the metal fins were warped during the fabrication process. There were obvious signs of fin to fin breakdown and burning with reduced standoff voltage. Further examination of the fabrication process will be needed to obtain a reliable insulator. The maximum electric field reached 150 kV/cm.

A base configuration was used as a control, the configuration consisted of a solid LEXAN insulator with the same ID and OD of a typical MicroStack. The results from two tests with this configuration varied considerable. The first time the insulator was tested the electric field did not exceed 80 kV/cm. After cleaning and re-assembly, the insulator was re-tested and reach a single point high of 133 kV/cm. The values were higher than expected and also higher than data reported by others².

Summary and Conclusions

In summary, the MicroStack insulators tested showed an improved hold-off voltage as compared to a conventional insulator. A maximum electric field was achieved of 160 kV/cm for a 2 us pulse as compared to 50 kV for a conventional insulator. The fabrication process and preparation process was simplified to that which would most likely be followed during the assembly of the DARHT accelerator.

There were no significant difference for insulators that were fabricated with no overhang of the conducting rings, $\gamma=0$. The easy in cleaning and maintenance is significant, however, there is no shielding from stray electrons, which may be unacceptable for accelerator applications.

After reviewing all of the insulator breakdown data it became evident that more electrode cleaning would be necessary for accurate results of insulator hold-off. Earlier experiments were conducted on insulator slugs which were mounted between two electrodes. The electrodes were glow cleaned between each insulator test, which would take from a single day to several days. The preparation procedure we used was much less exhaustive but more representative of what would be performed during DARHT assembly. The values of electric field were well above the reported value of 50 kV/cm for a conventional insulator for a 2 us pulse width. However, our own testing showed that one conventional insulator reached a value of only 20-30% less than the best MicroStack tested. This was probably a fluke and more testing would be necessary to determine this effect.

Further review of the data showed that each series tested had a higher average breakdown field. It is postulated that the electrodes were becoming better conditioned as more shots were fired. Many of the breakdowns that were observed during postmortem of the testing were seen to occur on the electrodes rather than the insulator it self. It is believed that many of the data points taken for the insulators represent the breakdown strength of the electrodes in vacuum and *not* the breakdown strength of the insulators.

Even when there was evidence of a breakdown on the insulating surface, it was near an obvious breakdown on the electrodes. The materials that were blasted from the electrodes and the high intensity of the UV that would be present that close to the insulator could easily have contributed to the insulator failure.

The insulators show an improved performance over conventional insulators and may offer many advantages when it comes to beam instabilities.

Sampayan and Elizondro¹² have reported recently that they have seen much higher voltage hold-off levels when increasing the number of layers into the double digits with a deposition process. They seem to indicate that there is an undetermined maximum that will be achieved as the number of layers is increased. We will have to wait for this data as the process is perfected.

REFERENCES

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2. Sampayan, S.E., et al, "High-Performance Insulator Structure for Accelerator Applications", 1997 Particle Accelerator Conference, Vancouver, Canada, 1997.