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A STUDY OF PULSE SURFACE FLASHOVER IN A VACUUM

By

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By

Vishnukumar K. Lakdawala*

INTRODUCTION

The phenomenon of breakdown in gases and in a vacuum has been the object of research of many workers for many years and is rather well understood. Excellent review articles and books are available on this subject (ref.1). However, the mechanism of pulsed surface flashover across solid insulators in a vacuum, which occurs in the nanosecond time regime, is not well understood. It only has been during the last few years that vacuum flashover has been extensively investigated. Interest in this kind of investigation is demonstrated by the fact that recent advancements in vacuum insulator technology have permitted extremely high-power density applications (ref. 2).

Solid-state switches are desirable for use in space systems from the point of view of reduction of size and weight. However, their application is limited to low-voltage systems only. For high-voltage space systems high-voltage vacuum switches are the obvious choice due to the fact that the natural and unavoidable insulating medium available in space is a vacuum. Also, all electrical systems in space inherently depend on this omnipresent medium for insulation. However, the mechanical design of any high-voltage vacuum device must inevitably incorporate an insulating member for supporting the high-voltage electrodes. Failure of high-voltage vacuum switches is often attributed to surface flashover across the insulating members. The dielectric strength of these vacuum switches used in space systems is often limited to a value of 500 volts due to surface flashover (ref. 3).

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The role played by the surface of the insulator in the breakdown performance of a vacuum gap (or switch) cannot be overemphasized. Even though the bulk insulating properties of a solid insulator are superior to those of a vacuum gap, the actual performance of a solid insulator is poorer than that of a vacuumm gap. A proper understanding of the surface flashover mechanism is therefore a key factor in the design and development of better high-voltage vacuum switches.

A uniform breakdown over the insulator surface is highly desirable for the production of high-density, high-temperature plasmas which find application in various z-pinch devices. However, in actual practice, nonuniform discharges initiated by filamentary surface flashovers are often encountered. An understanding of the physical mechanism responsible for this type of breakdown would probably lead to methods for obtaining more uniform discharges and may contribute to the advancement of vacuum insulator flashover technology in general.

An experimental investigation of pulsed surface flashover across solid insulators in a vacuum is reported. Two major aspects of investigation were carried out during the project period namely:

1. Investigation of pulsed surface flashover (single channel discharge) across solid insulators in a vacuum using image converter photography.
2. Schemes for obtaining uniform surface discharges (multichannel) across the insulator gap in a vacuum.

The first aspect is aimed to obtain a better understanding of the fast transition (in ns time regime) from the nonconducting to the conducting state of the vacuum gap. The second aspect is important from the point of view of its applicability in high voltage vacuum switches, which require homogeneous surface discharge for switching with a minimum inductance.

Experimental Apparatus:

The experimental apparatus used for the study is shown in Fig. 1. The system shown in this figure is a modified and improved version of the earlier system used by H. Isa et al. (NASA Grant NAG-1-332). The modifications and improvements are presented in brief in Appendix I at the end of this report.

RESULTS AND DISCUSSION

The significant findings of the experimental work performed during the project period are reported in two papers published in International Conference Proceedings, Proceedings of the 8th International Conference on Gas Discharges and Applications, Oxford, United Kingdom (ref. 4) and Conference on Electrical Insulation and Dielectric Phenomenon, Amherst, NY (ref. 5). These papers are included as Appendices II and III with this report. The reader is referred to these two appendices for a detailed discussion of the results of the research work carried out during the project period.

SUMMARY

In this research, we have observed the prebreakdown phenomenon of pulsed surface flashover across solid insulators in a vacuum using image converter photography. A very good time and space resolution has been obtained. In summary, it was found that visible light (low luminosity) is initially emitted from the cathode and the light front propagates at a constant speed of approximately 1×10^7 ms. This low luminous light is emitted until the gap is bridged by the bright light. The low luminous light has a banded structure (corresponding to the electron hopping distance

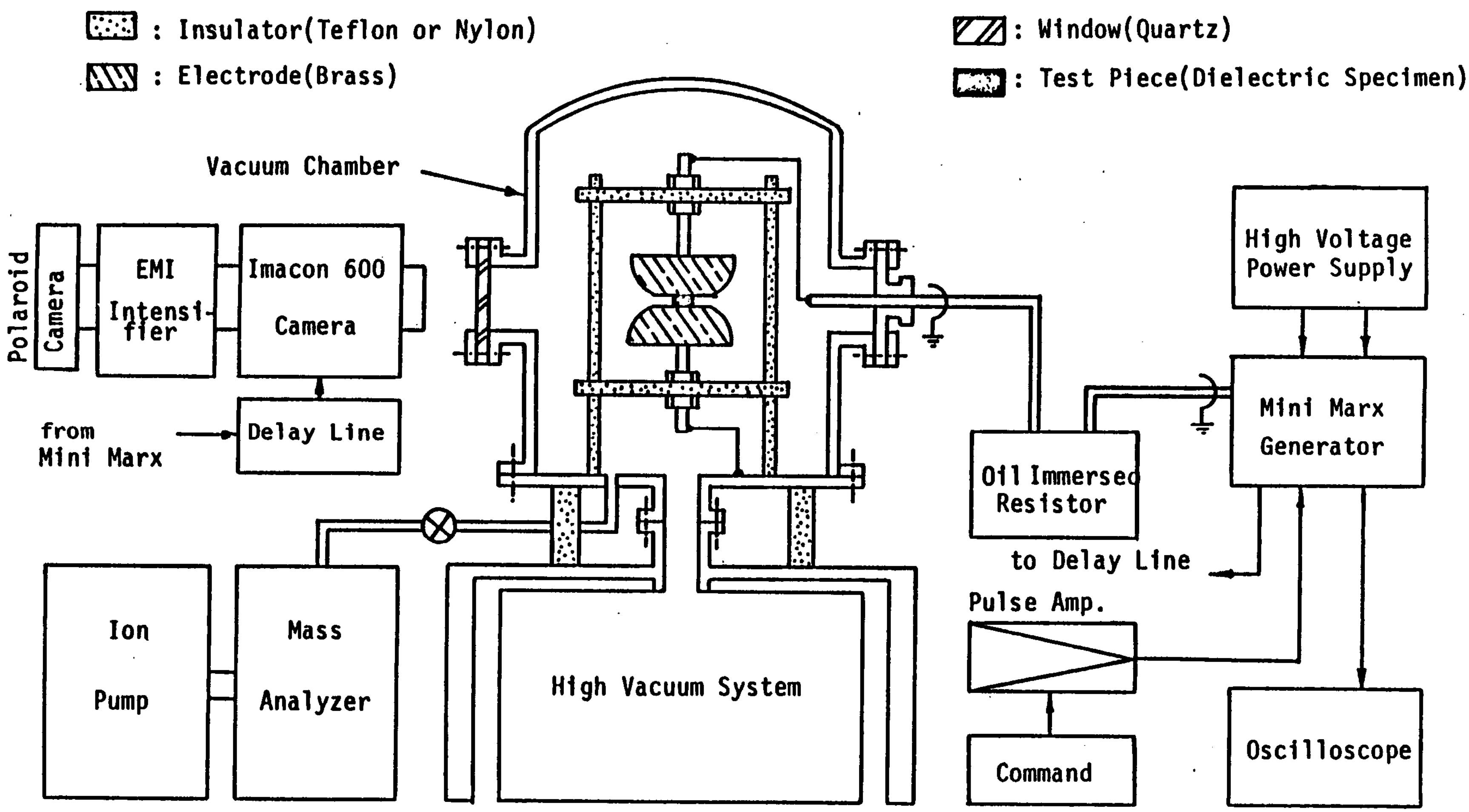
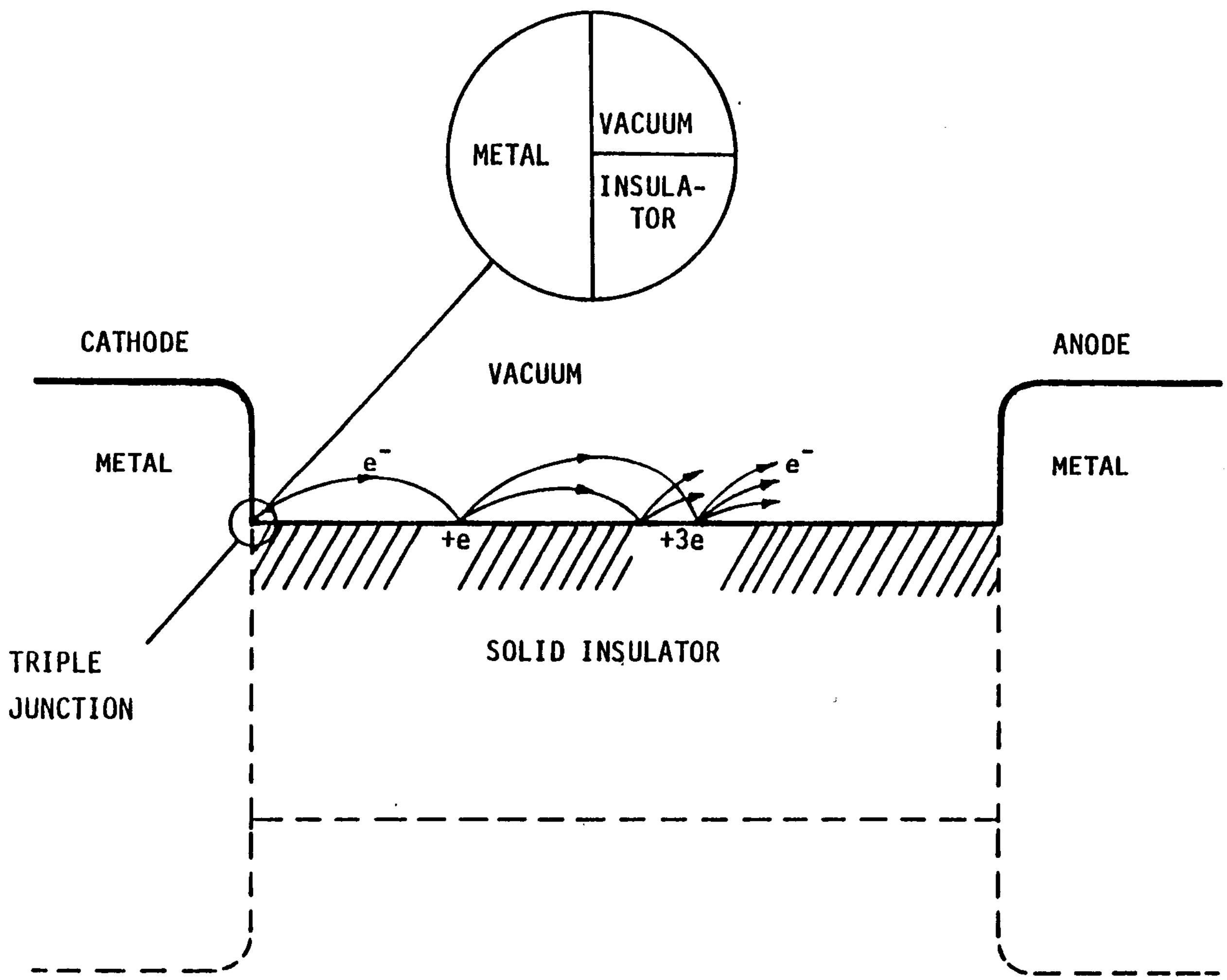


Fig. 1. Schematic Diagram of the Experimental Setup

as proposed in the theoretical model of flashover (ref. 6) (See Fig. 2), and the light intensity gradually increases as it travels towards the anode. The bright light starts from the anode and expands towards the cathode, bridging the gap within 0.5 ns.



FIG, 2: A THEORETICAL MODEL OF SURFACE FLASHOVER

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Appendix I

System Modifications and Improvements:

The following modifications and improvements in the existing system (used by H. Isa et. al., NASA Grant No. NAG1-332) have been incorporated during the period of the report.

1. The vacuum system was redesigned by improving the conductance of the pumping lines and eliminating the sources of virtual leaks inside the test chamber. An improvement in the base pressure by two orders of magnitude has been obtained (ultimate base pressure now is 4×10^{-4} Pa). No further improvement is possible without major changes, since the system cannot be baked, and also the only available high voltage feedthrough is a source of virtual leak.

2. For some test specimens much higher voltage was required for conducting breakdown measurements. The limiting factors are the connecting cable and the high voltage bushing. The bushing design has been altered and new bushing is incorporated on the system. However the only available cable has a limiting breakdown strength of 120 kV, hence the present measurements will be limited to 110 kV impulses.

3. The impulse generator had to be calibrated with a substandard. A 5 cm diameter sphere gap calibration arrangement has been designed and constructed. This is being used to calibrate the Mini Marx generator.

4. An existing quadrapole mass analyser and associated vacuum system has been acquired and connected to the test chamber. This was intended to observe any gas species desorbed from the surface of the specimen during and after flashover . This system has been made just operational. The preliminary mass scan of a gas sample taken from the test chamber is shown in figure 7. As is seen from the figure that the background spectra shows large peaks at mass 28(N_2, CO), 32(O_2) and 40(Ar) indicating that there is a leak on the main system. Even though a base pressure of 4 x 10^{-4} Pa is acceptable for carrying out breakdown studies and streak photography, it is essential to have a ultra high vacuum system if gas desorption measurements are to be made since these measurement involve detecting few hundred parts per million of desorbed species and hence very low base pressure (10^{-7} - 10^{-8} Pa) is desirable. Preliminary design of an UHV system is in progress.

5. An oil immersed current limiting resistor has been designed and constructed. This is installed in series with the gap so as to reduce damage to the specimen when breakdown occurs.