Electrostatic Analysis of Triggered Spark Gaps

INTRODUCTION

One of the major considerations associated with the overall performance of a high pressure trigatron is that of lifetime and this becomes particularly important for high repetition rate applications. The problems associated with short trigatron lifetimes are usually related to the erosion of the trigger pin due to successive arcing. Although the erosion per pulse will be dependent upon the specific operating conditions it will eventually lead to an insufficient level of field distortion in the main electrode gas region when triggered, resulting in poor switch performance. In order to maximize the lifetime of a trigatron switch whilst still maintaining good switching performance, an experimental programme was undertaken in which the preliminary design of the trigatron was determined through electrostatic field modelling.

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Andrew J. McPhee, Scott J. MacGregor & Steve M. Turnbull

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The level of field distortion present in a trigatron spark gap has been evaluated as a function of the trigger pin dimensions and position by employing electrostatic field modelling techniques. This has allowed the operating lifetime of the spark gap to be predicted by considering the range of trigger pin positions which would result in an acceptable level of field enhancement. Electrostatic profiling of the adjacent conductors and insulators has also been carried out, resulting in an overall switch design with optimised performance and minimal volume.

The above procedure has led to the production and testing of a 500kV triggered switch which has been operated successfully with a sub nanosecond jitter and relatively long lifetime. The final trigatron design also contains a small corona discharge cell which generates a negative ion population in the gas, which is SF_6. This ensures initiatory electron production through ion detachment resulting in sub-nanosecond jitter. In order to spatially optimise the overall switch design, electrostatic field analysis has been applied to all regions of gaseous and solid insulation in the switch,

Electrostatic Modelling of Low Jitter Trigatron

The electrostatic modelling software package Electro[1] was used to determine the electric field and potential distributions in the proposed geometry of the low jitter trigatron. This code was capable of evaluating the 3D electrostatic field distribution for rotationally symmetrical geometries. The initial field modelling studies were carried out using the simple uniform field switch geometry. The regions of interest in this analysis were the electric field distribution on the y-axis, the field along the high voltage electrode surface, and the field on the earthed electrode surface. As expected, the highest electric field is present along the y-axis for an applied potential of 500kV. It is on this axis that the trigger pin will be located in order to achieve maximum field. The first parameter investigated was the effect of the trigger pin diameter. For a given voltage, the effect of reducing the pin diameter results in an increase in the level of field distortion associated with the pin when triggered. However a consequence of minimising the pin diameter is to reduce the switch lifetime due to a more rapid erosion of the pin tip. Moreover the trigger pin dimensions must also conform to fabrication limitations. After considering these factors, a trigger pin diameter of 1.2mm was chosen to provide a balance between the degree of field distortion required and the predicted reduction in trigatron lifetime.

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Trigger Pin Modelling

Once the diameter of the trigger pin was determined, it was necessary to design a switch in which this trigger pin, when un-energised, had minimal effect on the electric field in the main body of the switch when 500kV was applied. Initially, an estimate was made of a uniform field gap incorporating a trigger pin. Thereafter, this geometry was modified and re-tested until the switch profile shown in Fig 1 was established.

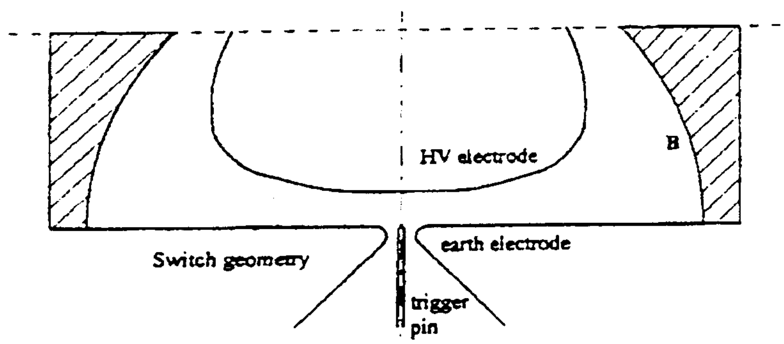
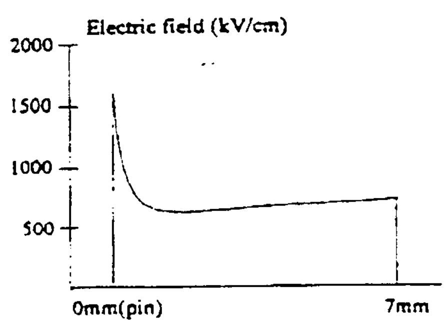


Fig.1

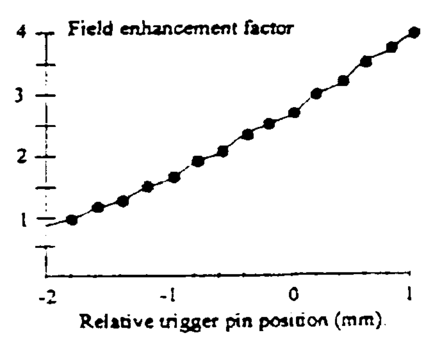
Analysis was carried out with the trigger pin flush with the lower electrode and set to 0V. These results demonstrated that the electric field across the main gap region is almost uniform in the presence of the trigger pin. The electric field along the surface of segment B (along the insulator inner surface) was also determined in order to ensure that the electric stress on the acrylic housing, which contained the electrodes, was acceptable The curvature and dimensions of the housing were designed to minimize the field along the inner surface. The field at the triple junction (gas, insulator and electrode interface), which is normally accepted to be one of the weaker points in any insulating system, was reduced to about 20% of the strength of the field in the main gap region when un-triggered.

Trigger Pin Position

The other variable considered in the design of the switch was that of the position of the trigger pin with respect to the inner surface of the ground electrode. This is important as the trigatron will not operate in the most efficient mode if the pin is not in a position to produce a sufficient level of field distortion on application of the trigger pulse. The E-field distribution of Fig.2, calculated for 500kV applied to the switch, shows an enhancement of the field on the grounded electrode by a factor of ~2.5 for the trigger pin lying flush with the electrode.



The electric field distribution between the trigger pin tip and the upper electrode with the pin flush mounted with the earthed electrode.
Fig 2



The field enhancement at the trigger pin relative to the uniform field as a function of the trigger pin position.
Fig.3

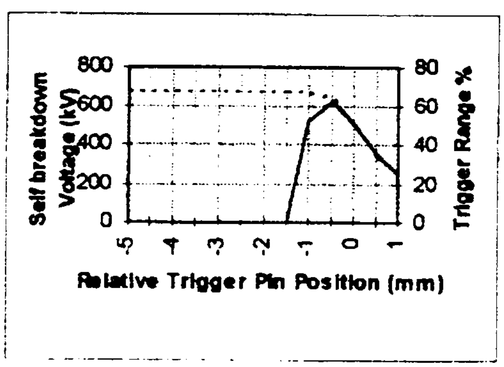
The results shown in Fig.3 display the variation of the electric field at the tip of the trigger pin, expressed as a factor of the uniform field strength, with vertical position. It can be seen that a recessed trigger pin position of between 0.3mm and 0.7mm results in an enhancement of the main gap field of between ~130% and 70% respectively. Although it is not generally a problem to have some degree of field enhancement from the trigger pin, which usually facilitates a rapid trigatron operation when energised, too much enhancement can result in the self-breakdown voltage of the gap being reduced significantly. Therefore, a compromise design position for the trigger pin of 0.5mm below the surface of the earthed electrode was selected, which produced an enhancement of ~2.

The final aspect of the design procedure was to check that there were no excessively high field sites present which could reduce the effective operation of the switch by lowering the self-breakdown voltage. All of these analyses were carried out with the trigger pin at zero potential. The field along the surface of the earthed electrode was also examined for the 0.5mm recessed pin. This was carried out to ensure that the field decayed radially, at a sufficient rate, from the spark axis. The field distribution form the pin tip to the high voltage electrode along the axis of rotation was found to show a relatively uniform field across the main portion of the gap with the field increasing to more that double the uniform field value at the pin tip.

Experimental Trigatron Evaluation

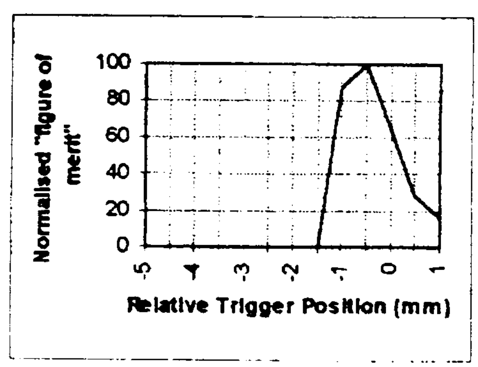
In order to verify the above design, experimental testing of the switch was required and a detailed account of the results of the low jitter testing of this switch can be found elsewhere[2]. The switch has been successfully operated at voltages of up to 500kV, the specified design level, and triggered with a 40kV voltage pulse. Initiatory electrons in the trigatron pin region were supplied by a pre-ionising corona source[3] which resulted in sub-nanosecond jitter performance.

The optimum operating position for the trigatron is a compromise between sustaining a relatively high self-breakdown voltage when un-triggered and achieving trigatron breakdown over as great a dynamic range as possible. This will result in an efficient high voltage switch with the ability to trigger down to about 40% of self-breakdown voltage. When combining such a switch with the corona induced negative ion source this results in high voltage, low jitter operation over a significant voltage range. The measured self-breakdown voltage and the triggering range of the spark gap switch are shown in Fig.4. The operating curve for this trigatron will be the product of these two factors and is estimated in Fig.5. This shows the switch with a 100% "figure of merit" for a -0.5mm pin position, falling to 50% for -1.2mm and +0.2mm, it would be undesirable to operate outside this range. This triggering range was found to be consistent with that predicted from the electrostatic model. Given the overall switch performance coupled with the requirement for a reasonable lifetime, the predicted position of 0.5mm below the surface is in good agreement with the experimental results.



The trigger range of the trigatron and the variation of the self-breakdown voltage of the trigatron as a function of the position of the trigger pin.

Fig.4



Trigatron operating curve with arbitrary "figure of merit"

Fig.5

Conclusions

An electrostatic modelling procedure has been used to model and design a high voltage trigatron. This procedure involved modelling the electrode and insulator profiles to produce a switch with minimised volume, long lifetime and optimised performance. The procedure has been used in the design of a trigatron spark gap which has been operated at voltages of up to 500kV with subnanosecond jitter. The model predictions of the triggering range of the switch and the optimum trigger pin position have been experimentally verified. This information has also been used to estimate the maximum operating lifetime of the switch with a switch operating curve being derived for this particular trigatron. The jitters performance of the switch has been measured experimentally for both single shot and repetitive operation (for PRF's of up to 100pps) and good agreement has been observed.

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