Arc control systems for AMF high voltage vacuum interrupters - modeling the contact gap

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***Abstract-* At present there is a clear trend for vacuum circuit breakers to move up in voltage class from distribution voltages to transmission and sub-transmission voltages.**

Developing new vacuum interrupters for these voltages poses a number of challenges, not least the requirement to interrupt large short circuit currents at high voltages. This requires the development of new arc control systems which are effective at the large contact gaps necessary for these high voltages and also have relatively low resistance when closed. The paper forms part of a study examining the design challenges in extending the operation of existing geometries to higher voltages suitable for the larger contact gaps necessary for systems up to 245kV, and in particular investigates the effect of large contact gaps on the magnetic field which is used to control the arc. This paper concentrates on the Axial Magnetic Field (AMF) type of arc control systems. The alternative Radial Magnetic Field (RMF) type of arc control for this application will be the subject of a future paper.

INTRODUCTION

A. *Overview of the Problem*

The vast majority of Vacuum Interrupters today are used at Medium Voltage levels up to 40.5kV, although significant numbers have been used at higher voltages such as 72.5/84kV and more recently in the 132/145kV range [1]. Many of these higher voltage circuit breakers use a single vacuum interrupter to perform the switching operation and also to provide the full isolation for BIL. But as the voltage to be interrupted increases, it becomes necessary to increase the open gap between the contacts to provide sufficient insulation, and this in turn brings its own problems. The present AMF contact designs work by using the large magnetic fields generated by the short circuit currents to control the arc between the contacts and prevent it constricting which would lead to overheating of the contact surfaces and a dielectric failure of the gap which would cause a failure to interrupt [2] [3]. However, the contact designs use special geometries which are behind each contact surface in order to generate these fields [4]. For small contact gaps these "coils" generate magnetic fields which work together to give a significant axial magnetic field in order to prevent arc constriction. As the contact gaps become larger there are three critical points as shown in Figure 1

Firstly when the contacts are touching the magnetic field generated from the coils on each contact work together to give a maximum magnetic field at the contact surface (Position 0).

Then as the contacts move apart there is a point (Position 1) where the magnetic field from contact A no longer adds significantly to the magnetic field on contact face B, and vice versa.

Finally there must come a point where the fields from the two contacts no longer significantly interact within the gap (Position 2), and in fact for larger gaps than this a zone of low magnetic field between the contacts will form.

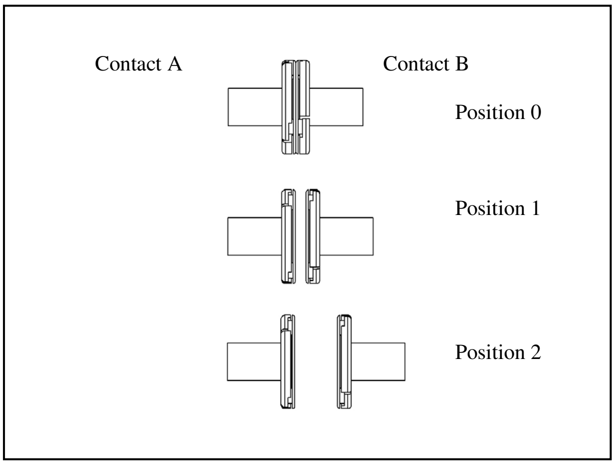

Fig. 1. The critical positions of the contact gap

Previous researchers have shown that it is necessary to have a significant axial magnetic field in order to prevent constriction of the arc [5]. A number of researchers have investigated longer gaps for high voltage interrupters [6]. Our interest is the shape of the magnetic field developed between the contacts with contact gap, and how this interacts with the arc.

In order to investigate this we plan to take a two step approach. The first step is to model the magnetic fields generated by a typical AMF contact geometry, using a five dimensional mathematical model (x space, y space, z space, time & motion) and to establish at what point the magnetic fields from the two contacts cease to interact significantly at the contact surfaces, and also cease to interact significantly at all. The second step is

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then to perform short circuit current interruption tests on identical contact geometries using a high speed camera to investigate the effect of this "field gap" on the actual arc behaviour, and which will be the subject of a later paper. The results of the first step are reported here.

II. The Modelling

For this work we decided to use a three legged "Wheel" style AMF contact, as shown in Figure 2.

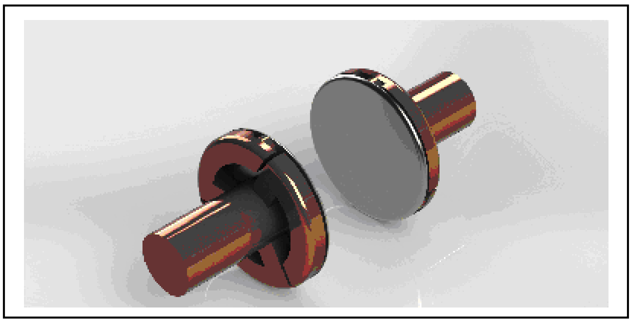

Fig. 2. The AMF contacts to be modelled

This type of contact has been widely used in vacuum interrupters at medium voltages and is now being used at high voltages. The contact modelled is 75mm in diameter using Cu Cr contact material, and we used a simple conductive model of the diffuse arc to provide the current circuit. The modelling was performed with the contact being drawn in Solidworks and the arcing model created using MagNet software. The model can be seen in Figure 3.

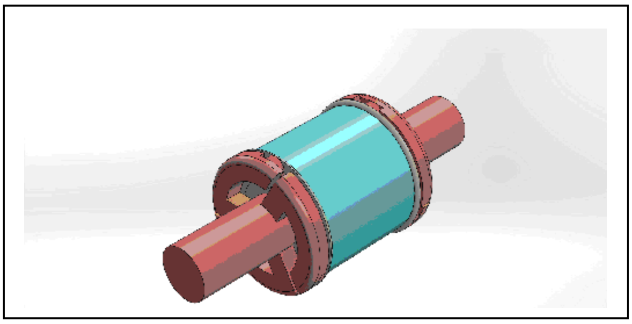

Fig. 3. The model of the contacts including the diffuse arc

The modelling was in 3D and all calculations included a full half cycle of power at 31.5kA, with contact opening speed at 2m/s.

In order to present the data it is necessary to slice the model and to view segments of data. For this paper the data selected was two sections of the model, taken at right angles in the axis of the contacts and showing the magnetic field across the full diameter of the contact, together with three slices taken radially, at each contact face, and at the centre of the gap, as shown in Figure 4.

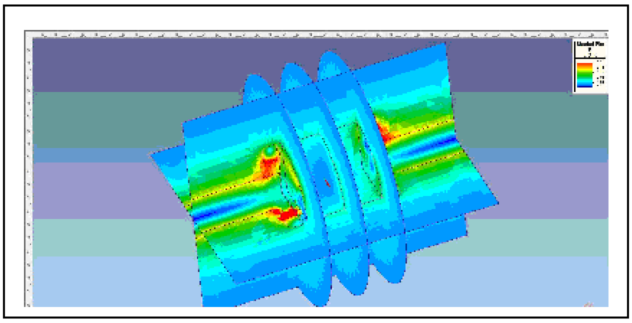

Fig. 4. View of the model showing "slicing of data"

III. The Results

Figure 5 shows that, as predicted, the magnetic field at the contact surface reduces from a maximum at contact touch, to an asymptotic value where the opposite contact no longer affects the field at the contact surface. This was determined to be at around 20mm gap, indicating that for larger gaps each single contact must provide sufficient axial magnetic field to prevent constriction of the arc.

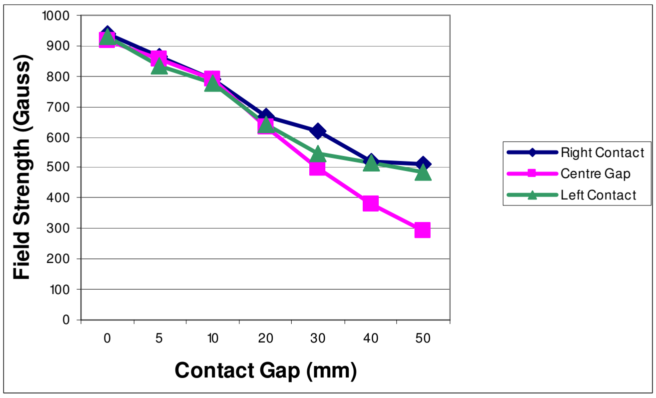

Fig. 5. Graph of the change in axial magnetic field in the centre of the contact surface as the contact gap is increased

As the contact gap is increased further the field at the centre of the gap reduces until the field is below 300 Gauss. This is clearly seen in Figures 6 to Figure 14. A clear "zone" of low field appears where the magnetic field reduces to a low level. As the contact gap is increased further this zone increases in size, both axially and in diameter. The figures show the contacts at different separations, but each with the peak current for 31.5kA rms.

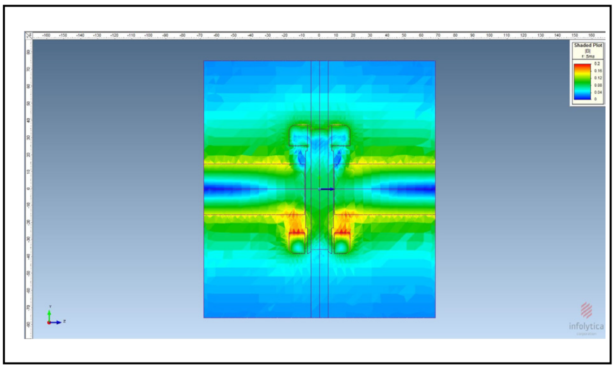

Fig. 6. View of the model showing the axial magnetic field with the contacts separated by 10mm

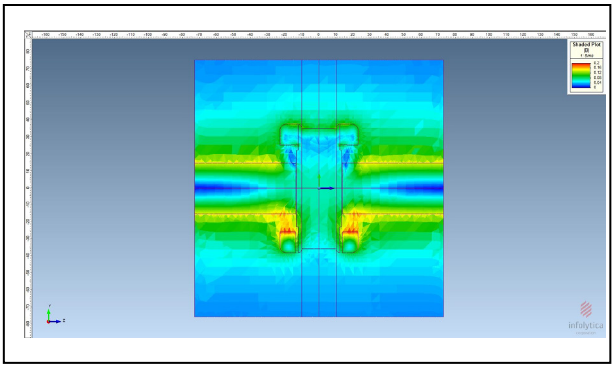

Fig. 7. View of the model showing the axial magnetic field with the contacts separated by 20mm

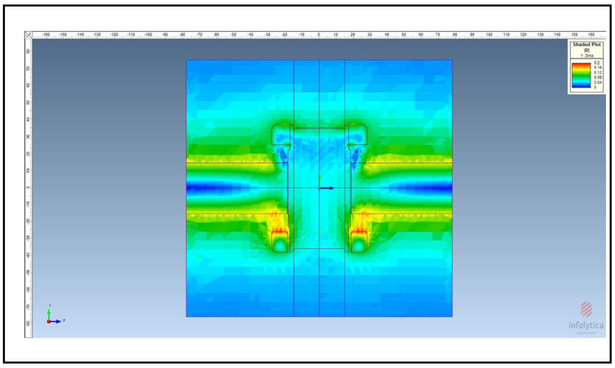

Fig. 8. View of the model showing the axial magnetic field with the contacts separated by 30mm

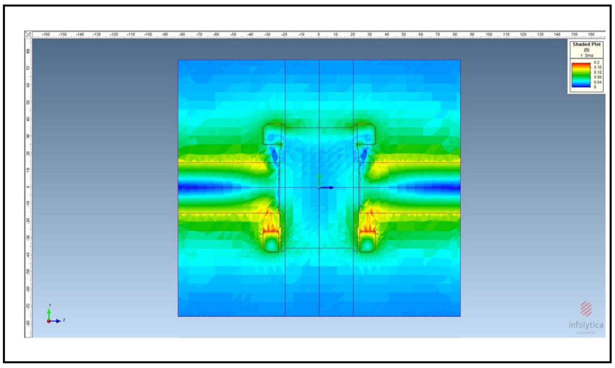

Fig. 9. View of the model showing the axial magnetic field with the contacts separated by 40mm

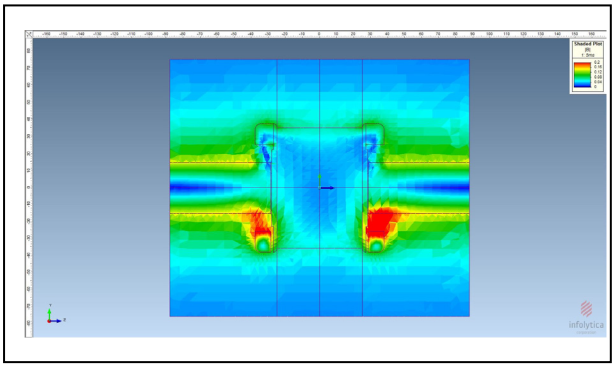

Fig. 10. View of the model showing the axial magnetic field with the contacts separated by 50mm

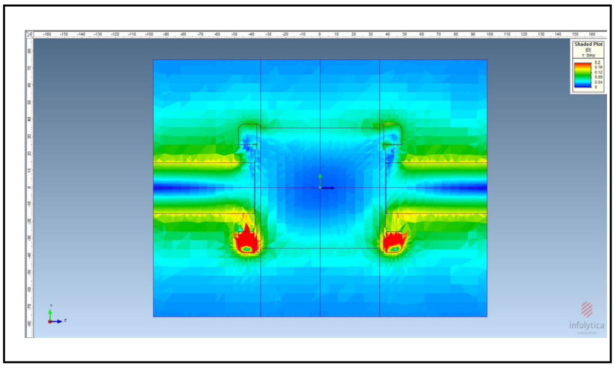

Fig. 11. View of the model showing the axial magnetic field with the contacts separated by 70mm

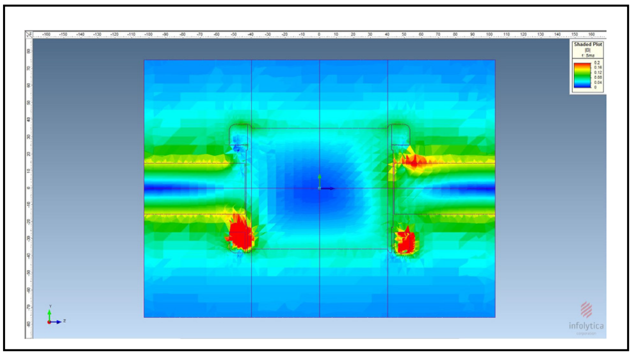

Fig. 12. View of the model showing the axial magnetic field with the contacts separated by 80mm

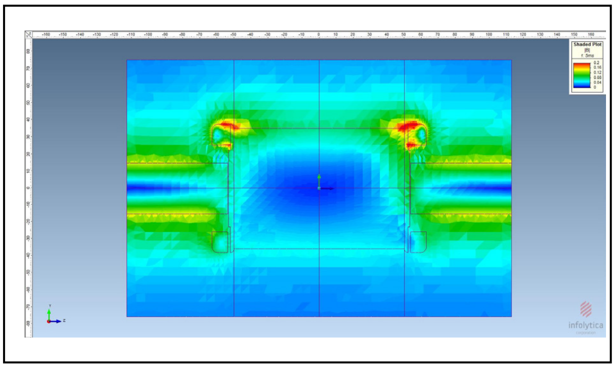

Fig. 13. View of the model showing the axial magnetic field with the contacts separated by 100mm

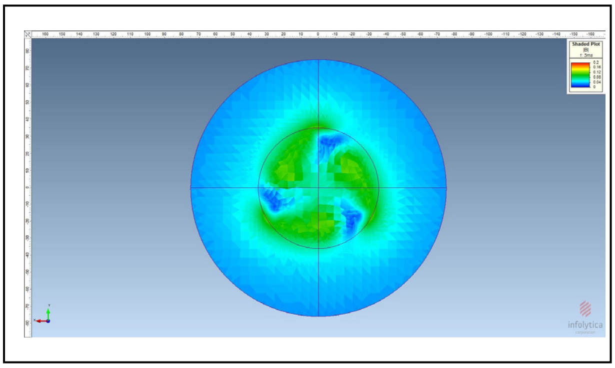

Fig. 14.The magnetic field seen at the contact surface

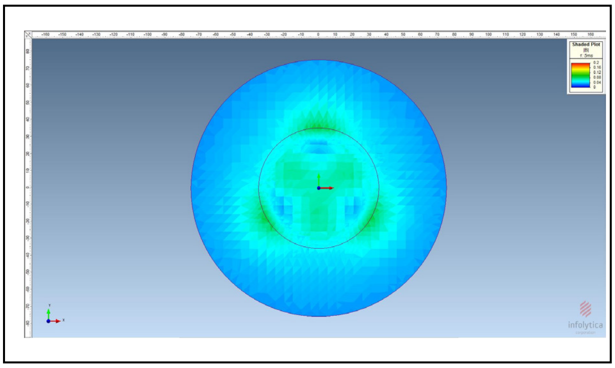

Fig. 15.The magnetic field seen at the centre of the gap with 20mm contact gap

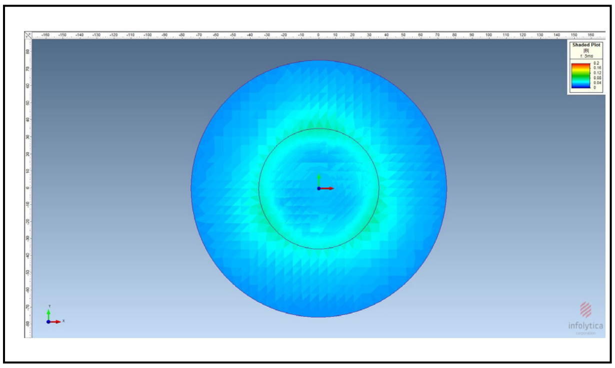

Fig. 16.The magnetic field seen at the centre of the gap with 40mm contact gap

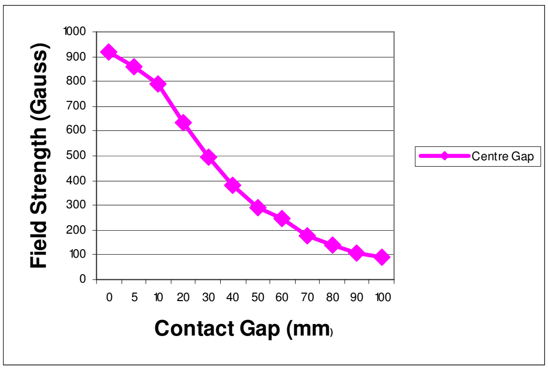

Fig. 17.The magnetic field seen at the centre of the gap

IV. DISCUSSION

Figures 6 to 12 show the contact gap increasing from 10mm contact gap to 70mm, after 30mm a low field zone appears in the centre and this zone is seen to expand and become stronger as the gap increase. Figures 14 to 18 show the same fields but sliced in a radial direction. Figure 14 shows the magnetic field at the contact surface and Figures 15 & 16 show how the field reduces as the contact gap increases and an almost field free zone is created in the centre of the gap. Figure 17 shows how the field in the centre of the gap reduces with gap distance until it becomes effectively negligible.

As predicted the results show that increasing the contact gap significantly reduces the axial magnetic field strength, both at the contact surface and in the contact gap. Once the contacts separate the effect of the magnetic field from the opposite contact drops rapidly until at a quite small distance it ceases to be important.

As the contact gap is increased further then the axial magnetic field in the centre of the contact gap continues to reduce eventually to a very low level, creating a low magnetic field zone between the contacts.

Based on these results the next question is, " Does this lack of axial magnetic field in the centre of the contact gap have a significant effect on the arc control and subsequently on the interrupting performance of the vacuum interrupter?"

V. FURTHER WORK

The next step in this work is to perform short circuit testing on the modelled contacts using a high speed video camera to evaluate the effect of the contact gap on the form of the arc. The intention is to relate the calculated fields with the physical phenomena seen and to establish if there is a maximum contact gap at which this type of contact is effective.

VI. REFERENCES

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