THE DESIGN OF HIGH POWER VACUUM INTERRUPTERS WITHOUT THE USE OF METAL VAPOUR DEPOSITION SHIELDS OR VOLTAGE GRADING SHIELDS.

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Abstract

A study was performed to investigate the role of metal vapour deposition shields and voltage grading shields in high power vacuum interrupters.

The devices selected are required to hold off power frequency voltages of up to 50kV (rms) (50-60 Hz) and also lightning impulse voltages in both polarities of up to 95kV (crest) (1.2/50 micro second waveform). This level of performance must be maintained after many switching operations at up to 20kA (rms), which is a particularly onerous duty resulting in very high levels of metal vapour deposition on internal surfaces after arcing.

The original study led to the concept of building devices without including metal vapour deposition shields or voltage grading shields. This was investigated and successfully carried out by means of specially shaped Alumina ceramic insulators which were designed to protect sections of their surfaces from the effects of metal deposition which otherwise would have led to significant degradation of the voltage withstand capabilities of the insulators. This geometry also included protection for the triple junction giving improved voltage withstand capability at either polarity, resulting in a substantially simpler and smaller 'shieldless' vacuum interrupter, which did not suffer degradation in voltage performance even after large numbers of arcing operations.

Introduction

Vacuum interrupters have now been in service in distribution switchgear worldwide for over twenty years [1]. The interrupters constitute the key high technology component of the switchgear, and utilise the properties of the high energy power arc in vacuum to control and provide interruption over a wide range of system voltages and short circuit ratings [2]. The design and construction of these devices has been widely published and discussed [3], however, all designs to date have one common aspect in that they incorporate a metal vapour deposition shield in order to protect the insulating envelope from the effects of metal vapour deposition from the power arc. This paper describes recent advances made in the design of vacuum interrupters utilising a new concept whereby a metal vapour deposition shield was no longer necessary and in fact by careful design a substantially simplified device was constructed.

Discussion

The construction of vacuum interrupters follows a fairly standard layout and although devices differ in details of design and construction their overall layout tends to be as shown in Fig.[1], this is an interrupter with insulators which may be made from Alumina ceramic or glass but their function is identical in that they are required to provide both a vacuum wall and an electrically insulated zone capable of holding off the applied voltage and any lightning impulse withstand requirement in air externally and in vacuum on the internal surface.

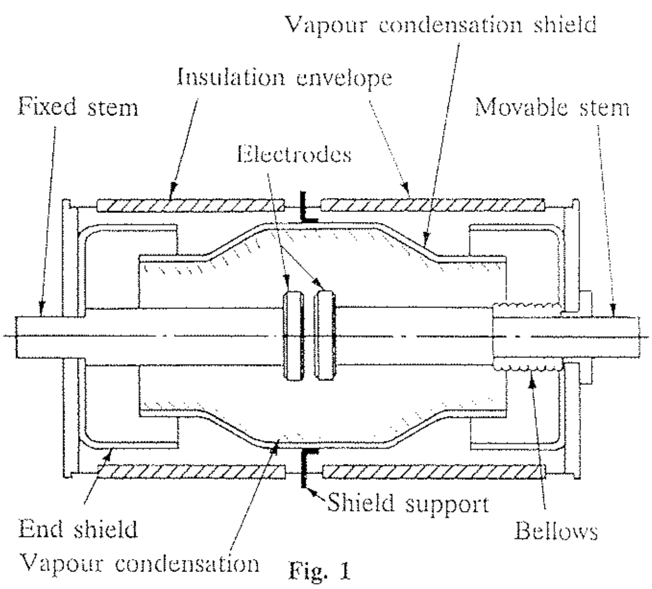

Fig. 1

Basic construction of a typical vacuum interrupter.

In order to protect the inner surface from the effects of the vacuum arc - specifically the deposition of metallic vapour onto the surface, a metal shield is hung in position to provide this protection. Normally also a pair of voltage grading shields are mounted at either end which de-stress the triple junction where the metal end caps are connected to the insulators. These voltage grading shields allow the capability for high power frequency voltages and high lightning impulse levels to be withstood in a relatively small device.

Theoretical Concept

Our first move was to study the role of the insulator and this shield arrangement from first principles. The reason for the relatively long insulator is the poor dielectric strength of air compared to vacuum. If the device had vacuum both sides of the insulator then it would be possible to design a unit with a substantially reduced insulator and in this sense a large part of the internal surface of the insulator is wasted. Interrupters designed for use in other dielectric media than air, such as SF6 or oil use this principle to allow slightly smaller devices. A secondary role of the vapour deposition shield is to prevent damage to the ceramic from the high energy vacuum arc. This is a function of the arc control regime used by the interrupter and these vary substantially from design to design. However, a well controlled arc should not cause severe damage to the shielding and if the interrupter is correctly designed this requirement should not be necessary. Similarly the voltage grading shields are required to provide a reduction in the field stress at the triple junction on the insulator as well as providing evenly distributed stress throughout the insulation or body. Although effective this can be performed in other ways which are simpler and eliminate the need for these extra components. [4].

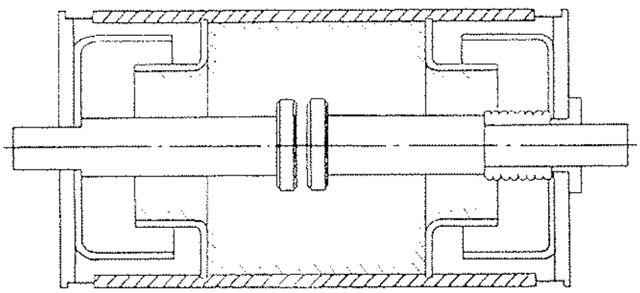

Fig. 2
Concept of partially protected insulator.

Out of this theoretical investigation came the concept that if in some way a small proportion of the insulators internal surface could be protected from the metal vapour deposition, then a simpler more easily constructed device could be devised. Shown diagramatically in Fig. [2]. This concept allows metal vapour to cover most of the insulator while protecting the end sections giving an adequate zone in vacuum in order to withstand any applied voltage. This concept evolved into a single piece ceramic as shown in Fig.[3], whereby internal folds within the ceramic surface protect areas of the surface allowing the insulator to withstand applied voltages even after many switching operations resulting in very high levels of metal vapour deposition.

Experimental Results

We initially performed tests on a glass ceramic bodied device incorporating partially shielded surfaces as shown Fig. [4]. From this we established that the pattern of vapour deposition tended to show a rapid reduction in intensity with distance from the arc,being eventually restricted to line of sight from the power arc with some slight tendency to deposit material at the edge of concealed areas. This result was crucial to the concept of a practical "shieldless" design and also led on to the possibility of eliminating the voltage grading shield.

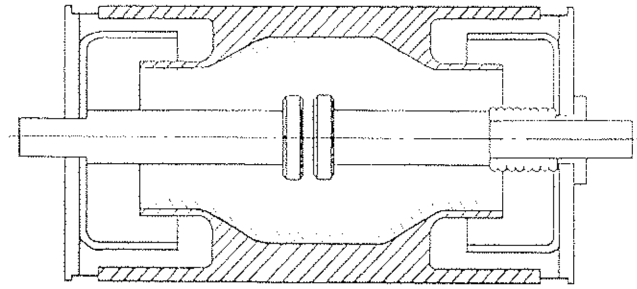

Fig. 3
One piece self shielding ceramic.

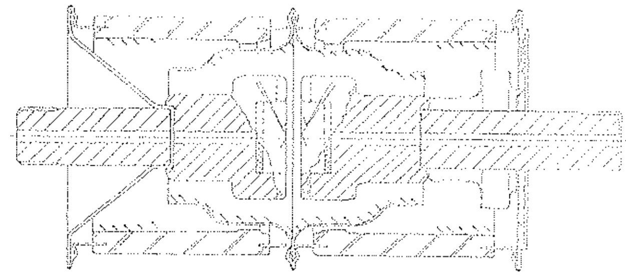

Fig. 4
Experimental partially shielded device.

This effect supported the concept of an insulator which protected areas of its own surface by means of a folding of the insulator. Several possible configurations were considered as shown Fig. [5] but eventually the design type C was selected as being the most practical in that it was not too difficult to manufacture and it had the added advantage that the inner surface exposed to metal deposited vapour deposition would build a metallic pseudo-shield from the vapour with a very similar geometry to that of the classic metallic shielded device. This was useful in that once a metallic pseudo-shield was deposited it assisted in the action of the normal process of vacuum pressure measurement whereby a magnetron discharge is induced between the contact and shield, followed by a reverse discharge from the shield to the second contact, current flowing being proportional to the pressure [5].

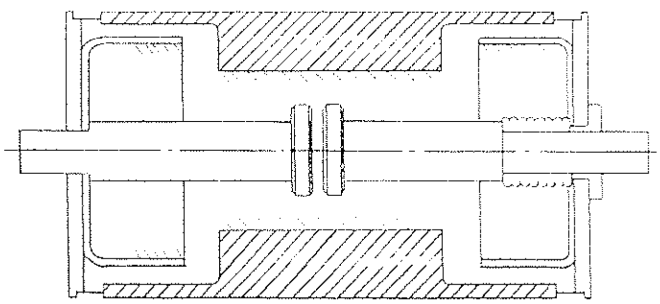

Fig. 5A

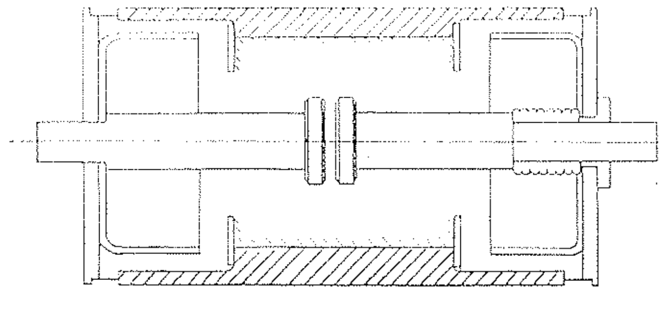

Fig. 5B

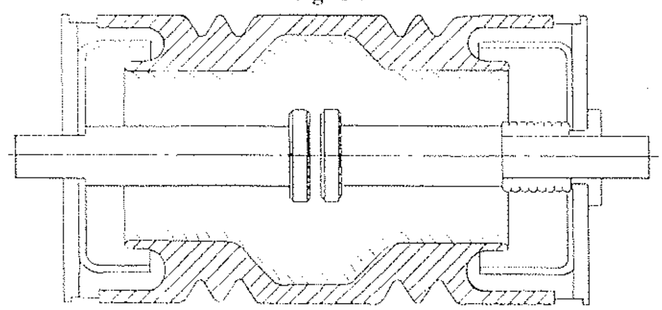

Fig. 5C

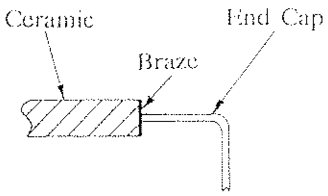

Fig. 6A Normal Braze

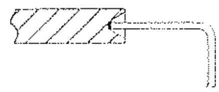

Fig. 6B Pseudo Embedded Braze

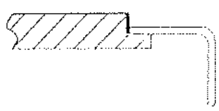

Fig. 6C Shielded Braze

Our original experiments were very successful proving that deposition did not occur significantly in the concealed areas of the insulator despite many operations at currents of from a few amps up to 20kA rms, as are service requirements for these devices. However, the triple junctions at the end of the insulators needed either voltage grading shields or enhanced protection as they are quite highly stressed by this configuration. In order to cope with this problem we looked very carefully at the triple junction geometry and considered several possibilities to overcome this problem, some of which are shown in Fig. [6].

The simplest practical geometry was to provide a stepped ceramic in which the ceramic itself provided a screen to the triple junction, removing the sharp edge from the metallised brazing layer and improving the voltage field stress as shown Fig. [7]. As can clearly be seen the maximum stress appears across the small contact gap, with the ceramic being quite lightly stressed. The results shown in Fig. [8] emphasise the level of improvement seen with this shielded braze geometry as opposed to the normal braze geometry. The improvement in voltage performance seen after arcing on type 6C is due to surface conditioning of the contacts.

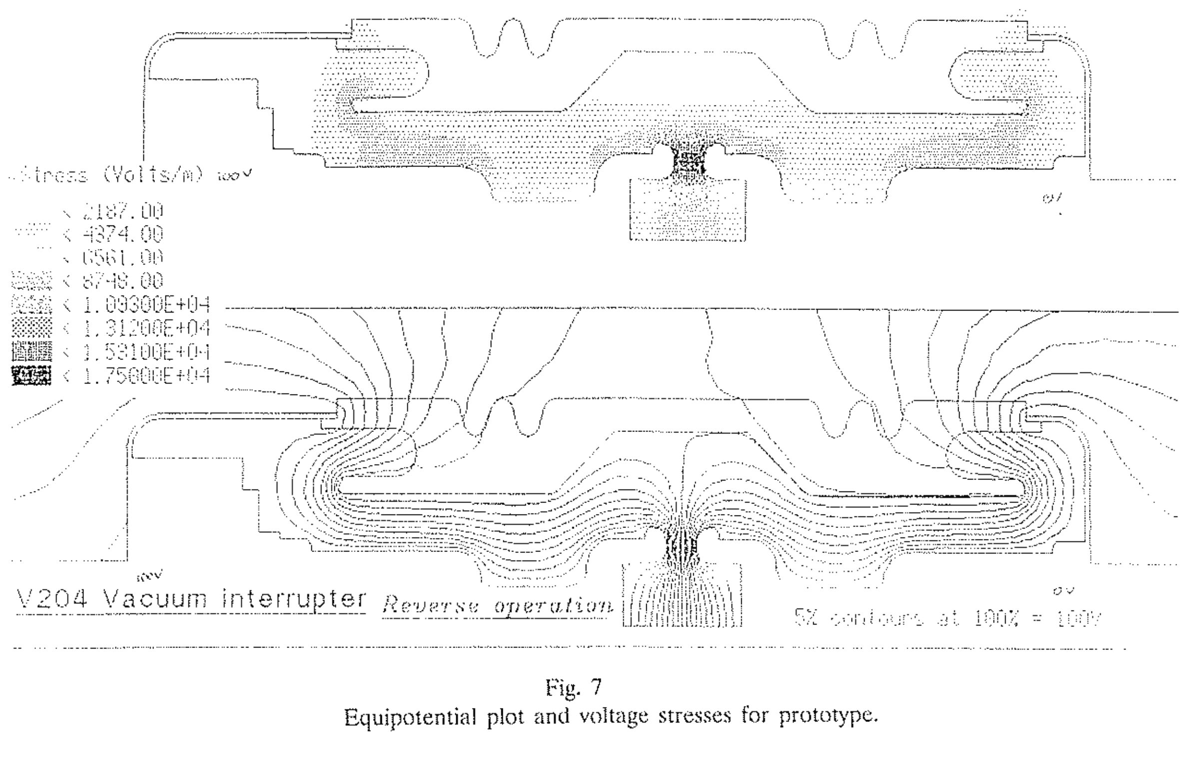

Fig. 7
Equipotential plot and voltage stresses for prototype.

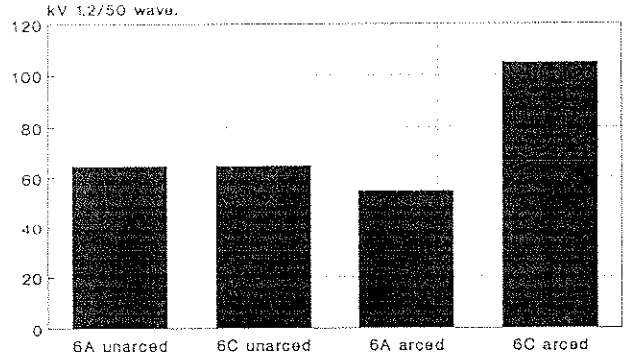

Fig. 8
Voltage performance of devices using 6A and 6C geometries.

Once prototypes had been built and the concept tested, the units were subjected to extensive short circuit testing at up to 20kA rms and test voltages of up to 50kV rms 50Hz as well as lightning impulse voltages in both polarities of up to 105kV crest on a 1.2/50 micro second waveform. It was established that with the geometries used no significant degradation in dielectric performance was found even after building very high levels of deposited material on the internal surfaces as shown. Fig. [9]. This insulator has seen many operations at low currents together with twenty operations of 10 millisecond duration, 20kA (rms).

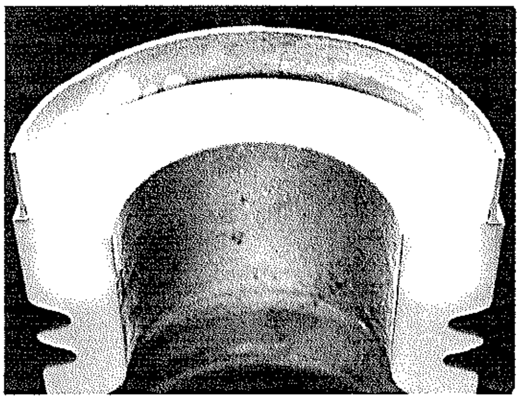

Fig. 9
Vapour deposition on ceramic after heavy arcing.

Summary

The inclusion of these concepts in vacuum interrupter design resulted in a substantially simpler and smaller device as can be seen from Fig.[10]. The device on the left is a prototype using the new "shieldless" concept, the interrupter on the right is an older design using classic shield geometries and glass ceramic insulators.

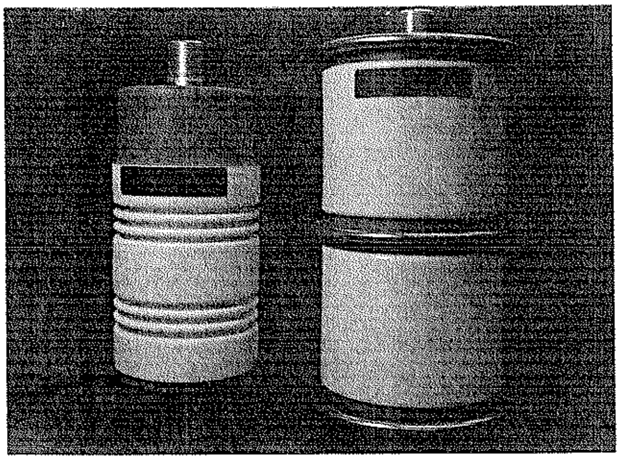

Fig. 10
New "shieldless" interrupter and "classic" interrupter.

The new design interrupter has many advantages over the classic design, not least in removing two or three vacuum seals from the product as well as reducing tolerance and assembly problems in mounting a metallic shield from the insulator(s). We followed this principle of maximum simplicity by designing the device to be totally self jigging allowing us to perform the assembly and seal off brazing operation in one furnace run, as opposed to the normal procedure of multiple braze runs utilising sub assemblies.This in turn was made possible by the development of a new arc control geometry [6]. The overall effect is a substantially smaller, simpler, device manufactured at lower cost than its predecessors.

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