THE EVOLUTION OF VACUUM INTERRUPTER ARC CONTROL SYSTEMS

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INTRODUCTION

The paper is intended to give a very basic introduction to vacuum interrupter technology sufficient to allow an understanding of the technology and its strengths and weaknesses, and its current and future evolution. The paper concentrates on arc control and contact materials as these are the key features, which to a great extent determine the performance of the interrupters.

VACUUM INTERRUPTER TECHNOLOGY

Basic Design

Vacuum interrupters today come in a range of shapes and sizes. But they all have a number of design features in common [1]. Figure 1 shows a cross section of a typical vacuum interrupter.

Figure 1. V8 type interrupter from VIL (AREVA) from the 1980's rated at 12kV 25kA 1250A.

As can be seen the interrupter consists of cylindrical insulators normally of Glass or Ceramic to which are attached metal shields. These shields protect the interior surface of the insulators from damage from the arc during interruption, and most importantly prevent metal vapour from depositing on the surface, which would then degrade the dielectric strength of the insulators.

The interrupters have two contacts, one fixed and one moving. In a Vacuum Interrupter, which has fault interrupting capability, these have a special geometry which allows the interrupter to interrupt

The moving contact is moved by the switchgear mechanism during a switching operation, to form a gap of between 6mm and 24mm depending on the interrupter and system voltage.

Currently vacuum interrupter designs use a range of arc control systems ranging from no arc control – (diffuse arc system for low currents), to a number of Radial Magnetic Field (RMF) systems, and Axial Magnetic Field (AMF) systems using both internal and external methods of generating the necessary magnetic fields. In addition today a range of contact materials are used to provide the optimum interrupter performance. This performance can be significantly changed by using a different contact material, a subject which will be discussed later.

THE VACUUM ARC

Arcs in Vacuum exist effectively in four forms, two natural, and two forced. Interruption in vacuum always occurs at a current zero, and can be seen to be a dielectric race whereby the ability to interrupt is determined by the speed with which the Transient Recovery Voltage (TRV) appears across the open gap versus the increase in dielectric strength of the contact gap. If the strength recovers fast enough then the device will interrupt [2].

Natural Diffuse Mode

At low currents (<7kA) the arc in vacuum is naturally diffuse and spreads itself over the cathode, with the cathode spots repelling each other as seen in Figure 2.

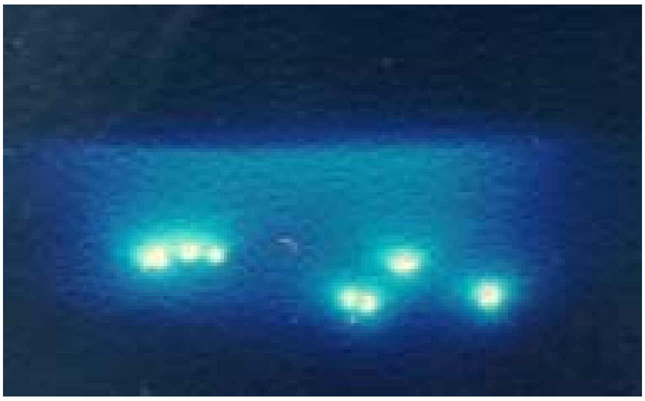

Figure 2. Natural Diffuse Mode. High speed film @ 10,000 pps on plain butt contact 200A@12kV.

Under these circumstances the energy of the arc is spread quite evenly over the contact surface, there is no overheating, and the interrupter or switch has no difficulty in interrupting at the next available current zero. Therefore Vacuum Switches which have limited fault current interruption capability and are supported by fuses, normally have plain butt contacts which allow the arc to diffuse naturally at their rated currents, and rely on the fuse to interrupt the higher currents.

Natural Constricted Mode

At higher currents however, things change. Above about 7kA the arc naturally constricts to a slim column. This means that now all of the arc energy is concentrated over an area of a few square millimetres. As a result at current zero the surface temperature locally is very high, and the surface consists of boiling contact material. This gives off metal vapour which destroys the vacuum between the contacts and significantly reduces the dielectric strength. As a consequence the dielectric strength of the gap is too low to hold the TRV and the device will restrike. Figure 3.

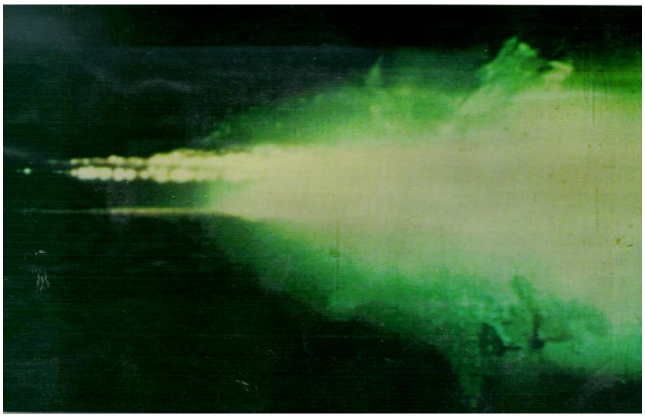

Figure 3. Plain butt contact carrying 5kA@12kV Boiling Copper and Chromium can be clearly seen.

Radial Magnetic Field

Although fuse devices are fine for contactors, and fuse switches, in circuit breakers it is necessary for the interrupting device to interrupt all currents up to the highest fault level. In order to do this in vacuum it is necessary to prevent the natural constriction of the arc from overheating the contact surface. The original and still most popular method is to apply a magnetic field radially to the axis of the arc. This allows the arc to constrict, but makes it move. Basically it acts as an electric motor, with the arc playing the part of the armature. This prevents the arc from overheating the contact surface by spreading the heat over the contact. In 10 mS the arc may make up to four revolutions of the periphery of the contact.

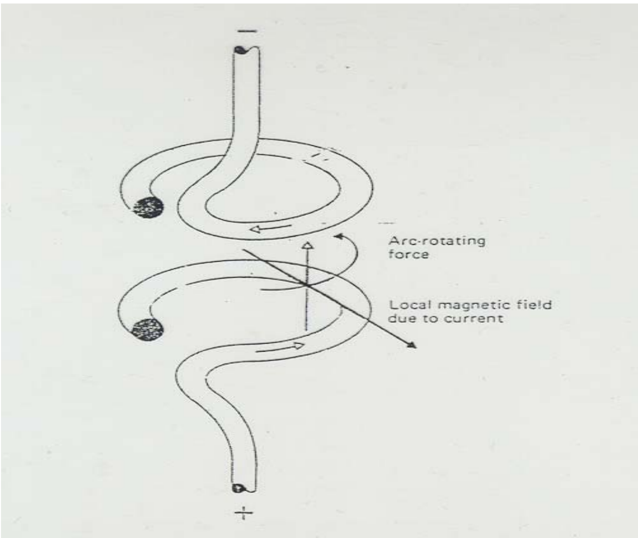

Figure 4. Principle of operation of Radial Magnetic Field device.

This technique is so effective that short circuit currents of up to 50kA rms can be interrupted.

Ingeniously the magnetic field is self induced by the short circuit current itself. This is achieved by forcing the current to move along defined paths which in turn create the required Radial Magnetic Field. The first contact to do this was the Spiral Petal contact invented in the USA in the 1960's. This contact consists simply of a disk of contact material which has a series of spiral or angular slots cut in it. The arc initiated near the centre and is driven outwards and the around the periphery of the contact. The contact in Figure 5 is typical and is a Swastika design by Eaton Corporation (formerly Westinghouse)

Figure 5. Spiral Petal contact

In the 1970's from the UK came the "Contrate" contact which used a cup shaped contact with a large number of slots in the walls of the cup. This worked in the same way as the Spiral Petal in that the slots forced the current to generate a radial magnetic field which made the arc move around the lip of the contact. This contact had the advantage that only the lip of the contact needed to be made from special material. The rest of the contact is in copper.

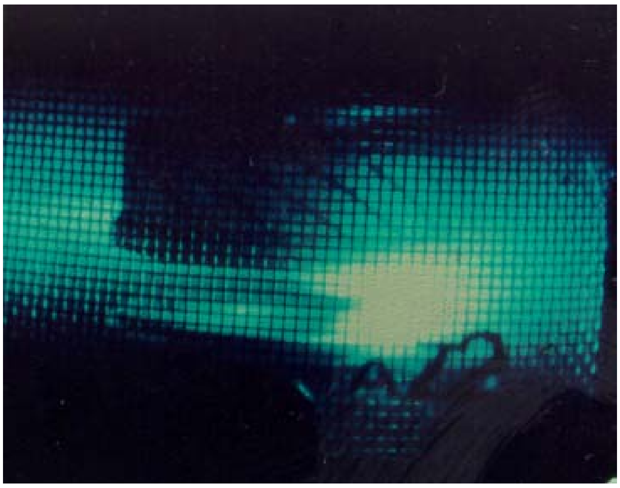

Figure 5. "Contrate" RMF contact interrupting 40kA @12kV.

Perhaps the ultimate refinement of the RMF contact is the "Folded Petal " contact developed during the 1980's and shown in Figure 6. This balances the magnetic field on the contact extremely well, and Figure 7 shows the difference this made to the effectiveness of the contact [3].

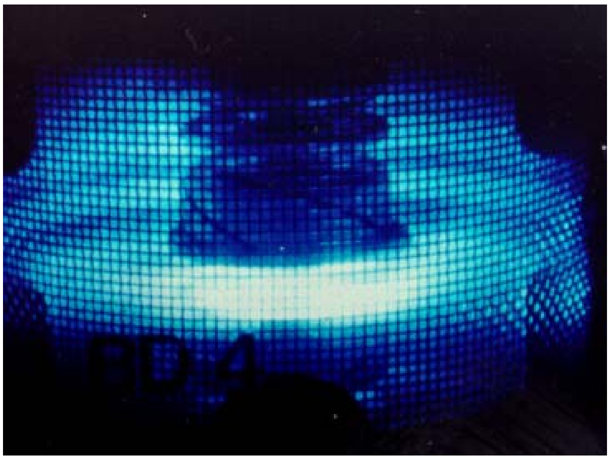

Figure 6 "Folded Petal" RMF Contact interrupting 20kA @12kV.

Figure 7 "Comparison of sizes of Contrate and Folded Petal contact for the same rating (20kA@12kV).

Axial Magnetic Field

An alternative to the RMF solution is to apply a magnetic field Axially to the arc. This Axial Magnetic Field (AMF) works quite differently from the RMF solution in that it does not make the arc move, but instead forces the arc to remain diffuse above its natural constriction point.

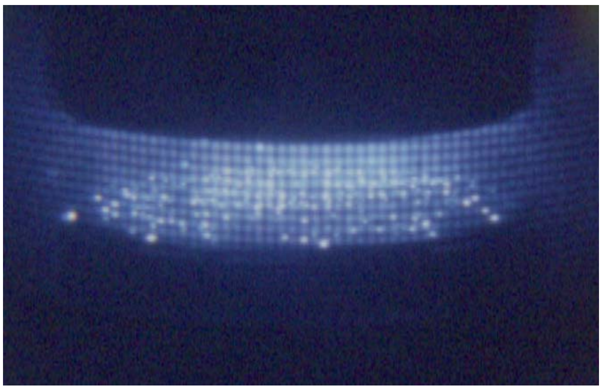

Figure 8. Diffuse arc using AMF contact interrupting 31.5kA@12kV

The axial magnetic field can be supplied in several ways. Manufacturers today achieve this by simply wrapping the main conductor around the interrupter to form a ½ or 1 turn coil, by using specially shaped contact geometries as shown in Figure 9, or by using soft iron to induce the required field. However this is done the technique works well and in fact is so successful that currents of over 100kArms have been interrupted in this way. Figure 9. Shows a typical AMF contact geometry designed by Toshiba Corporation.

Figure 9. AMF contact geometry

CONTACT MATERIALS

As mentioned earlier, the material of the contacts provides the conducting medium for the arc. This is a fundamental difference to all other interrupting technologies, and means that changing the contact material does not only change properties such as welding and conductivity, but also the fundamental arc properties affecting interruption performance, voltage withstand, and current chopping. Thus the contact material is as important as the ac control geometries discussed previously in determining the performance of the interrupter.

A large number of materials have been used over the years for a variety of reasons but this is a complex subject and only the very basics and most popular materials will be covered here. The original material was Oxygen Free High Conductivity (OFHC) Copper due to its excellent conductivity and very low gas content. The gas content is very important in a sealed vacuum device as if large quantities of gas were evolved during the melting and arcing of the contacts this would eventually result in a degradation of the vacuum to a level which could interfere with the operation of the device. However pure Copper cannot be used as although very good at interruption, contacts made of OFHC copper when closed onto a fault – which is a service requirement would weld solidly preventing the circuit breaker form opening again.

Figure 10. Photomicrograph of Copper Bismuth.

This was overcome by adding a small amount of Bismuth to the contact material. This embrittles the material making any welds formed weak and easy to break (Figure 10).

As with the Copper-Bismuth material it was found that no one material had the exact properties required for vacuum switching, and so a number of binary or trinary combinations of materials were developed. For power interrupters the material of choice today is based on Copper Chromium, a material originally developed by English Electric in the 1970's. It exists in two main forms, an infiltrated version whereby liquid copper is infiltrated into a pre-sintered Chromium matrix under vacuum shown in Figure 11, and a version made of compressed mixed Copper and Chromium powders which are sintered together under vacuum, Figure 12

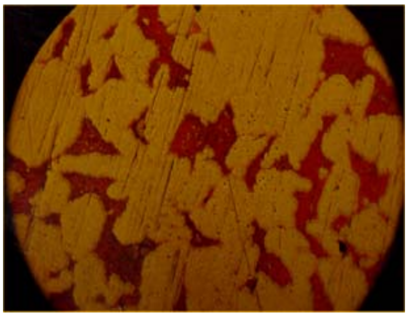

Figure 11 Photomicrograph of CLR
- Infiltrated Copper Chromium.

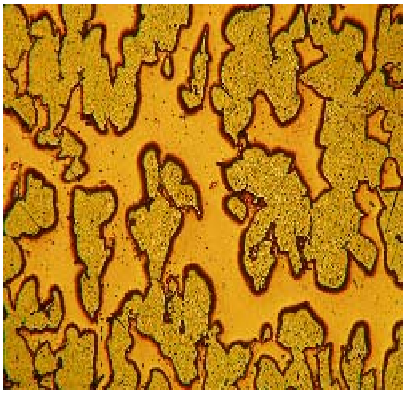

Figure 12 Photomicrograph of ZLR
- sintered powder Copper Chromium.

The Copper Chromium materials give an almost perfect combination of dielectric strength, interruption capability and conductivity as well as low current chopping. Current chopping is where the arc extinguishes before zero current. The reason is that all arcs need some minimum level of current to power them, and once the current dips below this critical level then the arc self extinguishes and an overvoltage is created which is strongly dependant on the chopping current level. For example Copper Bismuth chops at a very high level of @18A whereas Copper Chromium chops @ 4A or less. These overvoltages can stress insulation on the system, and so care must be taken to select the correct material for the application. For motor switching contactors, for example Tungsten-carbide Silver is used which has a current chopping level of only 0.5A. However it cannot be used for power interrupters as it has very poor interruption capability and poor dielectric strength.

Figure 12 Photomicrograph of Tungsten-carbide Silver

CONCLUSIONS

Vacuum interrupter arc control systems have evolved over the past forty years to cover all of the specified fault currents needed for Medium Voltage distribution systems [4]. As has been shown for vacuum switches, the properties of the device are decided almost solely by the selection of the special contact material which dominated the properties of the arc, with the natural diffuse arc mode causing natural interruption at the next available current zero. For power rated vacuum interrupters it is also necessary to have systems of arc control based on RMF or AMF technologies to allow interruption of fault currents as well as different contact materials tuned to the requirements of the arc control system used.

Both contact materials and arc control systems are now mature technologies and for the past twenty years or more the research and development of vacuum interrupters and switches has been driven by the need to reduce costs. The development of the Folded Petal contact geometry being an example of this. The diameter of a vacuum interrupter is defined by the diameter of the arc control system. By significantly reducing the size of the arc control contacts the interrupter is also reduced in both size and cost [5].

It is believed that future developments will continue to be driven by cost reduction motives, and that RMF and AMF arc control systems will continue to be optimised to produce interrupters of ever lower cost.

REFERENCES

[1] M.P.Reece, 1959, "The Vacuum Switch and Its Application to Power Switching", *J.IEE*, 275. [1] Laffarty 1980, *Vacuum Arcs* Wiley, New York USA.

[2] R.V.Latham, 1981. *High Voltage Vacuum Insulation: The Physical Basis*, Academic Press, UK

[3] L. T. Falkingham, 1986 "Recent Advances in Vacuum Interrupter Design" CIGRE 13.01,

[4] T.H.Lee et al 1962, "Development of Power Vacuum Interrupters", *IEEE Trans. Power Appar. Syst.* PAS-81, 629-639

[5] L.T. Falkingham, 2002 "Fifty years of Vacuum Interrupter Development in the UK" ISDEIV XX Tours, France.