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RECENT ADVANCES IN VACUUM INTERRUPTER DESIGN

by

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Resume

Making and breaking phenomena of vacuum interrupters are generally known, but characteristics of a particular interrupter are greatly dependent on the contact geometry and contact material used.

The paper describes the development of new interrupters performed using a demountable vacuum chamber designed so that the arc can be photographed using a high speed cine camera.

A significant result of this work is the development of a new contact geometry, which combines simplicity and high performance. The work leading up to this development and the results of tests on contact assemblies within the demountable chamber and in complete interrupters are described.

Keywords

Vacuum - Interrupter - Contacts - Demountable - Development

1. Introduction

Arcs in vacuum have been widely studied [1], [2],[3] and the physical principles of operation of vacuum interruption established. However the optimisation of the performance of commercial interrupters requires a study of practical interrupter contacts operating under service conditions.

Historically this was achieved by designing interrupter contacts from theory and constructing prototype devices. These devices were then tested under short circuit conditions, and their performance noted. After test the devices were then opened and the contacts studied for clues as to the behaviour of the arc. In this way, over several generations of prototypes, practical devices were empirically developed. This technique, although effective in producing usable interrupter designs, was very expensive in both time and money, the high cost of repeated short circuit testing preventing true optimisation of designs, the design normally being frozen when a workable device was achieved. The development also tended to be separate from the research work, often performed in different establishments. This, coupled with the low level of information generated from the testing of prototypes, hindered further design improvements.

An alternative approach is to study vacuum interrupter contacts operating under short circuit conditions by means of high speed photography, a technique used to a limited extent by A.E.I. in the 1960's in the development of early VIL contacts. With this approach the movement and conditions of the arc can be filmed during a complete half cycle of fault current, and in this way far more information on the arcing performance of the contacts can be obtained, and the contacts optimised for a particular rating. This approach can be used by the vacuum interrupter manufacturer and closely relates contact research to practical interrupter development. It requires far less short circuit testing of prototypes and contributes greatly to the understanding of interrupter performance leading directly to new and improved designs. This technique was the one used in the development described herein.

2. Discussion

In order to use this approach two major items of equipment are necessary. The first is a test plant capable of subjecting the device on test to full short circuit test conditions at a range of system voltages. The second is a device in which vacuum interrupter contacts can be mounted and operated in such a way as to effectively simulate their operation within a vacuum interrupter fitted in a circuit breaker, and thereby to enable the performance of these contacts to be studied in various ways, particularly by means of high speed photography.

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The test facility used was an in-house capacitive synthetic test plant, (Figure 1), consisting of a low voltage, high-current source provided by a 3.2 F capacitor bank built as eight separate units each with its own series resonant inductance and ignitron. The plant is capable of supplying a 37.5 Hz half loop of up to 120 kA peak, which is equivalent to a 53 kA (rms) fault with 60 percent asymmetry. The bank is isolated from the high voltage side by a vacuum interrupter. The high voltage injection is provided by a 50 kV (peak) capacitor bank discharging through a series inductance via a triggered spark gap. Thus a single half loop of current followed by the correct transient recovery voltage can be provided to the device on test, and clearance or failure detected. A full half loop of current was determined early on as the most onerous duty for vacuum interrupter contacts, and this was adopted as our standard test.

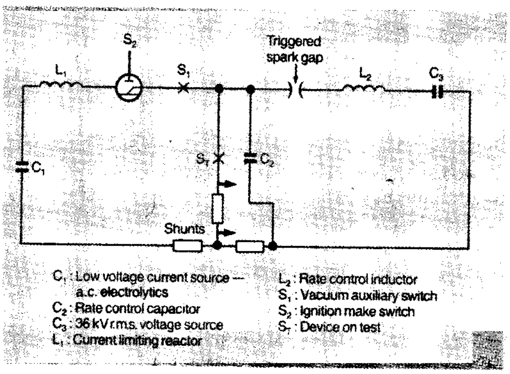

Figure 1: Simplified circuit diagram for capacitive synthetic short circuit test plant.

The device used to simulate vacuum interrupter operation is shown in (Figure 2). It consists of a vacuum chamber fitted with high voltage, high current electrical feedthroughs and a large viewport to enable filming.

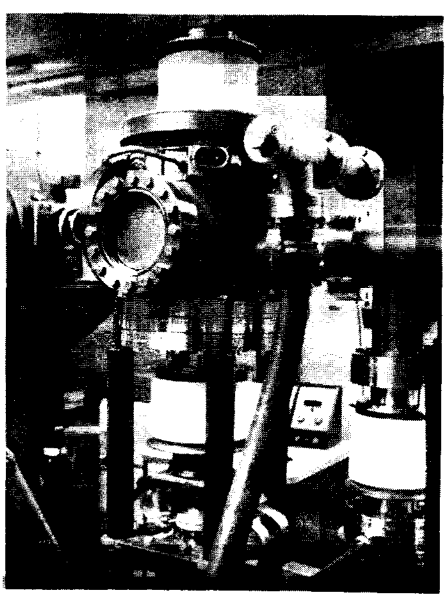

Figure 2: Demountable vacuum chamber.

The chamber can be fitted with vacuum interrupter contacts to be tested and a dummy centre shield which simulates electrically and magnetically the actual interrupter centre shield, but allows filming of the contacts. (Figure 3).

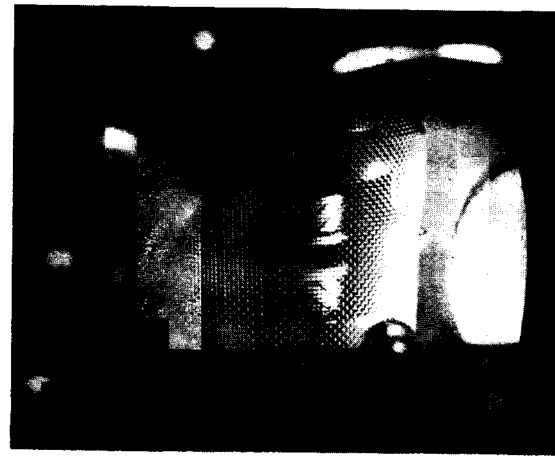

Figure 3: View into demountable vacuum chamber showing vacuum interrupter contacts in position.

Once sealed the chamber is evacuated by integral vacuum pumps and baked by means of heating jackets to remove surface gases and water vapour. This effectively reproduces the normal manufacturing processes for a vacuum interrupter. Once the chamber is prepared it is installed in the test plant. The unit is fitted with a simple solenoid operating mechanism which allows the contacts to be opened and closed, as in a circuit breaker, and various diagnostic probes including a quadrupole mass spectrometer which allows the residual gases to be analysed before and after arcing of the contacts. The most important instrument however is the high speed camera, which films the arcing of the contacts at 10,000 frames per second, and so allows events to be studied in some detail. (Figure 4).

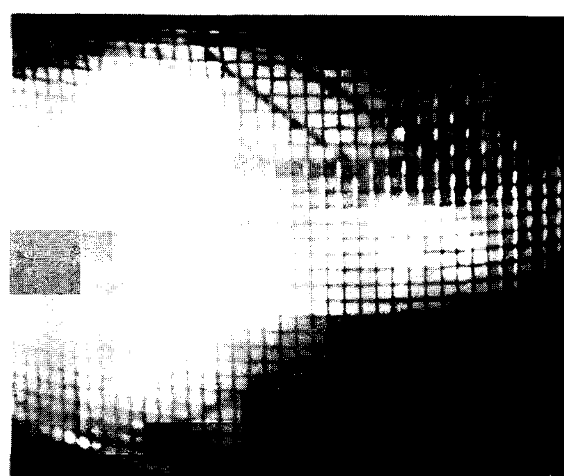

Figure 4: Still photo from high speed film showing V807 contacts (50mm diameter) interrupting 31.5 kA (rms) at 12 kV (rms).

This system was used initially to study the performance of a range of contacts used in our then current vacuum interrupter types. These contacts were of the "Contrate" type (Figure 5), Once these performances were established within the demountable unit, prototype interrupters were built and tested in our synthetic test plant and the results confirmed at direct short circuit test stations. Since then all these interrupter types have been successfully certified in commercial switchgear, and are now in service worldwide.

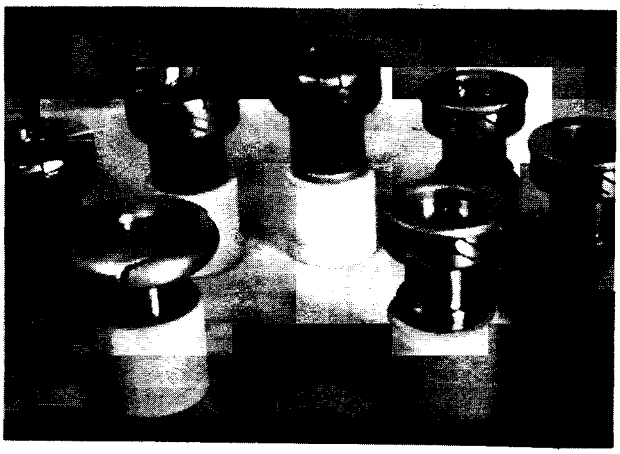

Figure 12: Evolution of contacts showing, clockwise from front left:-

Spiral petal	V3,	12 kV	16 kA
Contrate	V801,	12 kV	13 kA
"	V802,	12 kV	20 kA
"	V803,	17.5 kV	25 kA
"	V804,	17.5 kV	25 kA
"	V806,	38 kV	16 kA
"	V807,	17.5 kV	31.5 kA

More recent work involved the development of a new contact geometry which would optimise the effects used to date.

Theoretically a geometry was required which would provide good drive, would locate the arc reliably and would be easy and cheap to manufacture. A major expense in manufacturing 'contrate' type contacts is the large number of slots required, and this geometry will not provide sufficient drive if less than say, ten slots are provided (Figure 13). However, spiral petal contacts (Figure 14) usually have only three or four slots because they are very efficient at providing drive in the correct plane, although they suffer from the disadvantages of high manufacturing cost and poor arc location.

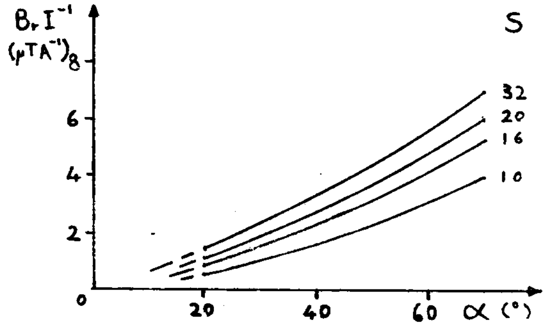

Figure 13: Graph showing relationship of the ratio of radial component of magnetic flux density (Br) to arc current (I) as a function of inclination (α) and number of slots (s) for a 'contrate' contact.

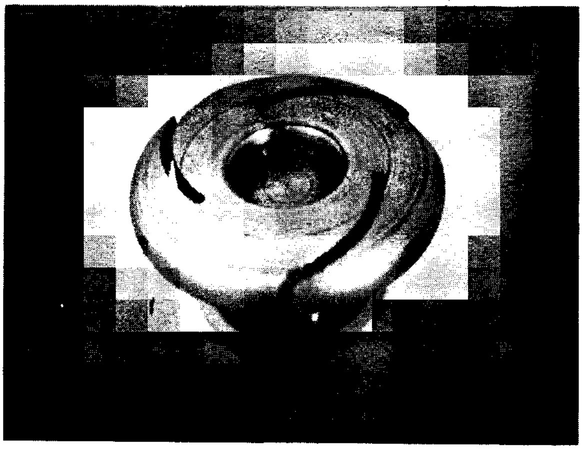

Figure 14: Spiral petal contact.

Using the demountable unit it has proved possible to combine the best effects of both geometries resulting in a new type, the 'Folded Petal' which is in the process of being patented. This has slots cut into the side wall which continue tangentially into the base of the contact, thereby achieving drive for the arc from the base (as in the spiral petal contact), and from the side walls (as in the contrate contact). The fields were also balanced to achieve good location on the contact ring (Figure 15). This contact design provides adequate drive with only three or four slots, and is far more efficient at current interruption than its predecessors (Figures 16 and 17). The contact shown is only 35mm in diameter, and yet interrupts 20 kA (rms). It is cheaper to manufacture and has enabled the development of prototype devices which are considerably reduced in size and cost (Figure 18).

These modifications enabled the interrupter to be uprated to 20 kA (rms) but with a considerable increase in manufacturing costs.

Studies of these arcs showed that whereas the 'V5' geometry had a component of magnetic field which tended to force the arc outwards with excess current, the 'V8' contact did not. Changes in contact geometry were made on the 'V8' contact to produce a magnetic field which would bias the arc inwards to the centre of the contact, where the disc of 'CLR' arc resistant material was placed. This was successfully accomplished, and it was found that the arc was more stable and could reliably interrupt rated currents of up to 25 kA (rms), resulting in an uprated interrupter which was also cheaper, as no special 'armour' for the centre shield was now required (Figure 9).

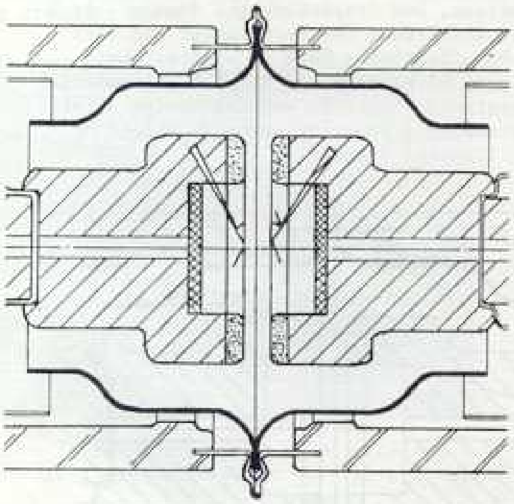

Figure 9: New 'V8' geometry 25 kA (rms) incorporating 'CLR' disc, but no added shielding.

This result emphasised the low efficiency of the 100mm diameter contact rated at 31.5 kA, and so this contact geometry was re-designed in order to try to stabilize the arc as had been achieved on the 'V8'. Simultaneously it was determined that if the tip material was left unslotted, a more constricted arc was established, however this disadvantage was more than offset by the fact that the arc was more stable, and more easily controlled.

Thus a new 'V5' contact was developed, only 80mm in diameter, which securely fixed the arc on the contact ring, was substantially cheaper to manufacture than its predecessor, and was rated successfully at 40 kA (rms). As this contact was physically smaller than the previous one, a slight tendancy for the arc to move outwards towards the centre shield was incorporated, thus utilising the extra clearance available. (Figure 10).

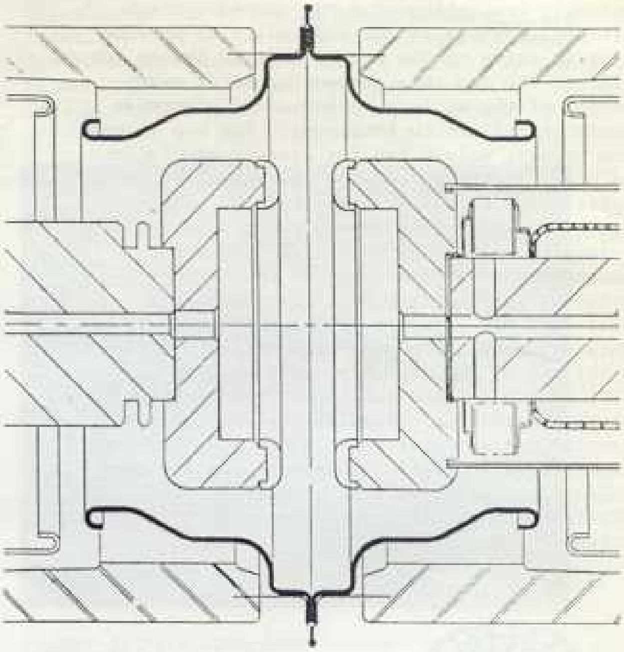

Figure 10: 'New' style 'V5' contact showing clearance from the arcing zone to the shield.

Having firmly established the principle of securing the arc on the contact ring, a variant of this principle was fed back into the 'V8' design, but now incorporating the solid ring concept to help stability (Figure 11). This resulted in two new interrupters, the basic version rated at 25 kA (rms) as the previous improvement, but substantially cheaper to manufacture, and an enhanced version rated at 31.5 kA. The evolution of the contacts is shown (Figure 12). A further advantage of the new smaller contacts was an improvement in voltage performance, partially due to the ability now to fit more complex shields within existing vacuum interrupter envelopes. This resulted in new interrupter ratings at up to 36 kV (IEC) and 38 kV (ANSI).

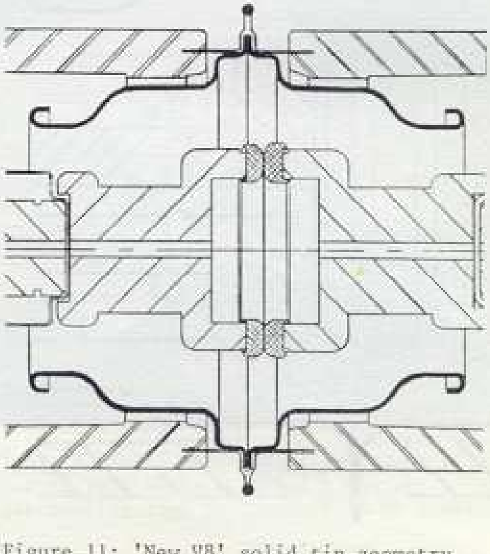

Figure 11: 'New V8' solid tip geometry 25 kA (rms) - no centre disc, and smaller contact allows improved high voltage shield geometries.

basically consisting of a cup shaped contact with angled slots in the side walls to provide magnetic drive to the arc to move it around the "rim" of the cup thus preventing local overheating of the surface, which would otherwise result in failure to interrupt. The cup is made from copper, mainly for its ease of manufacture and high electrical and thermal conductivity. Copper alone is not suitable for the arcing zone of an interrupter contact due principally to its low resistance to arcing, and its tendancy to form welds between the contact surfaces, particularly when closing onto a fault current. Because of this all the contacts described have a ring of 'CLR' fitted to the rim of the cup where arcing takes place. 'CLR' is a code name for the copper chromium material developed originally by The English Electric Company Limited at the Nelson Research Laboratories in Stafford. Apart from its good antiweld and arc resistant properties the material also exhibits very low chopping current.

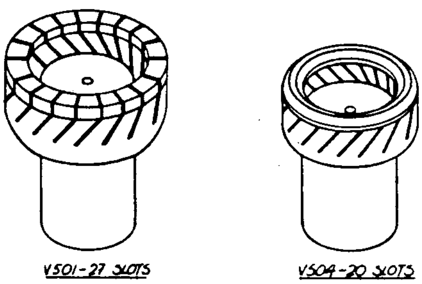

Figure 5: Contrate contacts, showing 'old' and 'new' designs.

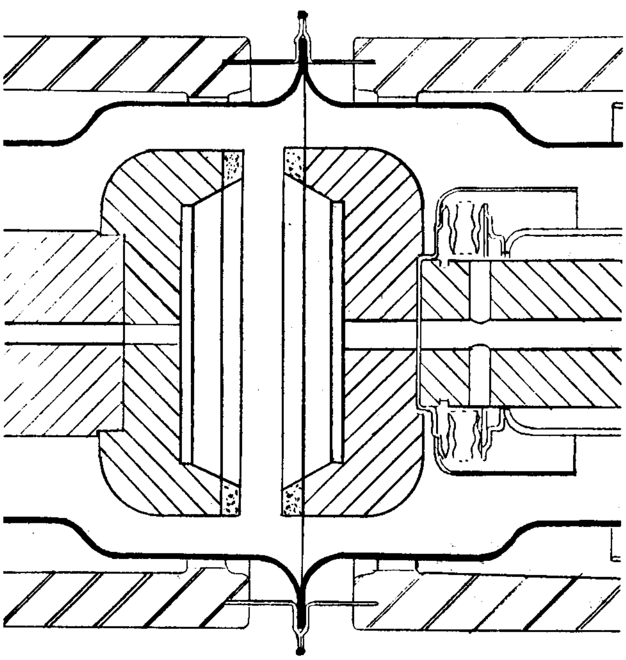

Figure 6: 'Old' style 'V5' contact and shield geometry. Arc movement outwards caused damage to centre shield.

The series of tests conducted showed that the 100mm diameter 'V5' contact caused the arc to break up and to rotate at current levels of up to 45 kA (peak) - equivalent to 31.5 kA (rms). Above this level however, the arc became unstable and tended to move outwards towards the interrupter centre shield causing failure (Figure 6). The 55mm diameter 'V8' contact was found to behave in a similar manner, instabilities occurring at current levels of above 20 kA (peak) equivalent to 13 kA (rms), although in this contact the arc at failure could move either outwards or towards the centre of the contact. Both modes of failure caused a breakdown in dielectric strength, and thereby failure to interrupt, due to the large amounts of metallic vapour produced by the arcing in these areas. The mode of failure of the 'V8' contact had been established previously by opening interrupters tested at short circuit test stations, and inspecting the damage. As a result of this study the interrupter had been uprated by effectively "armour plating" both the contact, by placing a disc of 'CLR' material in the centre of the cup, and the centre shield zone, by adding a substantial extra shield of copper. (Figures 7 and 8).

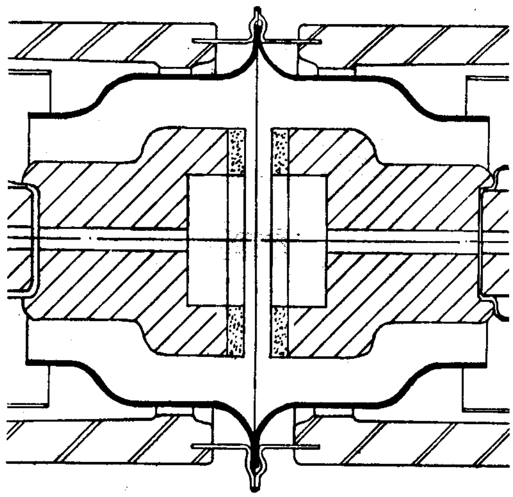

Figure 7: 'Old V8' contact and shield geometry 13 kA (rms).

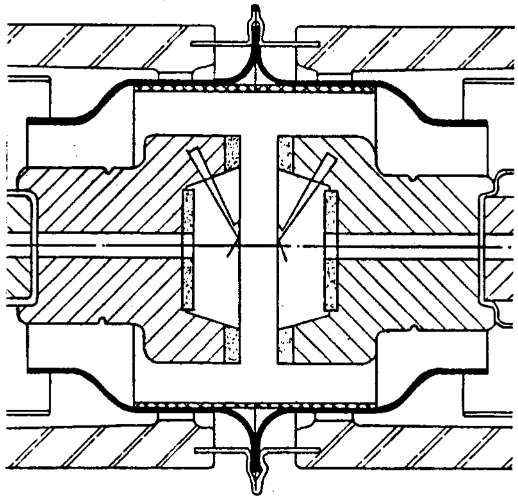

Figure 8: Improved 'V8' assembly 20 kA (rms). Note extra 'CLR' disc in cup of contact and extra centre shield.

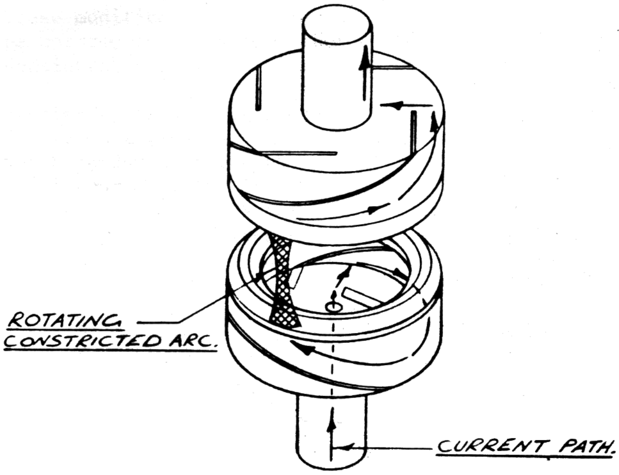

Figure 15: 'Folded Petal' contact geometry

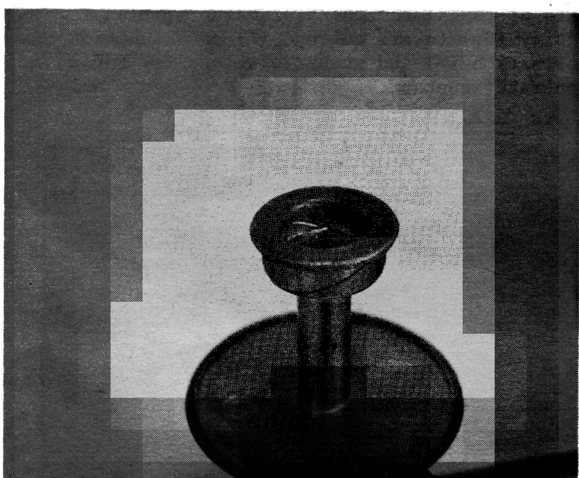

Figure 16: Prototype 'Folded Petal' contacts after several operations at 12 kV (rms) 20 KA (rms).

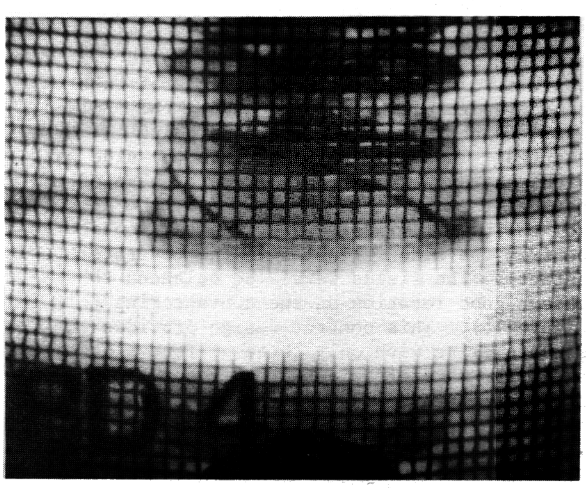

Figure 17: 'Folded Petal' contacts 35mm in diameter interrupting 12 kV (rms) 20 kA (rms).

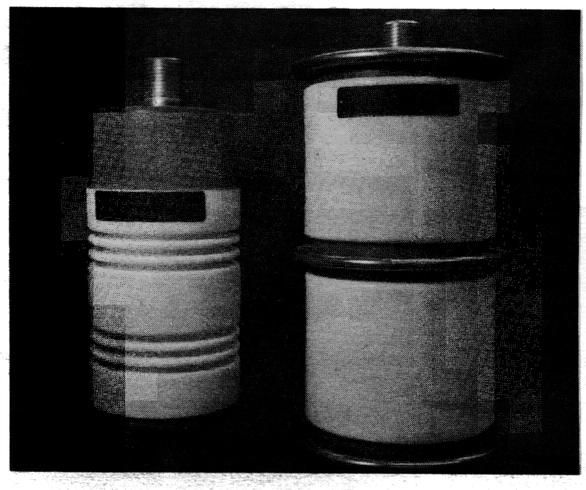

Figure 18: Size comparison of 'V8' interrupter using contrate contacts and prototype 'V2' interrupter using 'Folded Petal' contacts. The 'V2' is 85mm in diameter as compared to 125mm for the 'V8'.

3. Conclusions

In conclusion, the development of efficient contacts is at the heart of vacuum interrupter design, and by a combination of theoretical analysis, testing, and some empirical study, existing geometries have been both reduced in cost and improved in performance. The new 'Folded Petal' geometry heralds a new generation of low cost vacuum interrupters which are physically small and relatively simple to manufacture. The search for means to better locate and control the arc is not over however, and the existance of a facility to study vacuum interrupter behaviour in this way will inevitably result in further development and the evolution of new contact geometries.

4. References

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5. Acknowledgements

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