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RECENT PROGRESS IN VACUUM INTERRUPTER DEVELOPMENT

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INTRODUCTION

In previous papers on this subject the programme for vacuum interrupter development was outlined. In this paper we are now able to report on the success of this work which will result in a complete range of interrupters covering 16 types and 3 frame sizes. We are now in a position to predict with confidence that the new range will restore VIL's position as a market leader in this technology.

A. DESIGN FEATURES

The new range of interrupters has been designed by careful study and optimisation of the existing contrate contact interrupters, particular attention being given to the following areas: -

A(1) Contact Tips

It was found that the contact tip slots effectively delayed the onset of current constriction. When arc constriction did occur the arc covered a relatively large area which helped to limit contact damage. However some serious disadvantages of the design also became evident in that the manufacturing process was expensive, the contacts required heavy current conditioning and rotational speed was limited. In addition the edges created by tip slotting gave rise to voltage limitations that would not allow interrupters to operate effectively at voltages above 24kV.

For these reasons it was decided to use the solid contact ring version of the contrate contact which had originally been developed and patented by VIL in 1965. This overcomes the inherent disadvantages of the slotted tip although the interrupters have to be operated at slightly higher contact loadings.

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A(2) Contact Design

The change from a slotted ring to a solid ring contact may seem a trivial process. However, initial tests showed that if the rings of the previous design were simply left unslotted, the interruption capability dropped by almost 50 per cent.

In fact the contacts had to be totally redesigned, specifically to ensure that the rapidly rotating constricted arc was located accurately on the arcing ring. The contact designs of the old (V501) and new (V504) types are shown in figure 1.

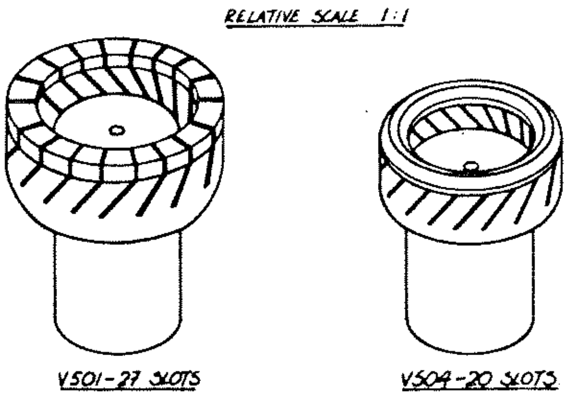

FIG. 1.

In addition changes were made to improve voltage distribution in the contact gap. These were accomplished by altering current flow in the radial plane so as to ensure that the azimuthal component of magnetic field is close to zero at a radial position corresponding to the contact tip. This magnetic field is responsible for arc motion in the radial direction and therefore, as the arc is drawn on the tip, its position will be relatively stable. This process also assists the effective rotational velocity of the arc. Other factors affecting the arc rotation are the slot angle and the number of slots and these relationships are illustrated in figure 2. These factors must be maximised

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consistent with the mechanical strength requirements of the contact. VIL's patented use of 0.5% chrome-copper material for contact bases ensures that this is achieved.

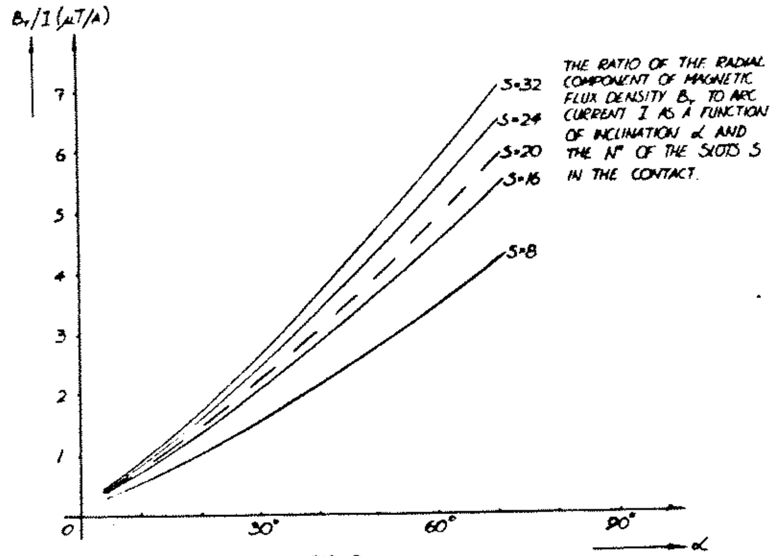

FIG. 2

A(3) <u>Shield Design</u>

The central sputter shield is an extremely important component of the vacuum interrupter, for both voltage and short circuit current considerations.

A(3.1) <u>Short Circuit Current Considerations</u>

At high current values a significant proportion of the current flows through the electrically isolated centre shield .

It is important therefore that:-

(a) The shield to contact distance is optimised to give maximum current flow without damage.

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(b) The electrical conductivity is maximised.

(c) Thermal conductivity must be high and surface conditions such that sputter deposition cools rapidly and bonds firmly to the surface.

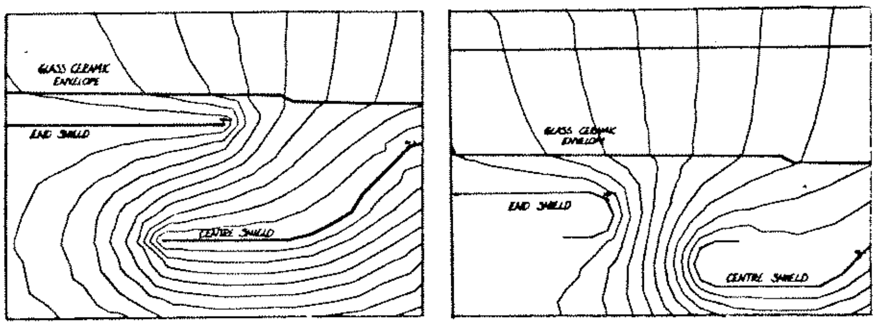
The shields have been totally redesigned to accommodate these requirements.

A(3.2) <u>Voltage Design Considerations</u>

The voltage applied to an open vacuum interrupter appears across the contact gap in parallel with the two intershield gaps. It is pointless therefore improving the electrostatic field distribution of the contacts without ensuring that the inter-shield gaps are also improved.

Electrostatic field distributions were studied with the aid of computer predictions from a finite element analysis programme. From this it was found possible to create a significant improvement to the shield profiles with values of field strength in critical areas being reduced to almost half of the previous values. Typical field distributions are shown in figure 3.

FIG. 3



V803 OLD TYPE SHIELD V806 NEW TYPE SHIELD

NOTES:- EQUIPOTENTIAL LINES AT 5% INTERVALS
CENTRE SHIELD ASSUMED AT 50%
CONTACTS FULLY OPEN

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A(4) Contact Material

Chrome-copper (CLR) material has been successfully used for many years, not only by VIL, but also by VIL's previous licensees, Westinghouse and Siemens. The properties of chrome-copper are extremely good but in the present form this material has two areas capable of improvement:-

(i) High contact resistance.

(ii) Significant weld strength under certain adverse conditions.

New variants of CLR have recently been developed to overcome these disadvantages.

A(5) Cleaning Procedures

The cleanliness of interrupters has long been regarded as important to the proper function of these devices. Recent work has highlighted the importance of surface cleaning particularly in relation to voltage performance and changes in VIL's cleaning processes have resulted in improved and more consistent performance.

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A(6) V200 Interrupters

As interrupter ratings have increased a need for a smaller diameter interrupter for use at 12kV,13kA or 12kV, 20kA ratings has been established.

The V200 interrupter range will utilise an 80mm diameter envelope and the new 'folded petal' contact. This contact design which is shown in figure 4, is a cost reduced version of the contrate and operates in a manner that combines the characteristics of both the spiral petal and contrate designs.

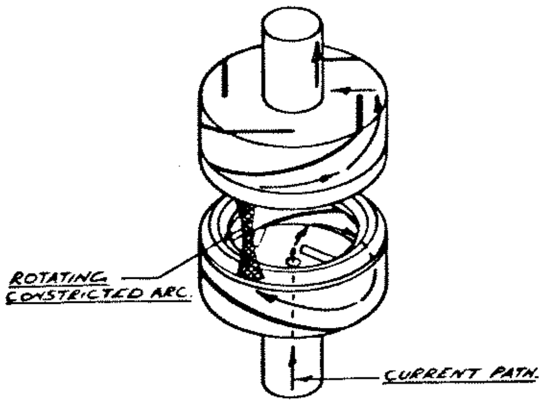

FIG. 4

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B INTERRUPTER PERFORMANCE AND RATINGS

Extensive changes have been made to improve and broaden the range of vacuum interrupters available. The design work involved in this task has resulted in a significant number of patent applications.

The range of interrupters may be summarised as follows:-

Interrupter Type	System Voltage (kV)	Short Circuit Current (kA)	Normal Current (A)	Impulse Level (kVp)	Availability *	Comments
V201	12	10	630	75	6-9 Months	- Butt Contact
V204	12	20	630	75	6-9 Months	- Folded Petal
V801	17.5	20	1250	95	Now	- Old Design
V802	17.5	20	1250	95	-	-Now Superseded
V803	17.5	25	1250	95	Now	- Old Design
V804	17.5	25	1250	95	Now	
V805	17.5	25	1600	95	3-6 Months	
V806	36/38	16/20	1250	170/200	Now	
V807	17.5	32	1250	95	3-6 Months	
V501	17.5	26	2000	95	Now	- Old Design
V502	17.5	32	2000	95	Now	- Old Design
V503	17.5	40	2000	95	Now - Limited Quantities Only	
V504	17.5	40	2000	95	Now	
V505	17.5	40	2500	95	3-6 Months	
V506	36/38	25	2000	170/200	Now	
V507	17.5	48/53	2000	95	3-6 Months	

*Availability subject to demand and plant capacity.
Outline dimensions of the three interrupter frame sizes are shown in figure 5.

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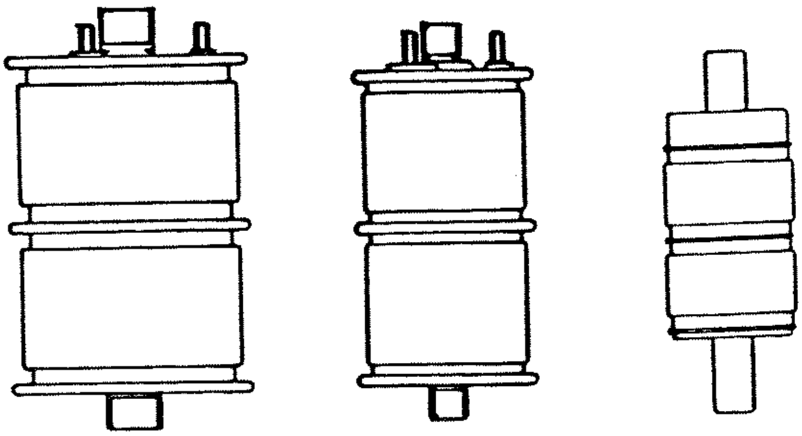

V500 V800 V200

0 100

Scale mm

FRAME SIZE	EXTERNAL DIMENSIONS		
	O/A DIA	BODY LENGTH	O/A LENGTH
V200 V800 V500	80 125 160	150 220 233	239 272 290

FIGURE 5

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B(1) Short Circuit Interruption Ratings

The combination of design changes outlined previously has resulted in considerable upratings being achieved. This is reflected particularly in the V507/807 versions with the V807 being capable of 32 kA within the V800 size envelope. These levels are not necessarily the limits of the devices and further upratings can be anticipated in the future.

B(2) Voltage Performance

The improvements in voltage performance are reflected in the performance of the V806 and V506 interrupters which have been tested for 38kV ratings including extensive capacitor bank switching. These tests have been completely successful.

Whilst the standard impulse level of these interrupters is 170kV (crest), selected interrupters are also available for 200 kV duties.

B(3) Normal Current

The rating of a vacuum interrupter for normal current duties is always difficult to define due to the fact that so much depends on the thermal design of the circuit breaker.

However the V805 and V505 will utilize a number of changes which will reduce their overall resistance by 25 - 30%, this reduction being maintained after short circuit operation . This should enable 1600A and 2500A ratings respectively to be obtained in most circuit breaker designs.

B(4) Electrical Life

In general the electrical life of the new types is comparable in this respect with the excellent performance of earlier VIL designs. In some cases there will be some improvements , however in the case of the V805 and V505 some increase in the rate of contact erosion must be expected, although this will be negligible in most normal service applications.

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B(5) Weld Strength

One of the disadvantages of adopting the solid contact ring design has been an increase in weld strength particularly after three second through tests. Whilst in most cases the circuit breaker can be designed to cope with this problem, this is not always convenient or possible. In order to cater for this situation reduced weld strength versions of V804, V805, V504 and V505 will be available shortly.

B(6) V200 Range

The 80mm interrupter will at first be available in two versions. The V204 interrupter for 20kA at 12kV, whilst the V201 will be a butt contact version interrupting approximately 10kA. The V201 might also be available with an extended mechanical life option particularly to cater for duties such as on-load transformer tap changing.

The availability of V200 range interrupters will depend on demand and will be subject to manufacturing capacity limitations.

C FACILITIES AVAILABLE FOR RESEARCH AND DEVELOPMENT

The progress reported in this paper has been made possible by a significant increase in facilities available for design, development and research at VIL. These facilities may be summarized as follows:-

C(1) Synthetic Test Plant with Digital Transient Recording

The all-capacitive synthetic test plant has proved to be an extremely effective tool for research and development as well as for quality assurance testing. The plant has also proved to be highly reliable, with over 70,000 tests carried out since its commissioning in 1981.

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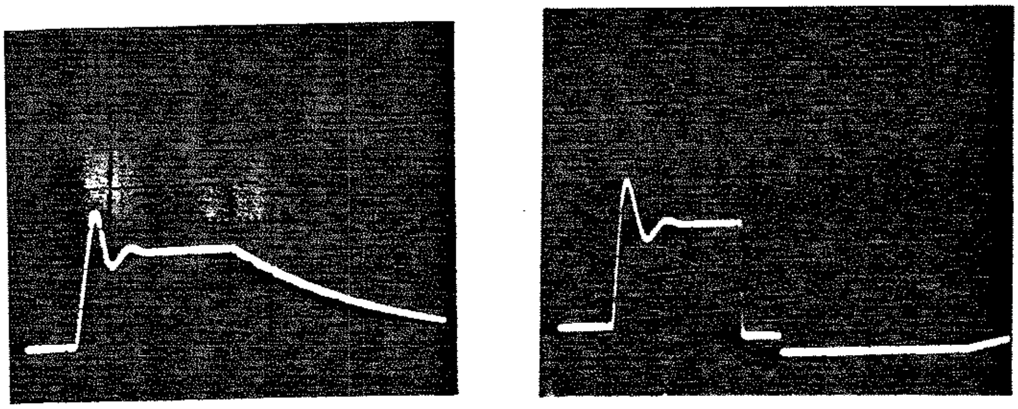
The recording facilities have recently been extended by the use of a digital transient recording system. The system used employs three Data Lab DL 902 units. Each unit has two channels of recording capability with 2K memory and 8 bits of vertical resolution. As well as providing an extremely flexible triggering system it is also possible to recover pre-trigger information. Additionally, each channel can be sampled at a different rate up to a given change-over point. The advantage of this system is that more information can be recovered from the test plant. For example one channel sampling at 1 MHz can be used to record T.R.V signals then after 1ms the sampling rate can be reduced to 2kHz to look for any voltage events occuring over a longer time scale. This is shown in figure 6.

The system has been designed to interface with an IBM PC-XT micro-computer which will eventually be used to control and analyse test results.



(a) (b)

FIGURE 6.

Split sample rate trace of applied TRV, first half at 200 us/division, second at 0.1s/division.

(a) Showing successful withstand.

(b) Showing restrike after approximately 560 us.

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C(2) <u>Demountable Vacuum System</u>

The demountable system has been expanded to enable greater information recovery. The most important single item is a built-in mass spectrometer system that provides accurate readings of gas partial pressures. This not only gives information as to the cleanliness of the system during and after bakeout but also provides information on gas evolution immediately after arcing. Typical results from the mass spectrometer are shown in figure 7.

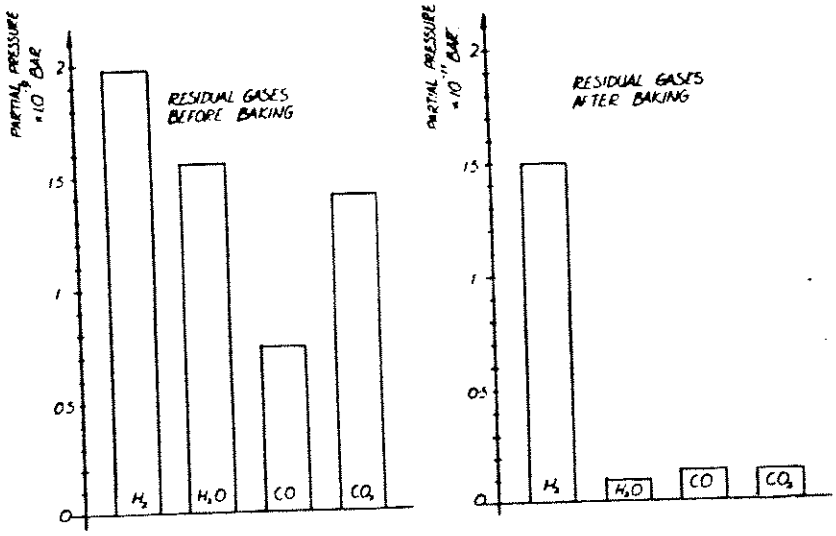

FIG. 7

Other items include an improved pumping system, higher temperature bakeout cycle and a new optical shutter to enable more effective high speed photography.

C(3) <u>Electrical Test Laboratory</u>

A new electrical test laboratory has now been commissioned at VIL and includes the following equipment:-

C(3.1) <u>Current Chopping Test Rig</u>

Using microprocessor based circuits this test rig

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allows two interrupters to be tested simultaneously and automatically records their chopping current levels. Each test takes approximately 30 seconds enabling a large number of tests to be carried out in a relatively short time.

C(3.2) Impulse Testing Area

A 450 kV (crest) impulse unit using the well known Marx Bank principle of charging capacitors in parallel and discharging in series, is now in operation.

Results are recorded using a Philips PM3310 high speed digital recording oscilloscope. This enables standard waveforms to be recorded and held in the memory for subsequent comparison with the results from the device on test. See figure 8.

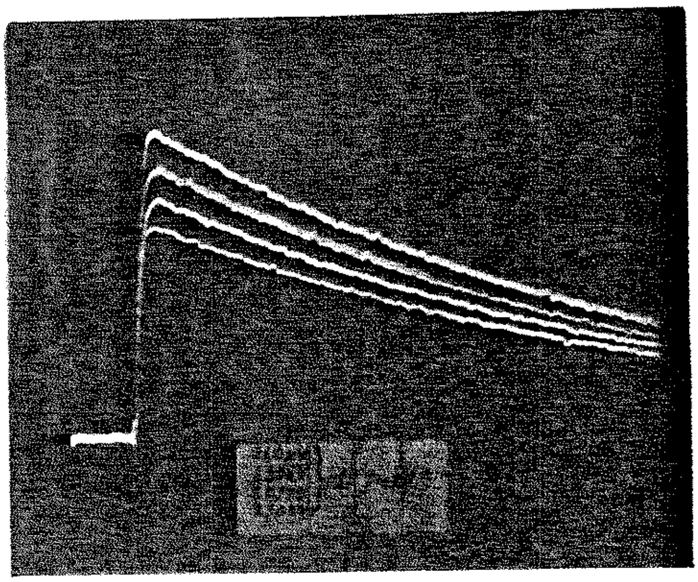

FIGURE 8.

Trace of high speed recordings from 1/50 μs. lightning impulse generator showing peak voltages of 160 kV, 180 kV, 205 kV, 230 kV.

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C(3.3) Normal Current Test Rig

A transformer capable of supplying 4000A continuous current is used to check long term power dissipation of interrupters for normal current ratings at various added loads.

C(4) Metallurgical/Chemical Laboratories

New chemical and metallurgical laboratories are now in use at VIL and enable a wide range of analytical work to be carried out .

C(5) Research Project

A collaborative project at Oxford University to study the fundamental properties of vacuum arcs on chrome-copper contacts is making considerable progress.

The project utilises digital recording facilities and a microcomputer to control and analyse the results from probes and an electrostatic energy analyser in a low current vacuum arc.

From these results conclusions can be drawn concerning the composition of the arcing plasma.

Further research projects are also planned to investigate vacuum breakdown effects.

D FUTURE WORK

Significant progress has been made in the development of VIL interrupters . However, in the author's opinion progress will continue particularly in relation to interrupter short circuit ratings. This work will utilise both optimised transverse field contact design and some radical new contact designs. For example it would not now seem unreasonable to expect a V800 size interrupter to achieve 40kA ratings or a V200 size interrupter to achieve 25kA in the future.

Voltage performance continues to be of interest particularly with the use of a single VIL interrupter for 36kV ratings. The limitations above this voltage are dictated by surface effects on vacuum breakdown. There is a possibility that at

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these levels the dominant breakdown mechanism is insulating inclusions in the contact surfaces and VIL's collaborative research project will be expanded to investigate this.

Other aspects of interrupter application such as temperature rise on normal current and circuit breaker load requirements for make and short time fault duties will be progressed.

It may be confidently predicted therefore that the work described in this paper will restore VIL's position as market leader in this technology.

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