EXPERIMENTS IN HIGH CURRENT SWITCHING USING SMALL CONTACT GAPS

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ABSTRACT

A series of tests were performed on two types of commercial vacuum interrupters, herein called Type A and Type B to ascertain the effect of the contact gap on their high current interruption ability. The tests were carried out on a synthetic test plant at 12 kV; 31.5 kA for the Type A and 12 kV; 13.1 kA for the Type B, all values are rms. Three interrupters of each type were tested at contact gaps of between 8 mm and 1 mm. In addition, identical contacts were subjected to short circuit testing in a vacuum demountable chamber which allowed filming of the arc by means of a high speed camera. The results indicate that one type, Type A, showed a significant reduction in the probability of interruption of the rated short circuit current at contact gaps below 4 mm, whereas the other type, Type B, showed no degradation at contact gaps down to 1 mm. The reasons for this are discussed.

1. INTRODUCTION

The paper reports results of a series of experiments conducted on commercial vacuum interrupters which were intended to investigate the relationship between the contact gap and the current interrupting ability of the devices. All interrupters tested utilised existing transverse field arc control systems, of the Contrate or Folded Petal types, although of differing size and rating. The currents to be switched were up to 31.5 kA (rms.) at 12 kV(rms.), and were supplied by our in-house synthetic short circuit test facility. Operation of the interrupters was by means of a solenoid operating mechanism, and as far as possible other parameters such as opening speed, and contact bounce were frozen at a specific value so as not to affect results, although at very short gaps mechanical considerations cannot be ignored. The investigation is of interest in that as contact gap is reduced two opposing factors come into play. Firstly a reduced gap will result in a reduced dielectric strength between the electrodes due to distance, a trapping of the residual vapour in the gap, and at very small gaps, the effect of uneven surfaces after arcing due to gross melting and the magnetohydrodynamic forces on the liquid metal, in total giving a lower probability of interruption. However on the plus side the arc voltage is to some extent proportional to the contact gap, and so a smaller gap will result in lower arc energy to be coped with, less heating of the contacts, less vapour, and a higher probability of interruption.

2. TECHNICAL DETAILS

The investigation was carried out on two different types of vacuum interrupter, Fig. 1. The first interrupter, Type A, was rated at 12 kV; 31.5 kA.. This interrupter with a body diameter of 130 mm utilises a "Contrate" arc control geometry which provides a component of magnetic field which is transverse to the arc and provides a force which causes a constricted arc to move rapidly over the contact surface, preventing overheating, and allowing interruption to take place. The contact outside diameter is 53 mm with a contact ring of 33 mm inside diameter. The second interrupter, Type B, was rated at 27 kV; 13.1 kA. This interrupter with a body diameter of 80 mm utilises a "Folded Petal" arc control geometry which acts in a similar way to the "Contrate" geometry described earlier. The contact diameter in this case is much smaller with an outside diameter of only 34 mm and an internal diameter for the contact ring of 22.5 mm.

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Fig. 1 Vacuum Interrupters under Test. Type A left, Type B right.

Three standard production interrupters of each type were subjected to the following tests with contact gaps of 8 mm, 6 mm, 4 mm ,2 mm, and 1 mm;

1). Basic Insulation Level (BIL). Impulse testing with a standard 1.2/50 waveform, each interrupter was subjected to reducing voltages, until a voltage was withstood, this was defined as five operations on each polarity with no failures allowed.

2). Short Circuit Testing. Synthetic test with a single loop of 10 ms duration. The loop of current simulated one symmetrical loop of either 32 kA rms., or 13.1 kA rms. for a 50 Hz system. The injected Transient Recovery Voltage (TRV) conformed to IEC standards for a 12 kV 50 Hz system.

In addition an identical pair of contacts of each type of geometry were fitted to a bakeable vacuum demountable system, Fig. 2, which allowed the contacts to be filmed by a high speed camera while being short circuit tested. This was to investigate further the effect of the short contact gaps on the arc and its motion for each type of contact geometry.

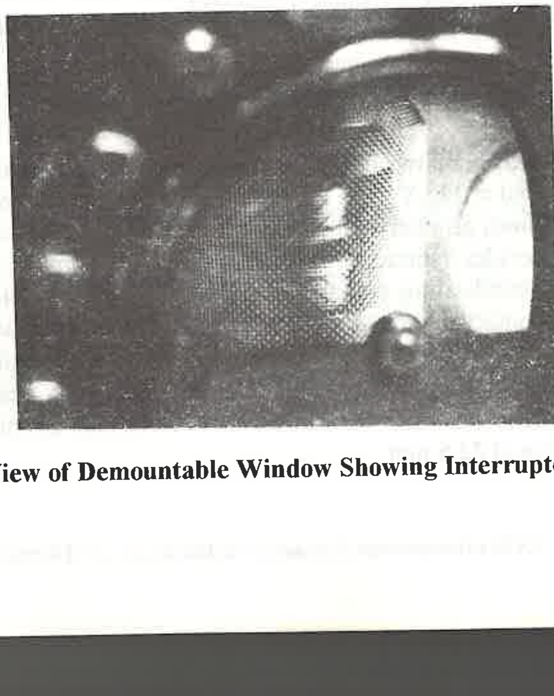


Fig. 2. View of Demountable Window Showing Interrupter Contacts.

3. RESULTS AND DISCUSSION

For Type A there are clear indications that reducing the contact gap below 4 mm led to an increasing probability of failure to interrupt, although even at 1 mm gap the probability of a successful interruption was greater than 60%. Fig. 3. Type B however continued with a perfect interruption record down to 1 mm gap. Fig. 4. Due to mechanical limitations with our test equipment it was not possible to reduce the gap further, and so the point at which gap length affected the ability to interrupt on this device was not determined. It was possible to continue testing on the same devices after a failure to interrupt, as with the synthetic test circuit minimal current flowed after current zero, and so no damage was done to the interrupter. Each interrupter was subjected to 20 or 21 switching operations in total.

Contact Gap(mm)	Number of Tests	Number of Clearances	Number of Failures
8	12	12	0
6	12	12	0
4	13	12	1
2	13	10	3
1	13	9	4

Fig 3. Synthetic Testing on Three off Type A Interrupters at various contact Gaps
These interrupters were tested at 12 kV; 32 kA rms. 50Hz full cycle (10 ms).

Contact Gap(mm)	Number of Tests	Number of Clearances	Number of Failures
8	12	12	0
6	12	12	0
4	12	12	0
2	12	12	0
1	12	12	0

Fig. 4. Synthetic Testing on Three off Type B Interrupters at various contact Gaps
These interrupters were tested at 12 kV; 13.1 kA rms. 50Hz full cycle (10 ms).

In addition it was noted that small contact gaps also affected the wear rate of the interrupters significantly, with wear increasing rapidly below a contact gap of 4 mm for both types of contact. This is believed to be due to magnetohydrodynamic forces forcing liquid metal out of the gap during interruption. Intriguingly the rate of wear decreased slightly on both types of interrupter at 2 mm contact gap. At present we have no explanation for this effect. Fig. 5.

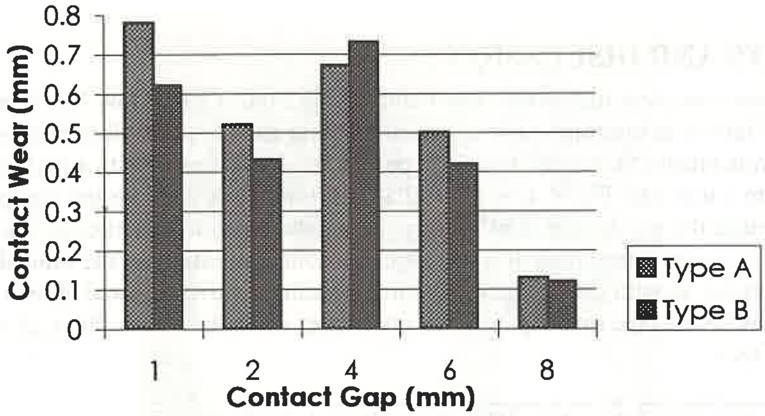


Fig. 5 Average Contact Wear During Synthetic Testing
Measured contact wear for four operations at each contact gap, averaged for three devices.

The arc voltage was also measured during the interruption sequence and the results are shown. Fig. 6. It is interesting to note that although the arc voltage decreased with contact gap, on both types of interrupter there appeared to be a significant change between 4 mm and 6 mm gap. It was also noted that for contact gaps of over 4 mm the arc voltage was "noisy" an effect normally seen with an arc in "Constricted" mode. Fig. 7. However the arc voltage became much smoother at gaps of 4 mm or less which is normally associated with arcs in a "Diffuse" mode. Fig. 8. Initial examination of the high speed films taken of these contacts at small contact gaps indicates that the arc remained constricted even at very low contact gaps.

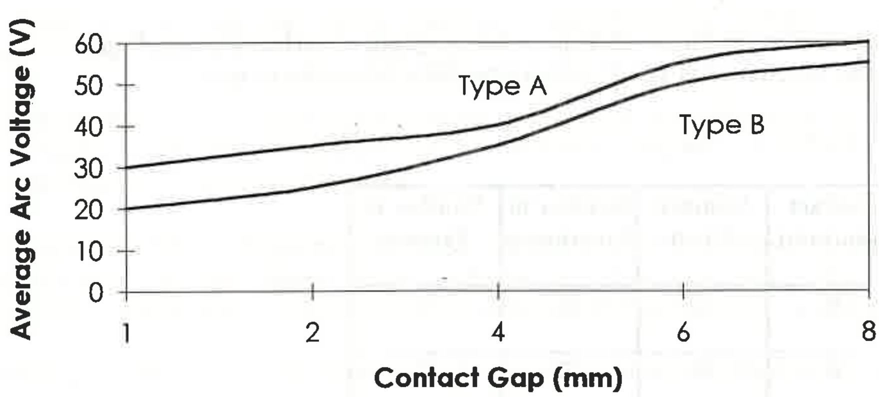
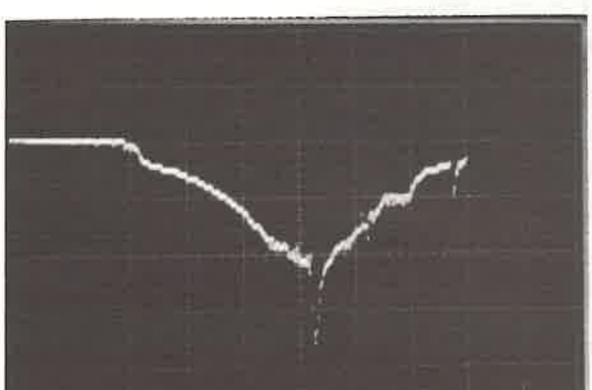


Fig. 6. Average Arc Voltage at Differing Contact Gaps.
The arc voltage was averaged both over the arcing period, and for each operation.



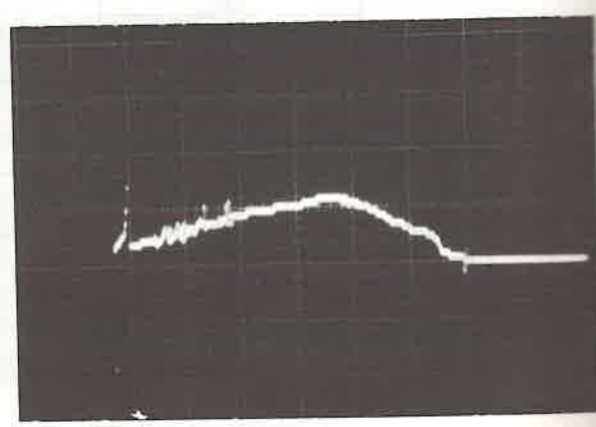


Fig. 7 Type A Contacts 8 mm Gap

Fig. 8 Type A Contacts 2 mm Gap.

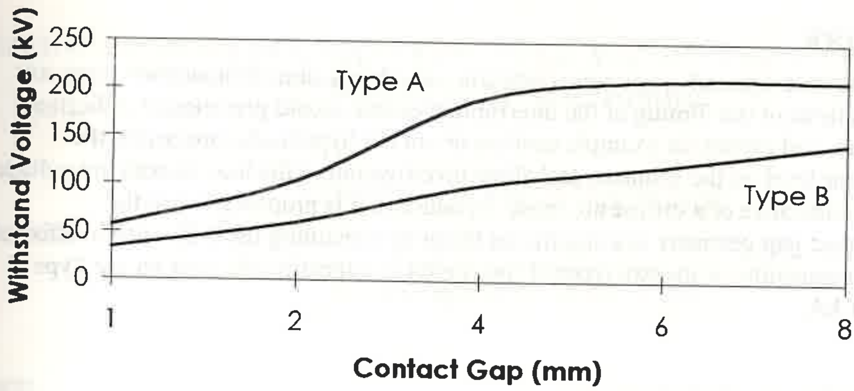


Fig. 9. Impulse Performance at Different Contact Gaps.

Finally the BIL capability of the interrupters was tested and on both devices a reduction in contact gap below 4 mm significantly degraded the dielectric strength of the contact gap. This was expected, and confirmed that at gaps of 6 mm or less the contact gap dominated the breakdown level of the interrupter. Fig. 9.

4. CONCLUSIONS

The results indicate that the effect of small contact gaps on short circuit interruption ability is different between the two types of interrupters tested. The difference in results between the two interrupters is interesting, and there are several possible explanations;

Firstly it is possible that the two contact geometries work in slightly different ways, and that the "Folded Petal" geometry is less affected by small contact gaps than the "Contrate" geometry.

Secondly it is possible that Type A has more excess interruption capability at 13.1 kA than Type B has at 32 kA.

Thirdly, it is possible that the size differences between the two contact geometries was a significant factor. The Type A contact geometry has a contact track width of 10 mm, and with a contact gap of 1 mm this traps the metal vapour from the arc between the contacts, resulting in a degradation of the interruption capability, Fig 6. The Type B contact however has a track width of only 6 mm and the trapping effect is much less at a 1 mm gap, Fig 10.

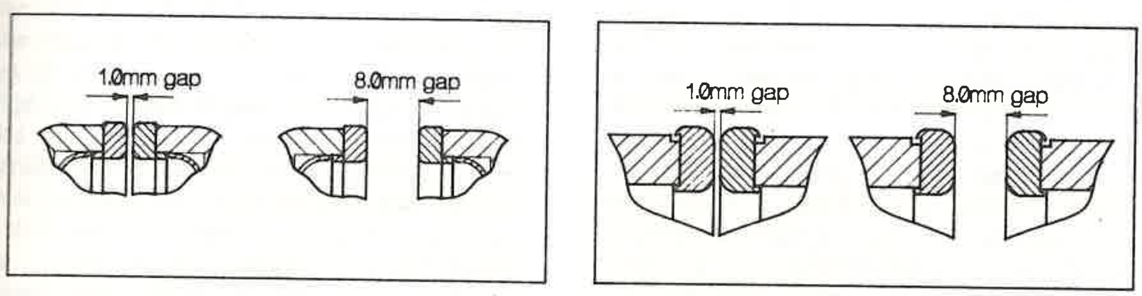


Fig. 10. Geometry of Contact Gap

It is thought that the most likely explanation is a combination of this effect with the fact that at 31.5 kA Type A generates considerably more metal vapour during arcing than Type B does at 12.5 kA, and this exacerbates the situation.

5. FURTHER WORK

At this point in time the investigation is not quite complete with the vacuum demountable work still in progress. Further analysis of the filming of the interruption events should give clearer indications of the arcing phenomena and should for example confirm or not the hypothesis concerning the reasons for the high wear level on the contacts, and allow investigation of the low, smooth arc voltage at small gaps, possibly indicative of a diffuse arc mode. In addition it is proposed to test the hypothesis that the contact gap geometry is a significant factor in explaining the difference in effect of the gap on interruption capability of the two types of interrupter by repeating the tests on the Type B interrupters but at 13.1 kA.

6. ACKNOWLEDGEMENTS

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