FURTHER EXPERIMENTS IN HIGH CURRENT SWITCHING USING SMALL CONTACT GAPS

Leslie T.Falkingham, Kam Cheng
GEC ALSTHOM T&D Vacuum Equipment Limited,
Leicester Road, Rugby, CV21 1BD, England.

ABSTRACT

Previously 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. These tests are a continuation of the earlier series, intended to test hypotheses concerning the results seen. For all tests, three interrupters of each type were tested at reduced contact gaps. the first series consisted of gaps between 8mm and 1mm. This work has now been extended to include gaps of 1mm to 0.25mm. 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 earlier results indicated that one type, Type A, showed a significant reduction in the probability of interruption of the rated short circuit current at contact gaps below 4mm, whereas the other type, Type B, showed no degradation at contact gaps down to 1mm. The new work confirmed this showing that Type B only showed significant degradation in performance at gaps of 0.5mm and below. The reasons for this are discussed.

1. INTRODUCTION

A great deal of work has been carried out over the past few years into the study of commercial vacuum interrupters and circuit breakers [12]. In addition, substantial work has been performed on studying vacuum arcs between commercial vacuum interrupter contact geometries[34]. However, this has mainly concentrated on relatively large gaps of over 6mm[56]. All interrupters we tested in this series of experiments utilised existing transverse field arc control systems, of the Contrate or Folded Petal types, although of differing size and rating[78]. The currents to be switched were 13.1kA (rms.) at 12kV (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 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 capability of the devices. The original series of experiments, previously reported[9], concerned the ability of two interrupter contact geometries to interrupt rated short circuit current with gaps between 8mm and 1mm. The results found led to a series of hypotheses and the second series of experiments was intended to provide further information to validate or disprove these, and to extend the testing to contact gaps down to 0.25mm.

In summary the results of our previous experiments were as follows;

1. 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% . Type B however continued with a perfect interruption record down to 1 mm gap.

   The arc voltage was also measured during the interruption sequence. 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 in level between 6 mm and 4 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. However the arc voltage became much smoother at gaps of 4 mm or less which is normally associated with arcs in a "Diffuse" mode.

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

2. TECHNICAL DETAILS

The investigations were carried out on two different types of vacuum interrupter, Fig. 1. The large interrupter, Type A, was rated at 12kV; 31.5kA. This interrupter with a body diameter of 130mm utilises a "Contrate" arc control geometry which provides a component of magnetic field which is transverse to the arc and thereby 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 smaller interrupter, Type B, was rated at 27kV; 13.1kA, (subsequently rerated at 12kV; 20kA). This interrupter with a body diameter of 60 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. Both types of contact use Chrome Copper tip material, (75/25), named ZLR. 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,1 mm in the original series of tests, and in addition 0.75mm, 0.5mm, 0.25 mm; in the latest series.

1). Basic Insulation Level (BIL). Impulse testing with a standard 1.2/50 waveform, each interrupter was subjected to reducing voltages, until a voltage level was reached that the interrupter could withstand, this was defined as five operations on each polarity with no failures allowed.
2). Short Circuit Testing. Synthetic test with a single half cycle of 12ms duration. The half cycle of current simulated one symmetrical half cycle of either 31.5 kA rms., or 13.1 kA rms. for a 50Hz system. The injected Transient Recovery Voltage (TRV) conformed to IEC standards for a 12 kV 50Hz system. In addition an identical pair of contacts of each type of geometry were fitted to a bakeable vacuum demountable system, which allowed the contacts to be filmed by a high speed camera, (up to 10,000 fps) while being short circuit tested, Fig. 2.

3. RESULTS AND DISCUSSION

Due to mechanical limitations with our test equipment it was not possible in the original series of experiments to reduce the gap to less than 1mm. After modifying our equipment we continued to reduce the contact gap down to 0.25mm. and showed a reduction in performance for both types of contacts Fig. 3.

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. Three interrupters of each type were tested. Previous work investigating vacuum arcs with short contact gaps has been performed but using a different contact geometry. This work showed that with these other geometries the small gap resulted in severe damage and a failure of the normal arc control[10]. It would appear from our results that this effect is geometry dependant. 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. One hypothesis is that at these very small gaps, the metal vapour is trapped between the contact surfaces and this cloud of vapour acts as conductor in addition to the constricted arc column resulting in the smooth arc voltage normally associated with a "Diffuse" arc.

We hypothesised that the results indicated 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 Type B has more excess interruption capability at its' rating of 13.1 kA than Type A has at its' rating of 31.5 kA, and in fact subsequent work has shown that the Type B contact can, in fact, be rated at 20kA. In order to eliminate this possible effect we repeated the experiments on new interrupters of each type, but with a current of 13.1kA for both types of contact. We also extended the range of the experiment by using contact gaps of down to 0.25mm. The results showed quite clearly that the different interruption capability of type A and type B contacts is not related to the level of short circuit current at small gaps. When type A contacts were tested at 13.1kA, which is substantially lower than the 31.5kA rating, we had a slightly higher failure rate than before (31%@ 31.5kA v 40%@ 13.1kA), clearly indicating that the ability to interrupt was dominated by the gap, rather than the level of current.

We hypothesised that the difference in interruption ability seen was due to the geometry of the two contacts, with the type A trapping metal vapour more effectively in the gap than the type B, and that this was causing the difference in performance, in addition it is possible that the size differences between the two contact geometries was a significant factor, Fig. 4. The Type A contact geometry has a contact track width of 10 mm, and with a contact gap of 1 mm this effectively traps the metal vapour from the arc between the contacts, resulting in a degradation of the interruption capability, Fig. 5. 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 . The new results show that the level of short circuit current, and by implication the amount of vapour generated, is not significant, and it is now believed that there may be a critical level of vapour trapped within the gap above which interruption is inhibited.

In order to investigate this more thoroughly, we applied a simulated Transient Recovery Voltage to the interrupters to show the effect of contact gap on interrupting capability in the absence of power current. Due to plant limitations, this was performed on a modified BIL test plant. The tests showed that for contact gaps of over 0.25mm there were no failures to hold the applied voltage, and for a contact gap of 0.25mm type A had a failure rate of 28% and type B a failure rate of 47%, Fig. 6. This result is a little surprising as the short circuit interruption results clearly indicated that type B performed better than type A at small gaps, and also, importantly, for type A we saw a reduction in short circuit interruption performance for contact gaps of 2mm and less. These results indicate to us that the failure mode of type A is related to the post arc vapour, which starts to have an influence on short circuit interruption performance from 2mm gap downwards. Type B also showed a reduction in short circuit interruption performance but this effect started at only 0.5mm contact gap.

4. CONCLUSIONS

In summary both contacts had a reduction in short circuit interruption performance with reducing contact gap, and this reduction in performance could not be explained simply by the reduction in dielectric strength of the gap. In addition the reduction in probability of interruption for type A was at a similar level for currents of 31.5 kA and 13.1kA. This leads us to believe that the hypothesis that the reduction in performance is due mainly to the trapping of vapour in the contact gap, and that this is dominated by the contact geometry, is true, although it also indicates that there is a critical level of vapour which reduces performance, above which the performance is not affected further.

5. ACKNOWLEDGEMENTS

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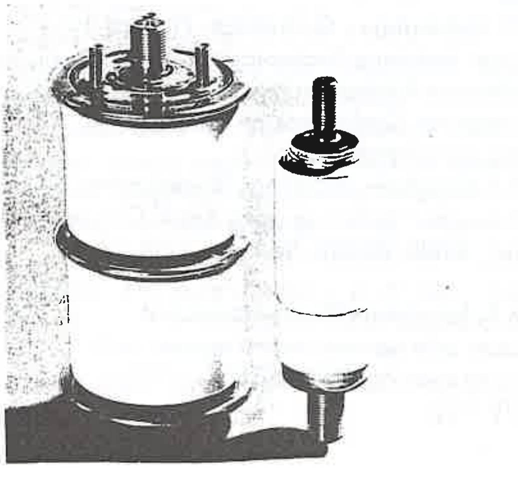

Fig. 1 Vacuum Interrupters under Test. Type A left, Type B right.

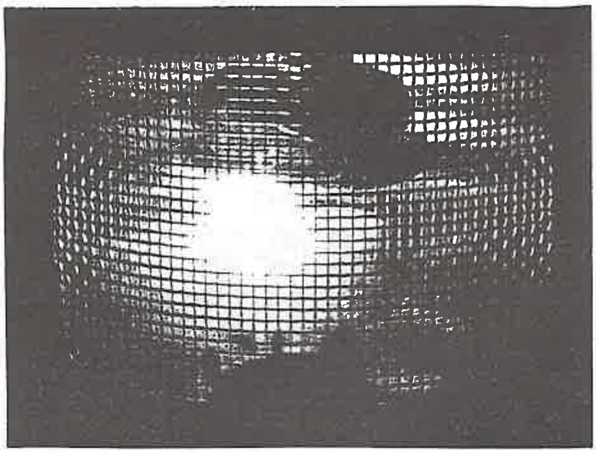

Fig. 2 View of Demountable Window Showing Interrupter Contacts.

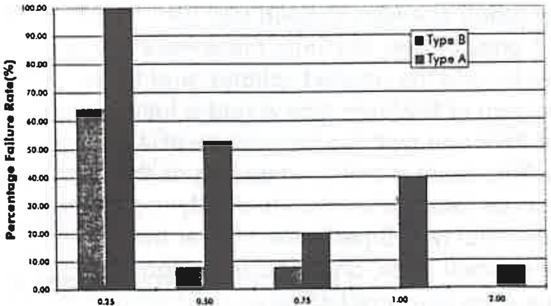

Figure 3 - Percentage of Failures During Synthetic Testing at 13.1kA; 12kV r.m.s

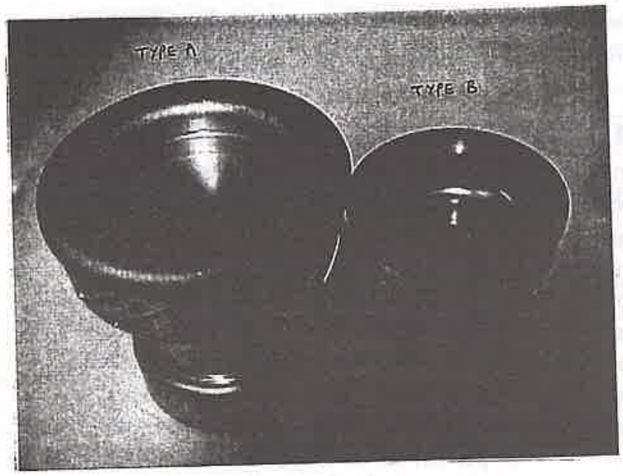

Figure 4 - Conductor. Type A left, Type B right.

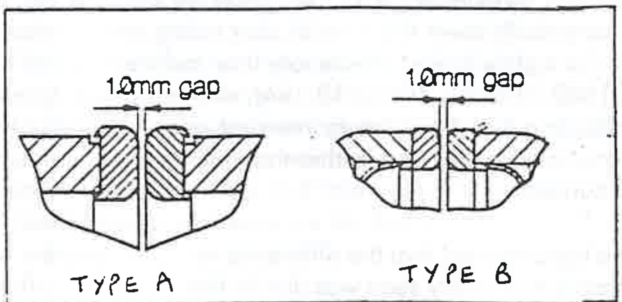

Figure 5 - Geometry of Contact Gap

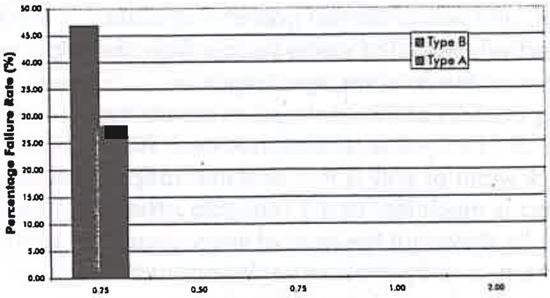

Figure 6 - Percentage of Failure During Simulated TRV Tested at 24.5kV Peak

6. REFERENCES

[1] J. M. Lafferty, "Vacuum Arcs, Theory and Application", John Wiley and Sons, New York 1980.

[2] E. Dullni, E. Schade, "Product Orientated Research in Industry Investigation of the High Current Interruption of Vacuum Circuit-Breakers", XVth ISDEIV Darmstadt 1992, P279-289.

[3] M.B. Schulman, "Separation of spiral contacts and the motion of vacuum arcs at high a.c current", IEEE Trans. Plasma Sci, Vol. 21, P484-488 Oct 1993.

[4] E. Dullini, "Motion of high current vacuum arcs on spiral -type contacts", IEEE Trans. Plasma Sci, Vol. 17, P875-879 Oct 1989.

[5] W. Shang, H. Schellekens, "The interrupting ability of vacuum interrupters with horseshoe electrode, VXIth ISDEIV, P183-186.

[6] G.R. Mitchell, "High current vacuum arcs part 1 and part 2", Proc. IEE Vol. 177, P2315-2332, 1970.

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

[8] L. T. Falkingham, G. Rushton, "Trends in Vacuum Switching Technology", IEE Conference Publication No. 400 1994, 4th International Conference on Trends in Distribution Switchgear.

[9] L.T.Falkingham, K.Cheng, "Experiments in High Current Switching using Small Contact Gaps", XVIIIth ISDEIV, Berkeley, USA,1996, p.

[10] M.B. Schulman,"The behaviour of vacuum arcs between spiral contact with reduced spacing, XVIth ISDEIV, 1992, p.179-182.