The Design and Development of the Shieldless Vacuum Interrupter Concept.

Dr Leslie T Falkingham
AREVA T&D MVB

SUMMARY

This paper briefly discusses the design and development of the shieldless vacuum interrupter concept as conceived by Vacuum Interrupters Limited (VIL) in London in the early 1980's. The introduction of the shieldless concept was a radical departure from all previous designs and was driven by a change in design philosophy. Previously vacuum interrupter designs were complex and used a complicated multistage manufacturing process. The new design philosophy reduced the man-hours required to manufacture a vacuum interrupter by over 50% and reduced the number of components to be assembled (excluding braze material) from 16 to 7.

The success of the design is shown by the fact that over a quarter of a million devices have been manufactured to date by GEC (later ALSTOM, then AREVA) plants around the world, and after twenty years the shieldless design is still in manufacture, unchanged.

I. INTRODUCTION

The development of the shieldless interrupter was the outcome of a deliberate decision taken in VIL at the beginning of the 1980's to produce a revolutionary new design of vacuum interrupter. The design had to be revolutionary because the intention was to meet new difficult requirements for the devices. The design concept was to develop a device with an optimised manufacturing process and construction which would be significantly smaller and lower cost than contemporary devices. Also the target was to have a lower reject rate in manufacture, and be able to be made in significantly larger numbers than existing designs, but with minimum additional capital investment for the company. With the existing technology these targets were quite impossible, and so to achieve this we had to come up with some quite radical ideas, and to question established practice and some widely held beliefs. These requirements led to the invention of the One-Shot Seal Off[1] technique and the Folded Petal[2] contact geometry which were fundamental to the creation of the shieldless design, and are described elsewhere. This paper will concentrate on the shieldless aspect of the design, and why such a radical approach was taken..

Figure 1. V204. 12kV:20kA. The world's first shieldless vacuum interrupter.

II. HISTORY

By the early 1980's vacuum interrupter development was changing. Previously it had been driven by a need to develop new interrupter ratings, and the technology was progressively introduced to higher and higher short circuit levels. But the electrical power industry uses standardised values for voltage and interruption currents and by 1980 all of the popular ratings up to 40kA could now be met. Although exotic ratings such as 100kA for Tokomak applications were possible, and indeed were later developed, these are not industrial ratings and are only needed in very small quantities. In addition economic voltage ratings for vacuum had stabilised in the 12kV to 38kV range.

The commercial market was now clearly understood and attention turned from stretching the technology to meet higher requirements, and towards industrialising the

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product to give lower manufacturing costs for mass production.

III. ESTABLISHED TECHNOLOGY

In order to function a vacuum interrupter needs certain attributes. Classically these were met by designs such as shown in Fig. 2.

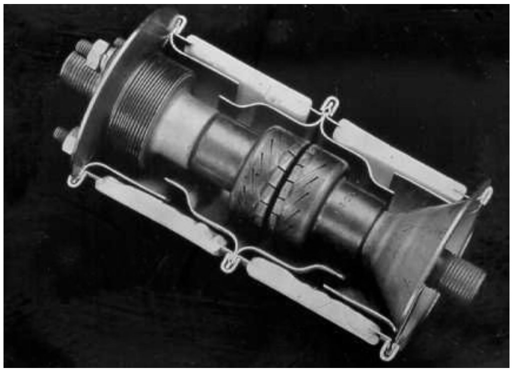

Figure 2. V8 12-25 interrupter, c.1981 using Contrate contact, Glass-Ceramic insulators, and a brazed-welded-furnace seal off manufacturing system.

In this interrupter there are two conductors and two electrical contacts, one movable, within a vacuum envelope. The interrupter operates by simply displacing the moving contact a few millimetres. The movement is enabled by means of a stainless steel bellows at the moving end. The interrupter will then arc until the next current zero, when, if all is well, the arc is extinguished and interruption takes place.

The other key features are specially shaped contacts which use self induced magnetic fields to assist interruption, and special contact material used on the contact arcing surfaces to assist the interruption and to define key properties of the interruption process, such as current chopping and dielectric strength.

The body consists of, in this case, two glass-ceramic insulators assembled by means of welds between embedded metal flanges, although in other designs metallized Alumina ceramic is used and the assembly is by means of brazing. At the ends of the interrupter and mounted from the centre weld can be seen metal vapour shields. These perform three functions;

- They prevent metal vapour generated durnig the interruption process from condensing on the inner surfaces of the insulators which would compromise their dielectric performance,
- They protect the glass-ceramic from the arc at high peak currents
- They control the electric fields across the insulator and thereby help attain the requires basic insulation level (bil)

Although other interrupter designs may vary in their use of insulator material, seal off technique, and contact geometry, they essentially have the same key features.

IV. CONCEPT & DESIGN

The new concept was to look at the whole process of manufacture and to design both the interrupter and the manufacturing system together in order to optimise the manufacturing process from a cost and capacity point of view. In addition this had to be done with minimal capital investment, as the company simply did not have the money to invest.

The intention was to optimise in particular the use of the existing vacuum furnaces and the assembly clean room. Clearly the theoretical optimum use of the furnaces would be to have a small interrupter so as to pack more into each furnace load, and to only put each interrupter through the furnace once, this later became known as the One Shot Seal Off process.

However at the time due to the complex contact geometry and the other key components needed in an interrupter this was not possible and all interrupters were made using a multi-stage brazing process followed by pump tube or furnace seal off. Clearly a completely new design would have to be made to accommodate the One Shot Seal Off process.

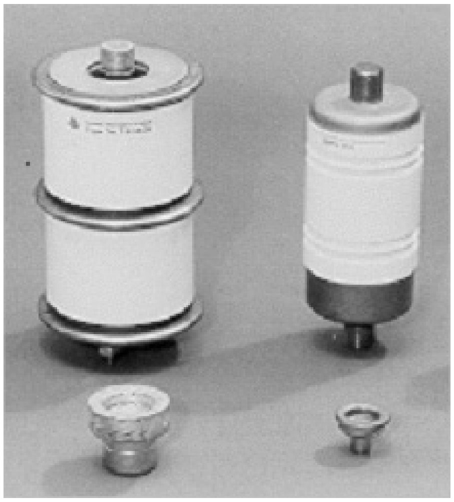

Figure 3. V8 12-25 interrupter and early prototype V204

If the interrupter was to be brazed in one operation then all of the internal components would have to be self jigging. In addition in a device with small diameter it would be necessary to align the components accurately, as internal clearances are small and misalignments of a few millimetres would be significant. The use of external alignment jigs was considered, but rejected, as these would take up space in the furnace and reduce the possible load, as well as increasing assembly time.

After investigating a number of possiblilities a completely self-aligning design of insulator was decided upon whereby the insulator had a flange on each end which would act to align the end caps. The next problem was the metal vapour shield. This is necessary to prevent the internal surface of the ceramic insulator from becoming coated with metal vapour after arcing. For low voltages it is possible to have the shield mounted from one end cap, which gives it the electrical potential of one of the contacts. It was decided that this was not appropriate for 12kV devices, as the electrical field stress is then concentrated at one end of the interrupter, and there is a possibility of the arc transferring to the shield during interruption. The metal vapour shield could be mounted between two ceramics, as in a classic design, and a form of jigging used to align the interrupter, but again this added cost and complexity while reducing furnace load due to the inclusion of location jigs.

The problem was solved by the revolutionary concept of molding the centre shield from ceramic and having it as an integral part of the insulator body. This is technically possible because depending on the design of the arc control, it is possible to prevent the arc from touching the ceramic (or shield). The shield then is simply a means for preventing metal vapour from depositing onto the ceramic surface. But we know that the vapour generally travels in straight lines and so will not turn far around corners. If it did so the classic metal shield design would also not work.

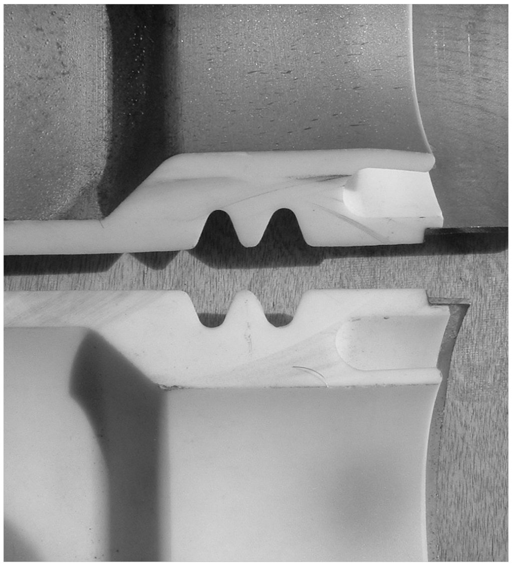

Figure 4. Sectioned insulators from V204 interrupters. Lower insulator unarced, upper insulator after 50 interruptions at 20kA.

Thus if the ceramic could be so designed as to protect a significant part of its surface then it should work, in effect, as a metal shield would. This in fact is what happens. [fig 4] shows two sectioned ceramics from V204 interrupters.

The bottom ceramic is in the “as sealed off” state. The top ceramic shows the insulator after a large number (50) of short circuit operations at 20kA. As can be clearly seen the internal surface of the ceramic is heavily coated with metal vapour, but the portion of ceramic protected by the molded fin is in fact completely clean, and provides more than sufficient insulation for 95kVbil rating. The geometry was optimised by means of computer generated electrostatic field plots, and then rigorously tested.

One disadvantage was the added complexity of the new insulator, which would clearly be more expensive to buy than the more normal simple cylindrical designs. However by integrating the functions of the voltage grading shields within the ceramic it was determined that the total cost was less than the cost of separate insulators plus metallic shields.

The added complexity of the ceramic also proved challenging for ceramic manufacturers, and the original development of the ceramic itself was performed by our then in-house company, GEC Ceramics Limited (now Advanced Ceramics Limited (ACL)). Later the design was and is fabricated by a number of ceramics manufacturers around the world including ACL.

Another consideration had also to be made when looking at the use of a shieldless design. This was the fact that with vacuum interrupters the normal way of measuring the vacuum is by means of a crossed field discharge between contact and shield. Obviously is there is no shield then this is not possible. This was a serious issue as without a proven technique for measuring the vacuum inside the interrupters after seal off the product would not be viable.

The issue was solved by arcing the interrupters with significant current (>2kA) after seal off.

This promoted the formation of a metallic coating on the surface of the ceramic, which acted as a pseudo-shield. It was found that this shield acted as a metallic shield as far as the crossed field discharge was concerned and allowed the vacuum measurement to be undertaken as normal. In addition due to careful design of the ceramic geometry, once coated the pseudo-shield also acted as a normal metallic shield as far as voltage grading is concerned.

The work on electrical processing of the interrupters also resulted in a significant simplification of the post seal off processes.

Previously interrupters were subjected to a number of processes, including High Frequency Arcing (HFA), High Current Arcing (HCA), and High Voltage Arcing (HVA). All of these processes were replaced with a single process termed Low Frequency Arcing (LFA) which also performed the coating of the insulator.

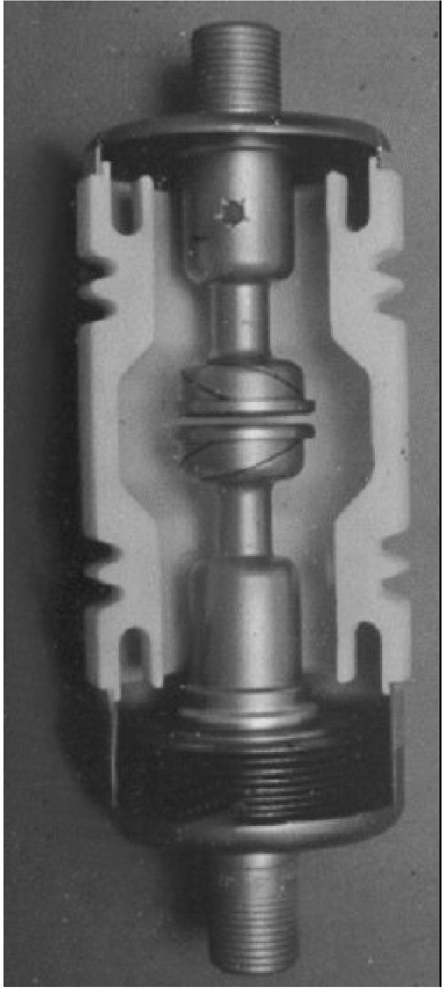

Figure 5. Sectioned V204 interrupter showing folded petal contact and shieldless insulator design.

V. TESTING & DESIGN VALIDATION

Obviously when a radical approach is taken it is necessary to rigorously test the new approach to ensure that there are no unforseen negative effects. This was done, and several hundred prototype interrupters were manufactured and tested in an extensive validation programme over a two year period before the design was judged suitable for release. This programme included many mechanical, electrical, and thermal tests as well as short circuit, and was intended to establish a clear understanding of the design under all foreseeable applications and conditions. Indeed as part of this programme tests were made where the high current arc was deliberately made to hit the ceramic to ensure survivability under extreme conditions.

VI. MANUFACTURE

After the V204 interrupter development was completed the shieldless design concept was extended to produce a family of devices as shown:

V103 6.6kV: 13.1kA :630A
V204 12kV: 20kA: 1250A
V304 12kV: 31.5kA: 1600A

Once the shieldless concept was fully established in VIL (a subsidiary of GEC), GEC decided to take advantage of the simplified manufacturing system and implemented two new manufacturing plants in India (Calcutta) and South Africa (Johannesburg). The manufacture and service history of the shieldless vacuum interrupter over the past twenty years is discussed in detail in another paper[3], and covers the implementation of these devices manufactured in the UK, South Africa, and India.

VII. CONCLUSIONS

The shieldless interrupter design was found to have limitations for high voltage applications above 12kV. However for a 12kV design the concept has proven highly successful and marked a revolutionary advance from the interrupters available in the 1980's. Today the one shot seal off concept is now widely used in the vacuum interrupter industry, but the shieldless design has not proven as popular, perhaps because it was too radical a change, with just one competitor introducing a shieldless design into their range of LV interrupters.

VIII. ACKNOWLEDGEMENTS

The author would like to thank the R&D team at VIL together with ACL and the GEC research Laboratory Stafford (now AREVA T&D Technology Centre) for their work carried out in developing these devices, and in particular acknowledge the contributions of the late Mr J. Rand, Mr D. Hodgeson, Mr H. Gibson, and of Dr R Henson to the technology.

IX. REFERENCES

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