Review of Vacuum Interrupter Development Carried Out in London by Vacuum Interrupters Limited

L.T.Falkingham

Technical Director ALSTOM T&D Vacuum Equipment Limited,
Leicester Road, Rugby.

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1.1 Introduction

Figure 1.1 An OX 36kV outdoor circuit breaker. This is a typical piece of outdoor Medium Voltage switchgear. Inside each tank is one V8 type vacuum interrupter rated at 36kV; 25kA;1250A. Circuit breakers are also housed indoors in substations and also used for special applications. For example the same type of vacuum interrupter is fitted in a different single phase 25kV circuit breaker mounted on the roof of the Eurostar train, just behind the pantograph.

Switchgear performs a vital role in the distribution of electrical power acting to control and protect the electrical distribution system. During the past century electrical switchgear has evolved from simple knife switches breaking the hundreds of Amps up to modern circuit breakers capable of interrupting tens of thousands of Amps. Medium voltage switchgear ranges from 1kV up to 38kV, and as the technology has evolved, so the preferred medium for arcing has changed. Originally this was Air, but in the 1920's Oil became dominant and remained so up until the 1970's when Vacuum appeared. Since then Vacuum has become the technology of choice, with a challenge from another technology, SF_6 gas, being fought off in the 1980's and 1990's. Both technologies are currently available but vacuum remains dominant.

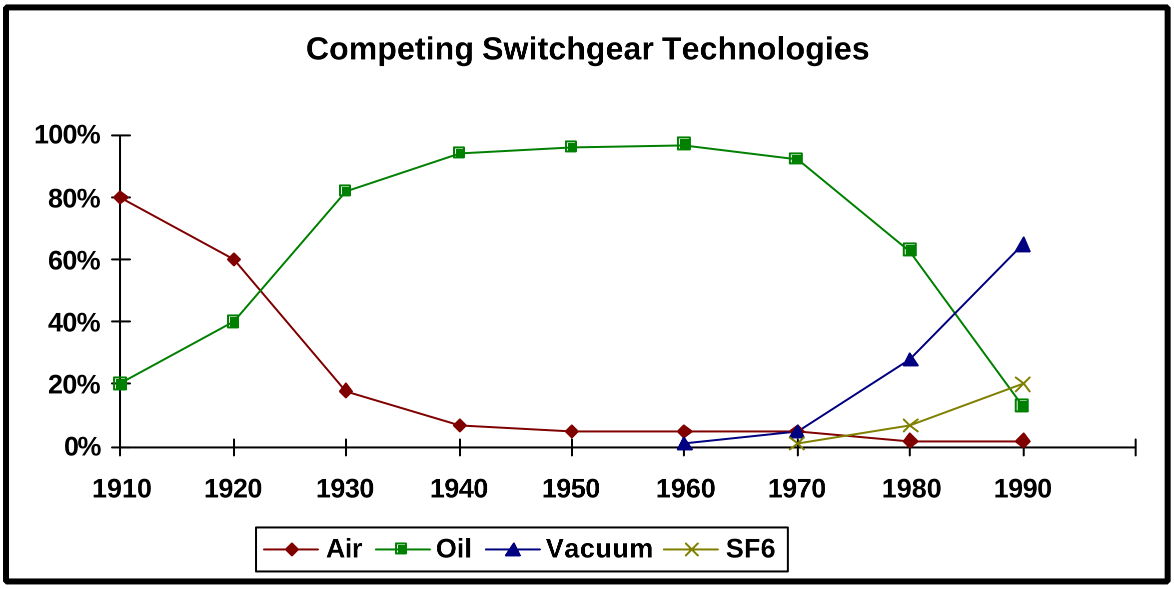

Figure 1.2 The competing switchgear technologies in Medium Voltage Switchgear during the 20th Century.

1.2 Company History

Vacuum switching technology was developed originally in the USA in the 1920's but remained non viable after the second world war, when the support technologies and expertise in vacuum systems, materials technology, and clean assembly had become mature and widely available as part of the war effort Serious development of Power Vacuum Interrupters started in the late 1950's in England. English Electric and the member companies of what became AEI were involved in this together with the Electrical Research Association (ERA). After the wave of mergers carried out in the 1960's it was decided to bring together the UK technology and VIL was founded in 1968. This was a joint venture originally between GEC which inherited the work carried out by English Electric and AEI, together with Reyrolle- Parsons, and later including Hawker-Sidderly (Brush).

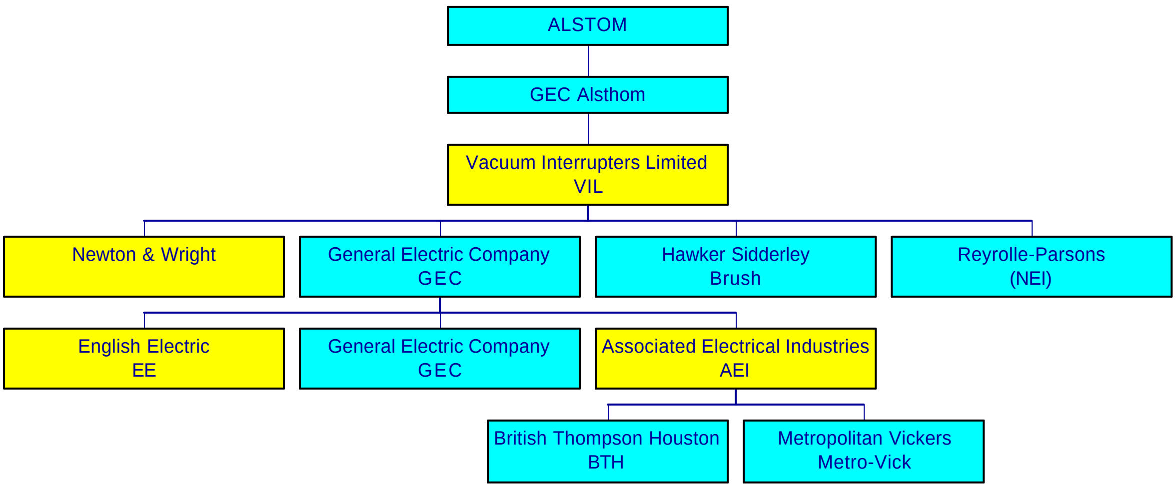

Figure 1.3 The family tree of Vacuum Interrupter technology in the UK. The company studied is Vacuum Interrupters Limited (VIL) The units indicated contributed directly to the technology.

VIL not only went on to produce world-leading technology over the following 20 years. Between 1972 and 1992 over 150,000 devices were produced in Finchley alone, and by 1992 VIL had three factories in total producing its designs. These were located in England, South Africa, and India. The early technology was also licensed to Siemens in Germany. This paper concentrates briefly on some of the innovative technology developed during this period.

1.3 Technology

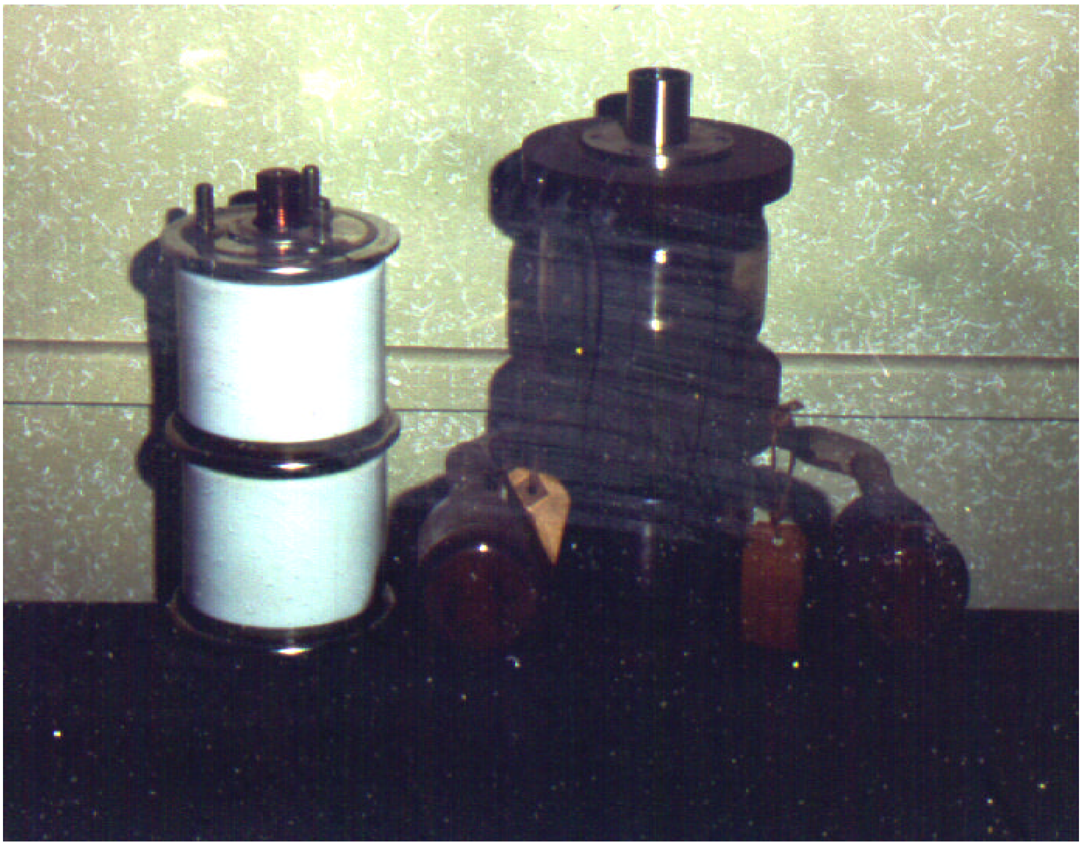

Figure 1.4 This shows the world's first contrate contact vacuum interrupter prototype built by Dr M.P.Reece at the ERA in 1966. The interrupter on the left is a V8 interrupter from the 1970's which commercially used this contact for comparison. The Interrupter prototype cleared 16kA @12kV during tests at the time, and is now in the Science Museum, London.

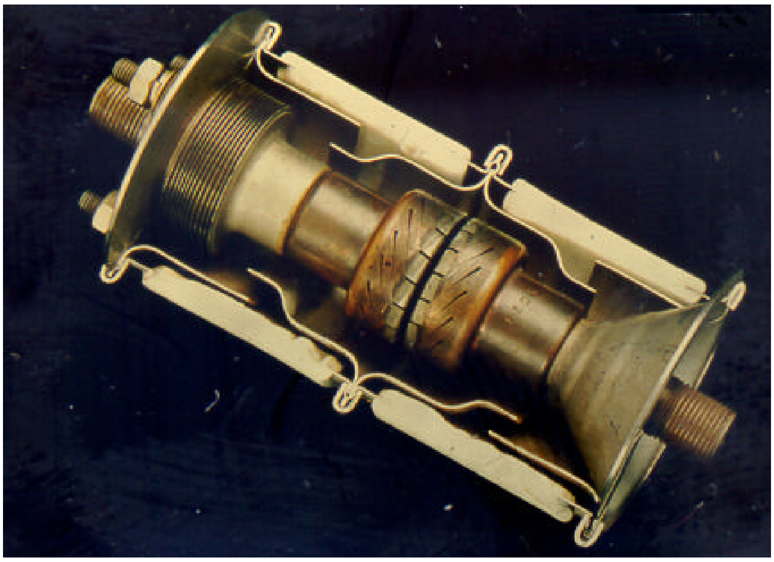

Figure 1.5 This shows a V8 interrupter designed by VIL the 1970's.

The basic design of VIL interrupters follows the style of Figure 1.5. This consists of cup shaped or Contrate arc control contacts, Glass-ceramic insulators, and metal anti-vapour shields to protect the insulators. The devices consisted of subassemblies, which were assembled, vacuum brazed, and then subsequently welded together, after which they were sealed off in a vacuum furnace. All of this was carried out under strictly controlled conditions in a Class 100 Laminar Flow clean room.

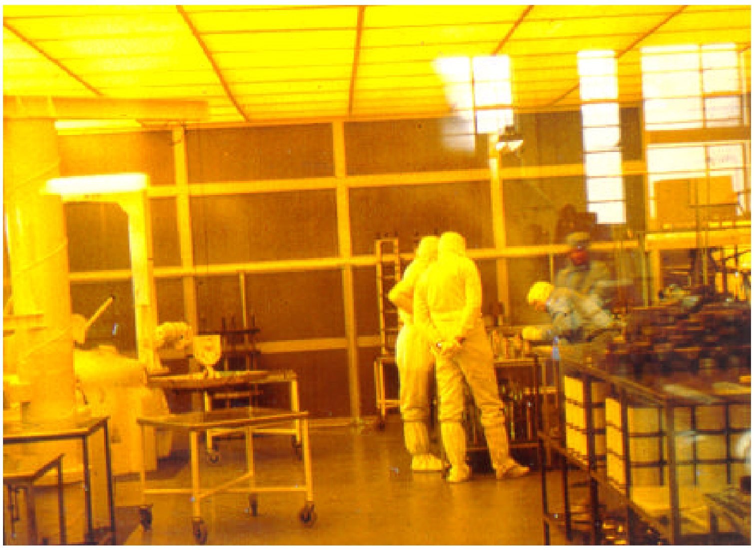

Figure 1.6 The Assembly Clean Room (Class 100) in Finchley, c.1978.

1.5 Arc Control Geometry

A fundamental aspect of vacuum interrupter design is the arc control geometry. The interrupter is operated by means of the switchgear in which it is mounted opening the moving contact by a few millimetres. After which the interrupter normally interrupts the current at the first available current zero. A contact gap of 12mm is sufficient to allow interruption of voltages of 38kVrms, and currents up to 40kA. However there is a problem with interrupting large currents. At low currents (less than 7kApk) the arc is naturally diffuse, spreading the current evenly over the contact surface, and the contacts interrupt the current naturally (Figure 1.7).

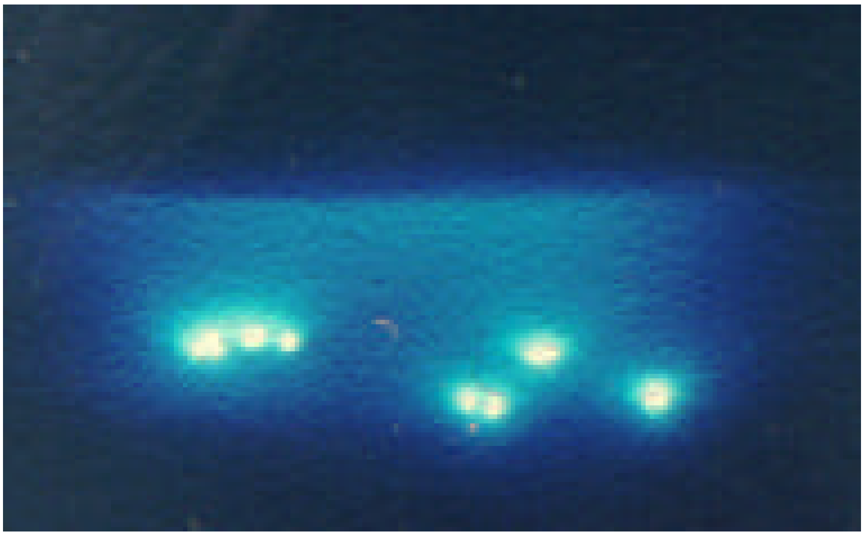

Figure 1.7. Still from High Speed film @ 10,000pps showing cathode spots on plain contact geometry (55mm diameter disc) CLR carrying @200A

However at higher currents the arc constricts and the energy is then concentrated over a small area of the contact resulting in local overheating and a failure to interrupt (Figure 1.8).

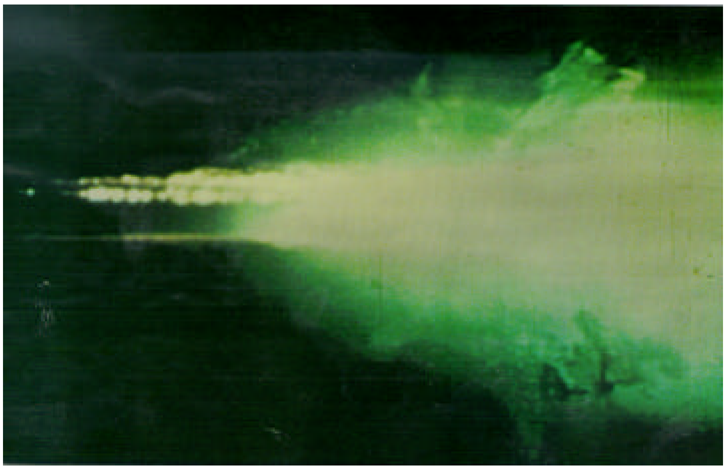

Figure 1.8 Still from HS film @ 10,000pps showing constricted arc on plain contact geometry (55mm diameter disc) CLR carrying @5000A. The liquid spilling over the edge of the contact is boiling chromium and copper.

This crucial problem was solved in a novel way. The large current to be interrupted was made to travel in such a way that the self induced magnetic field made the arc between the contacts move in exactly as an electric motor turns (Figure 1.9).

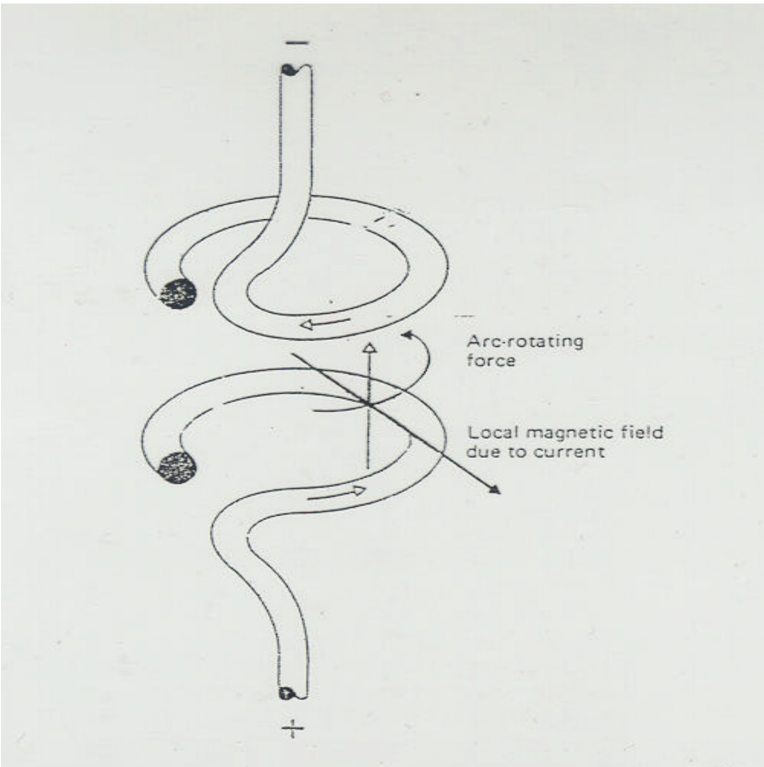

Figure 1.9. The principle of operation of a Radial Field Contact.

The slots in the side-walls of the cup force the current to flow in such a way as to develop this field and the result is shown in Figure 1.10. The arc is driven around the periphery of the contact in the same way that an electric motor turns.

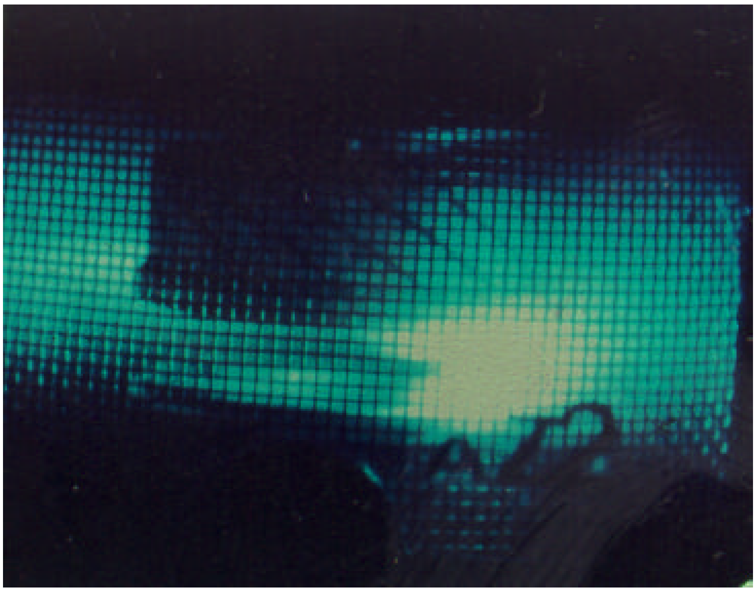

Figure 1.11. Still photo from a High Speed film @ 5,000 pps showing a 55mm diameter RMF contact interrupting 31.5kArms @12kVrms.

At VIL in 1983 a new form of RMF contact geometry was developed. This is the “Folded Petal Contact“, which significantly improved upon the power handling capability of the “Contrate“ and allowed the production of the world‘s smallest 20kA@12kV rated contact (35mm dia.) later reduced to 32mm dia.

Figure 1.12 shows the change in size of Arc Control System as developed by VIL between 1970 and 1984. Both contacts are rated at 20kA@12kV. The contact on the left (Folded Petal) actually performs better, and is till the smallest contact in the world for its rating (32mm diameter).

Figure 1.12 Comparison of size of contact for 12kV 20kA rating.

The size of contact fundamentally defines the size and cost of the interrupter, and Figure 1.13 shows how work to continually reduce the size of contact or a given rating resulted in constant reductions in product size. This figure shows four interrupters ranging from a V5 of 1975 to a VI 100 of 1995. All of these are production devices and are rated at 20kA@12kV. The smallest being only 60mm in body dia., and with a 32 mm dia. contact.

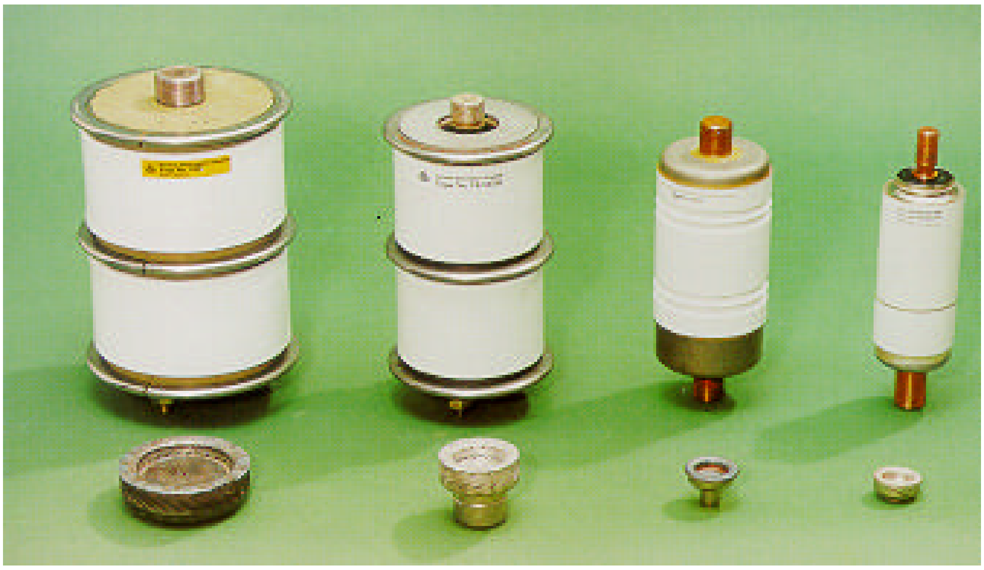

Figure 1.13 Reduction in size of interrupters from 1975 to 1995, for 12kV;20kA.

1.6 Interrupter Construction

In order to use this reduction is size of arc control contact VIL also looked at radically changing the construction of the interrupters, and their methods of manufacture. Traditional interrupter construction as shown previously in Figure 1.5 resulted in a device which comprised between 35 and 50 components, plus braze washers. This was dominated by the fact that an anti-vapour shield was needed to prevent metal vapour from arcing coating the insulating envelopes and causing electrical breakdown. For high voltages this had to be electrically floating which resulted in a need for two insulators with the vapour shields being mounted between them. This added complexity, cost, and resulted in a large number of vacuum seals being required. VIL's approach was to produce a "Shieldless" interrupter with one ceramic, and no metallic vapour shield. Together with the new "Folded Petal" arc control system, this allowed the device to be built using only seven components plus braze washers. The interrupter is shown in Figure 1.14.

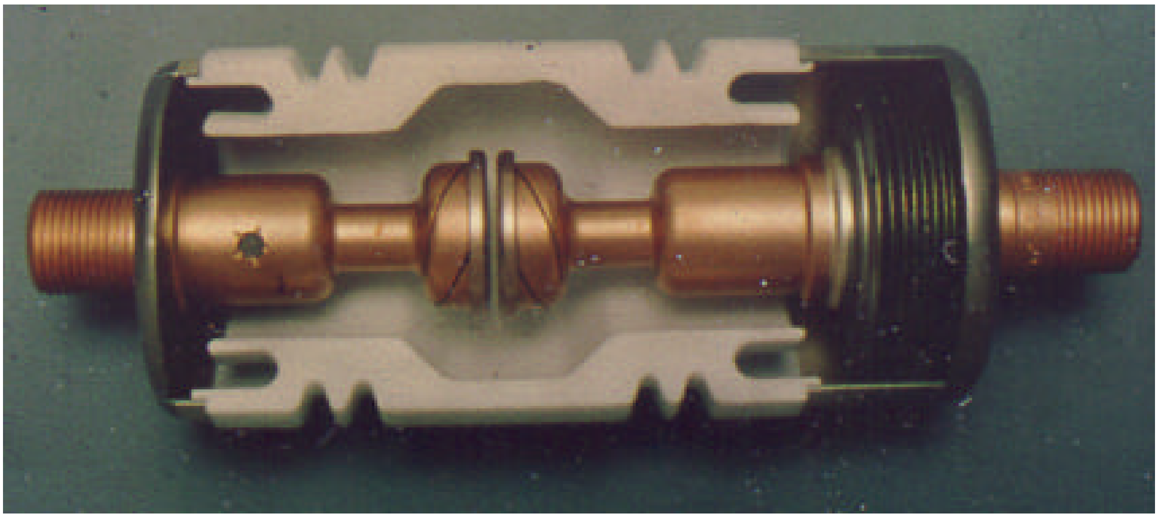

Figure 1.14. The V204 interrupter which was the world's first "shieldless" vacuum interrupter. It is rated at 12kV;20kA.

The design worked by including internal fins at each end of the ceramic which protected a small area of the surface of the ceramic. When metal vapour from the arcing arrived at the ceramic it coated the central section, but did not coat the ceramic protected by the fin. This small length of ceramic is more than sufficient to meet the dielectric requirements of the device (75kV or 95kV bil). By this innovation the size and cost of the devices was radically reduced. However a further significant innovation was also made.

The simplicity of construction allowed the possibility of assembling the device in one go, removing the need for subassemblies (excluding the bellows which on all devices were welded together separately). This allowed the possibility of making the device in one operation, However this concept was taken much further and the device was designed to be self jigging and self venting during brazing. This allowed the device to be completely assembled, then loaded into a vacuum furnace, pumped down and heated to clean the components. Finally the temperature was raised to melt the braze material which sealed the device as well as joining the components, and then cooled. At the end of the furnace cycle the device is fully assembled and sealed with vacuum inside. This is shown in Figure 1.15, and is now called the “One Shot Seal off” system. With a large furnace 100 or more interrupters can be sealed off in one go, and this innovation resulted in a very significant saving in time, effort and cost.

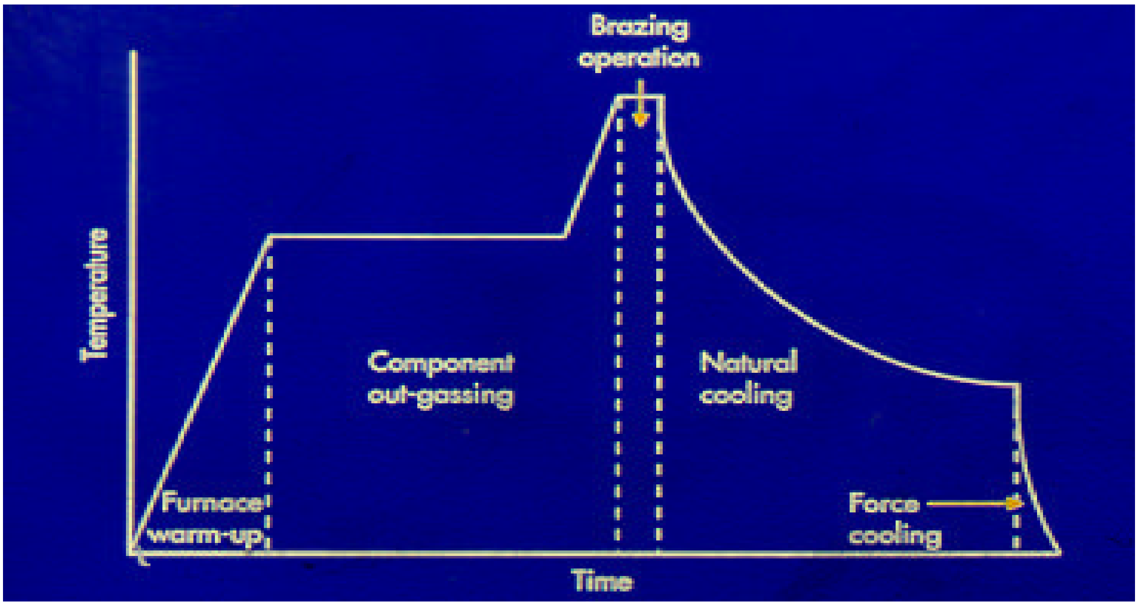

Figure 1.15 The “One Shot Seal Off Cycle

Figure 1.16. Shown is the V204, a very innovative design being both the world’s first “shieldless” interrupter as well as the world’s first “One Shot Seal Off” vacuum interrupter with production commencing in 1982.

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Figure 1.17 This shows One Shot Seal Off of V204 vacuum interrupters in a clean room in South Africa. After assembly the interrupters are loaded into a vacuum furnace and brazed and sealed at the same time.

1.7 Conclusions

Overall, the work formed in this field in Finchley contributed significantly to an advanced technology which has gone on to dominate its industry. Within GEC these innovations were recognised by the award of two Nelson Gold Medals for Outstanding Technical Innovation to workers in this field, one award in 1983 and one in 1996.

In 1992 the operation in Finchley was closed, and the UK vacuum interrupter manufacture and R&D work was transferred to Rugby at the old BTH Mill Road site, then part of GEC Alsthom (now ALSTOM) where the work has since continued resulting in a new generation of vacuum interrupters being launched in 2000, termed the VG range.