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Fifty years of Vacuum Interrupter Development in the UK

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3.1 Introduction

A Very Brief History

It is only possible to cover fifty years of innovation very briefly, and so this paper will touch upon key developments and ideas generated over this period.

Vacuum switching technology was developed originally in the USA in the 1920's but remained non viable until the 1950's, when the support technologies and expertise in vacuum systems, materials technology and clean assembly had become mature and widely available. Serious development of Power Vacuum Interrupters started both in England and the USA in 1953. English Electric and the member companies of what became AEI were involved in the English effort together with the Electrical Research Association (ERA).

Electrical Research Association (ERA)

The ERA were heavily involved in this development, led by Dr Michael Reece. Dr Reece had started work on this technology in early 1953, and went on to publish a number of internal reports within ERA[1]. At the time this work was secret, and was only finally made public in the seminal article "The Vacuum Switch and its Application to Power Switching"[2] published in 1959, followed by "The Vacuum Switch"[3] in 1963. ERA was primarily concerned with the interrupting process and the work was concentrated on developing arc control systems which would lift vacuum switching over its inherent ~7kA interruption limit (Fig.1). Good progress was made[4] and in 1968 the "Contrate " arc control system was patented[56].

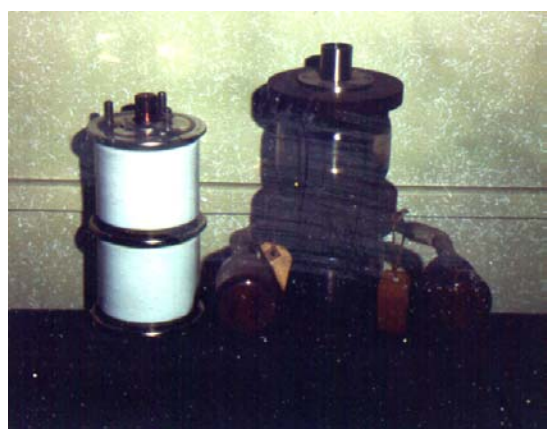

Fig.1 The world's first contrate contact vacuum interrupter prototype (Right) built by Dr M.P.Reece in 1966. The Interrupter cleared 16kA @12kV. The interrupter is now in the Science Museum, London.

AEI (BTH) & English Electric

In parallel English Electric were working on contact materials and the first patent for vacuum switching by English Electric concerning vacuum interrupter contact material based on Silver was registered in 1960. This proved not to be really viable for power interrupters, but after considerable work, English Electric created an almost perfect material with the invention of CLR Chrome copper contact material, patented in 1970[7]. English Electric had a technical co-operation agreement at that time with Westinghouse Corporation, and the material was then further developed by both organisations.

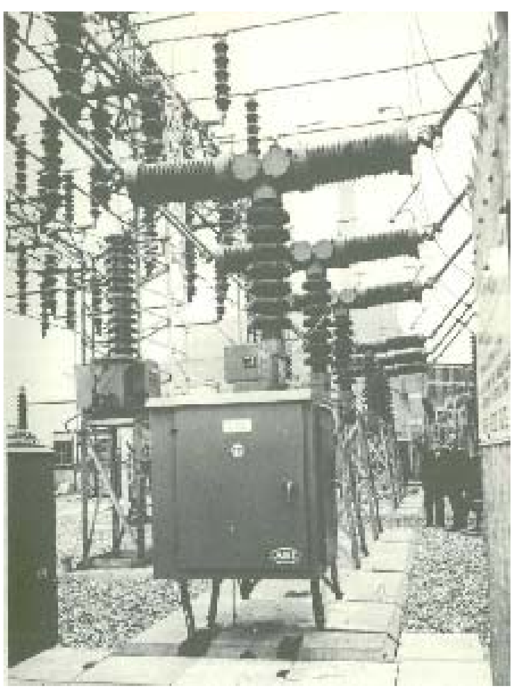

Fig.2 AEI 132kV Circuit Breaker, West Ham, London, 1967.

Meanwhile AEI produced the world's first 132kV circuit breaker in 1967. using eight vacuum interrupters per phase.

However, after the wave of mergers carried out in the 1960's, English Electric Joined AEI in the new GEC organisation, and at this time it was decided to bring together the UK technology under one organisation, and Vacuum Interrupters Limited (VIL) was founded in 1968.

Vacuum Interrupters Limited (VIL)

VIL was set up as a joint venture, originally between GEC and Reyrolle-Parsons later including Hawker-Sidderly (Brush), at that time effectively covering most of the UK switchgear industry.

At its foundation VIL had all of the key technical requirements for viable vacuum interrupters[8]. The Contrate Contact from ERA/AEI, the Chrome Copper contact material CLR from English Electric, plus vacuum knowledge and manufacturing capabilities from English Electric and AEI. In fact the unit was located in Finchley, London, in the premises of the AEI Medical unit (Newton & Wright) which had formerly made X-ray tubes, so that high voltage vacuum capability was readily available.

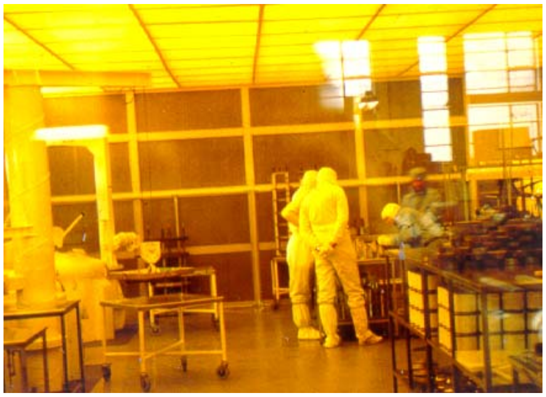

Figure 1.6 The Assembly Clean Room (Class 100) in Finchley, c.1978.

The Four Key Technologies

In order to develop viable vacuum interrupters four key technologies are needed. The contribution of the UK to these four technologies is the main aspect of the paper.

<u>1: Contact Material</u>

The key contribution in this field was the development of binary Chromium based contact materials. In a vacuum interrupter the contact material fundamentally determines the properties not only of the arc but also other important properties of the interrupter such as welding. The first Chromium based material was "CLR", patented by English Electric, which consisted of a matrix of Chromium infiltrated under vacuum with copper. Later variants included powder metallurgy versions such as "LR" developed by Westinghouse Corp., and "ZLR" developed by VIL[8].

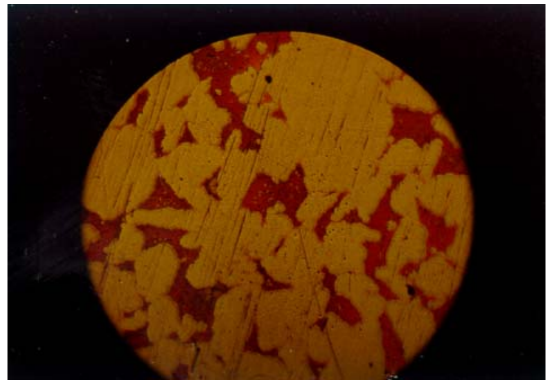

Fig.3 "CLR" Chrome Copper infiltrated contact material 57% Cr 43%Cu. (VIL c 1978)

Chrome copper materials have such advantages over other materials that they are now almost universally used for power vacuum interrupters worldwide.

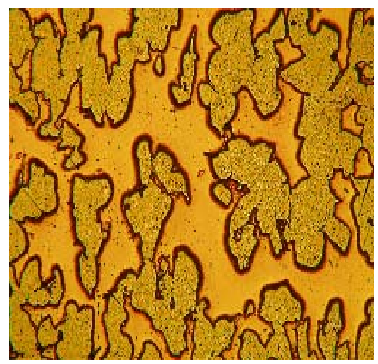

Fig.4 "ZLR" Chrome Copper sintered material 40% Cr 60%Cu. (VIL 1982)

<u>2: Arc Control</u>

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 at the first available current zero. (Fig. 5).

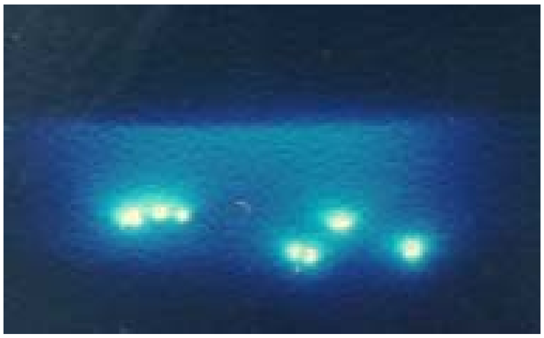

Fig.5 Still photo from High Speed film @ 10,000pps showing cathode spots on plain contact geometry (55mm diameter disc) CLR carrying @200A (VIL 1985)

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 (Fig.6). 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).

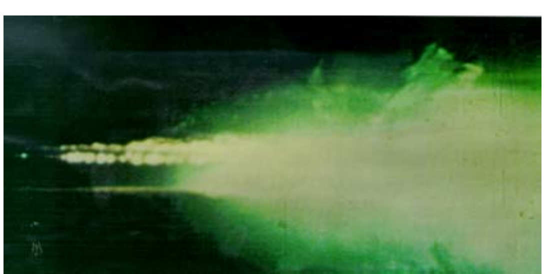

Fig.6 Still from HS film @ 10,000pps showing constricted arc on plain contact geometry CLR carrying @5000A. The liquid spilling over the edge of the contact is boiling chromium and copper. (VIL c1970)

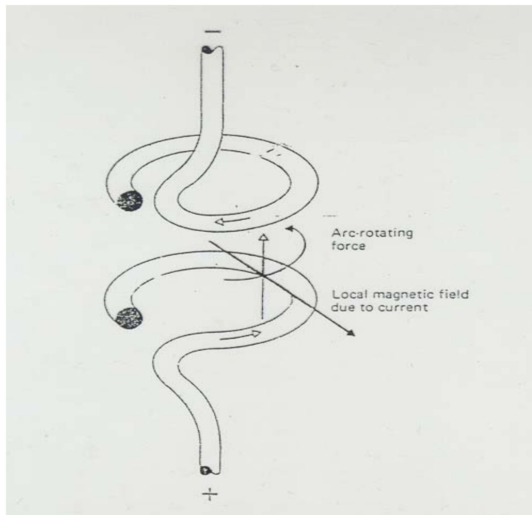

Fig.7. The principle of operation of a Radial Field Contact (RMF)

The slots in the sidewalls of the cup force the current to flow in such a way as to develop this field and the result is shown in Fig.7 & Fig.8. The arc is driven around periphery of the contact just like an electric motor.

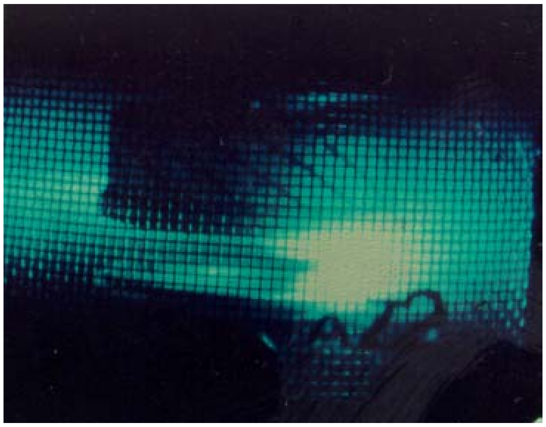

Fig.8 Still photo from a High Speed film @ 5,000 pps showing a 55mm diameter RMF contact interrupting 31.5kArms (VIL 1982)

At VIL in 1983 a new form of RMF contact geometry was developed. This is the “Folded Petal Contact“[9], which significantly improved upon the power handling capability of the “Contrate“ and allowed the production of the world‘s smallest 20kA@12kV rated contact (32mm dia.).

In the 1990’s this work continued with a new Axial Magnetic Field (AMF) contact geometry being developed by the ALSTOM team in Rugby.

Fig. 9 shows the change in size of Arc Control System as developed by VIL between 1968 and 1984[10][11]. Both contacts are rated at 20kA@12kV. The contact on the left (Folded Petal) actually performs better, and is still the smallest contact in the world for its rating (32mm diameter).

Fig. 9 Comparison of size of contact for 12kV 20kA rating.

The size of the contact fundamentally defines the size and cost of the interrupter, and Fig. 10 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.

3: Interrupter Construction

In order to use this reduction in the size of arc control contact VIL also looked at radically changing the construction of the interrupters, together with their methods of manufacture. Traditional interrupter construction as shown in Fig. 11 resulted in a device which comprised around 35 components, plus braze.

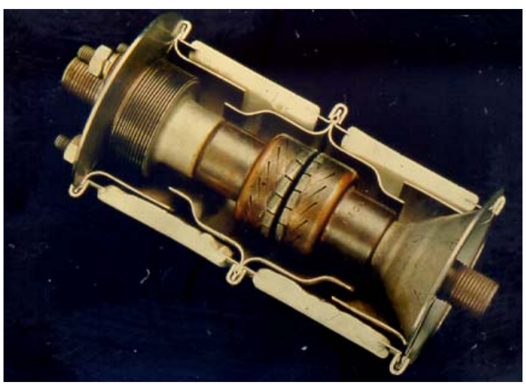

Fig. 10. Reduction in size of interrupters from 1975 to 1995, for 12kV;20kA.

Fig. 11. Typical interrupter design from the 1970's

The design was dominated by the fact that an anti-vapour shield was needed to prevent metal vapour produced by the arcing coating the insulating envelopes leading to electrical breakdown.

The basic design of VIL interrupters follows the style of Fig.11. 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. For high voltages this shield had to be electrically floating which resulted in a need for two insulators with the vapour shields being mounted between them. This added both complexity and cost, It also resulted in a large number of vacuum seals being required. VIL's approach was to produce a "Shieldless" interrupter with one ceramic, with 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 the braze washers The interrupter is shown in Fig. 12

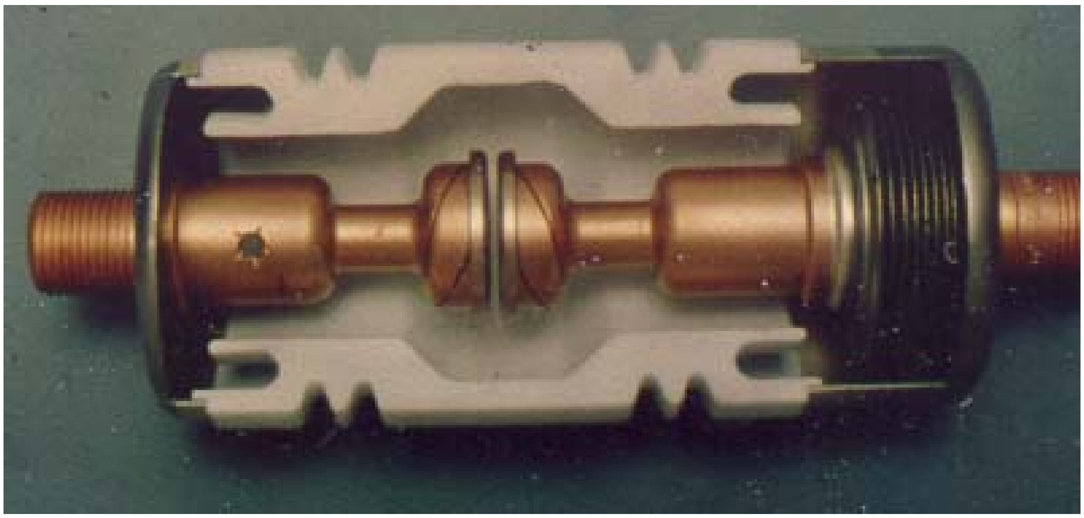

Fig. 11. The V204 interrupter which was the world's first "shieldless" vacuum interrupter. It is rated at 12kV;20kA.

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 complexity of the devices was radically reduced[12].

4: Interrupter Manufacture

However a further significant innovation was also made. The simplicity of construction of the shieldless interrupter allowed the possibility of assembling the device in one operation, removing the need for subassemblies. 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, loaded into a vacuum furnace, pumped down and heated to clean the components. Finally the temperature was raised to melt the braze material sealing the device with vacuum as well as joining the components. This is shown in Fig.12, 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.

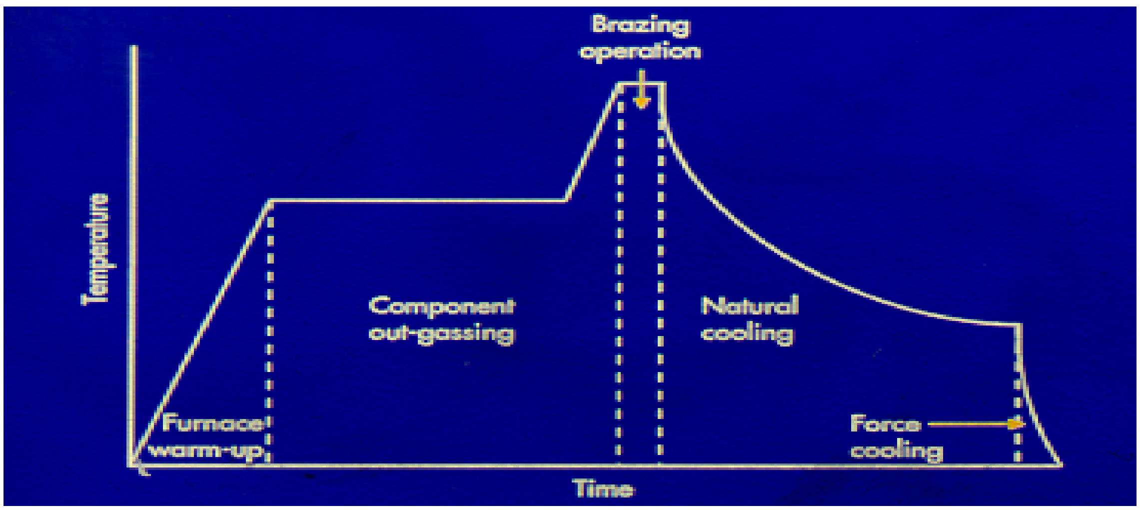

Fig. 12. The "One Shot Seal Off Cycle

Conclusions

Overall, from the very beginning the UK has significantly contributed to the development of the vacuum interrupter.

During the early years of the technology important techniques and materials were developed which today form the basis of much of modern design. The Copper Chromium material is now universally used. The approach of simultaneously designing both the product and the manufacturing process led to the "One Shot Seal Off" technique, which today is the manufacturing method of choice. Innovations such as the "Shieldless" interrupters have shown a willingness to try what conventional wisdom said was not possible, together with the skills to make the solutions work. The UK success was recognised by the award of two Nelson Gold Medals (1983 & 1996) for workers in this field.

Over the past fifty years the world has moved away from national companies and technology towards a multinational view. With the transfer of ALSTOM's facilities to France, Vacuum Interrupter design and manufacture has now physically ceased in the UK. However, the technology developed will continue in a European context with UK Engineers' continuing involvement, and future generations will be based on the solid foundations of fifty years of Vacuum Interrupter development in the UK.

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