Arc breakdown solid dielectric switch capable of making a parallel metal contact

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IPP/4/41 March 1967

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Die nachstehende Arbeit wurde im Rahmen des Vertrages zwischen dem Institut für Plasmaphysik GmbH und der Europäischen Atomgemeinschaft über die Zusammenarbeit auf dem Gebiete der Plasmaphysik durchgeführt.

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March, 1967 (in English)

Abstract

Using very simple equipment the feasibility of establishing a metal contact following an arc contact in a solid dielectric switch, has been demonstrated. Contact times of about 15 µsec have been measured and it is proposed that times of about 7 µsec will be achieved with a redesigned switch. Measurements of contact resistance and current carrying capability have not yet been made.

Index

Illustrations

1. Introduction

The development of solid dielectric switches is quite well advanced and the original developments (ref. 1.2) as well as some more recent applications have been reported. If the field is divided simply into two groups, then it is as follows -

1. electrically disrupted (ref. 3.4.5.)
2. mechanically punctured (ref. 6.7.)

There are many points which influence the comparison between these two types, butt for high coulomb rating and low resistance the mechanical switch predominates, while for speed of operation and low cost, the electrical switch is better. The mechanical switch must generally be used as a high-rating back-up for another switching system and this duplication is an expensive complication of the circuit.

It was to attempt ot bridge the gap between the two systems, that this present development was begun.

2. Basic Concept

When a solid dielectric switch (working by eletrical disruption) is triggered, a hole is burned through the main and trigger dieletrics to allow an arc contact between the main electrodes. The rapid combustion of this dielectric and the evaporation of pieces of copper foil produces a very high instantanious pressure in this region, which can cause mechanical failure of some parts of the switch unless designed vent controls this pressure. In this respect, the hole/recess configuration (ref. 3.4) has a distinct advantage over the bar electrode switch (ref. 5). The basic concept is then, to build a hole/recess type switch in which the very high gas pressure can be controlled and utilised to force a copper foil into contact with an electrode plate. Such a switch would therefore be a hybrid of the two previous ones and would establish an arc contact with the usual delay (~ 1 /usec) and at the same time later would generate a metal to metal contact in parallel with the arc. The principle of operation is that the high gas pressure produced when the trigger circuit is discharged causes a piece of the main dielectric (polythene) to be sheared against the sharp edges of the electrode and ejected from the switch. The way is now cleared for a copper foil to be swung upwards until it makes contact with the electrode.

Once the feasibility of such an operation has been proved, three important questions will remain to be answered -

1. how fast can the metal contact be made (and with what jitter)?
2. how many coulombs can the switch carry?
3. how low is the resistance?

These three questions are of course inter-related, but a higher rating and lower resistance could be achieved for a whole system by parallel operation of many switches, as one condition of the design is that it should not greatly complicate the switch, its trigger circuit, or the replaceable insulation sandwiches. Hence every effort should be made to make the contact time as small as possible.

3. Test switch and circuit

The test circuit shown in fig 1 was assembled using components which were readily available. A Siemens 1.1 μF capacitor was used, with a matching parallel plate line, as a suitable support for the prototype switch. A 15 μF, 2o kV Tobey Deutschmann capacitor with switching unit was used as the source of trigger energy, being connected to the prototype by a low inductance line. The switch electrodes were made of steel as shown in fig 2. The switch was held together during firing by a simple P.V.C. clamp and in the first tests the lower plate had a square hole into which a reflector, which was adjustable in depth, was fitted and secured. The exhaust gas and pieces of ejected material were released through the hole in the top electrode and clamp plate.

The early tests with this equipment proved the feasibility of the operation and so the apparatus was slightly modified to improve the control of the gas pressure and the exhaust flow. This was by adding a steel block to the earth electrode to contain and support the reflector and by adding a P.V.C. block to the top electrode, with a specially profiled slot to direct the exhaust flow, as shown in fig 3 and the photograph in fig 4. A later improvement was to overlay the earth electrode with a copper sheet and form the depression into it by firing the switch and annealing the copper between shots.

4. Development of the sandwich

The first sandwiches were of the exploding wire type but the development from this to the present design has given two important improvements -

1. the absence of a wire makes the sandwich much easier to install and remove and may therefore allow automatic changing.
2. the high trigger current now makes a useful contribution to the force available for the movement of the foil.

Fig 5 shows the present design. The trigger mechanism is therefore initially a surface flashover from the point of the trigger foil to the edge of the "moving" foil whose remote edge is in contact with the earth electrode. The high trigger current 300 kA then flows in the foil which experiences the magnetic force. The heat of the arc burns a hole in both the sheets of insulation and the trigger discharge then transfers to an arc directly through the trigger insulation to earth. When a voltage stands across the switch, it is at this point that the arc contact is made. The shearing and ejection of a piece of the main dielectric is then thought to take place within one or two μsec and the way is then clear for the movement of the foil into contact with the electrode. The "moving" foil is scored or cut to correspond to two edges of the cutting electrode, so that the size of the moving piece is predetermined and also that energy is not wasted in tearing the foil.

The "cutting electrode" is assembled as part of the sandwich in this prototype in order to keep the design flexible and the electrodes cheap. However in a more practical design this will be recessed into the top electrode and will be demountable to allow its exchange when too badly eroded. Also, the side of the cutting electrode at which the arc contact is made will be of heavy metal to extend the life. For the cutting electrode to be an integral part of the top electrode a method must be provided for removing the copper foil which will be in contact with the electrode after the shot and may be welded to it. In the further development it is projected that the reflector in the earth electrode hole should be made of tool steel and be driven upwards, acting as a punch. The weld will therefore be sheared off leaving the edge of the cutting electrode clean and sharp-edged for the next operation while the sheared foil and any remaining polythene and pieces of trigger foil are ejected into the exhaust system. After withdrawal of the punch the spent insulation sandwich will have a clean hole punched through it with no projections of hard, burnt polythene or torn copper. If the sandwiches were made on rolls of insulation, it should not be difficult to pull this used section through the switch and so achieve an automatic change.

5. Measurements

The switch produces an arc contact and then at some time later, a metal contact in parallel. Measurements on the arc contact are relatively simple but not of very great interest in this development, while the important measurements on the metal contact have proved very difficult. From fig 1 it is clear that the switch has been assembled as a short circuit switch on the 1.1 μF capacitor and the observation of the voltage on this capacitor has been the measuring technique. In order to allow the trigger circuit to discharge normally but to remove the possibility of an arc contact across the switch, the top electrode was replaced by one made of polythene. The cutting electrode was made mainly of P.V.C. and only having one side made of copper, which was connected to the capacitor by a short foil on the top "electrode" (polythene). In this way the 1.1 μF capacitor should only be discharged by the metal contact.

Once the piece of polythene under the cutting electrode has been sheared and ejected, the separation between the switch electrodes is only the sheared edge of the o.5 mm polythene. Hence, the monitoring voltage on the 1.1 μF capacitor can only be a few hundred volts to avoid a flash-over on this edge, particularly as the high energy trigger discharge arc is only 2o mm away.

One difficulty is that the burning of the polythene causes a lot of smoke and as a result the contact area becomes very sooty, which in a practical application, would prevent a weld from being made between the contacts. One attempt to overcome this problem was to allow the trigger discharge to take place only 1o mm from the contact edge, on the assumption that the soot was condensed out of the hot exhaust gases on cooling. The resulting contacts were greatly improved and the appearance of the contact edge suggested that it had been blasted with copper vapour, it was roughened but reasonably clean. The measurements made under these conditions gave low "contact" times with low jitter, but later work revealed that the blast of copper vapour reaching the contact area caused the discharge of the 1.1 μF capacitor and hence a false measurement of "contact" time. Returning to the previous trigger position removes the false signal, but still leaves the problem of measuring with a sooty contact.

A constant difficulty is that of interference in the monitoring circuit from the trigger circuit. This is particularly acute when the measuring oscilloscope stands in the open laboratory and is not completely removed when the oscilloscope is in a remote screened room. The interpretation of the measurements is complicated by this error signal and aggravated by the low signal voltage in the measuring circuit.

6. Results

Because of the important difficulties mentioned above, it is not possible to produce with confidence a value of contact time for each measurement taken, but using a o.2 mm copper foil the value recurring most constantly is about 15 $\pm$ 3 μsec. However, under certain conditions a few shots have been measured with contact times of about 7 μsec. Because the main driving force is gas pressure, the efficiency of the containment of the pressure within the switch will greatly influence the contact time achieved. Observation of the switch during firing (photograph in fig 7) has shown that with the present system, the containment is not very good and it is expected that a redesign of the switch parts and in particular the clamping arrangements, will bring more consistent contact times in the region of 7 μsec. The fig 6 shows a photograph of a sandwich after it has been used in the switch. The cleanly cut hole in the main dielectric can be seen, as can the rest position of the moving foil, which is in good contact with the cutting electrode.

It will be seen that most of the above work has been directed at achieving a reasonable mechanical contact and in trying to measure the contact time. In this, the 1.1 μF capacitor has only been used to monitor the switch and has been charged to very low voltages, typically 2oo V. When the time for the establishment of the contact can be quoted with confidence, a future test will require this capacitor to be charged to a high voltage, to test the performance of the contact when carrying a discharge current.

7. Conclusions

Using very inelegant test equipment, the feasibility of forming the metal contact following an arc contact, has been established. The measured contact times of about 15 μsec are rather long, but it is expected that times of about 7 μsec will be consistently attained with a redesigned switch, substancially built to improve the gas containment.

At present, the "moving" foil is o.2 mm thick copper used without heat treatment. The thinness of this foil is a serious limitation to the coulomb rating of an individual switch and an increase in the foil thickness to improve the rating would be reflected in correspondingly longer contact times. However, the switch is being developed with special regard to its suitability for parallel operation. In this respect it must be emphasised that the production of the metal contact does not require any additional circuitry or energy source to that required for normal dielectric switch operation (electrically disrupted type). The trigger energy used in these tests (3 kJ max) is not greater than that used in some normal dielectric switches with hole/recess geometry. In addition, the design of the sandwich is simple and the production costs will certainly not be greater for this switch than for normal types.

The problem of the smoke released can be minimised by good containment within the switch and by an efficient extract system. The deposition of soot in the contact area can be overcome by allowing the trigger discharge to take place nearer the contact surface, which probably calls for a reduction in the hole/recess dimensions from 2o x 2o mm to 2o x 1o mm for optimum results.

8. Acknowledgements

The work reported above was carried out in the Institut für Plasmaphysik, Garching, Germany while the author was on a period of exchange from Culham Laboratory, England. The assistance

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of the Management of both Laboratories in encourageing and administering the exchange is gratefully acknowledged. The provision of the equipment and test facilities by the High Voltage Technology Group is also acknowledged.

9. References

1. Alston, L.L. "A solid dielectric switch"
   CLM - M 26 December 1963

2. Alston, L.L. "Some experiments on a high-
   Whittle, H.R. power closing switch with poly-
   Mosson, G.A.G. thene as the main dielectric"
   Barnes, G.C.
   CLM-P 66 October 1964

3. James, T.E. "Development of fast 100 kV
   Harried, K. IMA. solid dielectric switches
   Medford, R.D. and associated triggering studies"
   Proceedings of Symposium of Engineering Problems of Controlled Thermonuclear Research, Livermore California P 77, May 1965

4. James, T.E. "The development of a 100 kV,
   Lewis, C. 500 kA solid dielectric switch
   Harries, K. and associated triggering studies"
   Medford, R.D.
   CLM - M 41 1965

5. Bayes, D.V. "A passive crowbar for the Theta-
   Hucklesby, R.J. tron IMJ Bank using 32 parallel solid dielectric switches"
   4th Symposium of Engineering Problems in Thermonuclear Research. Frascati, May 1966

6. Rogers, P.J. "A fast mechanically closed switch"
   Whittle, H.R.
   4th Symposium of Engineering Problems in Thermonuclear Research, Frascati, May 1966

7. Hellegouarc'h, J. "A fast mechanical switch"
   4th Symposium of Engineering Problems in Thermonuclear Research, Frascati, May 1966

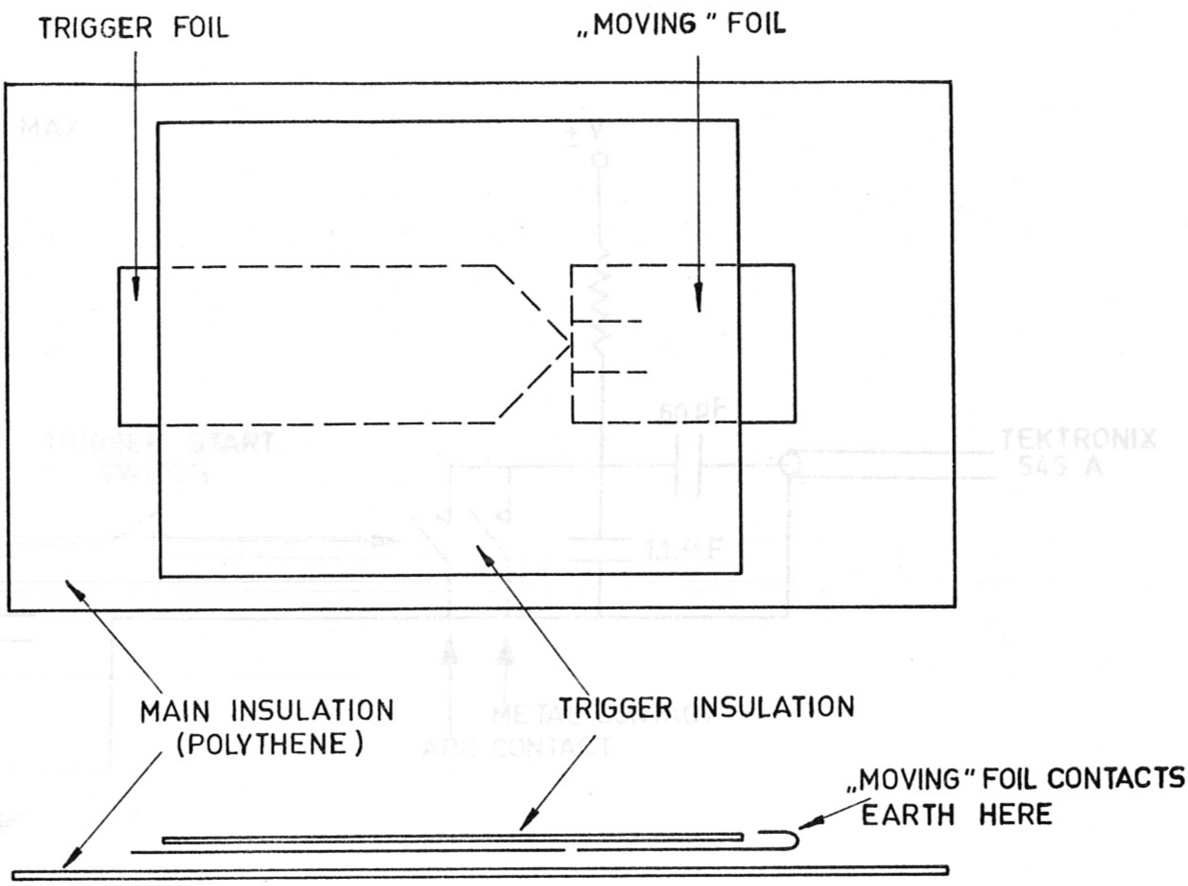

FIG 5 (a) SANDWICH - SHOWN WITHOUT THE „CUTTING" ELECTRODE

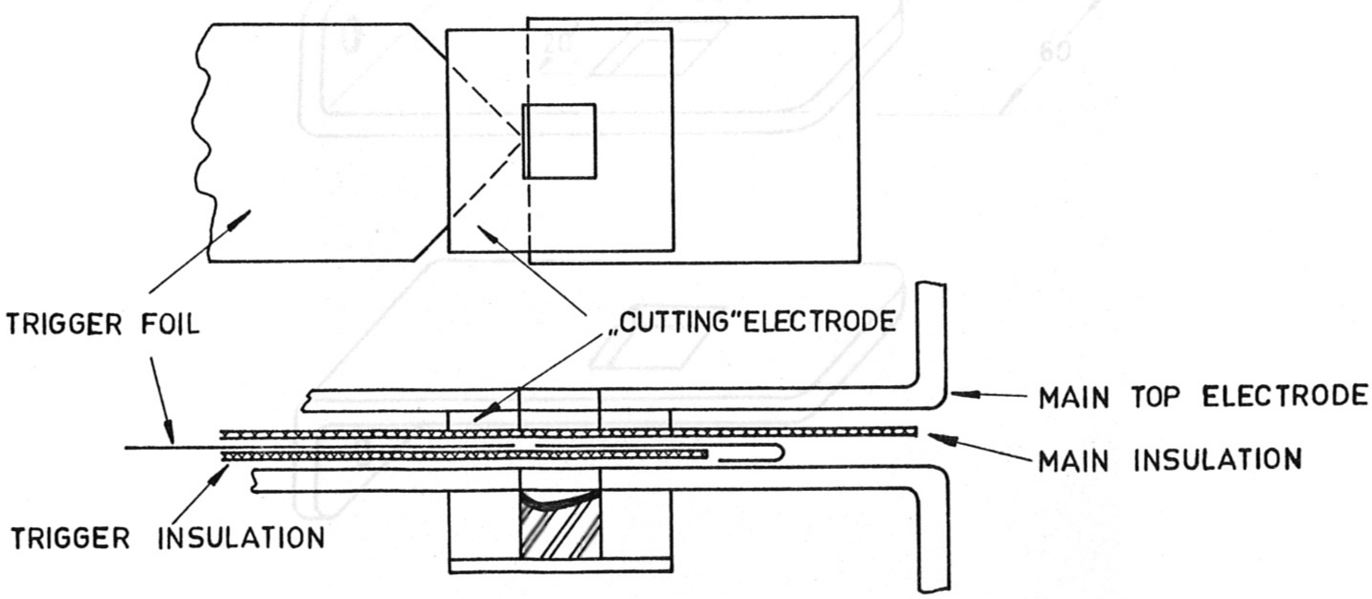

FIG 5 (b) SANDWICH - SHOWING ALSO THE CUTTING ELECTRODE

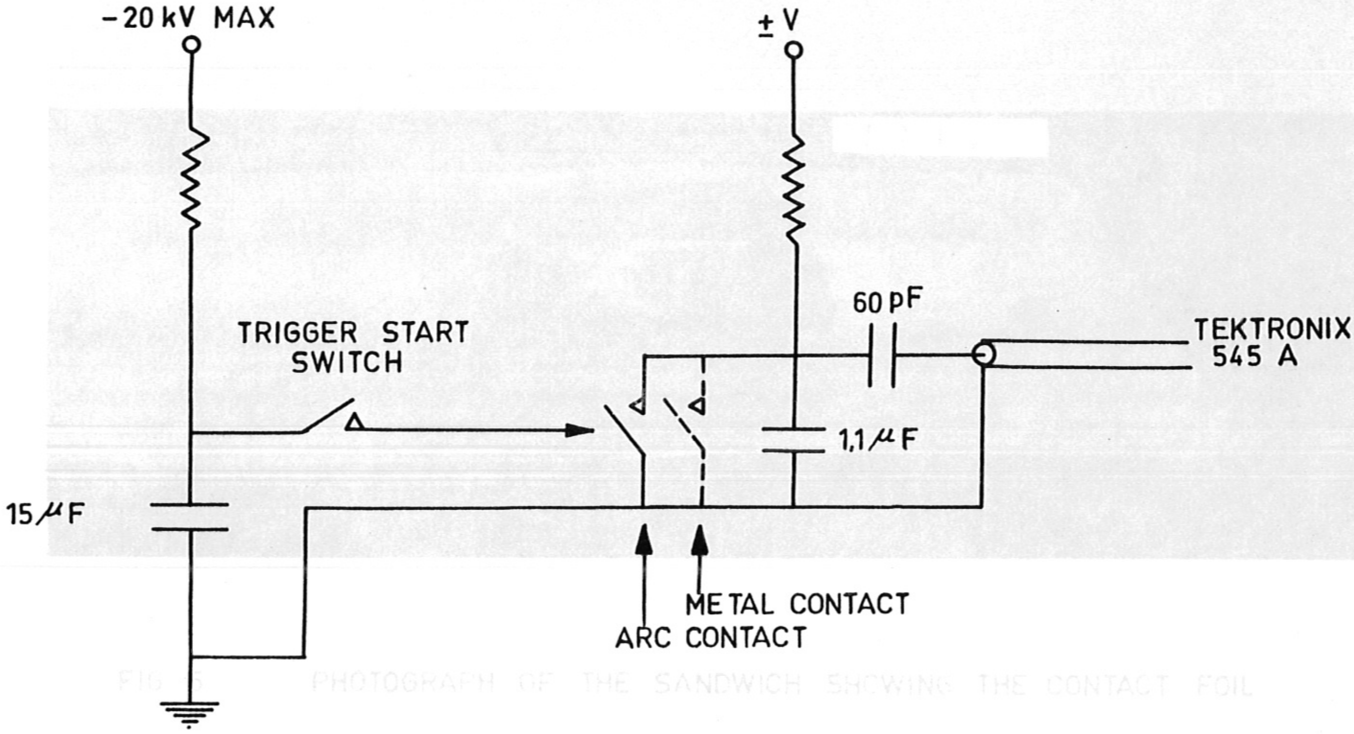

FIG 1 TEST CIRCUIT DIAGRAM

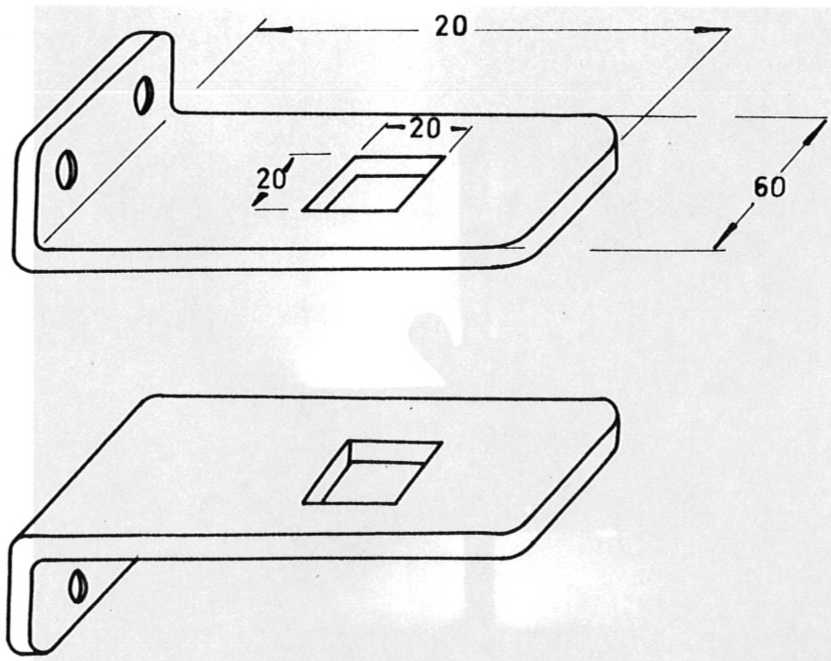

FIG 2 SWITCH ELECTRODES

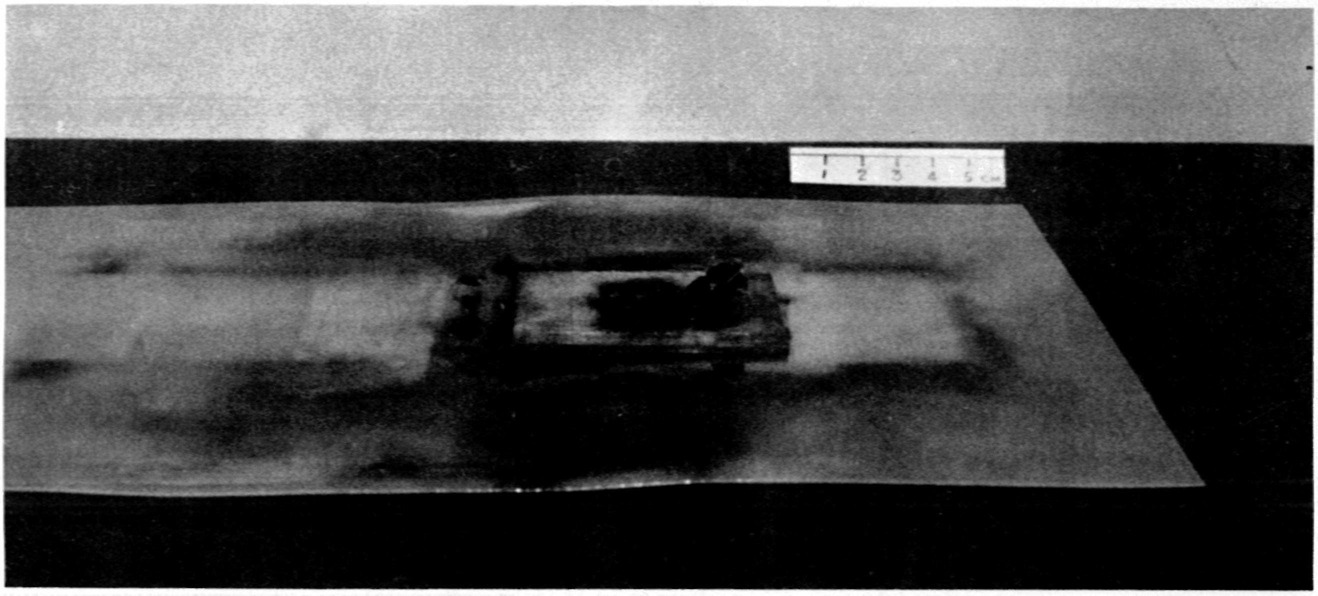

FIG 6 PHOTOGRAPH OF THE SANDWICH SHOWING THE CONTACT FOIL

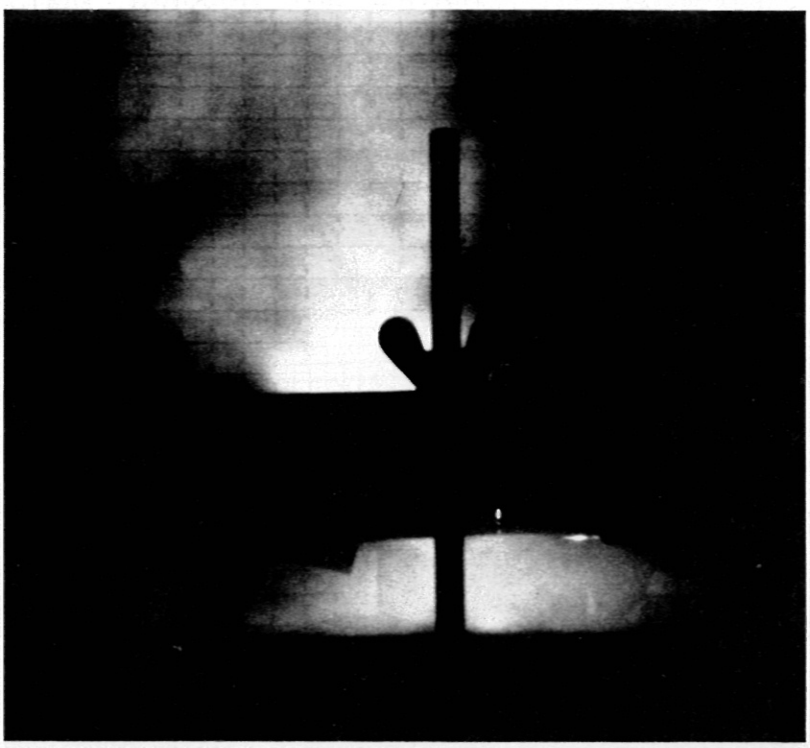

FIG 7 PHOTOGRAPH OF THE SWITCH DURING FIRING

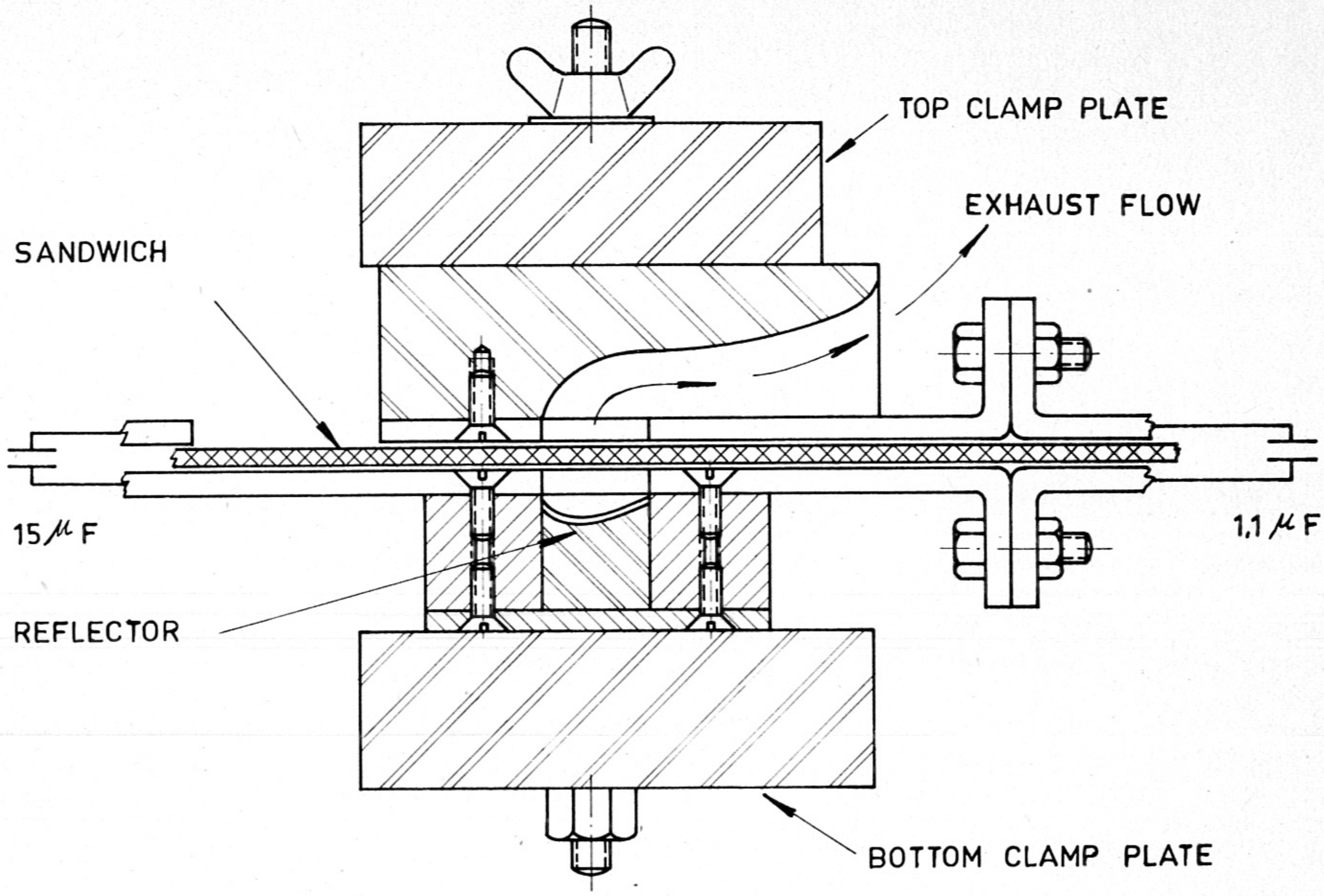

FIG 3 SECTION THROUGH THE SWITCH

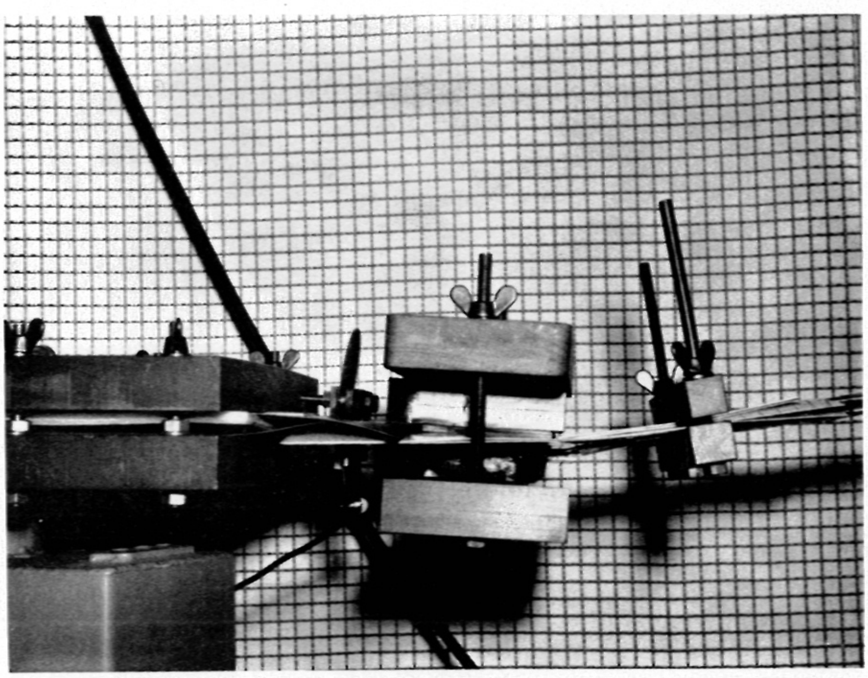

FIG 4 PHOTOGRAPH OF THE SWITCH