

# AN INVESTIGATION OF ARCING IN THE ELECTROLYTIC SWITCH/TEST LOAD USED WITH THE CANBERRA HOMOPOLAR GENERATOR

EP-RR 22

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*October, 1969*

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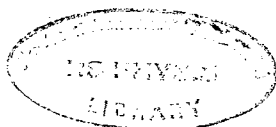
by

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## SUMMARY

The Electrolytic Switch/Test Load used with the Canberra Homopolar Generator had, over a number of years successfully interrupted currents of over  $10^6$  amps, but on one occasion during an unusual operating mode, arced and failed to break a current of less than 20,000 amps.

Subsequent investigation showed that there are well defined conditions under which such a failure will occur and that these can be defined most conveniently in terms of a single parameter, a critical depth of immersion. Operating the switch with a full immersion less than this depth will result in almost certain failure while conversely, a depth reasonably in excess of this critical value will ensure the safe operation.

## 1. INTRODUCTION

The investigation reported here was undertaken because of anomalous behaviour of the electrolytic switch used with the Canberra Homopolar Generator. This variable resistor/switch, which has consistently over a number of years controlled and broken currents of over  $10^6$  amps, on one occasion arced and failed to break a current of less than 20,000 amps under a condition of extremely small initial plate immersion. (See Report EP-RR 23)

The series of tests reported herein was designed to investigate the characteristics of arcing from two approaches. The first part established experimentally the conditions under which arcing is likely to occur between the electrode plates, as a function of several variables. To this end, over 500 operations were recorded under varying conditions - with just under half resulting in arcs.

The variables considered were:

- (i) Depth of Immersion of plates
- (ii) Speed of operation of the switch in terms of angular velocity of the driving cam.
- (iii) Open circuit volts applied
- (iv) Current carried
- (v) Electrolyte resistivity

The geometry of the switch was fixed namely, 4 anode plates with 3 interleaved cathode plates, and all the calibration runs were done with one polarity.

The second part of the investigation was to determine the mechanism of arc initiation. Four high speed films at 3000 frames per second (f.p.s.) and a number at 64 f.p.s. were taken with simultaneous voltage, current and tank position records. This section also included comparative measurements for opposite polarities in the asymmetrical switch used, and the testing of a simple method of arc suppression.

## 2. EXPERIMENTAL ARRANGEMENT

The main power circuit (Figure 1) consisted of a 500 volt, 400 kW d.c. generator set and a  $1\Omega$  watercooled ballast resistor in series with the electrolytic switch. An additional 0 -  $4\Omega$  variable resistor was included in the circuit and a shunt contactor was used to terminate the arc soon after initiation, so as to minimise damage to the plates.

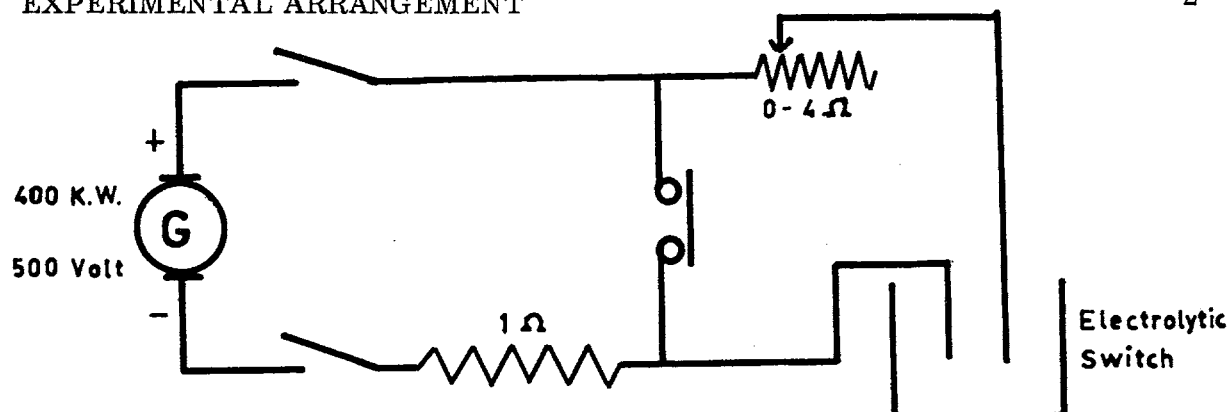


Figure 1 Power Circuit

The electrolytic switch used was a section of the main Test Load. Seven adjacent plates at one corner were enclosed in a small tank fitted inside the main Test Load tank (figure 2). This small tank contained the electrolyte under test, while the main body of the Test Load tank was filled with water as ballast. The level of the water was such that it did not wet the unused plates so that the total current measured was in fact passing through the electrolyte.

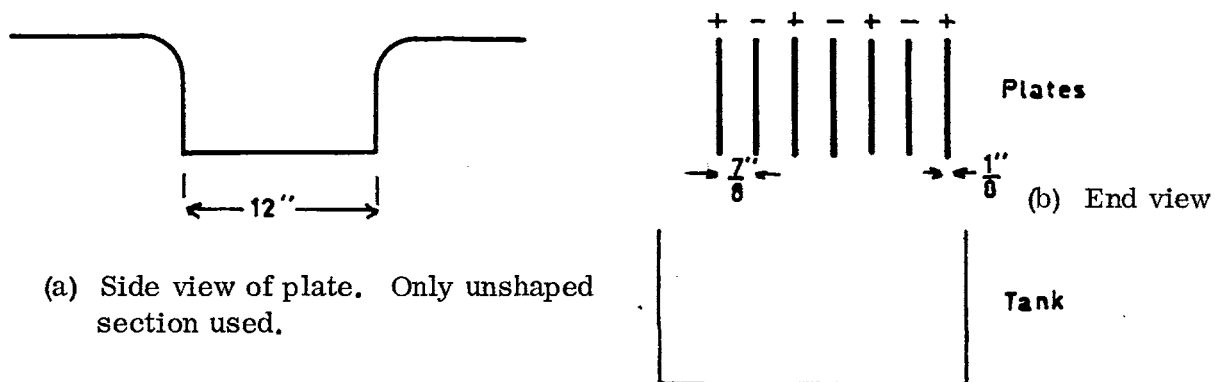


Figure 2 Showing construction of the electrolytic switch used in the tests.

An ultraviolet chart recorder was used to take concurrent records of:-

- (i) Voltage across the electrode plates
- (ii) Current
- (iii) Tank position
- (iv)  $\frac{di}{dt}$  for each of the seven plates

This last was measured as the output of seven Rogowski belts, one to each plate, and served as an indication of current change in the individual plates.

The current and voltage were measured with galvanometers having a flat response up to 1200 cycles/second while the other records were made with 50 cycle/second galvanometers.

### 3. RESULTS

#### 3.1 Arcing Depth

It became evident fairly early in the trials that the most convenient parameter in which to measure the likelihood of arcing was the depth to which the plates were immersed in the electrolyte. If all other conditions remain constant, there is a fairly well defined depth of immersion above which arcing will not occur and below which it will occur. This depth is called here the "arcing depth". As will be seen in the next section (3.2) if we wish to define a completely safe region we must exclude a band of depths of which the "arcing depth" is the lower limit.

The arcing depth is dependent on all the other variables considered and the results of this section have been presented as a set of graphs, showing arcing depth as a function of each of the other variables, while holding the remaining ones constant. (See Figures 3, 4 and 5)

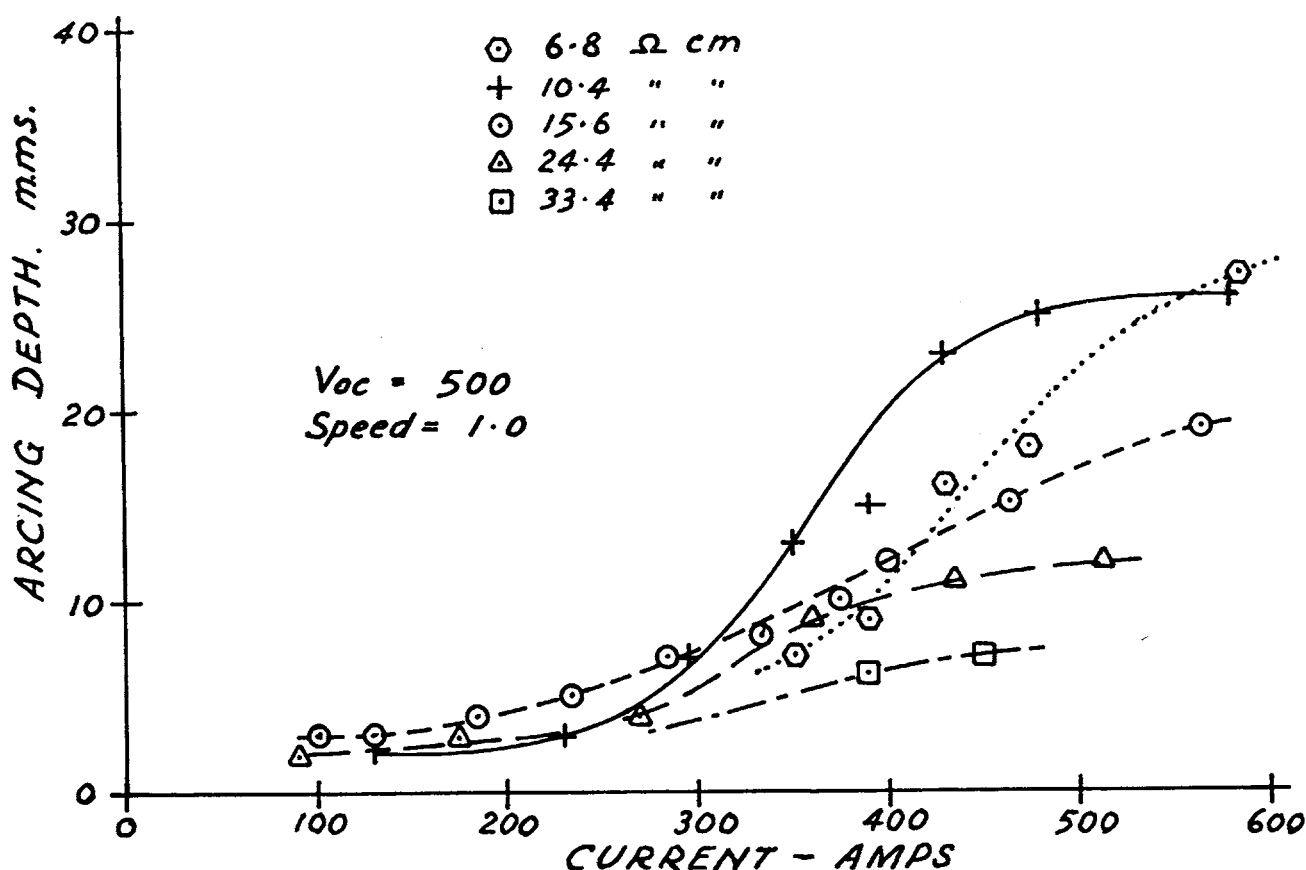


Figure 3 Arcing depth shown as a function of full immersion current.

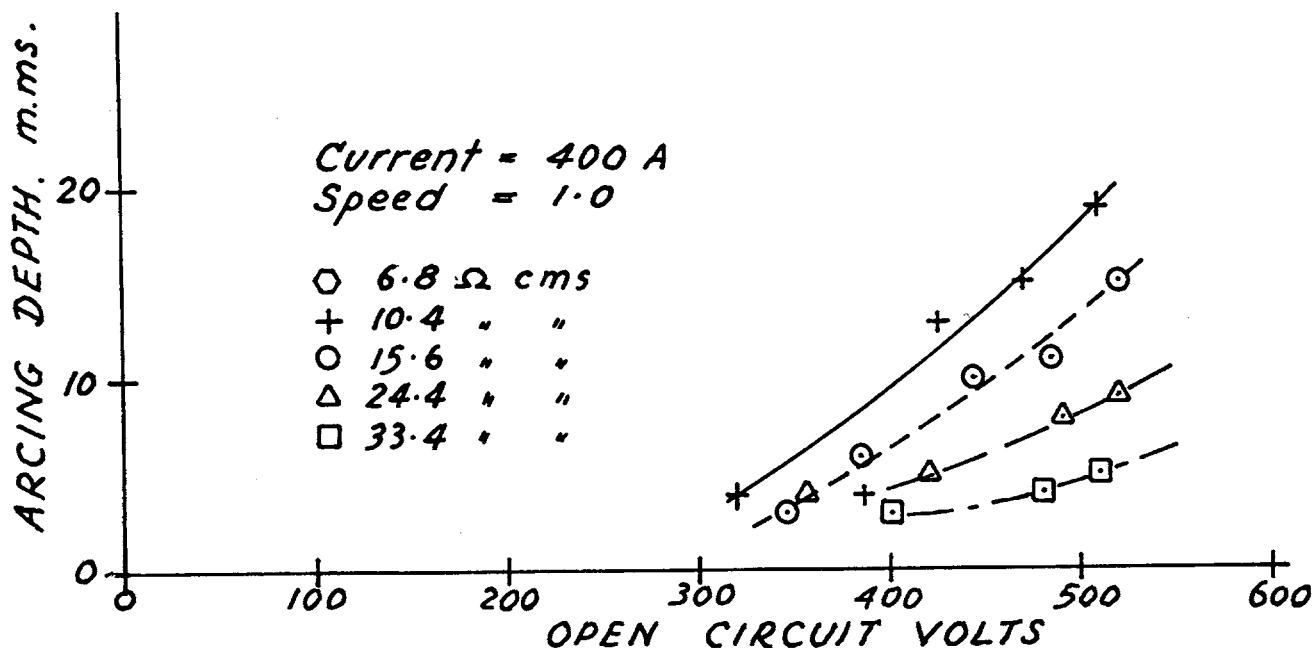


Figure 4 Arcing depth shown as a function of open circuit voltage applied.

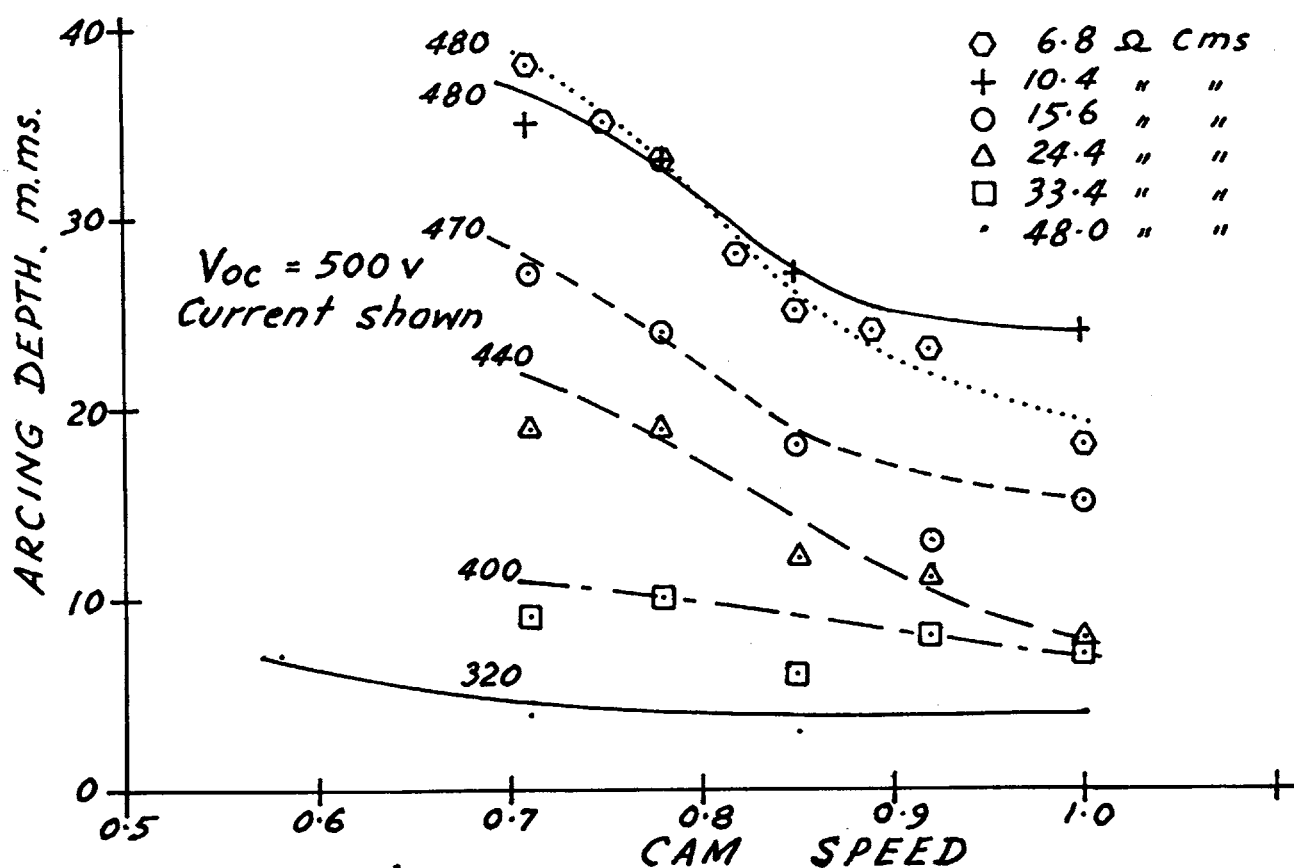


Figure 5 Arcing depth shown as a function of speed of operation.

Definitions:

- (i) Current: Figures given for current refer to total current flowing through all plates i. e. 3 cathode and 4 anode plates.
- (ii) Arcing depth: The deepest immersion for which arcing would occur under the specified conditions. It was generally determined as the mean of two depths 2 mm. apart, such that the lower arced and the upper did not.
- (iii) Volts: measured across the electrode plates
- (iv) Speed: This is proportional to the angular velocity of the cam. 1.00 corresponds to tank movement cycle of 1.1 sec. period (approximately sine wave).

### 3.2 Operation as a Circuit Breaker

Records of current against time and tank position, show that the switch continues to conduct an appreciable current even after the electrolyte has fallen below the bottom of the electrode plates. This is due to streams of electrolyte running off the plate, continuing to provide a current path.

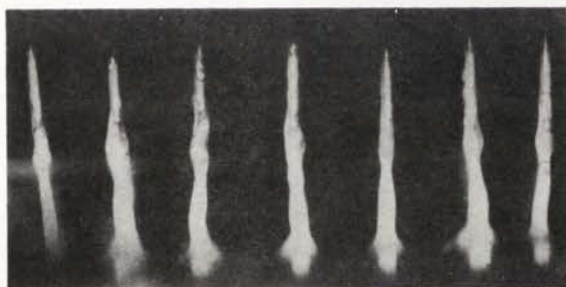


Figure 6 Photograph showing electrolyte streams from plates.

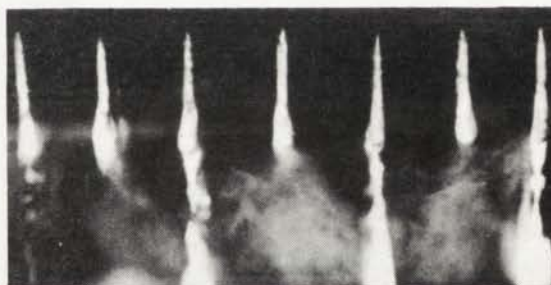


Figure 7 Photograph showing streams exploding.

In fact the ability of the electrolytic switch to "break" large currents depends on these streams which must be maintained until their increasing resistance implies a relatively small current.

In figure 8 we see typical current vs. time curves for various depths of immersion.

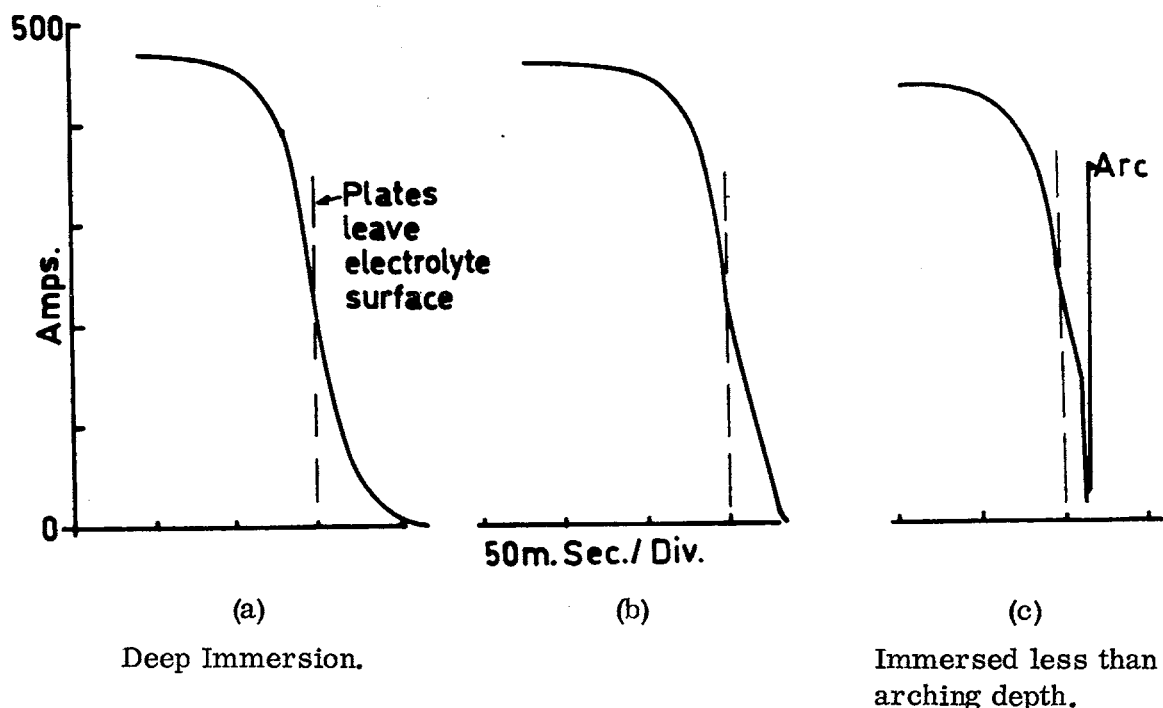


Figure 8 Tracings of record showing current vs. time characteristics for deep and shallow immersion.

Figure 8 (a) is a typical current curve as the plates are withdrawn from an immersion well in excess of the arcing depth. The first downward curve represents the increasing resistance as the depth of plate immersed in the electrolyte becomes small. After the surface has fallen below the bottom of the plates, the electrolyte streams remain intact; at least until no measurable current remains, e.g. with 60 millimeters immersion under conditions giving an arcing depth of 4 mm, the streams were still intact at 40 mm. length when the current was virtually zero.

Arcing was never observed in conjunction with this curve, and further, once this form of curve appeared, all deeper immersions under the same conditions, produced the same form of curve.

Figure 8 (c) is a typical current curve for an immersion near or below the arcing depth. Part of the way down, the electrolyte stream ruptures and the current drops suddenly. The shallower the immersion, the higher is the break point and the more likely is the process to develop to an arc. Except in the case of very shallow immersion (1 or 2 mm.) where arcing resulted from contact rather than separation, an arc was always preceded by this break in the current curve.

This rupture of the streams is quite evident on photographs taken with immersion near or within the arcing range - Figure 7. The break occurred at the end of the stream in contact with the electrode plates - in this instance the three cathode plates. However, on reversing the polarity it was still the three even-numbered streams, this time from the anode plates, which broke, suggesting it was due to the greater current density in these plates. The curve of Figure 8 (b) is for an intermediate immersion, and could be regarded as a limiting case of figure 8 (c) where the break is very close to zero current.

An example of the relative depths involved for the different forms of current curve, we have the following experimental results:

24.4 ohm cm electrolyte, 500 volts, 450 amps (i. e. 150 amps/  
cathode plate) 1.00 cam speed

Depths from 38 mm. gave curves of type (a), while at 23 mm. immersion, the graph assumed form (b). At 16 mm., a definite increase in slope appeared at 100 amps which, by 12 mm., became a complete break at 110 amps. Immersion of 11 mm. produced a break at 140 A, resulting in an arc.

### 3.3 Arc Initiation - High Speed Photographs

Four high speed films, (3000 frames/second) two of each polarity, were taken and show the arc starting. In each case, it starts as a point of light at the tip of a cathode plate, and stays typically 2 - 3 milliseconds in this form before striking across to the adjacent anode plate. At this stage the current is relatively low and the voltage high, e. g. in a typical record at this stage, the current is  $\sim 45$  amps with the voltage from 445 - 490 Volts. Assuming that most of

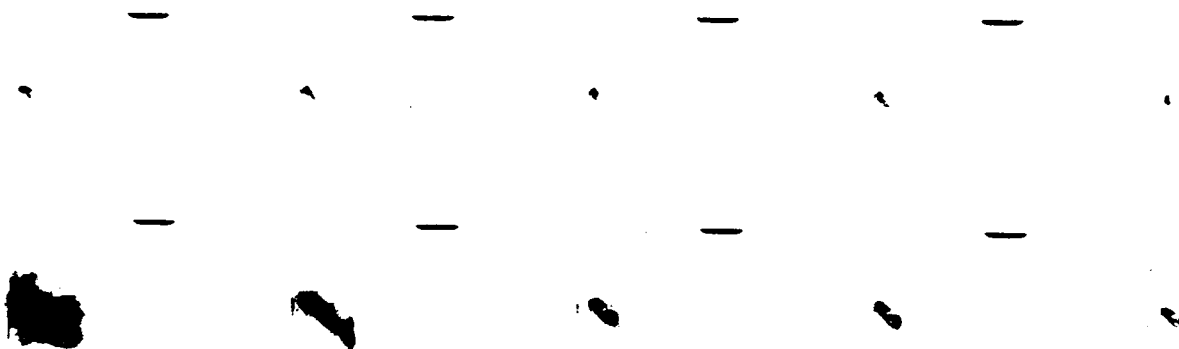


Figure 9 Ten consecutive frames (negative) at 3000 p.p.s., showing the arc initiating as a spot at a cathode plate and developing into an arc to an anode plate. Sequence right to left, top row first.

the interelectrode voltage drop occurs across this spot, it fits the characteristics of a glow discharge.

The time spent in this form can vary greatly from the Typical 2 - 3 msec; delays of 25 msec have appeared on some records while others show a delay too small to be measured accurately from the chart ( $< \frac{1}{2}$  msec)

Changing polarity in this case, moved the initiating point from an even numbered plate to an odd numbered plate. i. e., the arc insisted on starting from a cathode plate. Changing only the polarity, increased the minimum total current required for arcing from 300 amps with 3 cathode plates, to 400 amps for 4 cathode plates: this seems to suggest that the current density in the cathode plates is the relevant constant. It is not immediately obvious how this fits in with the earlier evidence that it is the higher current density stream that breaks first, irrespective of polarity.

The photographs also showed that arcing can occur on entry of the plates into the electrolyte. Of the 4 high speed films taken, the distinctive cathode spot appears on three at the time of entry. One of these develops into an arc between two plates and lasts about 10 msec before being quenched by reduced voltage drop as the electrolyte level rises. This contact arc appears on several of the recorder charts, and becomes evident for very shallow immersions when the arc does not extinguish.

#### 4. BAFFLE PLATE TESTS

4.1 On a suggestion from Mr P. O. Carden\* insulating plates were tried between the electrode plates as a method of preventing arcing between them. The intended function of the baffle plates was two-fold.

- (i) To increase the current path length, and so the resistance, in the latter stages of withdrawal, before the plates leave the surface.
- (ii) To provide a physical barrier to arcing, at least for a few inches up from the bottom of the plates.

Both these actions were evident in the results, and the technique proved very successful, providing some further confirmatory information on the arc initiation.

The baffle plates used were strips of eighth inch bakelite, 5" deep and the full length of the electrolyte tank (24") extending 3" past the electrode plates at one end, and 9" at the other. They were level with the top of the electrolyte tank and came to within 1" of the bottom of the tank. Figure 10.

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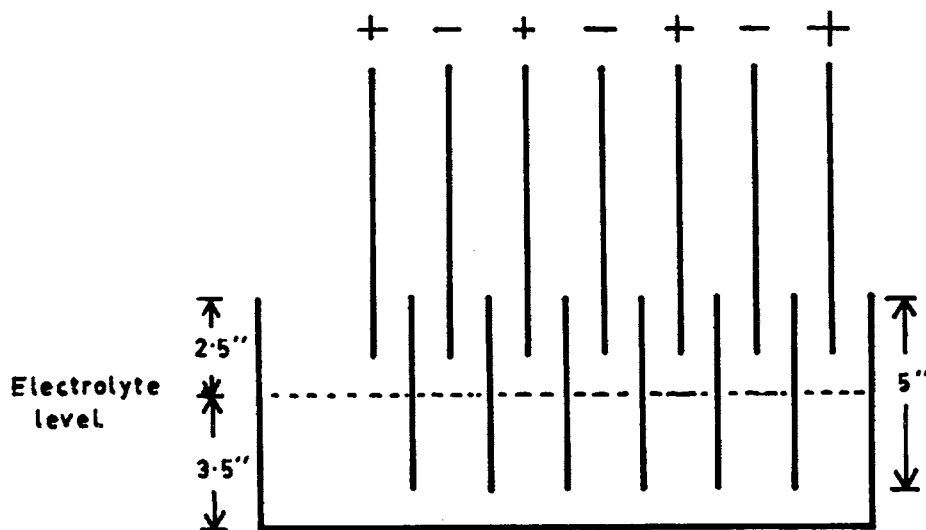


Figure 10 Arrangement of baffle plates in electrolytic switch.

The electrolyte was  $3\frac{1}{2}$ " deep, thus providing  $2\frac{1}{2}$ " of baffle plate above and below the electrolyte surface. The plates could be fitted and removed individually.

#### 4.2 Tests

For the first set of tests, parameters were: 10.6 ohm cm electrolyte, 500 V, 470 amps, and a cam speed of 1.00, with 4 anode plates polarity. This has an arcing depth of 25 mm. The run started at 14 mm. immersion and rose to 18 mm. when all the baffle plates were in place - thus was well within the arcing range at all times.

Initially with no baffle plates employed, six successive identical cycles produced six successful arcs.

A baffle plate was then placed between the two plates most frequently involved in arcing. The next run of 6 cycles produced 2 arcs - neither initiating across the baffle plate. This process was continued until all six baffles were in place, when no arcs resulted from a run of 6 cycles.

Further, a set of runs at various depths from well above the arcing depth through to zero, showed no arc, while on removing one baffle plate, arcing reappeared across the unbaffled electrode plates.

During these baffle plate tests, under conditions that would normally produce an arc, a new variation of the current curve appeared.

In a typical record chart, for an immersion of  $\frac{2}{3}$  of the arcing depth, the break appears at 245 amps and drops to 65 amps where it remains more or less steady for 10 msec before tapering off to zero when the electrolyte surface is 42 mm. below the plates. Figure 11.

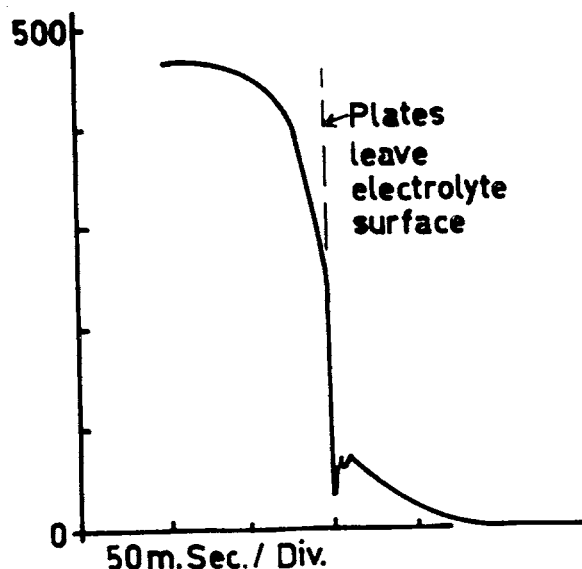


Figure 11 Tracing of current characteristic with baffle plates in and immersion of two-thirds arcing depth.

This corresponds well with the cathode glow stage that appears before every arc, but apparently the baffle plate prevents the arc striking to the adjacent anode plate.

## 5. CONCLUSIONS

From the curves of Figures 3, 4, 5, it is evident that under any circumstances a deep immersion is much less likely to result in an arc and that below some critical immersion depth, arcing is virtually certain. On the other hand, an immersion deep enough to produce a smooth current curve of the form in figure 8 (a) will not arc. For the small number of tests that covered the full range (three), this "safe" curve appeared at about twice the arcing depth.

For the conditions under which the original failure occurred, the arcing depth was about 25 mm., so that the safe region could be expected at no less than 50 mm. With this in mind, the actual immersion of 54 mm. could be considered uncomfortably close, allowing no margin for uneven current distribution across the switch or any irregularities in operation.

Many variables are involved, and it is difficult from the somewhat limited scope of the investigation to predict the behaviour of an electrolytic switch under specified circumstances. However it can be said that a tendency to arc lies

## CONCLUSIONS

in the following direction:

- (i) Shallow immersion
- (ii) High current densities
- (iii) Low electrolyte resistivities
- (iv) Slow operation of the switch
- (v) High voltage

Normal operating requirements will generally necessitate some of these conditions, but safe operation could be insured by allowing sufficient margin in the unrestricted terms. The final test of satisfactory and safe operation is a smooth current characteristic of the form in figure 8 (a).

(b) The baffle plates proved a very effective method of preventing an incipient arc from striking, and of reducing the tendency to arc, so long as all were in place.

(c) In view of the evidence that the arc must start at the cathode, it would have been interesting to see what would happen if the cathode plates were made somewhat longer than the anode plates so that the break would occur at the anode, while the cathode is still immersed. This, of course implies a single polarity circuit breaker. This was not examined because of time limitations.

Publications by Department of Engineering Physics

No.	Author	Title	First Published	Re-issued
EP-RR 1	Hibbard, L. U.	Cementing Rotors for the Canberra Homopolar Generator	May, 1959	April, 1967
EP-RR 2	Carden, P. O.	Limitations of Rate of Rise of Pulse Current Imposed by Skin Effect in Rotors	Sept., 1962	April, 1967
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EP-RR 19	Carden, P. O.	Features of the High Field Magnet Laboratory at the Australian National University, Canberra	Jan., 1967	
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