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FLAME ARRESTERS AS BARRIERS AGAINST HOT METAL PARTICLES

by

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SUMMARY

Crimped ribbon flame arresters mounted on a 9 l vessel exposed to arc discharges obtained by fusing of copper wires within the vessel, prevented the ignition of 4 per cent propane-air on the outside of the vessel. However, a 6.5 per cent ethylene-air mixture and a 3.4 per cent diethyl-ether-air mixture were ignited by the hot metal particles produced by the discharge.

The particles produced by fusing of copper wires were, however, safely and easily contained within reinforced insulating sleeving, providing it was strong enough to withstand the transient pressures and the temperatures generated during fusing of such wires.

KEY WORDS: Flame arresters, particle incendive, electrical equipment.

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INTRODUCTION

Laboratory investigations have been carried out in the past exploring the possibility of using flame arresters for the protection of electrical and other equipment used in flammable atmospheres[1,2]. The results of these investigations indicated that the flame arresters were capable of relieving the explosions without igniting the external explosive gas when applied to vessels of various volumes up to 85 l, which was the largest tested. Past work has been mainly concerned with obtaining the relation between arrester area and the maximum explosion pressure under a variety of conditions.

The present investigation evaluates the performance of crimped ribbon arresters when these are exposed to electrical arc discharges of various energies, obtained when fusing copper wires with direct currents, in atmospheres of propane and air, ethylene-air and diethyl-ether-air. Such discharges might be obtained from an electrical fault in the wiring of equipment protected with flame arresters.

APPARATUS AND MATERIALS

EXPLOSION VESSEL

A 9 l mild steel cubical vessel was used for the experiments. This had detachable aluminium alloy (B.S. HP 30) covers, with central venting holes, for mounting flame arresters of diameters 2.9 and 11 cm. Several bosses were provided for introducing the power supply and the insertion of gauges. This vessel rested within a 440 l cubical enclosure, one side of which was provided with a relief vent sealed with 0.0038 cm thick polyethylene film.

FLAME ARRESTERS

Two different types of flame arrester were used; both were made of crimped ribbon. Commercial flame arresters were made from cupronickel ribbon; one layer of crimped ribbon together with a layer of straight ribbon were wound round a central core and then cased into a length of brass tubing. Non-commercial flame arresters were of nickel or a nickel-chromium-iron alloy and were made from alternate lengths of straight and crimped ribbon packed together. This metal is designated Alloy A. The layers of ribbon were joined by welds on both sides of the arrester, outside the working area. Both types of arrester were mounted in an appropriate vessel cover with a central vent of 2.9 or 11 cm diameter for non-commercial arresters, and 11 cm diameter for commercial arresters. Table 1 shows details of the arresters used in the experiments.

Table 1

Details of the arresters

Diameter of arrester cm	Ribbon metal	Ribbon thickness cm	Crimp height cm	Thickness of arrester cm
11.0	Cupronickel	0.0063	0.11	3.8
11.0	Alloy A	0.0185	0.051	2.5
2.9	Alloy A	0.0185	0.051	2.5
11.0	Nickel	0.010	0.051	2.5

PRESSURE MEASURING APPARATUS

In some experiments explosion pressures were determined by the use of a quartz piezo-gauge. This was situated in one wall of the explosion vessel.

POWER SOURCE AND POWER REGULATING UNIT

Twenty lead-acid accumulators were used as a power source at 250 V. With these it would be possible to obtain for a short time a maximum current of 1700 A. with no external resistance. Figure 1 shows the diagram of the circuit used.

Resistance A could be adjusted to obtain the desired prospective current. The prospective current is that which would flow in the circuit if the fuse wire were replaced by a resistance of negligible value, and which did not fuse. Contactor B was actuated by a relay to make the circuit. A double beam oscilloscope measured the voltage across the fuse wire C and the current across the shunt D. The traces of both current and voltage were obtained for all the wires with prospective currents of 330 and 1200 A.

Figure 2 shows a photograph of the power supply and the control gear. E indicates accumulators, and A is the variable resistance; B is the contactor with an actuating solenoid through an intermediate relay, in order to reduce interference on the cathode ray oscilloscope.

WIRES

Tinned copper of 10 cm lengths of 0.019, 0.025, 0.046, 0.056 and 0.071 cm diameter (36, 33, 26, 24 and 22 SWG) were fused. These were mounted in such a way that with the 11 cm diameter arresters a 5 cm length of wire was 1.3 cm away and parallel with the arrester; with the 2.9 cm diameter arresters, 2.9 cm length of wire was 1.3 cm away and parallel with the arrester.

OBSTACLES

In some of the tests obstacles were inserted in front of the arrester. This was a mild steel plate 16 cm diameter held in position 5 cm above the arrester.

PHOTOGRAPHS OF INCANDESCENT PARTICLES

Copper wires of various diameters were fused and the particles emerging from the arrester were photographed with a still camera. Such photographs showed the trajectories of the incandescent particles. These experiments were carried out with the explosion vessel filled with air.

PROCEDURE

The explosion vessel fitted with the appropriate arrester and fuse wire was placed inside the 440 l enclosure fitted with the polyethylene diaphragm. Both vessels were then charged with a 4 per cent propane-air or 6.5 per cent ethylene-air or 3.4 per cent diethyl ether-air mixture. The volume of gas mixture passed was equal to ten volumes of the large enclosure. The fusing circuit was then made and if ignition occurred in the outer enclosure it vented by rupturing the polyethylene diaphragm. If there was no ignition the mixture was disposed of by igniting it subsequently with an electric spark. When photographs of fused particles were taken only the explosion vessel was filled with the propane-air mixture.

RESULTS

CHARACTERISTICS OF CURRENT AND VOLTAGE DURING FUSING OF COPPER WIRES

Figure 3 shows the record of voltage and current while fusing a copper wire. Soon after making the circuit the current rose to the peak value A and then slightly declined to B. During this period the voltage across the wire rose steadily to C. Both traces during this period are represented by solid lines. At point B the current commenced to decline rapidly until it reached zero, at the same time the voltage rose and with some wires exceeded for a short time the open circuit value. The traces during this period were represented by a broken line and this was accepted as the arcing period. With thicker wires the maximum current attained the value of the prospective current; with thinner wires, however, this value was never reached. Figures 4 and 5 show the arc energies in joules plotted against the cross sectional area of the wire for the prospective currents of 330 and 1200 A respectively.

PERFORMANCE OF THE ARRESTERS WITH FUSED COPPER WIRES

Figures 6A and B show the probability of explosion transmission with copper wires of various diameters, using prospective currents of 650 and 1200 A, with the cupronickel arrester in propane-air. There was no transmission. Figure 6C illustrates the probability of ignition with copper wires of various diameters fused with a prospective current of 1200 A with an Alloy A arrester (2.9 cm diameter). With thicker wires some transmission occurred. Figure 6D shows the results of similar experiments but with the aluminium cover lined in the vicinity of the arrester with nickel foil. No transmission occurred in these tests when wires of 0.056 cm diameter (24 SWG) and 0.071 cm diameter (22 SWG) were used.

Figure 7A shows the probability of the explosion transmission in 6.5 per cent ethylene-air flammable mixture, with Alloy A and nickel arresters, with and without the obstacle. Evidently in some explosions using thick wires some transmission of explosions occurred. The presence of the obstacle and use of a different arrester had little effect on the performance.

Figure 7B shows the repeat of these experiments using the Alloy A ribbon arrester with 3.4 per cent diethyl-ether-air flammable mixture. The performance of the arrester was similar to the performance in the ethylene-air flammable mixture.

PHOTOGRAPHIC EVIDENCE

All the photographs obtained with a still camera showed traces of incandescent metal particles coming from the arrester apertures. These particles were free to travel over a distance of 39 cm before colliding with the roof of the 440 l outer enclosure. In no tests in which photographs were taken did this enclosure hold a flammable mixture, and when the inner vessel contained propane-air flammable mixture this is indicated.

Figure 8 shows a photograph of particles of copper wire 0.07 cm diameter (22 SWG) and with the cupronickel arrester. This wire was fused with a prospective current of 1200 A and no propane-air mixture was present. Four traces of particles are visible; these rose a few centimetres above the arrester, decelerated and fell by gravity. One particle left a trace which is only visible at the peak of its flight. Figures 9A and B show photographs of the traces obtained with the same wire in the same position but with the 9 l vessel containing a 4 per cent propane-air mixture. A 2.9 cm diameter Alloy A arrester was used and the aluminium cover holding the arrester was lined with nickel foil for the test recorded at Fig. 9A. The photographs showed that in both tests most of the particles impacted the roof of the enclosure and gave faint traces, with the exception of one bright particle emitted from the arrester while the cover was unlined, Fig.9B.

MAXIMUM EXPLOSION PRESSURES

Table 2 shows the maximum explosion pressures obtained while igniting the flammable gas with copper wires of 0.019 cm (33 SWG) and 0.07 cm diameter (22 SWG) at prospective currents of 330 and 1200 A, with 2.9 cm diameter arresters. The corresponding pressures obtained with an inductive spark across a 1 mm gap are shown for comparison. The maximum explosion pressures obtained with ignition by fused wire increased with the increase of wire diameter but decreased with the increase of prospective current. The maximum explosion pressures obtained with fused wires and with an inductive spark did not differ greatly.

Attempts were made to contain the fragmented wire inside insulating sleeving having both ends clipped. Various materials were tested and the results are summarised in Table 3 for ether-air and ethylene-air flammable mixtures. In the majority of the tests where the explosion was transmitted through the arrester the sleeve burst. When glass fibre sleeves coated with PVC or Terylene were used the ends of the wire were joined to 3 mm diameter copper electrodes which were attached to the ends of the sleeves with an epoxy resin. Wire mounted in this way in a polyvinyl chloride glass fibre sleeve did not fracture the sleeve, and did not ignite the surrounding flammable gas. A Terylene sleeve, however, was fractured in one test out of eight and the gas outside the arrester was ignited.

Sleeves which contained the explosion without damage prevented the ignition of the surrounding flammable mixture. Woven glass fibre covered with PVC arrested the hot particles in all tests.

DISCUSSION

MECHANISM OF FUSING WIRES WITH AN ELECTRIC CURRENT

With currents of similar magnitude to those used in this work, the disruption of the wire occurs in two distinct stages. Initially the applied electric energy is spent on heating the wire element. While this occurs there is considerable magnetic pinch effect, and the metal may reach a temperature considerably higher than the melting point before the breaks in the wire are formed. At this stage arcs are established and persist until the wire element is destroyed by fragmentation and vaporization and the gaps are wide enough to extinguish the arcs. The size and velocity of particles depend on the arc energy, the thickness and the length of wire. Greater arc energies tend to produce smaller particles travelling at higher velocities; increase in wire thickness has the opposite effect. With short wires the arc energy attains high values before the failure of the element takes place. As the length of wire is increased, the arc energy decreases but it cannot be less than the inductive energy stored in the circuit. The increase in length causes the energy per unit length of wire to diminish, thus reducing the corresponding stresses on the wire.

Direct current may produce arcs of longer duration than alternating current. With the latter, arcing may only occur during part of the cycle, moreover within that period voltage fluctuates. For these reasons tests with direct current may be expected to produce arc energies at least equal or greater than alternating current of the same R.M.S. value.

Table 2

Comparison of the maximum explosion pressures obtained when igniting 4 per cent propane-air flammable mixtures by fuse wires and an inductive spark

Arrester type and diameter	Wire diameter cm (SWG)	Prospective current A	Pressure kg/cm^2 (lb/in^2)	Maximum pressure with an inductive spark 5 cm below arrester kgf/cm^2 (lbf/in^2)
Alloy A 2.9 cm	0.019 (33)	1200	1.3 (18.5)	1.5 (21.5)
	0.07 (33)	1200	1.3 (19.3)	
	0.019 (22)	330	1.4 (21.2)	
	0.07 (22)	330	1.8 (26.0)	

Table 3

Performance of arrester with copper wires protected by various insulating sleeves

6.5 per cent ethylene-air

wire 0.07 cm diameter 22 SWG

Type of sleeve	Explosion transmitted number of tests	Explosion contained number of tests
Woven glass fibre	6	4
Woven glass fibre covered with PVC	0	10
Varnished woven Terylene	3	7

3.4 per cent ethyl ether

wire 0.07 cm diameter 22 SWG

Type of sleeve	Explosion transmitted number of tests	Explosion contained number of tests
Woven glass fibre	-	10
Woven glass fibre covered with PVC	-	10
Varnished woven Terylene	-	10

The behaviour of heated copper particles is largely unknown, copper being a less reactive metal cannot sustain a self supporting combustion in air. On the basis of the present tests a generalisation may be made on temperatures of copper particles in the experiments. Since fused copper wires ignited eroded aluminium, it is reasonable to assumed that copper particles reached or exceeded a temperature of 2300°K.

TRANSMISSION OF HOT METAL PARTICLES THROUGH THE ARRESTER APERTURES

Some work has been carried out in the past on the transmission of hot aluminium and copper particles produced by fusing wires, through the flanged gaps of flameproof apparatus. These investigators,[3,4,5] used very high A.C. prospective currents and they showed that the presence of an explosive mixture in a vessel fitted with flanged gaps had no effect on the probability of an explosion transmission, but there was some evidence that larger currents result in higher probability of explosion transmission.

Although copper particles which penetrate the arrester are non-incendive in propane-air, they must be well above the ignition temperature of propane-air mixture before emerging from the arrester. Thus, incandescent copper ignited eroded aluminium which indicates that the copper particles had reached the ignition temperature of aluminium. It appears that the copper particles lost heat at a very high rate to emerge from the arrester at the temperature lower than the ignition temperature of the propane-air mixture, nevertheless they were capable of igniting diethyl either-air and ethylene-air flammable mixtures. There has been little work done in the past on such mechanism of ignition. Work which is directly comparable was reported[6,7,8] then the minimum ignition temperatures of various hydrocarbons by hot spherical projectiles were studied. The authors reported that: the ignition temperature increased substantially with the decrease in size of the particle, town gas and hydrogen-air flammable mixtures were ignited at lower temperatures than pentane-air mixtures. Particles made of material having good thermal conductivity ignited a given gas at a lower temperature than the same size particle made of high conductivity material.

EFFECT OF FUSE WIRE ON THE MAXIMUM EXPLOSION PRESSURE

Large ignition sources in vented explosions are known to increase the maximum explosion pressure by creating multiple flame fronts and by generating turbulence in the unburnt gas. Tests with ignition by the fused wires confirm this, and although the results were not directly comparable as the inductive spark source was further away from the arrester than the fuse wire, they do show some increase.

EFFECT OF TRANSMISSION OF AN EXPLOSION BY FUSED COPPER WIRES ON THE PRACTICAL APPLICATION OF THE METHOD

The tests have shown that the crimped ribbon arresters under certain conditions are ineffective as barriers against the hot metal particles produced by arc discharges. Copper wires when fused did not ignite group II B.S.229 gases, but they did ignite ethylene-air mixture and diethyl ether-air mixture when high prospective currents were used. Thus with apparatus protected by flame arresters, if a heavy electrical discharge occurs in the proximity of the arrester, could cause incendive particles of metal to penetrate the arrester unless additional precautions are taken, such as covering of the wires with strong insulating sleeve.

It is not known to what extent the behaviour of fused wires represents the conditions produced by the electrical faults in industrial electronic instruments. The majority of faults produced in such equipment is caused by the displacement of leads and components, followed by short duration arcs.

It is known that other investigators produced arcs by moving apart two touching electrodes[9], and it may be desirable to compare this method with the fuse wire method described in this paper.

CONCLUSIONS

1. Particles of copper produced by fusing copper wires of various thicknesses with currents of 300 to 1200 A at 240 V D.C. did not ignite the propane-air mixture after penetrating the apertures of crimped ribbon arresters. However, thicker wires when fused with 1200 A prospective current, produced particles which, after penetrating through the arrester, ignited ethylene-air and diethyl ether-air flammable mixture.

2. If particles of copper impacted aluminium alloy before entering the arrester, they eroded and ignited portions of this alloy, and these portions may penetrate the arrester and ignite the propane-air mixture outside the test vessel.

3. Particles of copper produced by fusing a wire within an insulating sleeving were contained within such sleeving providing its ends were sealed and the sleeving material was strong enough not to be disrupted by the arc.

REFERENCES

1. PALMER, K. N. and ROGOWSKI, Z. W. Third Symposium on Chemical Process Hazards 76-85 Inst. Chemical Engineers 1968, London.

2. PALMER, K. N. and ROGOWSKI, Z. W. Joint Fire Research Organization F.R. Note 658.

3. MASKOW, H. The Eighth International Conference of Directors of Safety in Mines Research 1954. S.M.R.E. Paper No.28.

4. HULSBERG, F. The Seventh International Conference of Directors of Safety in Mines Research 1952. S.M.R.E. Paper No.28.

5. EINSELLE, A. S.M.R.E. Translation. No.3679.

6. SILVER, R. S. Ignition of gaseous mixtures by hot particles. Phil. Mag. 1937. Series 7 <u>23</u> 633.

7. PATERSON, S. Ignition of flammable gases by hot moving particles. Phil. Mag. 1939. Series 7 <u>28</u> 1.

8. PATERSON, S. Ignition of flammable gases by hot moving particles. Phil. Mag. 1940. Series 7 <u>30</u> 437.

9. IKHNO, A. G. and TARGASHOV, V. S. F. Investigation into the flange gap shape of an explosion-proof enclosure with arc formation under fault condition. Trudy Nak NII Vol.16. Vorosy Gornoi Electromekhaniks pp 25-54 Moscow 1965.

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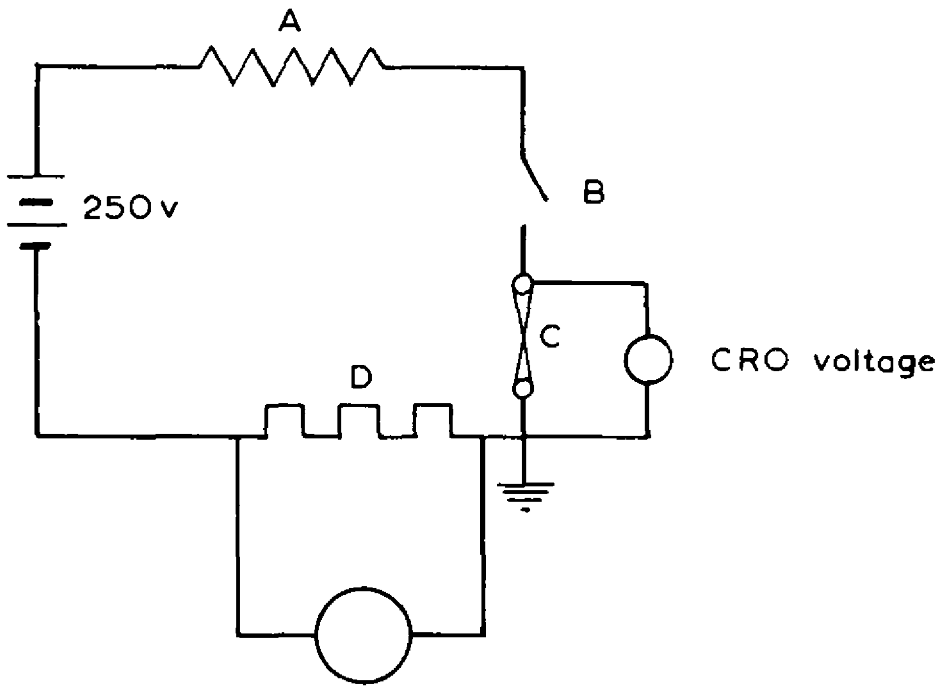

A. Variable resistance
B. Contactor
C. Fuse wire
D. Shunt

FIG. 1. DIAGRAM OF THE CIRCUIT USED FOR FUSING THE WIRES

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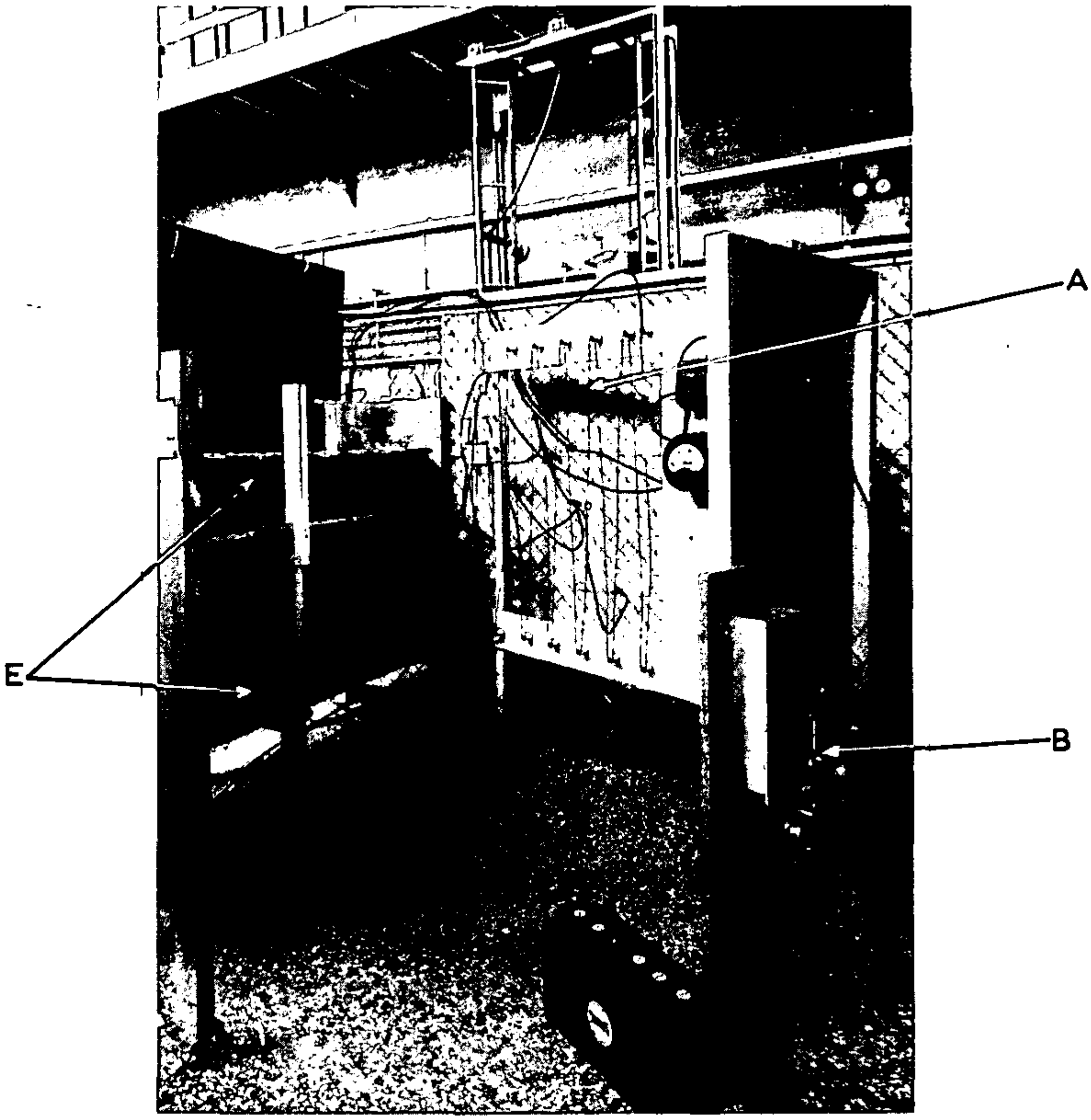

A VARIABLE RESISTANCE
B CONTACTOR
E ACCUMULATORS

FIG.2. POWER SUPPLY AND CONTROL GEAR

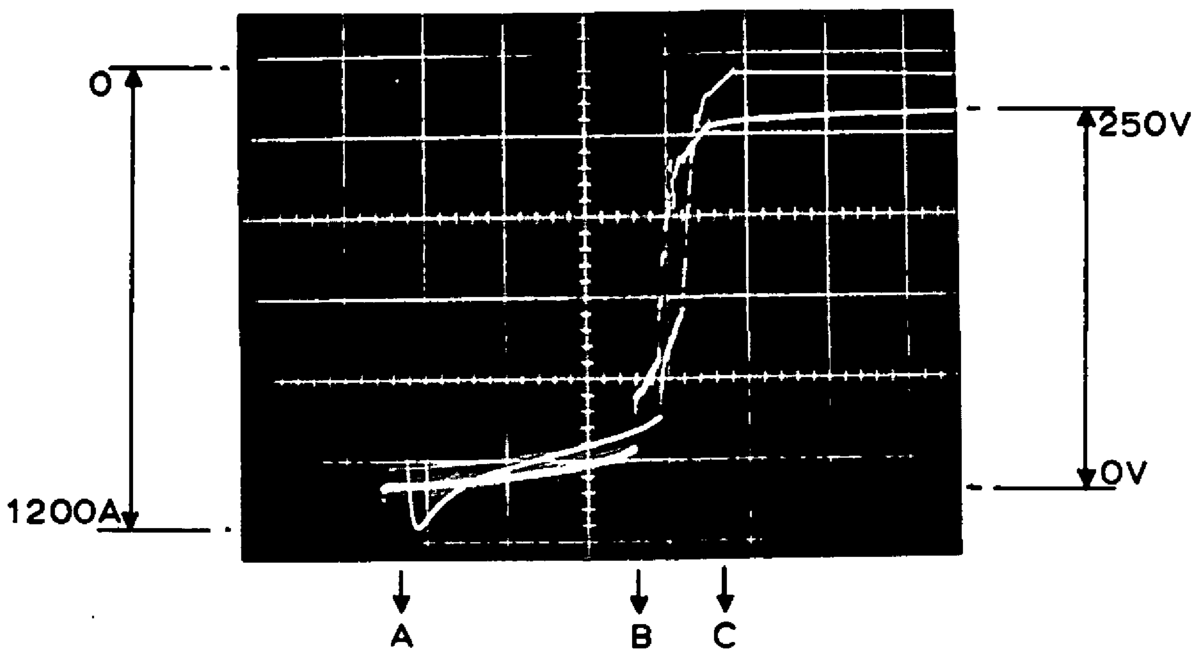

FIG. 3. OSCILLOSCOPE RECORD OF VOLTAGE AND CURRENT WHILE FUSING 0·07cm DIAMETER (22 S.W.G.) COPPER WIRE AT A PROSPECTIVE CURRENT OF 1200 A

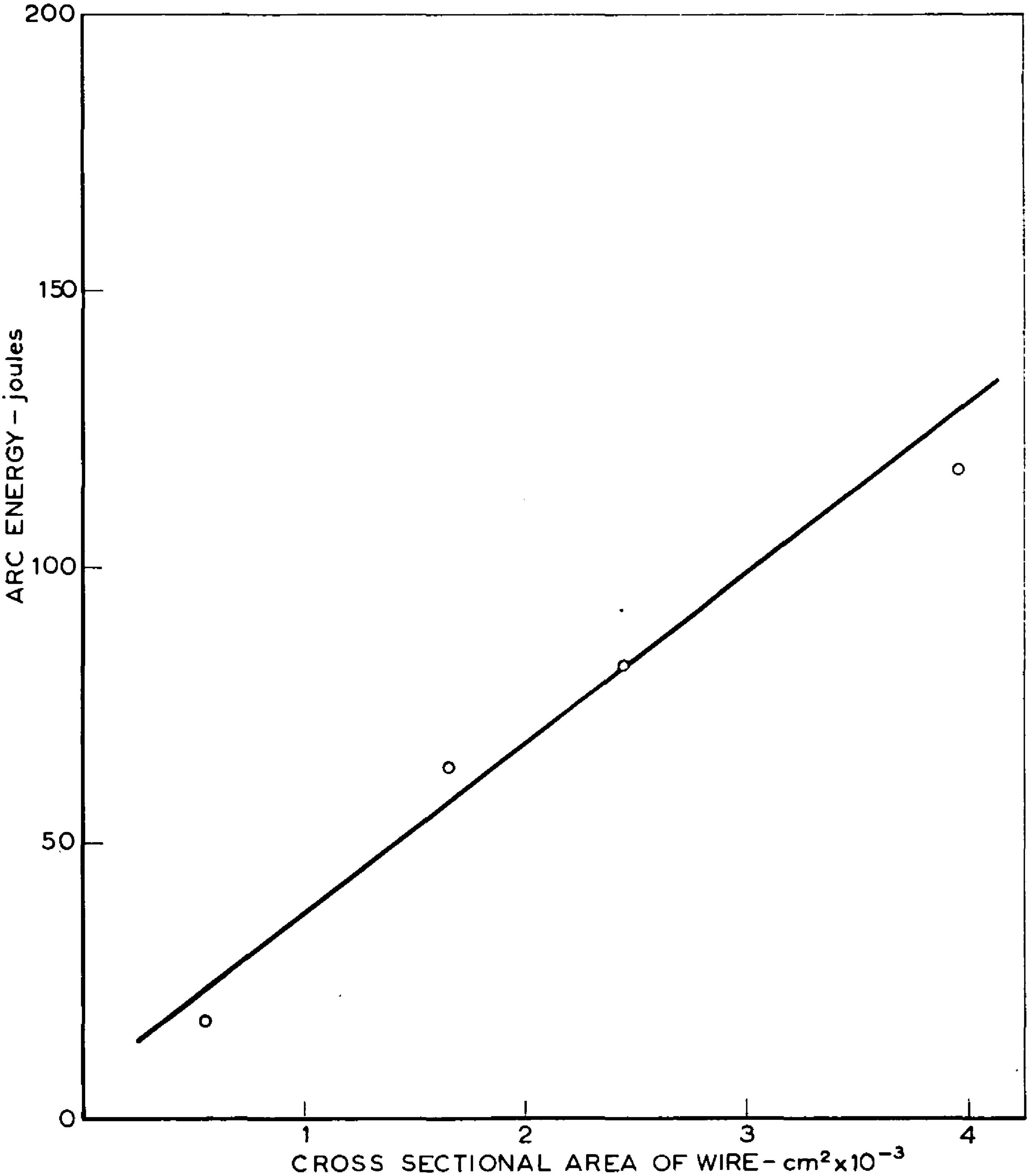

FIG. 4. RELATION BETWEEN THE THICKNESS OF WIRE AND ARC ENERGY

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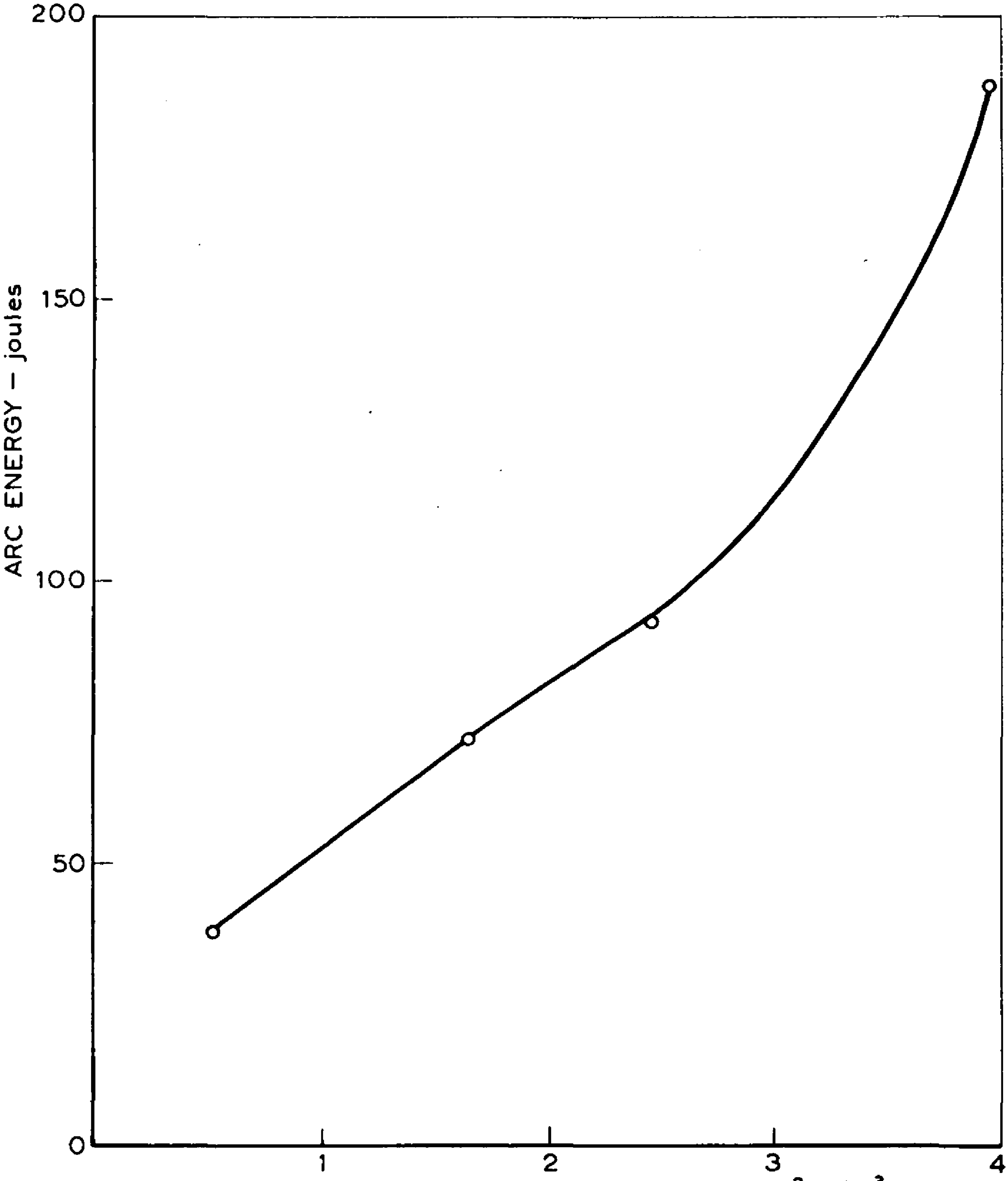

FIG. 5. RELATION BETWEEN THE THICKNESS OF WIRE AND ARC ENERGY

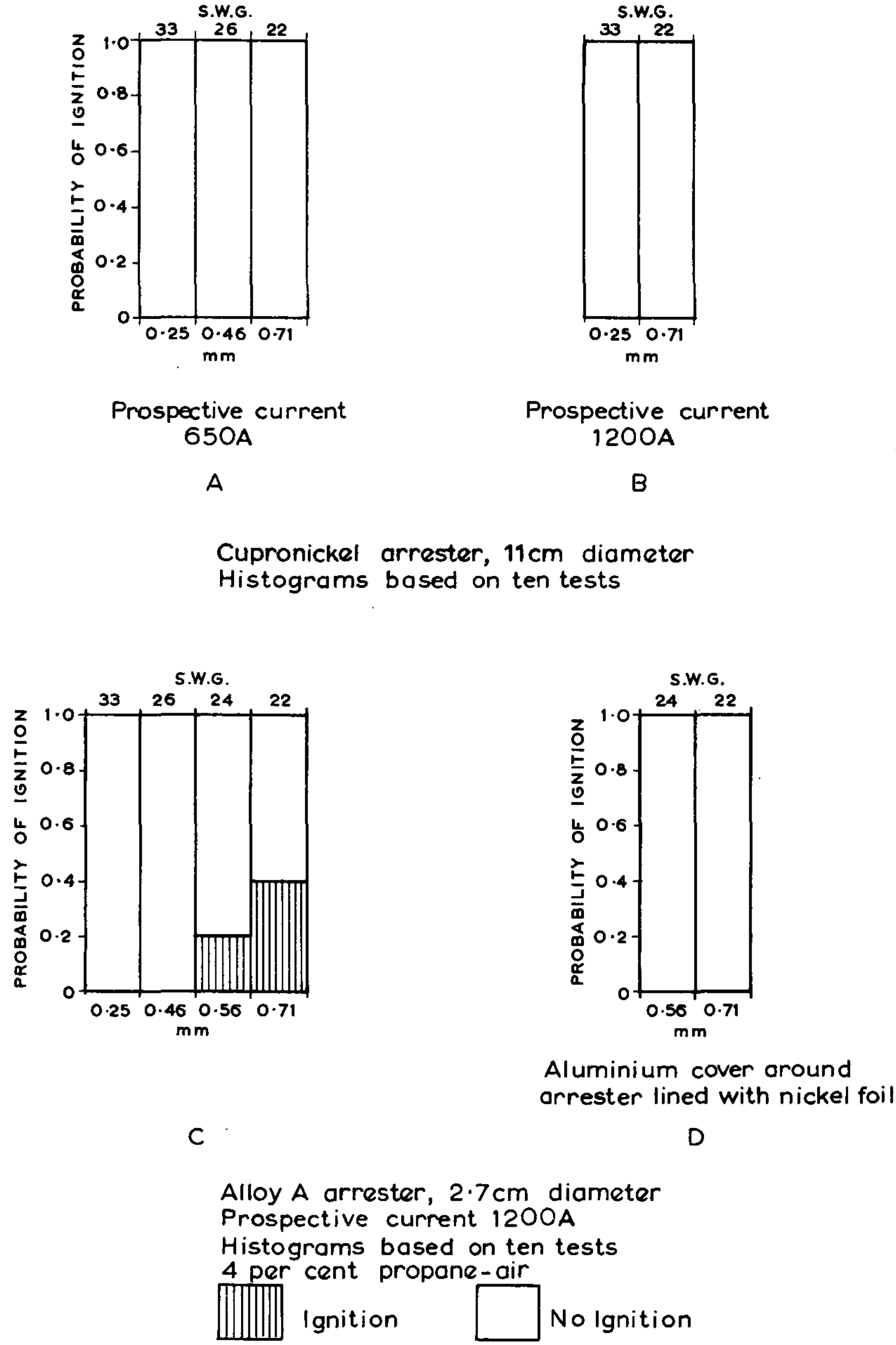

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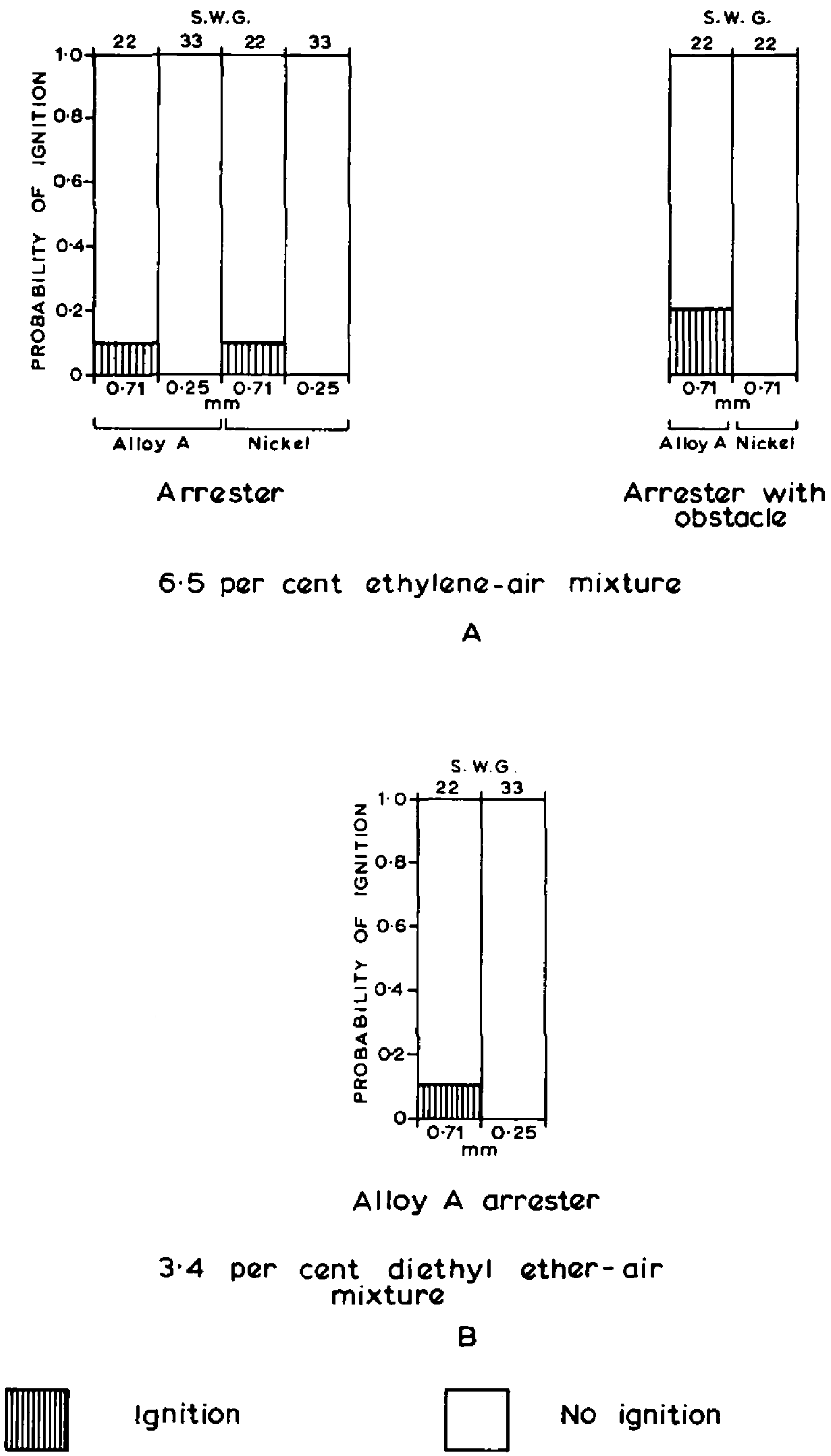
FIG. 6. PROBABILITY OF IGNITION BY FUSED COPPER WIRE



Prospective current 1200A

FIG. 7. PROBABILITY OF IGNITION BY FUSED COPPER WIRE

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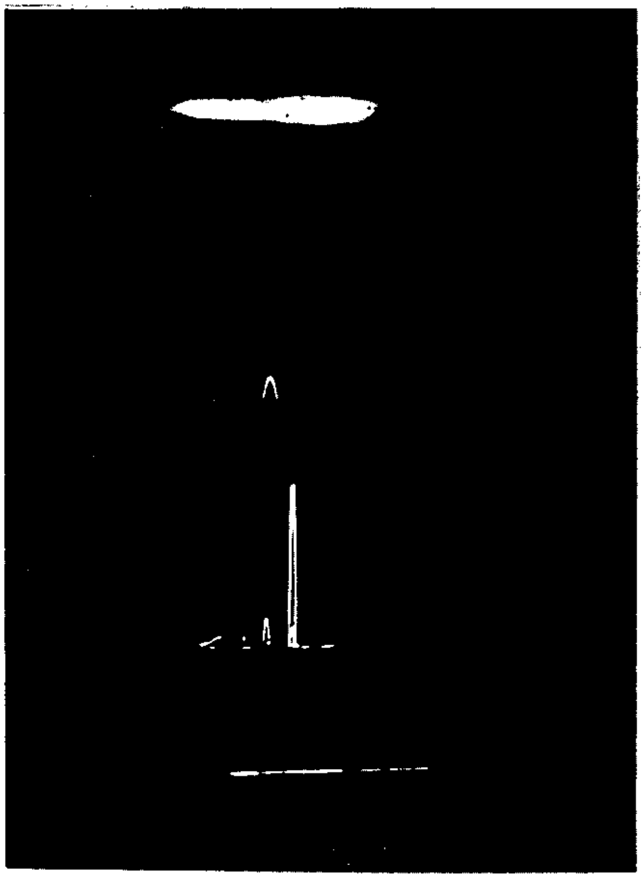
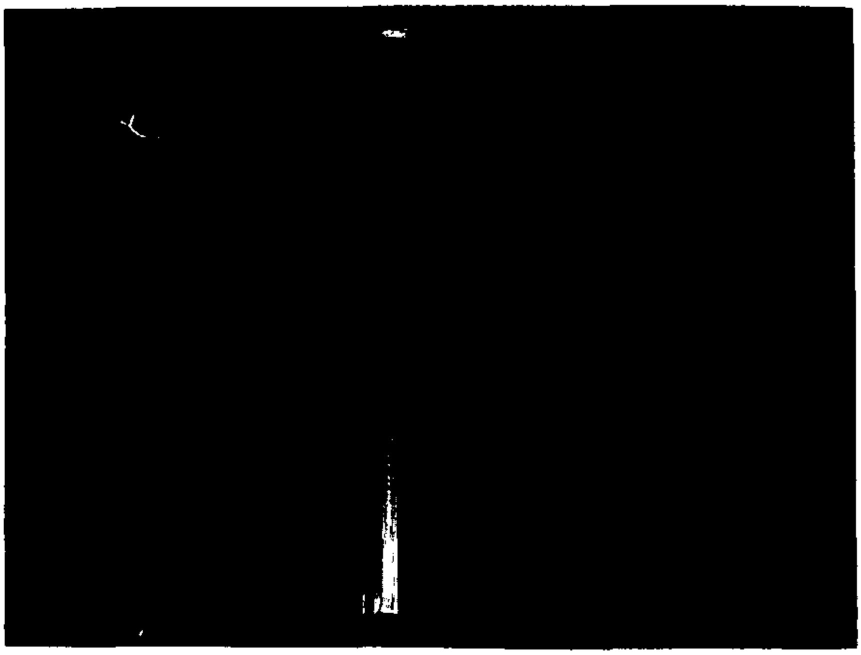
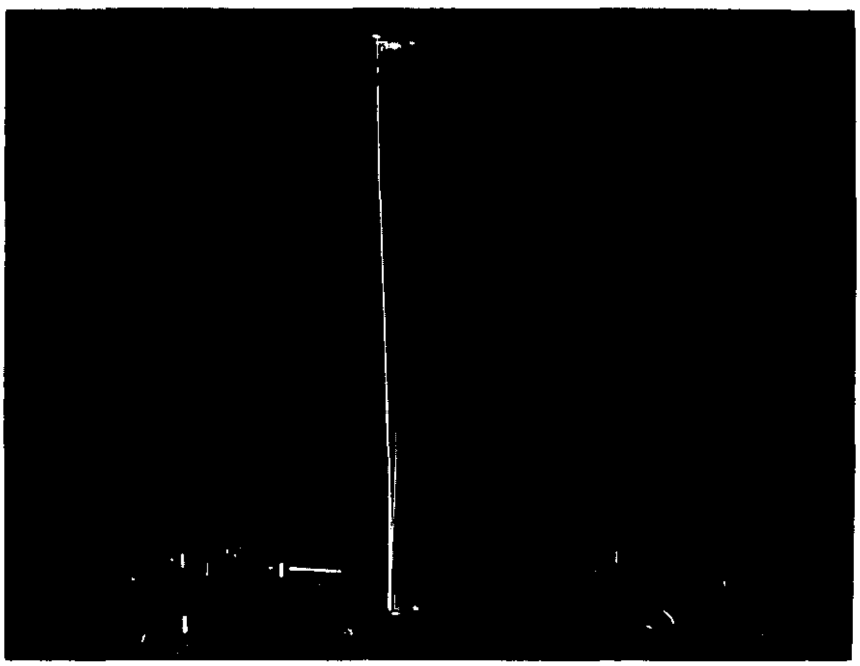


FIG. 8. TRAJECTORIES OF PARTICLES OF COPPER WIRE EMERGING FROM THE CUPRONICKEL ARRESTER 11 cm DIAMETER, WIRE 0·071 cm DIAMETER (22 S.W.G.), PROSPECTIVE CURRENT 1200A



(A) ALUMINIUM ALLOY COVER LINED WITH NICKEL FOIL



(B) ALUMINIUM COVER UNLINED

ALLOY A ARRESTER 2·9cm (1·15 in) DIAMETER, WIRE 0·07cm DIAMETER (22 S.W.G.), PROSPECTIVE CURRENT 1200 A

FIG. 9. TRAJECTORIES OF PARTICLES OF COPPER EMERGING FROM THE ARRESTER