Fire Research Note No 990

EFFECT OF PRESSURE RELIEF ON MAXIMUM EXPERIMENTAL SAFE GAPS OF HYDROGEN/AIR MIXTURES

by

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October 1973

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SUMMARY

The maximum experimental safe gaps in an 8 l volume vessel were measured for a range of flange breadths in a closed vessel, and a vessel fitted with the flame arresters, with hydrogen/air flammable mixtures. The insertion of the arrester increased the maximum experimental safe gaps and reduced considerably the maximum explosion pressures. The reduction in the maximum explosion pressure makes possible the manufacture of safe electrical equipment for hydrogen/air flammable mixtures, where the stresses imposed by high rates of burning make the design of such equipment difficult.

**DEPARTMENT OF THE ENVIRONMENT AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION**

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INTRODUCTION

Developments in the past at the Fire Research Station on the construction of electrical equipment protected by flame arresters have shown that apparatus suitable for gases in groups iia and iib (BS 4683) could be produced and prototypes were constructed. Some of these were produced in quantity and these have functioned satisfactorily in industrial environments for a number of years. Such efficient behaviour suggested that by using arresters made from metal foam now available, equipment suitable for hydrogen/air atmospheres could be constructed. This paper describes some preliminary experiments exploring the feasibility of such a design.

APPARATUS AND MATERIALS

Explosion vessel

The maximum experimental safe gaps were determined using an 8 litre stainless steel cylinder of height and diameter 216 mm (8.5 in) and 25 mm (1.0 in) wall thickness. The top and bottom of the vessel consisted of separate end plates, 25 mm (1.0 in) thick, which could be kept apart from the cylindrical wall by silver foil shims. The cylinder was sandwiched between two end cups (Fig. 1). All contact surfaces between the end cups, end plates and the cylinder were finished to an accuracy of ± 0.006 mm (0.00025 in).

The assembly was held together in a press (Fig. 2) in which a hydraulic ram exerted $7\frac{1}{4}$ tons axial compression on the whole cylinder assembly. When the assembly was under maximum stresses produced by an unvented explosion the yield of the frame holding the cylinder did not exceed 0.006 mm (0.00025 in).

The test cylinder was provided with a gas inlet, via a non-return valve, a pressure transducer and spark electrodes permitting ignition in various positions inside the cylinder (Fig. 1).

The whole cylinder assembly was enclosed in a 0.04 mm thick polyethylene sleeve which contained the flammable mixture during the experiments. This sleeve burst if the ignition of the flammable mixture surrounding the test vessel took place. It remained intact if there was no explosion transmission.

Flange gaps

The experimental flange gaps were produced by six stacks of 25 x 13 mm silver shims equally spaced between the cylinder and the upper end plate (see Figs 1 and 3). The shims were measured using a micrometer before being put in, and the gap finally verified with feel gauges after the apparatus was compressed by the hydraulic ram. For flange gaps of radial breadth less than 25 mm (1 in) a number of flange adaptor rings were manufactured, Fig. 4, having effective radial flange breadths of 12.7 mm ($\frac{1}{2}$ in), 6.4 mm ($\frac{1}{4}$ in), 3.2 mm ($\frac{1}{8}$ in) and 1.6 mm ($^1/_{16}$ in). These adaptor rings were placed between the top of the cylinder and the upper end plate. The same method of spacing was used to produce the experimental gaps as for the 25 mm (1 in) flanges. With the flange of 1.6 mm breadth three locating shoes were attached to each ring to prevent movement during the explosion, (Fig. 5).

Method of ignition

The flammable mixture was ignited inside the vessel by means of an inductive spark generated between a pair of spark electrodes 2 mm apart, using a 12 volt automotive induction coil.

In the majority of the tests the spark electrodes were placed 10 mm from the inner lip of the gap and midway between two of the stacks of shims as shown in Figs 3 and 6. In other tests the mixture was ignited in the centre of the vessel.

Flame arrester

Metal foam known commercially as 80 grade Retimet 13 mm ($\frac{1}{2}$ in) thick was the arrester material used in all experiments. This was mounted in a metal frame providing a vent of 110 mm (4.3 in) diameter. The arrester was held in the frame in a manner shown in Figs 7a and 7b.

Flammable mixture

A twenty-eight per cent hydrogen/air mixture was used in all experiments. This was produced by metering and mixing appropriate volumes of hydrogen and air. The composition of the mixture was checked by a chromatograph.

Measurements of pressure and flame movement

The pressure developed inside the test vessel was measured by means of a piezo pressure transducer, which was screwed into the lower end plate of the cylinder, see Fig. 1. The signal from the transducer was passed via a charge amplifier to a cathode ray tube oscilloscope, from which photographs of the time-resolved pressure travel were obtained. The flame front travel was monitored by two ionisation detectors. With the non-vented tests the arrival of the flame front at the centre of the lower blank flange was timed, also if the explosion was transmitted the appearance of flame outside the vessel opposite the igniting source was timed. With the vented tests, there was an ionisation flame detector on the outside of the vessel opposite the igniting source and another detector sensing the flame front at any position across the whole diameter of the arrester 10 mm above its upper surface. Thus the flame front penetrating the gap and the flame front arriving at the surface of the arrester were timed. In selected tests the arrival of the flame front at the centre of the lower blank flange was also timed.

PROCEDURE

The procedure used for the determination of a maximum experimental safe gap was as follows: an estimate of the maximum gap was made and six sets of silver shims were selected, with the aid of a micrometer, having a thickness a little over that anticipated for the gap. These were placed equally around the rim of the top of the cylinder as shown in Fig. 3. The end plate of the vessel was placed on the cylinder followed by the end cup. A polyethylene sleeve was placed over the apparatus and a hydraulic ram operated to compress the 'assembly' until a total force of $7\frac{1}{4}$ tons had been achieved. The experimental gap was checked using feeler gauges. The polyethylene sleeve was then sealed, top and bottom, and, with the exhaust valve open, the flammable mixture was passed through the whole apparatus until ten complete changes of atmosphere inside the vessel and inside the polyethylene sleeve had been achieved. The gas flow was then shut off and the inlet and exhaust valves closed.

The mixture inside the test vessel was ignited and the pressure developed was recorded from the oscilloscope by a polaroid camera. Bursting of the polyethylene sleeve indicated the transmission of the explosion.

Several tests were carried out before altering the gap. When the maximum experimental safe gap (MESG) was thought to have been achieved, at least twenty tests were carried out, and if no ignition of the outer mixture occurred this was recorded as the MESG for that particular set of conditions.

If transmission of the explosion occurred, which was indicated by the burst sleeve, the ionisation detectors' record was examined and with the vented vessel the arrival of the flame front at the detector situated near the arrester was used to indicate whether the arrester transmitted the flame. In fact no transmission through the arrester was recorded throughout the experiments.

RESULTS

Figure 8 shows maximum experimental safe gaps plotted against flange breadth in the unvented explosion vessel with ignition near the flange and in the centre of the vessel. The third curve is the maximum experimental gap for the vented vessel, with ignition near the flange. Table 1 gives list of all experiments. Evidently there are slight differences between the values obtained with the different positions of igniting source. The insertion of the arrester resulted in the increases of the MESG for the 6.4 x 12 mm flange gaps. The curves show that once the flange breadth was reduced below 0.25 in, the increase in MESG was smaller.

The examination of the pressure and the flame movement records has shown that in all tests, except for 1.6 mm ($^1/_{16}$ in) flange breadth with arrester, the flame reached the flame detector located opposite the igniting source when the pressure inside the vessel reached the maximum. With the smallest breadth of flange, 1.6 mm, the flame arrived much earlier; when the detector signalled the flame the maximum explosion pressure had attained approximately half of the peak value. Figure 10 shows the respective pressure and flame records.

In the initial series of vented experiments with the 3.2 mm ($\frac{1}{8}$ in) flange breadth, inconsistent performance was obtained. This was manifested by transmissions occurring over a wide range of gap widths, with a low probability of transmission remaining substantially unchanged. The experiments were discontinued when with a gap of 0.011 mm (0.0045 in) explosion transmissions occurred. There was also inconsistency in the explosion transmission timing; this occurred in an early stage of explosion when the maximum explosion pressure reached half of the peak value. The flanges used in these series showed several impact damages on inner and outer edges; these were caused by handling. The burrs caused by this damage protruded 0.025 - 0.050 mm (0.001 - 0.002 in) above the flange surface. When the protruding pieces of metal were removed consistent performance was obtained.

One arrester element was used for at least twenty tests. At this stage small cracks and discoloration were visible on the surface exposed to the flame front. Figure 9 shows the damaged surface of the arrester.

DISCUSSION

Provision of pressure relief covered with the metal foam flame arrester produced substantial reduction in the maximum explosion pressures with hydrogen/air flammable mixtures; at the same time most substantial increases in MESG were evident with 12.7 and 6.4 mm flange breadths. It is interesting that with the two flanges of breadths of 3.2 and 1.6 mm breadths such increases were smaller and they were associated with much earlier explosion transmission. This suggests that with the flanges of small breadths a different mechanism of explosion transmission may operate. The much delayed transmission with the broader flanges does, however, introduce the possibility that the MESG may be affected by the movement of gas outside the flange gap. With the polyethylene sleeve surrounding the explosion vessel such movement could be substantial if the polyethylene burst before the flame penetrated the gap. There is some evidence giving support to this[1].

Other work has been carried out elsewhere with hydrogen/air flammable mixtures. Electrical Research Association[2] determined the MESG for 25.4 mm (1 in) broad flanges in an 8 l closed spherical vessel with equatorial gap; this MESG was 0.28 mm (0.011 in) on the basis of forty tests. Safety in Mines Research Establishment[3] determined the MESG for 25.4 mm (1 in) and 12.7 mm ($\frac{1}{2}$ in) broad flanges in an 8 l volume closed vessel with equatorial gaps. The values were 0.28 mm (0.011 in) and 0.18 mm (0.007 in) respectively. The differences may be accounted for by the cylindrical shape of the vessel used at the Fire Research Station.

The effect of external obstacles and surface finish of the metal on the MESG was studied[4 and 5]. The results, however, obtained with the damaged 3.18 mm flange breadth indicate that effects of these may be more severe than appreciated.

APPLICATION OF THE METHOD

At present there is no standard for the manufacture of flameproof apparatus based on flange gap for use in hydrogen/air atmospheres. The construction of such apparatus was considered impracticable. This decision was mainly based on the value for the MESG quoted as 0.10 mm (0.004 in)in B.S. 229 1957. The present note and reference 3 indicate a case for the reconsideration of this decision.

The use of flame arresters and explosion relief does reduce the mechanical stresses produced by hydrogen/air explosions, thus removing one of the principal difficulties involved in designing such protective systems. The metal foam arrester can cope adequately with hydrogen/air flammable mixtures, and the foam has a number of other advantages which make it a suitable material for the construction of arresters. It is light, is easily shaped,and it has an adequate corrosion resistance.

Some more work is, however, needed to evaluate its safety margins and provide an adequate range of mountings. Although the arrester is dimensionally stable under normal conditions, it may change its dimensions when exposed to repeated explosions, and the arrester mount must be capable of compensating for such changes in order not to exceed the allowable clearances.

The MESG values for vented explosions and for the range of flange breadths of 6 mm or more, are large enough to accommodate the tolerances required in manufacture and usage, for apparatus of limited volume.

The effect of surface finish of flanges should be further investigaged.

REFERENCES

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3. Safety in Mines Research Establishment Annual Report 1964.

4. CIOK, J. and PILARSKI, J. Investigation into the influence of external factors on the limiting gap clearance for flameproof equipment for use in gassy mines. Pr. Glown.. Inst. Gorn. 1969 Document No. 457. (In Polish)

5. FREY, G. Investigation on the effects of the surface roughness on the explosion transmission through the flange gaps. International Conference of Directors of Safety in Mines Research, Warsaw, Poland, 1961.

Table 1

MESG for various experimental conditions

Closed vessel. Ignition close to gap

Flange breadth		Gap width		Mean pressures		No. of tests	Trans-missions	No trans-missions
in	mm	in x 10^{-3}	mm	lb/in^2	kN/m^2			
1	25.4	15 12.5 12	0.381 0.318 0.305	N.R. 79.0 79.0	– 545 545	1 2 25	1 2 –	– – 25
½	12.7	10 9 8.5 8	0.254 0.229 0.216 0.203	81.7 80.3 83.7 83.0	563 554 576 572	3 3 20 3	3 3 – –	– – 20 3
¼	6.4	8 7 6	0.203 0.178 0.153	84.5 84.0 84.3	583 579 581	2 2 20	2 2 –	– – 20
⅛	3.2	5 4	0.127 0.102	84.5 85.3	583 588	2 20	2 –	– 20
1/16	1.6	4 3 2	0.102 0.076 0.051	86.0 80.5 87.4	592 555 602	2 2 20	2 2 –	– – 20

N.R. Not recorded

Table 1

MESG for various experimental conditions (cont'd)

Closed vessel. Central ignition

Flange breadth		Gap width		Mean pressures		No. of tests	Trans- missions	No trans- missions
in	mm	in x 10^{-3}	mm	lb/in^2	kN/m^2			
1	25.4	15 14 13 12	0.381 0.356 0.33 0.305	79.0 80.0 83.1 81.5	545 552 573 562	2 3 20 3	2 2 - -	- 1 20 3
½	12.7	10 9 8	0.254 0.229 0.203	92.5 93.2 90.0	638 642 620	3 20 2	3 - -	- 20 2
¼	6.4	8 7 6.5	0.203 0.178 0.165	90.0 91.2 90.0	620 628 620	3 24 20	3 2 -	- 22 20
⅛	3.2	6 5	0.153 0.127	90.0 96.3	620 664	2 32	2 -	- 31
1/16	1.6	4 3.5 2	0.102 0.089 0.051	93.0 94.5 95.0	641 651 655	2 20 2	1 - -	1 20 2

Table 1

MESG for various experimental conditions (cont'd)

110 mm diameter arrester. Ignition close to gap

Flange breadth		Gap width		Mean pressures		No. of tests	Trans-missions	No trans-missions
in	mm	in x 10^{-3}	mm	lb/in^2	kN/m^2			
1	25.4	14	0.356	15.0	103	3	2	1
		13.5	0.343	15.0	103	25	3	22
		13	0.330	14.9	110	23	1	22
		12	0.305	15.7	108	20	-	20
½	12.7	11	0.279	20.0	138	2	2	-
		10	0.254	20.1	189	25	-	25
		9	0.229	21.0	145	3	-	3
¼	6.4	10	0.254	18.5	128	2	2	-
		9.5	0.241	18.5	128	3	1	2
		9	0.229	17.1	118	20	-	20
⅛	3.2	7	0.178	18.0	124	7	1	6
		6	0.153	18.1	125	20	-	20
1/16	1.6	5	0.127	18.3	127	7	1	6
		4.5	0.114	17.7	122	23	-	23
		4	0.102	18.8	131	3	-	3

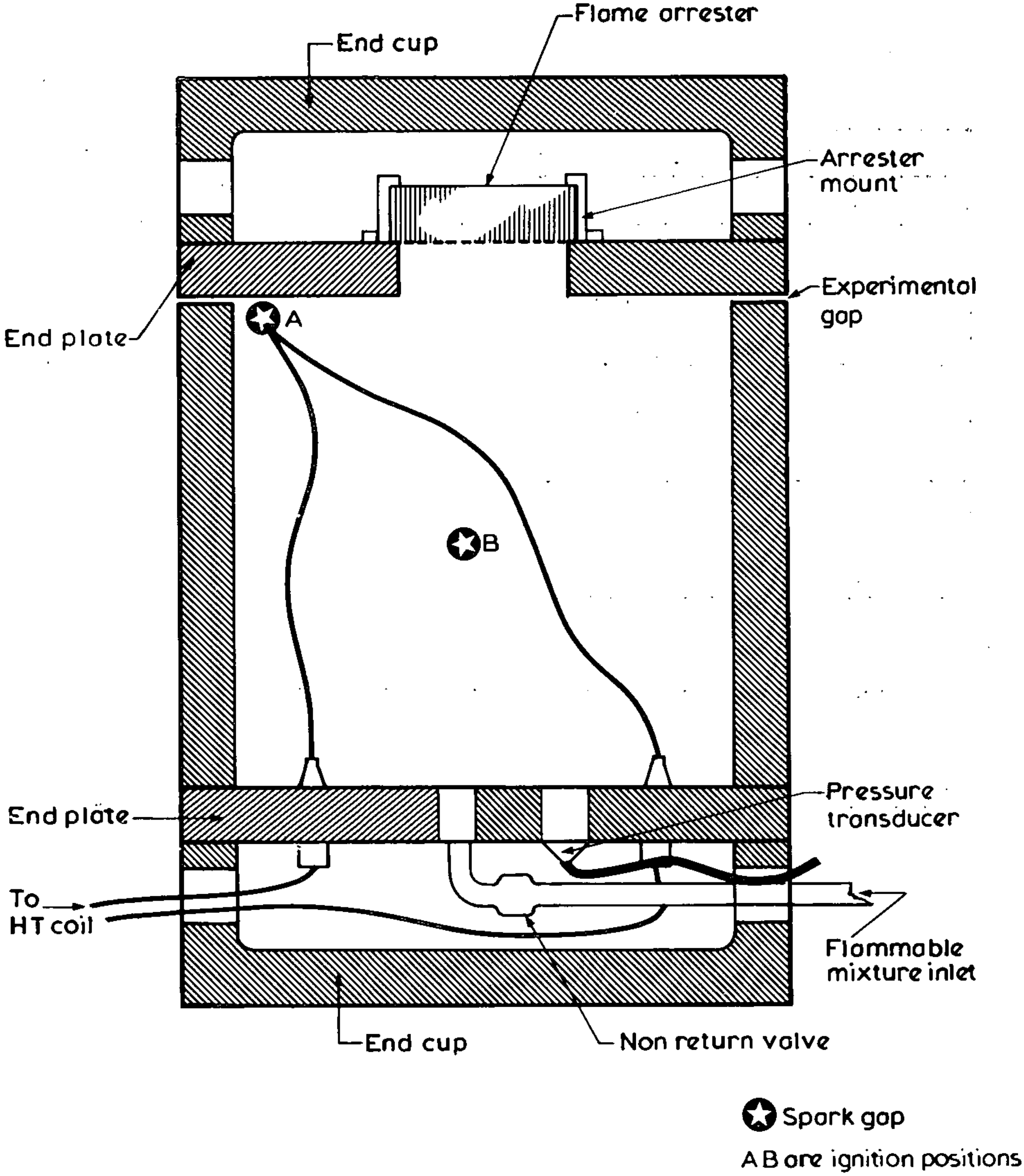


Figure 1 Cross-sectional view of the explosion vessel

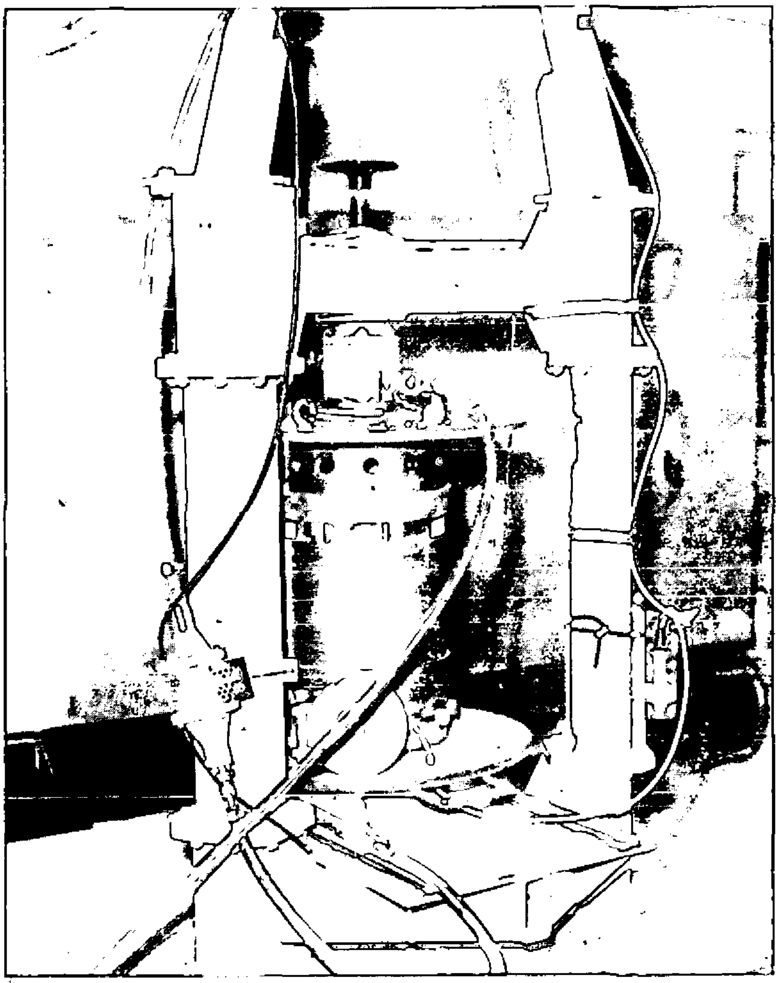


FIG. 2. TEST VESSEL ASSEMBLED IN PRESS

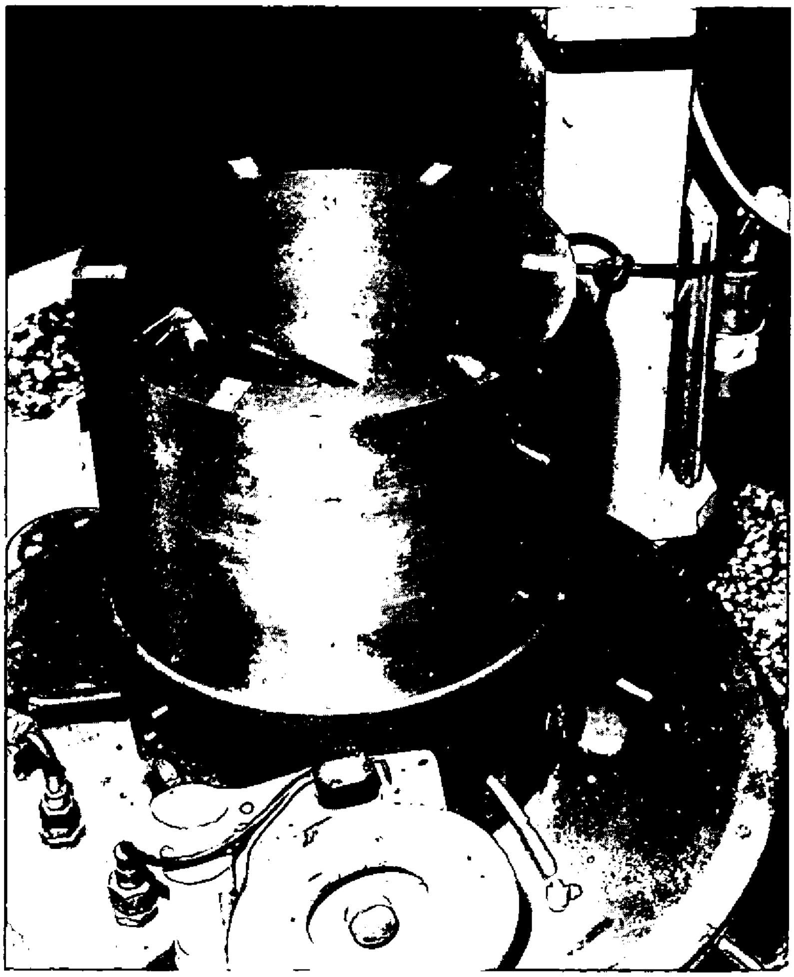


FIG. 3. TEST VESSEL WITH LID REMOVED SHOWING SIX SPACER SHIMS AND IGNITION ELECTRODES

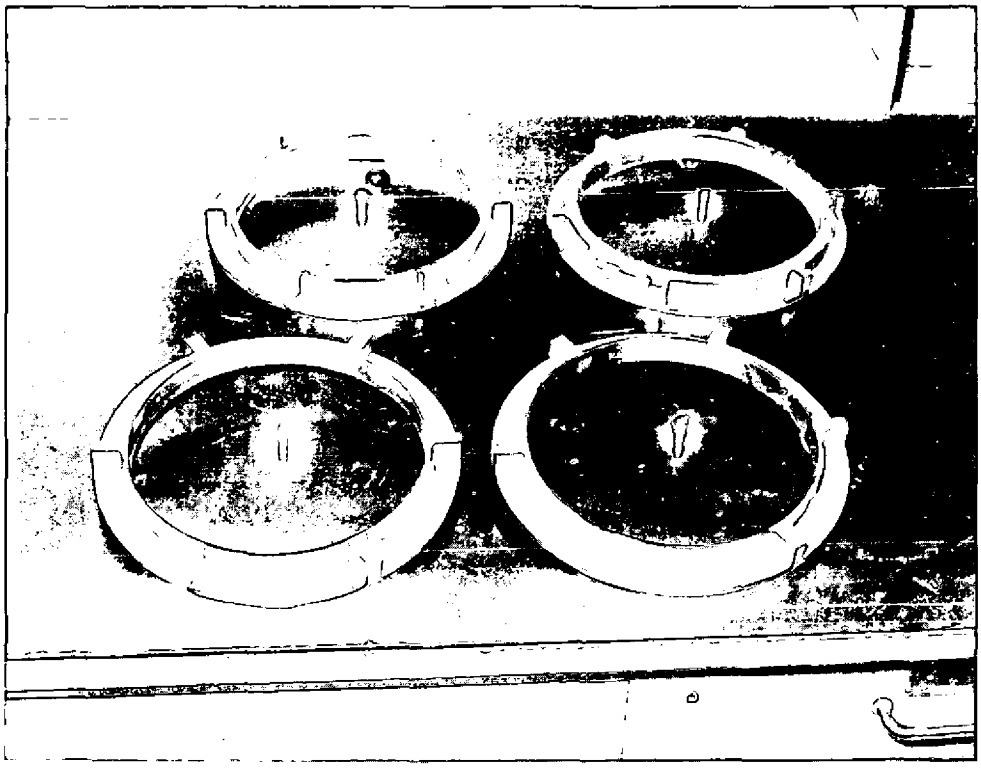


FIG. 4.- ADAPTOR RINGS FOR FLANGE BREADTHS LESS THAN 25 mm (1 inch)

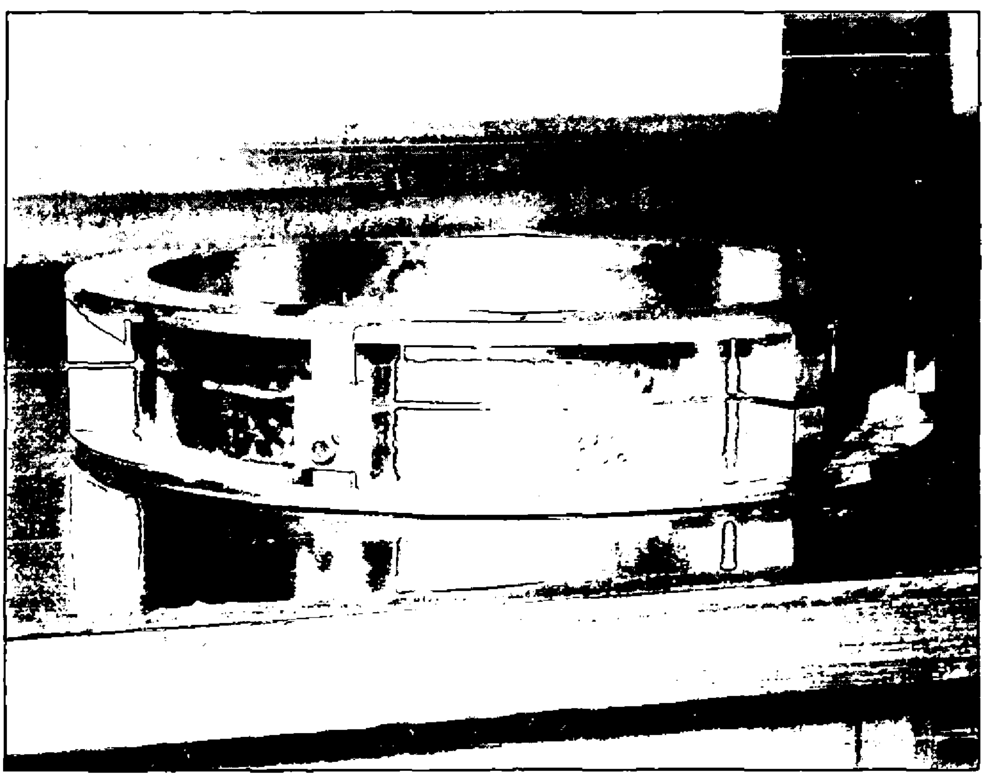
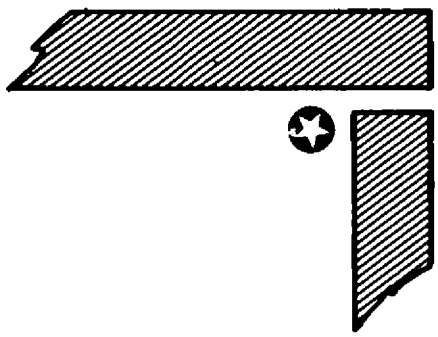
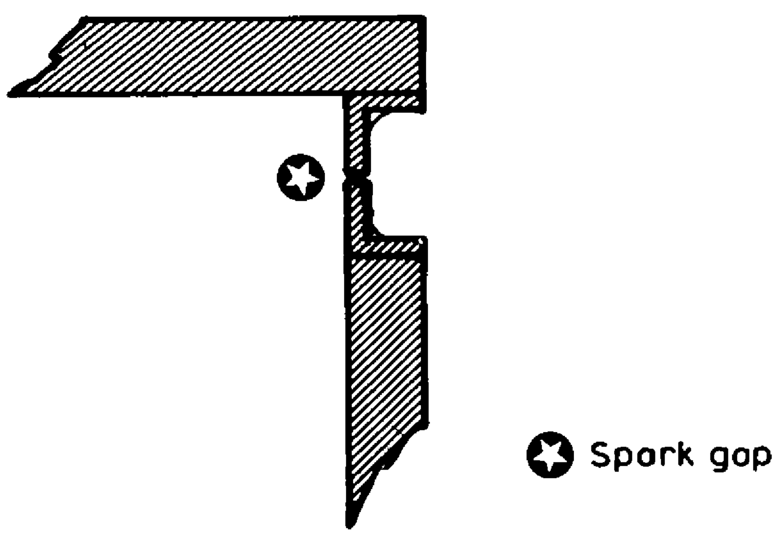


FIG. 5. FLANGE LOCATING DEVICE FOR THE 1.6 mm (1/16 inch) RING



Arrangement of gaps for 1 (1 inch) flange breadth



Arrangement of gaps and ignition for ($\frac{1}{16}$ inch to $\frac{1}{2}$ inch) flange breadth

Figure 6 Position of ignition electrodes relative to gap

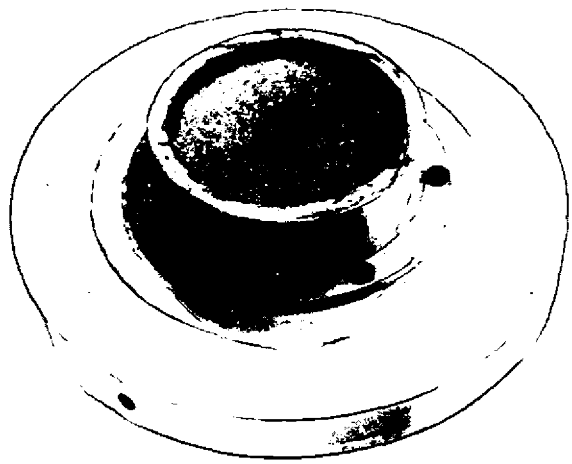


Figure 7a Arrester in the frame

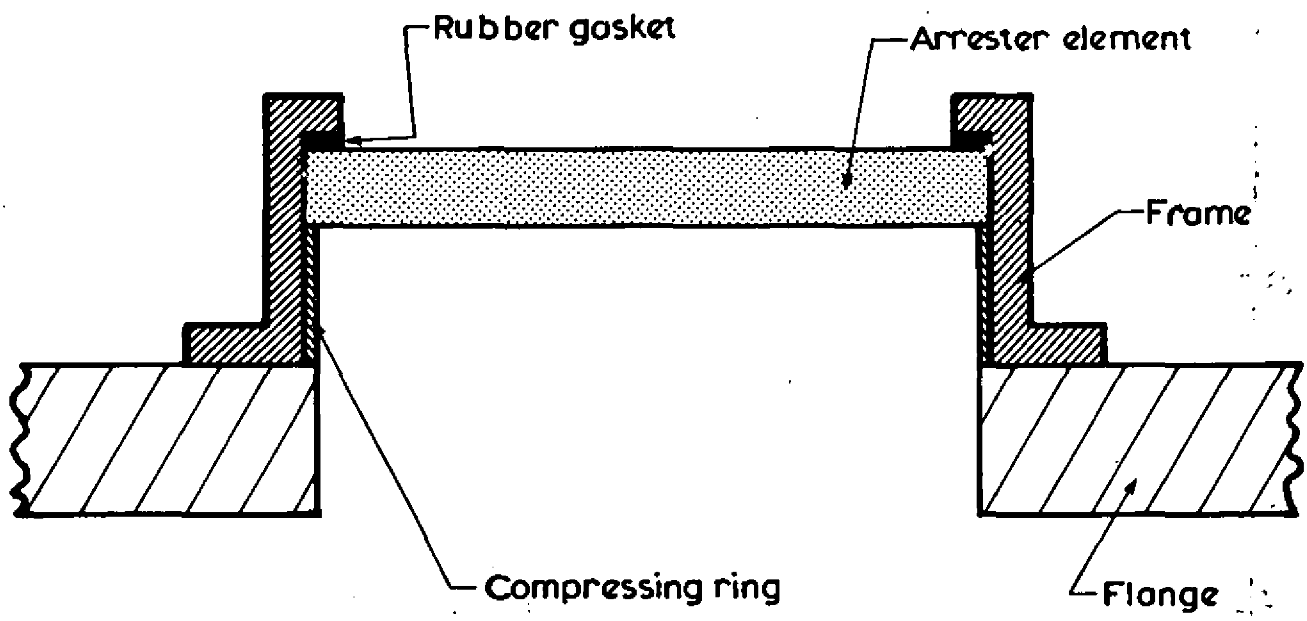


Figure 7b Arrester in the frame – cross section through the centre

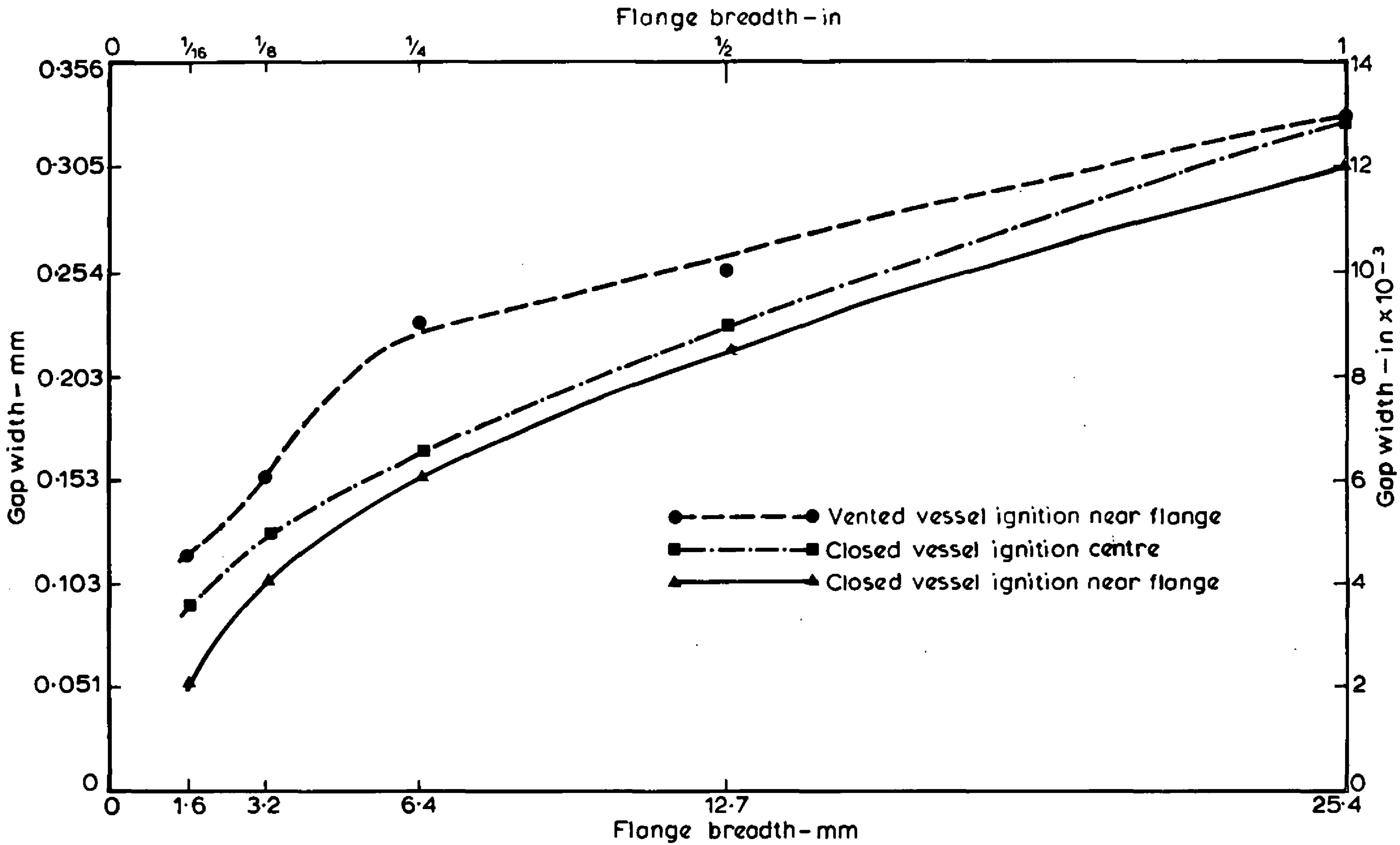


Figure 8 Maximum experimental safe gap for various flange breadths

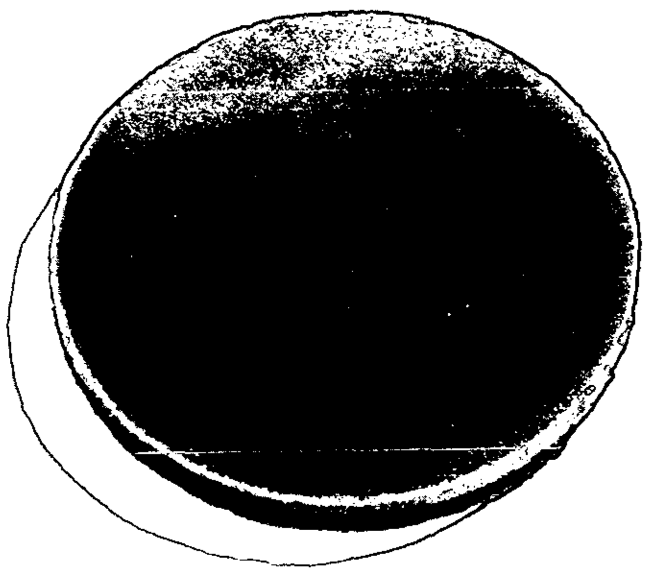
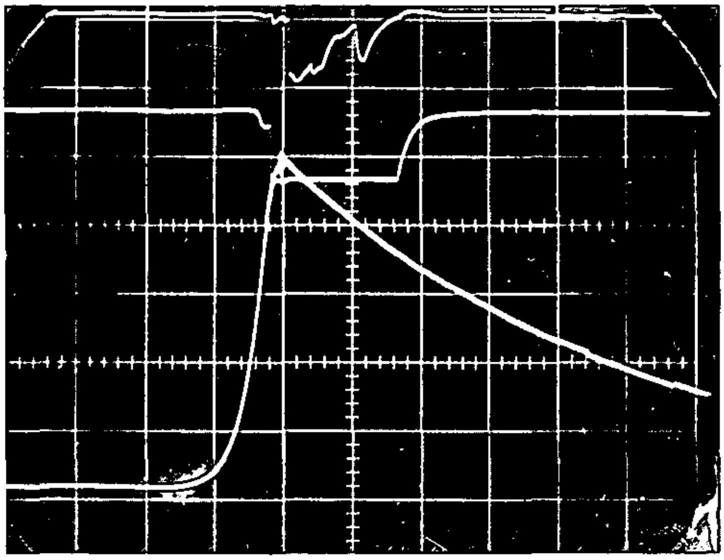


FIG. 9. DAMAGED SURFACE OF THE ARRESTER

DEFLECTION
INDICATES
FLAME AT
THE ARRESTER

DEFLECTION
INDICATES
FLAME
OUTSIDE

PRESSURE



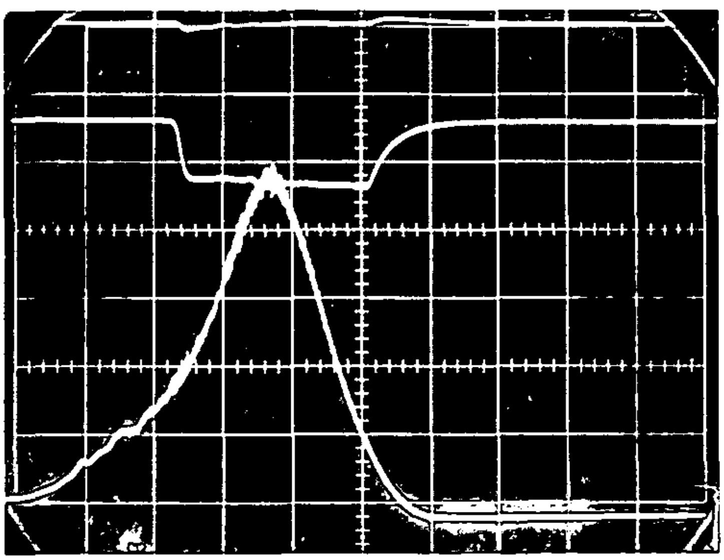
MAXIMUM
PRESSURE
655 KN/m^2
(95 lbf/m^2)

FLANGE BREADTH 12.7 mm

DEFLECTION
INDICATES
FLAME AT
THE ARRESTER

DEFLECTION
INDICATES
FLAME
OUTSIDE

PRESSURE



MAXIMUM
PRESSURE
149 KN/m^2
(23 lbf/m^2)

FLANGE BREADTH 1.59 mm

FIG. 10 EXAMPLES OF PRESSURE AND FLAME MOVEMENT RECORDS