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DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH AND FIRE OFFICES' COMMITTEE
JOINT FIRE RESEARCH ORGANIZATION

THE VENTING OF GASEOUS EXPLOSIONS IN DUCT SYSTEMS - PART V
VENT SYSTEMS FOR DUCTS CONTAINING OBSTRUCTIONS

by

D. J. Rasbash and Z. W. Rogowski

SUMMARY

Tests have been carried out to determine the nature of relief venting required in a duct containing an obstacle to prevent pressures in propane-air explosions rising above 2 lb/in^2. The tests were carried out in a duct 24 ft long and 1 ft square, the vents being closed either by a loose cover, a polythene film, or a cover clamped by magnets. In general, the provision of relief vents along the duct to the extent of 1 ft^2 of vent area for each 6 ft run of duct was sufficient to achieve the above object, although with some obstacles the pressure rose above 2 lb/in^2 if the gas was ignited near the obstacle.

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Introduction

Work done at the Joint Fire Research Organization in the past(1) has shown that gaseous explosions in duct systems containing obstructions which impede the gas flow, may generate very high maximum pressures accompanied by high rates of pressure rise. It has been shown that vent areas required for such ducts are larger than those applicable to straight ducts with no obstructions, and the conventional bursting disc closures could not be relied upon to protect such ducts, since these closures cannot be made to burst at a sufficiently low pressure. This note describes tests with modified vent systems and new types of vent closures in duct systems containing obstructions. These tests were carried out with the object of defining practical venting systems, which would limit maximum pressures in explosions to 2 lb/in^2, the maximum that many duct systems can withstand.

Apparatus

Ducts and obstructions

Experiments were carried out in a 24 ft length of 1 ft^2 ducting consisting of four sections each 6 ft long. Each section had a 5 ft length of one of the sides open and the sections were bolted together so that the open sides were aligned along the top of the duct. These open sides could be partly closed by plates of different size leaving openings of different size along the top of the duct to act as relief vents. When vents in the form of a slot were used appropriate covers containing slots 5 ft long were bolted to the top of the duct.

Three types of obstruction were used, strips, orifice plates and duct fittings. These obstructions when under test were always fixed between the second and third section of ducting, i.e. in the middle of the duct. Fig.1 gives details of the design and method of insertion of the orifice plate and strip obstacles. Two duct fittings were tested, a T and an elbow. Both of these are shown in Fig.2. When these fittings were inserted in the duct the total duct length was somewhat greater than 24 ft. These fittings were designed in a way which allowed the top side of the fitting to be replaced with a cover containing a slot vent.

Vents

The main object of the work was to compare different systems of venting the duct and to define those systems which would allow the maximum pressure during explosions to be reduced to 1-2 lb/sq.in. There was a limitation in the design of the vent systems in that in no test could the maximum pressure be allowed to rise above 10 lb/sq.in. since this was the maximum pressure for which the duct system was designed. It was apparent from earlier work that a substantial amount of venting along the top of the duct would be required to achieve even the latter object and that this venting would have to be well distributed along the whole duct length. It had also been found in earlier work with ducts not containing an obstruction, that vents in the form of a slot along the whole length of the duct were more efficient than the same area of vents placed at intervals along the duct. From these considerations two main methods of inserting venting space into the duct were tested. In the first, four rectangular vents measuring either 12 x 12 in. or 12 x 8 in. were inserted at 6 ft intervals along the top of the duct, the edge of the first vent being a distance of 6 in. from the closed end of the duct. In the second, the vents were present as slots 5 ft long along the top of each 6 ft section of the duct. Three widths of slots were used, 2.4 in., 1.6 in. and 0.8 in. corresponding to the venting area of 1 sq.ft, $\frac{2}{3}$ sq.ft and $\frac{1}{3}$ sq.ft for each 6 ft length of the duct. In most tests one end of the duct was completely open and provided an extra vent, although in a few tests this end was either half or three quarters closed by means of a plate containing a central square edged orifice of the required size.

Vent closures

To obtain a measure of the inherent efficiency of vents of different sizes and shapes, it is desirable to carry out tests with the vents completely open; this has been done in most of the tests described in previous reports. It was not possible, however, to follow this practice in the present instance because of the large number of relief vents that were used. For this reason in the series of experiments in which the different vent systems were compared, the vents along the top of the duct were covered with a loose cover weighting 250 g/sq.ft of vent area. Previous experiments had indicated that the presence of a cover of this type did not increase the maximum pressure reached in the explosion. A cover of the type described, however, cannot be regarded as a practical way of closing a vent and for this reason two methods of closing vents which could be employed in practice were also investigated. The first was to use closures made from polythene film either .0010 or .0015 in. thick, the film being held between two compressed soft rubber foam gaskets. This method of closure was tested for both the rectangular and slot vents; Fig.3 shows the method of clamping the film when using the slot vent. The second method was to use a cover clamped to the duct by means of magnets. This method was used only for the 12 in^2 rectangular vents and Fig.4 gives details of the method of construction of the vent and the cover held by magnets. The cover was made from resinated paper honeycomb, either $\frac{1}{2}$ in. or 1 in. thick, covered with Bristol board. Each cover was held by 8 magnets against a soft plastic foam gasket attached to the duct. The total force of the magnets acting on the cover was 21 lb weight, the weight of each cover was only 270 or 340 grms according to the thickness of paper honeycomb used in the construction. Fig.5 shows a picture of a duct with these covers taken during an explosion.

A few experiments were also carried out in a specially made duct consisting entirely of polythene .0010 in. thick. In these experiments the whole of the side of the duct could be considered as acting as a relief vent covered with polythene. Fig.6 shows pictures of this duct before and during an explosion.

In all experiments the vent in the end of the duct was open at the moment of ignition.

Experimental Programme

Experiments were carried out with all the strips and orifices as obstructions and with all the arrangements of the slot and rectangular vents using the loose covers to simulate conditions of open vents. The experiments carried out with duct fittings, and with vents using polythene or magnetically held closures, were not so extensive but were sufficient to allow a quantitative comparison with the main group of tests.

In all experiments a 5 per cent propane/air mixture was used and the duct was filled by displacement of the air present. The pressure in the explosion was measured at a point 6 in. downstream of the obstacle by means of a capacity gauge and the flame speed by a series of ionization gaps. In previous experiments the gas had generally been ignited at a point 6 in. from the closed end of the duct. This practice was followed in the present experiments for most of the tests in which slot vents were used. When the rectangular vents are being used this point of ignition was very close to the first vent, and a much less violent explosion would have occurred than if igntion had taken place between a pair of relief vents. For this reason, with rectangular vents, the gas was ignited at a point either 3 ft or 9 ft from the closed end of the ducts. Moreover, for purposes of making a comparison between slot vents and rectangular vents, some experiments were also carried out when slot vents were used with ignition 9 ft from the closed end of the duct.

Results

The maximum pressures and flame speeds reached in those tests, in which the end of the duct was fully open, are given in Tables 1 and 2, each figure given being a mean value obtained from at least two tests.

Table 1 shows that for a given venting system the maximum pressure developed in the explosion increased as the area blocked by either strips or orifice plates increased upt to a value of half the cross-sectional area of the duct. In some cases the maximum pressure was less when 108 sq.in. of the duct was blocked by an orifice plate than when 72 sq.in. was blocked in the same way. This suggests that for a given venting system there is an optimum amount of blockage that gives the highest maximum pressure.

In comparing the results for different venting systems in Table 2 the following points may be noted.

1. For a given area of venting, slot vents with loose covers generally gave lower maximum pressures than rectangular vents with loose covers (compare series 2 and 11, 6 and 14). However, in one case in which an orifice blocking 108 sq.in. of the duct was used, slot vents gave a higher maximum pressure than the rectangular vents. (Series 1 and 10).

2. For rectangular vents with loose covers ignition 9 ft from the closed end, i.e. 3 ft from the obstacle, gave higher maximum pressures than ignition 3 ft from the closed end (compare series 10 and 11), whereas with slot vents with loose covers ignition 9 ft from the closed end gave the same or lower pressures, (compare series 1 and 2).

3. When polythene was used to cover the vents a higher maximum pressure was obtained than with loose covers, although in most cases the maximum pressures were still less than 2 lb/sq.in. The increase in maximum pressure brought about by the polythene was greater for slot vents than for rectangular vents (compare series 1, 2, 3 and 4 with 10, 11, 12 and 13).

4. For a given venting system and obstacle the maximum pressure was approximately directly proportional to the thickness of polythene used to cover the relief vents (compare series 3 and 5).

5. When covers clamped with magnets were used to close the vents the maximum pressure was again higher than when loose covers were used (compare 10, 11, 15 and 16). The increase was not as great as was obtained when polythene was used (compare 12 and 13 with 15 and 16).

6. For both slot vents and rectangular vents, using both polythene and magnetic covers, the maximum pressure was greater when ignition took place 3 ft from the obstacle than when it took place at a more remote point. (Compare series 3 and 4, 12 and 13, 15 and 16).

7. With magnetic covers the maximum pressure was slightly higher with the heavier cover weighing 340 g than with the lighter cover weighing 270 g (compare series 15 and 17).

8. For any given type of vent and vent closure the maximum pressure increased

as the area of vent available increased. Thus for slot vents covered with polythene, for example, and with an orifice plate blocking 42 sq.in. of the cross section of the duct, the maximum pressure was 2.6, 1.56 and 1.18 lb/sq.in. for slot widths of 0.8, 1.6 and 2.4 in. respectively, and also the maximum pressure was less than 0.1 lb/sq.in. when the whole duct was constructed from polythene (series 17).

9. When a T piece was placed in the duct in such a way that the flames proceeding from the igntion source were smoothly deflected into the arm of the T, the maximum pressures obtained were similar to those obtained when 26 sq.in. of the duct was blocked by an orifice plate. A smooth bend in itself caused a similar effect (series 8). When the T piece was reversed such that the flames proceeding from the ignition source had to be deflected round a very sharp angle before proceeding to the open end of the duct, then the maximum pressure obtained was between 3 and 4 times greater (series 15).

With very few exceptions the maximum flame speeds occurred after the flame had passed the obstacle or was in the second half of the duct. Table 2 shows that these flame speeds were substantially higher when polythene was used to cover the vents than when light covers were used. There was also an increase when magnetic covers were used but this increase was not so great as with polythene (compare series 10 and 15).

Table 3 shows the effect of reducing the size of the end vent in the duct from 1 sq.ft to 0.25 sq.ft. This table shows that the maximum pressure was not very much affected by reducing the size of the end vent, although flame speeds were reduced.

Discussion

The performance of different vent systems varied considerably with the geometrical distribution of the vents and the nature of the vent closures. Nevertheless, maximum pressures in the explosions did not exceed values of 2 lb/sq.in. under most conditions. The exceptions occurred in tests with substantial obstructions in the duct and with magnetic covers or polythene closures to the vents, when pressures higher than 2 lb/sq.in. were obtained if the gas was ignited near the obstacle. The reason for this is that there was insufficient time for any vent to open effectively before the flame reached the obstacle.

In the tests with light covers, the slot vents were superior to rectangular vents. This was no doubt due to the availability of a certain amount of venting area at a point close to the ignition source. However, when the vents were covered with polythene, the situation was reversed and a lower pressure was obtained with the rectangular vents than with the slot vents. The initial bursting of the polythene was due both to direct heating by the flame and the pressure rise in the explosion; the polythene was first softened by the heat of the flame, until a point was reached at which it could not withstand the pressure which had been developed simultaneously. The bursting pressure of the polythene in the form of a slot was several times greater than the bursting pressure when in the form of a square vent. This difference more than outweighed the intrinsic efficiency of slot vents as compared with square vents and accounts for the reversal in performance noted above.

Practical applications

Although the maximum pressure obtained with a given vent system may be the most important aspect in the choice of a given venting system in practice it is not the only one. Other factors which depend very much on the structure and function of a duct system concerned also have to be considered.

Polythene closures cannot be used with ducts which conduct gases at high temperatures. They may not also withstand abrasive action of dusts that might be contained in the gas. Polythene is also susceptible to mechanical damage, although in this connection slot vents would probably be easier to protect than square vents. In addition to this vents covered with polythene appear to cause a discharge of a high velocity stream of combustion products at the moment when the first relief vents open. On the other hand it would be expected that the bulk of the relief vents behind a flame will open even if the pressure is very low, since the hot combustion products could, in themselves, melt the polythene.

Magnetically held closures can be made robust and can be made to withstand higher temperatures than polythene closures. It is possible, however, that if a long length of duct precedes an obstacle and ignition takes place at a point remote from the obstacle, vents may be removed near the source of ignition but not necessarily near the obstacle, since the rise in pressure may be insufficient. The flame may, therefore, accelerate as it approaches the obstacle and give a substantial rise of pressure as it passes the obstacle which might not be accommodated by the opening of vents nearby.

Whatever method is used for closing the vents it is necessary that the vents are opened at a very early stage in the explosion and, if possible, before the flame has travelled more than 3 ft. This implies that if the vent is opened by pressure then the cover should be removed before the pressure exceeds about $\frac{1}{3}$ lb/sq.in. If it is removed by melting, this should have occurred before the flame has been in contact with the melting diaphragm for 1/50 second. Even under these conditions it may not be possible to keep maximum pressures down to below 2 lb/sq.in. if ignition takes place at a point near an obstacle. For this reason, portions of a duct near an obstacle may require special strengthening.

It will be difficult to apply either of the above closures to ducts working at very high temperatures. Under these conditions the swinging door closure may be more suitable. However, this suffers from the disadvantage that it would require a comparatively heavy door to make the vent airtight and the inertia to which this would give rise may seriously affect its performance in an explosion. This point requires investigation.

Acknowledgment

Mr. M. Harris assisted in the tests.

Reference

(1) F.R. Notes in preparation.

TABLE 1

MAXIMUM PRESSURES OBTAINED WITH VARIOUS VENT SYSTEMS

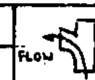
	Vent System and Vent Area Ft^2 in 6 Ft Length of Duct	Vent Closure	Ignition Ft from Closed end	No Obstruction	NATURE OF OBSTRUCTION									
					Strips Area in^2			Orifice Plates Area Blocked in^2						
					6.5	13	26	26	42	72	108			
1	Slots 1	Covers	.5	< 0.1	<0.1	<0.1	<0.1	<0.1	<0.1	.11	.32	<0.1	-	-
2	"	"	9	< 0.1	<0.1	<0.1	.12	<0.1	<0.1	.11	.11	-	-	-
3	"	Polythene .001 in.	.5	.60	.50	1.05	1.26	.50	1.18	1.79	1.76	1.03	-	-
4	"	"	9	-	-	-	-	.79	1.79	7.2	-	.83	-	-
5	"	Polythene .0015 in.	.5	.92	.63	1.62	1.96	.75	2.09	-	-	-	-	-
6	Slots $\frac{2}{3}$	Covers	.5	< 0.1	<0.1	<0.1	.10	<0.1	<0.1	.19	-	0.1	-	-
7	"	Polythene .001 in.	.5	.70	.65	1.59	1.81	.64	1.56	2.70	-	-	-	-
8	Slots $\frac{1}{3}$	Covers	.5	-	<0.1	.13	.27	<0.1	.29	.81	.84	.13	.10	-
9	"	Polythene .001 in.	.5	.70	.78	1.59	-	1.29	≏ 2.6	-	-	-	-	-
10	Square 1	Covers	3	< 0.1	<0.1	<0.1	0.1	<0.1	<0.1	.11	.16	-	-	-
11	"	"	9	< 0.1	<0.1	.18	.34	<0.1	.18	.29	.35	-	-	-
12 12	" "	Polythene .001 in.	3	.31	-	-	.50	.28	.36	-	-	-	-	-
13	"	"	9	.35	.26	.56	.96	.50	.76	2.40	2.50	-	-	-
14	Rectangular $\frac{2}{3}$	Covers	9	-	<0.1	.23	.61	.17	.46	.77	.55	-	-	-
15	Square 1	Covers Magnetic Weight 270g	3	.10	-	-	-	.13	.21	.27	-	.10	-	.38
16	Square 1	" " Weight 340g	3	-	-	-	-	-	.25	.43	-	-	-	-
17	Square 1	" " Weight 270g	9	< 0.1	-	-	-	-	-	1.94	-	.13	-	-
18	Duct constructed from .001 in. thick Polythene		.5	< 0.1	-	-	-	-	<0.1	-	-	-	-	-

TABLE 2

MAXIMUM FLAME SPEEDS WITH VARIOUS VENT SYSTEMS

	Vent System and Vent Area Ft^2 in 6 Ft Length of Duct	Vent Closure	Ignition Ft from Closed end	No Obstruction	NATURE OF OBSTRUCTION									
					Strips Area In^2			Orifice Plates Area Blocked in^2						
					6.5	13	26	26	42	72	108			
1	Slots 1	Covers	0.5	65*	61*	75	113	50*	46*	37	114	83	-	-
2	"	"	9	36	45	41	41	42	62	58	42	-	-	-
3	"	Polythene 0.001 in.	0.5	289	200	343	296	233	250	272	232	335	-	-
4	"	"	9	-	-	-	-	298	221	363	-	272	-	-
5	"	Polythene 0.0015 in.	0.5	284	214	373	346	385	281	-	-	-	-	-
6	Slots ⅔	Covers	0.5	50	57	52	54		61	107	-	99	-	-
7	"	Polythene 0.001 in.	0.5	204	274	241	244	226	266	355	-	-	-	-
8	Slots ⅓	Covers	0.5	247	82	90	145	77	133	182	224	117	115	-
9	"	Polythene 0.001 in.	0.5	-	238	292	-	352	305	-	-	-	-	-
10	Square 1	Covers	3	390	39	45	44	32	45	57	68	-	-	-
11	"	"	9	41	36	39	44	38	39	77	83	-	-	-
12	"	Polythene 0.001 in.	3	158	-	-	169	168	175	-	-	-	-	-
13	"	"	9	125	139	139	114	122	117	159	280	-	-	-
14	Rectangular ⅔	Covers	9	-	47	44	56	46	54	103	104	-	-	-
15	Square 1	Covers Magnetic Weight 270g	3	-	-	-	-	88	88	105	-	198	-	168
16	Square 1	Covers Magnetic Weight 340g	3	-	-	-	-	-	80	151	-	-	-	-
17	Square 1	Covers Magnetic Weight 270g	9	-	-	-	-	-	-	153	-	102	-	-

*IN THESE TESTS MAXIMUM SPEED OCCURRED BEFORE THE FLAME REACHED OBSTACLE.

TABLE 3

Effect of Restricting the Open End of Duct

Slot vents 1 sq.ft of vent area for 6 ft lengths of the duct

Ignition - 0.5 ft from closed end

End Vent Per cent Area Open	Vent Closure	Obstacle Area Blocked in^2	Flame Speed before Obstacle Ft sec^{-1}	Maximum Flame Speed after Obstacle Ft sec^{-1}	Maximum Pressure Lb in^2
100	Polythene .001	None	83	289	.6
25	Polythene .001	None	19	17	.6
100	Covers	Strip 6.5	61	52	<.1
50	Covers	Strip 6.5	50	74	<.1
100	Polythene .001	Strip 6.5	95	200	.50
50	Polythene .001	Strip 6.5	60	61	.51
100	Polythene .0015	Strip 6.5	101	214	.63
50	Polythene .0015	Strip 6.5	57	65	.7
100	Covers	Orifice 108	53	114	.32
50	Covers	Orifice 108	24	101	.25

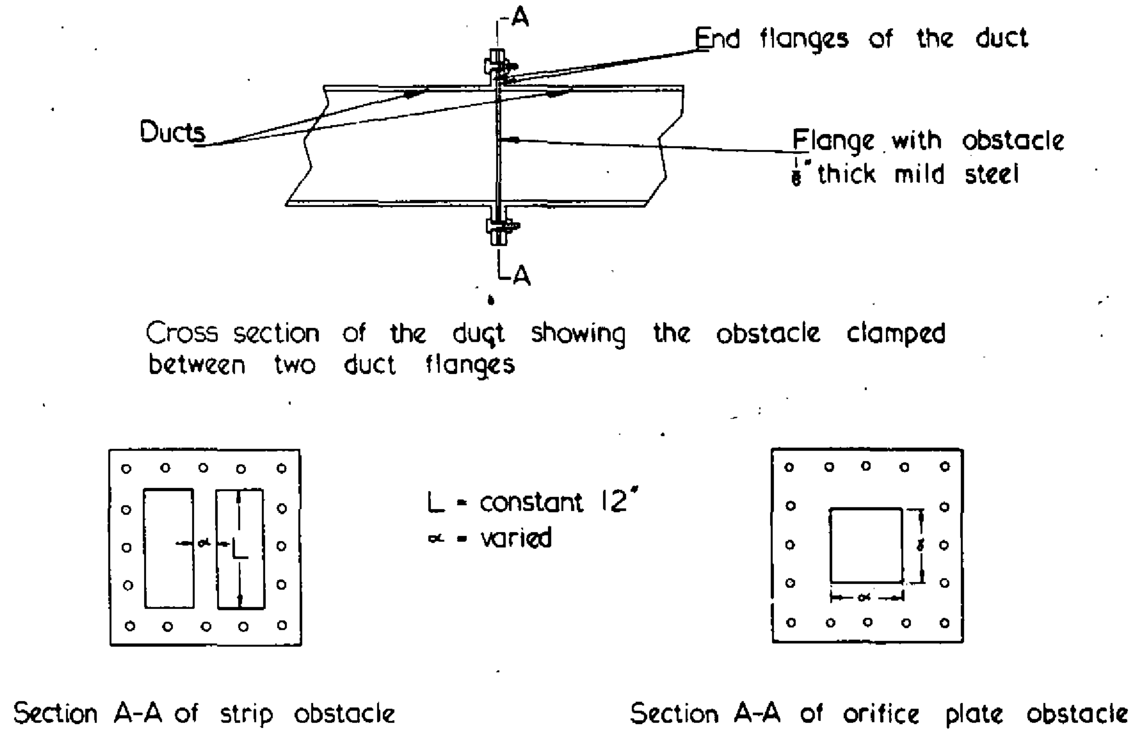


FIG. 1. DESIGN AND METHOD OF INSERTION OF THE ORIFICE PLATE AND STRIP OBSTACLES

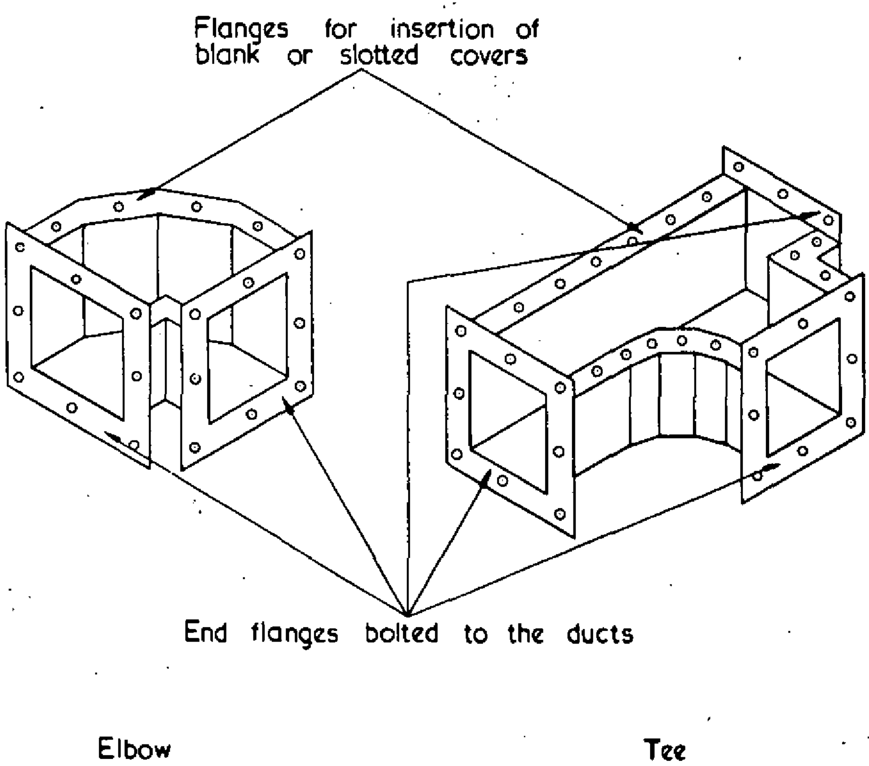


FIG. 2. FITTINGS

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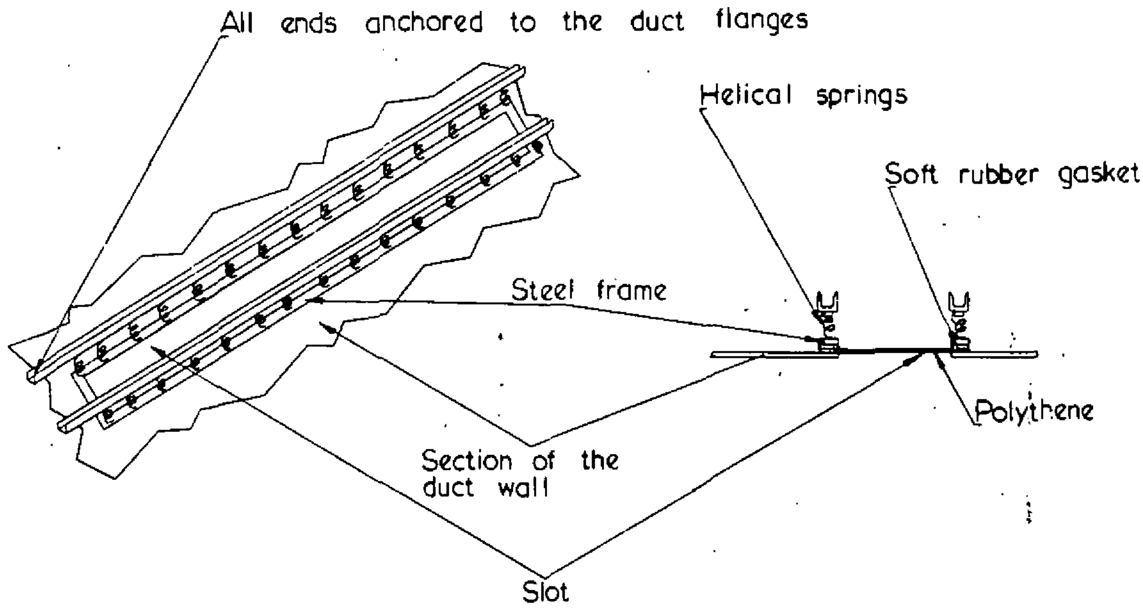


FIG. 3. METHOD OF CLAMPING POLYTHENE FILM

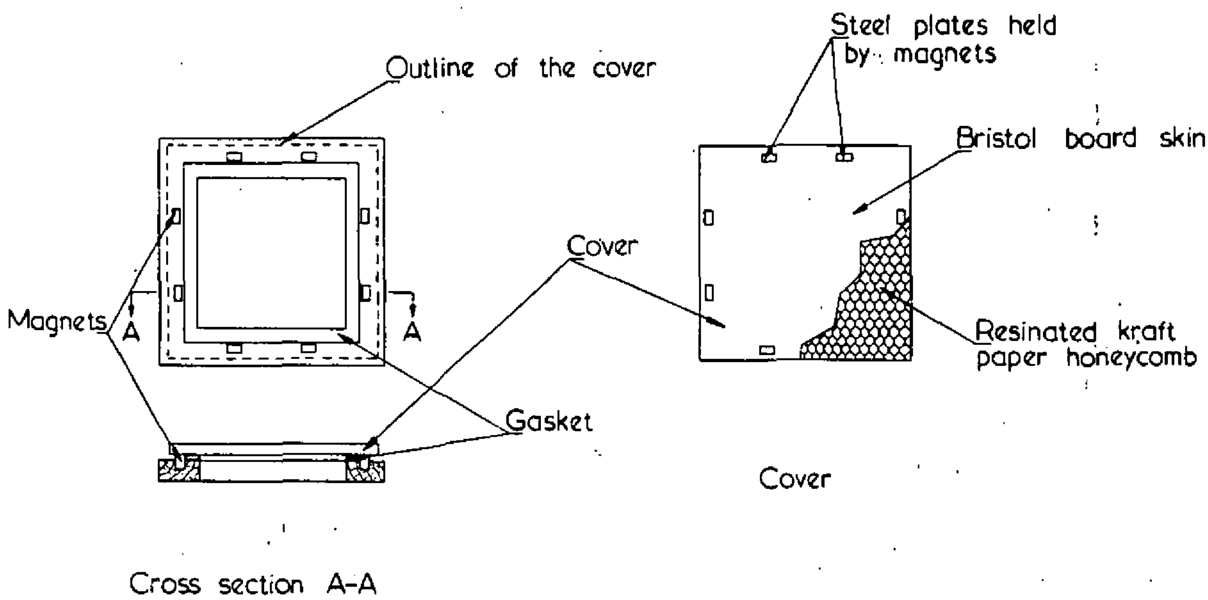
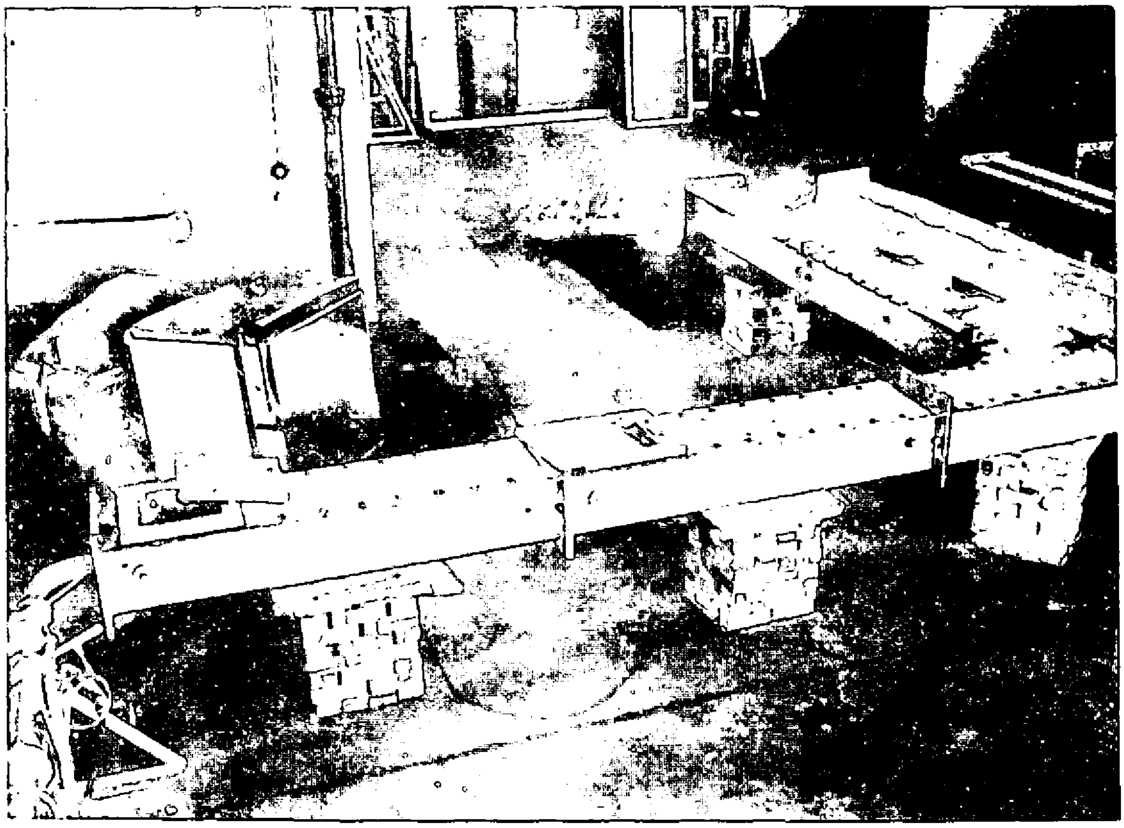
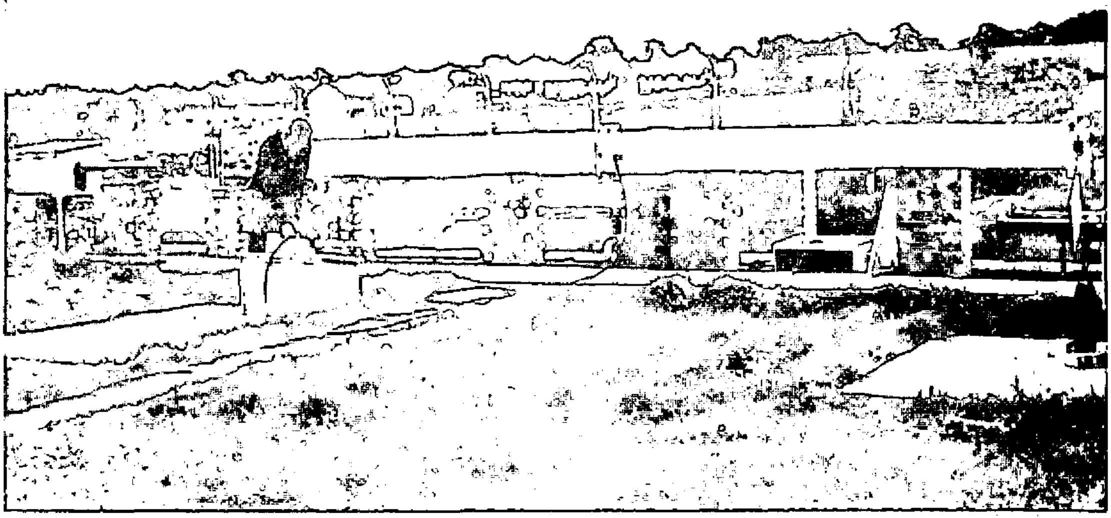


FIG. 4. MAGNETICALLY HELD VENT CLOSURE

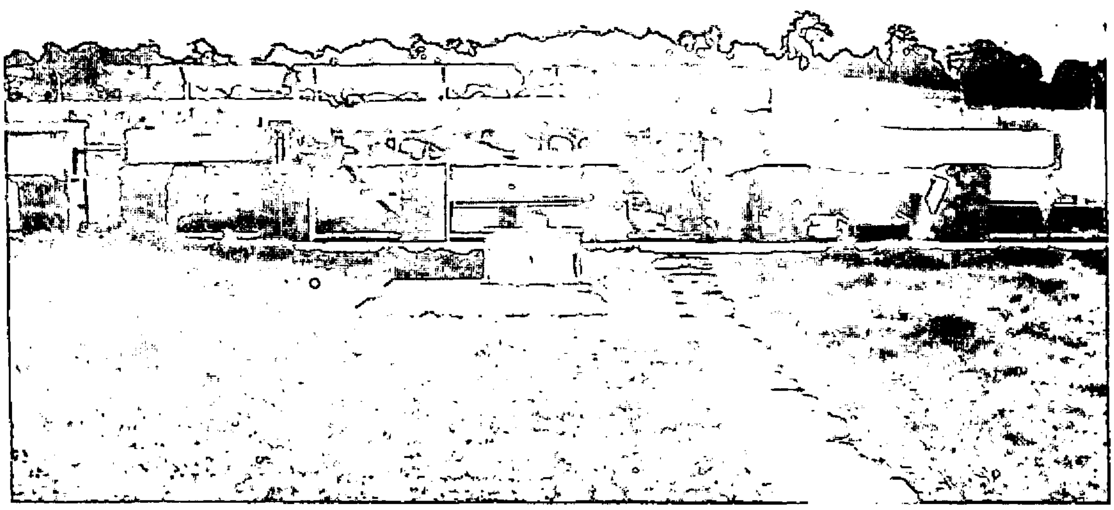


DUCT FITTED WITH VENTS CLAMPED BY MEANS OF MAGNETS

FIG.5.



DUCT BEFORE EXPLOSION



DUCT DURING EXPLOSION

DUCT CONSISTING OF POLYTHENE ·0010 IN. THICK

FIG.6.