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QUARTERLY PROGRESS REPORT NO. 5

DETONATIVE COMBUSTION

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By

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FOREWORD

The work reported herein is a continuation of the work on detonative combustion by the Aircraft Propulsion Laboratory of the University of Michigan. This research is conducted under Army Air Force contract W33-038-12657 (University of Michigan Project M898).

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DETONATIVE COMBUSTION

INTRODUCTION

As discussed in Progress Report No. 4, an extensive photographic study of detonation waves is being undertaken to further the understanding of the phenomenon. Also, tests will be made to determine the effects of pressure on detonation and the limits of detonation.

Accordingly, a larger schlieren system has been designed and fabricated which affords much more utility and rigidity than the previous system.* This optical system is now in operation and has been used in conjunction with the 3/8-inch by 1/2-inch shock tube to obtain some photographs of hydrogen-oxygen detonations.

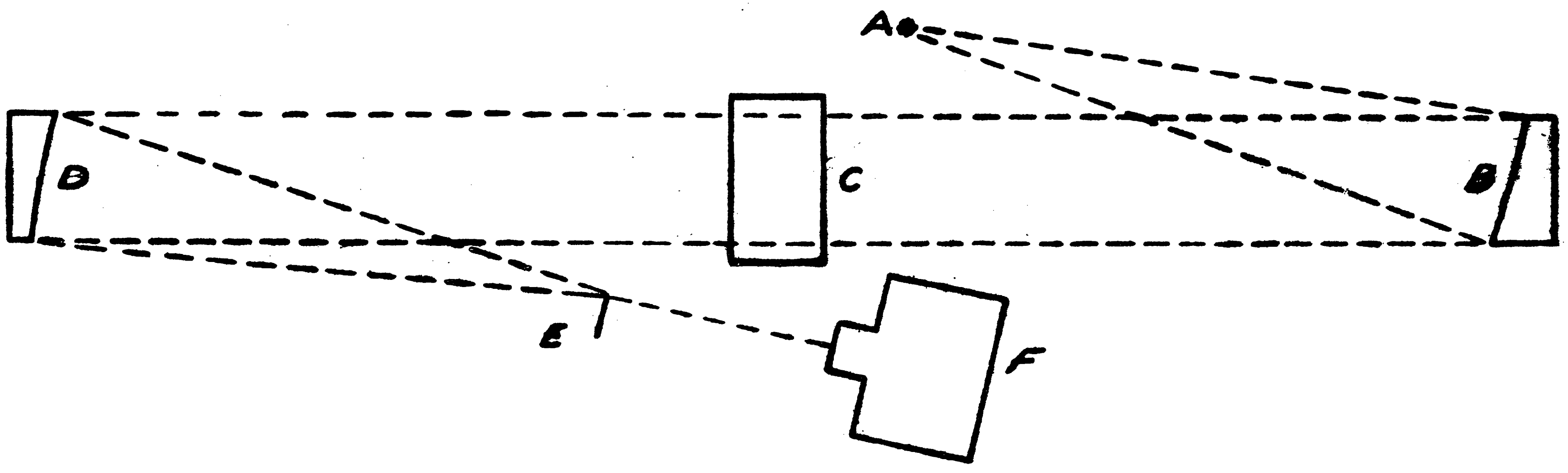
The 1/2-inch diameter shock tube has been set up in the Propulsion Laboratory of the Aeronautical Engineering Department and will be used to study the effects of pressure on detonation. No experimental results have been obtained on this phase as yet.

The larger shock tube, 2-1/4 inch by 3-1/4 inch, is near completion and will be placed in operation within the next few weeks.

PARABOLIC-MIRROR SCHLIEREN SYSTEM

A two-parabolic-mirror schlieren system has been designed and fabricated and is now in operation. The optical arrangement is shown in Fig. 1. The light source is at the focal point of mirror B and somewhat removed from the collimated light path. Mirror B is parabolic and has an

* Morrison, R. B., "A Shock Tube Investigation of Detonative Combustion," University of Michigan, UMM-97, January, 1952.



A - SPARK-GAP LIGHT SOURCE
B - PARABOLIC MIRROR
C - SHOCK TUBE
D - PARABOLIC MIRROR
E - KNIFE EDGE
F - CAMERA

FIG. 1 - PARABOLIC-MIRROR SCHLIEREN SYSTEM

f-number of 5.3 with a focal length of 38.5 inches. It is located as near to the shock tube as optical and physical dimensions permit. The letter C represents the shock tube which, to date, has been the 3/8-inch by 1/2-inch tube. Parabolic mirror D has an f-number of 12 with a focal length of 72 inches. It is located at a distance of twice its focal length from the shock tube. The camera, F, is an 8 inch by 10 inch Eastman View Camera No. 2-D with the lens board removed. It is mounted directly above the shock tube and thus gives actual-size photographs.

Figure 2 is a photograph of one of the mirror stands. The cast-aluminum base is fitted with casters as well as three-pointed threaded 1/2-inch bolts. Once the stands are located in approximate position the bolts are turned down so as to raise the stand off of the casters and give rigid three-point support. The elevation of the mirror can be adjusted to a finer degree by means of the threaded shaft shown. The pitch and yaw adjustments of the mirror are accomplished by three ball-and-socket joints mounted on the mirror housing. The joints are connected by 1/4-inch threaded bolts through a back plate. Adjustment of the lock nuts on the bolts then allows the control desired.

Figure 3 is a photograph of the schlieren knife-edge assembly. This unit is actually part of the 8-inch Mach-Zehnder interferometer, but is not required in the present interferometer studies. The knife edge can be turned through 360° with stops at every 90°. There are micrometer adjustments for translation along the light path as well as for the positioning of the knife edge perpendicular to the light path. Adjustment of the elevation of the assembly is accomplished in the same manner as for the mirror stands. The knife edge is located at one focal length from mirror D.

SPARK-GAP LIGHT SOURCE

In photographing these detonation waves an ionization probe acts as a sensor to detect the wave. The resultant electrical pulse is fed into a time-delay circuit which, after the preset delay, activates a tickler voltage to break down the main gap. A drawing of the spark gap (described in earlier reports*) is reproduced in Fig. 4 for convenience. In the past, the light was taken out through the small hole at a, which served as the apparent source. With this arrangement it was found necessary to locate a wafer of Mycalex near the grounded terminal, as shown in the drawing. The Mycalex had a small hole (No. 60 drill) in it which "guided" the spark to

* Morrison, R. B., "A Shock Tube Investigation of Detonative combustion," University of Michigan, UMM-97, January 1952.

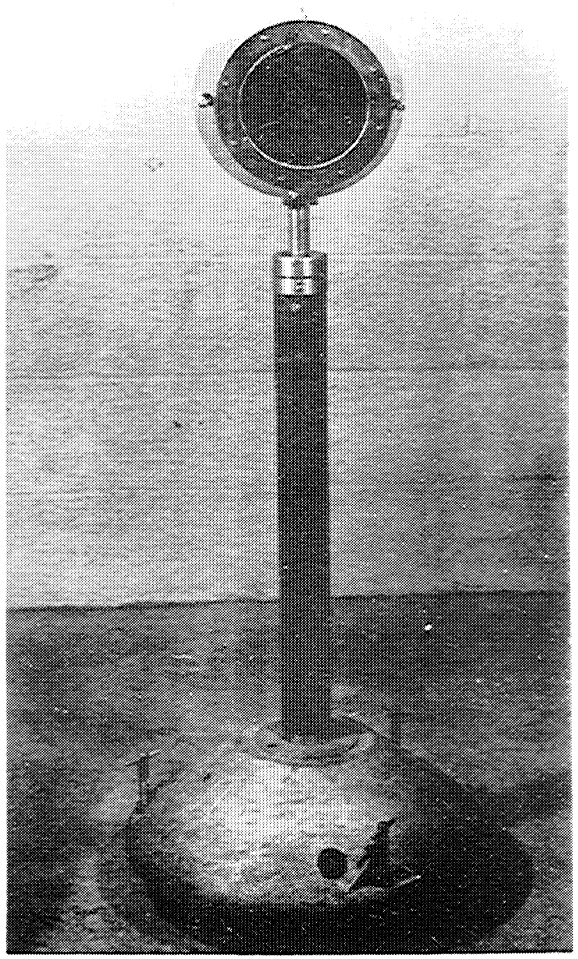


Fig. 2. Mirror Stand

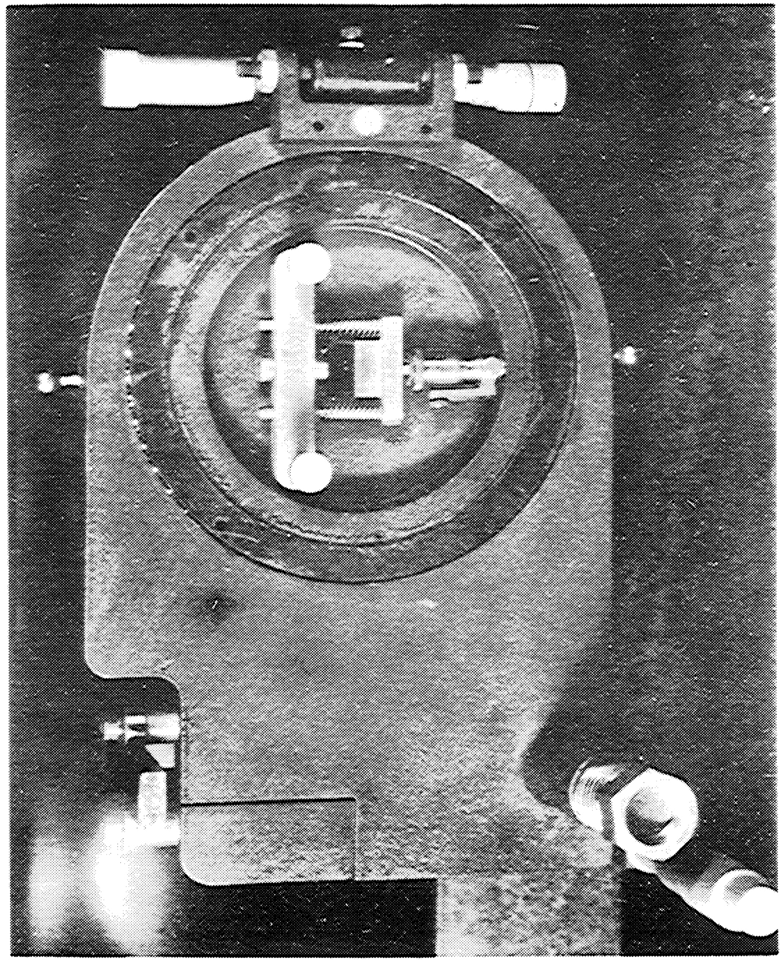


Fig. 3. Schlieren Knife-Edge Assembly

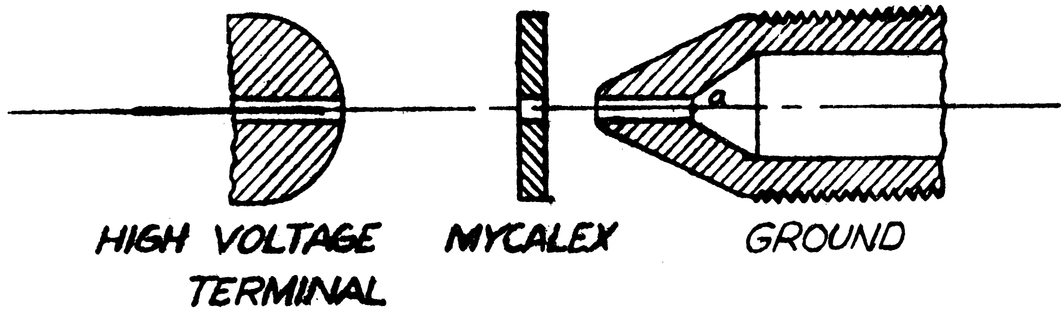


FIG. 4 - SPARK GAP

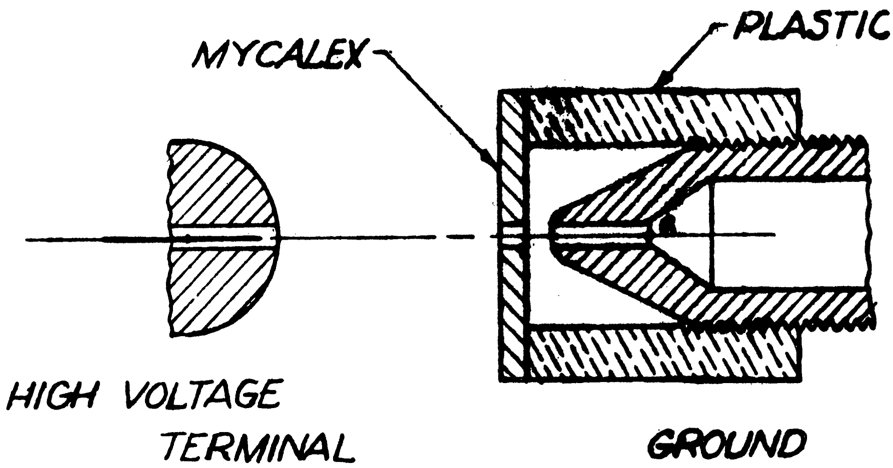


FIG. 5- MODIFIED SPARK GAP

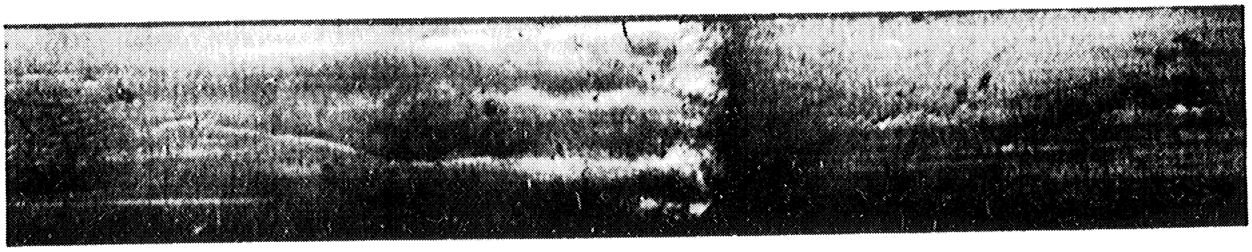
point a. The location of this wafer was quite critical and in need of constant adjustment. In connection with the new schlieren system, it was felt that this disadvantage could be circumvented and more light would be available if the light generated were taken off to the side (that is, a line source). This arrangement was tried, (with no Mycalex in the system) and proved unsatisfactory. Not only was the light marginal, but the line source was relatively thick and not reproducible. The spark would arc to different points on the terminal, thus giving varying degrees of schlieren effect on successive pictures. Consequently, the original system was restored with some modification. By making the Mycalex integral with the one terminal, as shown in Fig. 5, the tedious problem of adjustment was minimized. The light is now adequate (although not in excess) and the point source is quite reproducible. Modifications of the spark-gap terminals are in progress which should allow higher voltages for breakdown and hence more light. Currently, the Mycalex insulator is about 1/32-inch from the grounded terminal.

EXPERIMENTAL RESULTS

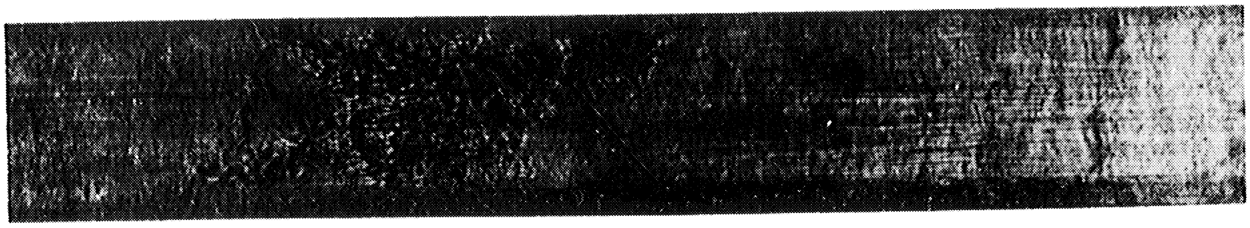
A number of spark schlieren photographs of hydrogen-oxygen detonations have been taken in conjunction with the 3/8-inch by 1/2-inch shock tube. Except for the 60% and 72% mixtures, the diaphragm material was one thickness of photographic film, which burst at approximately 400 psi. For the two exceptions it was found necessary to use a thickness of shim stock also in order to initiate detonation. This gave a bursting pressure of about 800 psi.

The film used for these photographs was Eastman-Kodak Contrast Process Ortho. This gives fine detail and is convenient from the processing standpoint. Some gain in overall lighting could probably be achieved by using a faster film, although this would be at the expense of definition. Other contemplated modifications, as mentioned earlier, should serve to alleviate this problem.

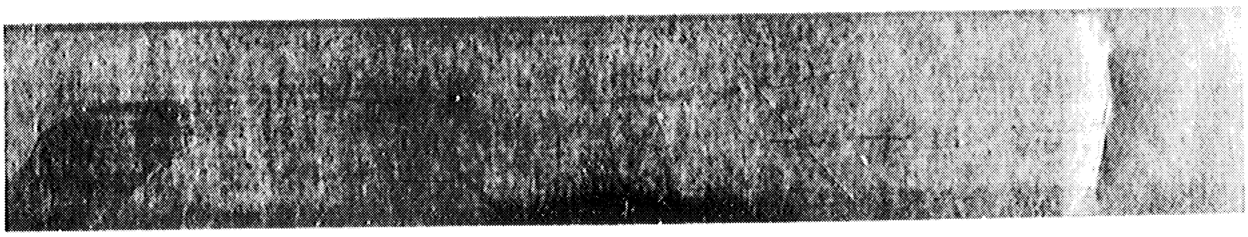
Figures 6, 7, 8, and 9 represent a series of hydrogen-oxygen detonations traversing the tube from left to right. Except for Fig. 6-A, the photographs are arranged in order of increasing hydrogen content, where the indicated mixture ratios are on a volume basis. It is interesting to note how the combustion process is distributed over an appreciable distance for the lean mixtures, but, as the mixture becomes richer, the process gradually shrinks to the case where the burning is intimately associated with the normal shock front. The transition from the relatively "clean" type of detonation to the type where the burning zone lags the shock front is seen to occur in the neighborhood of a 50% mixture.



A - 50%

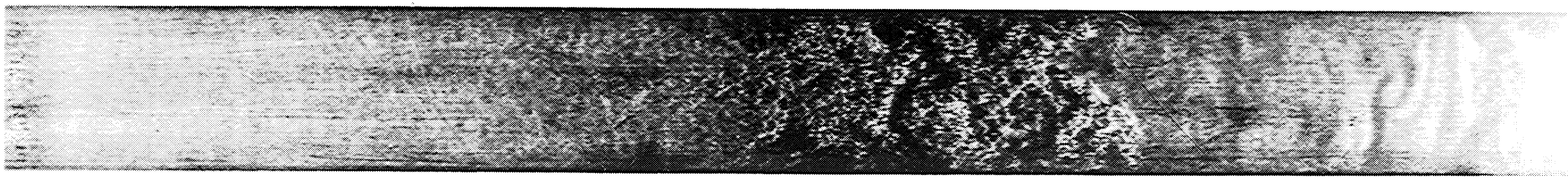


B - 15%

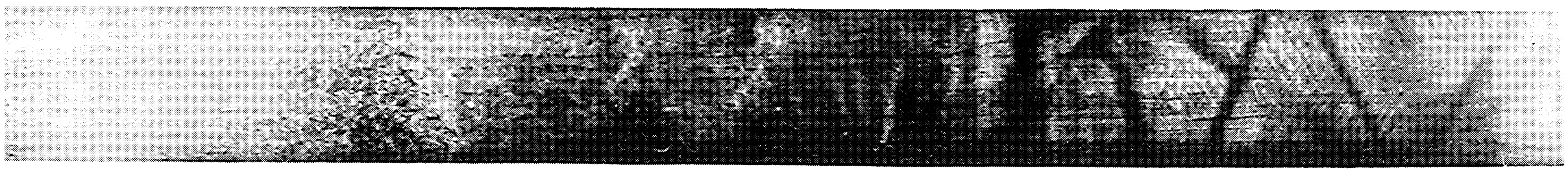


C - 15%

Fig. 6

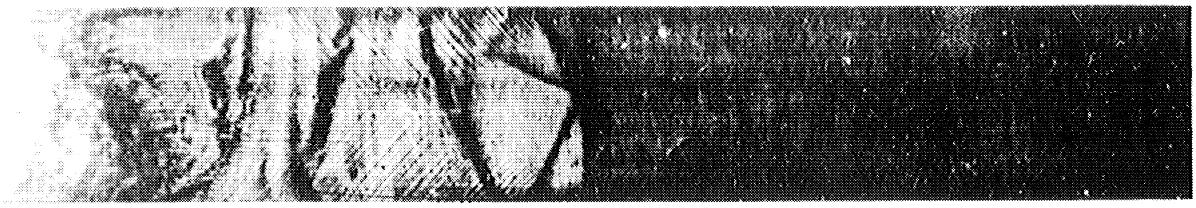


A - 17.5%

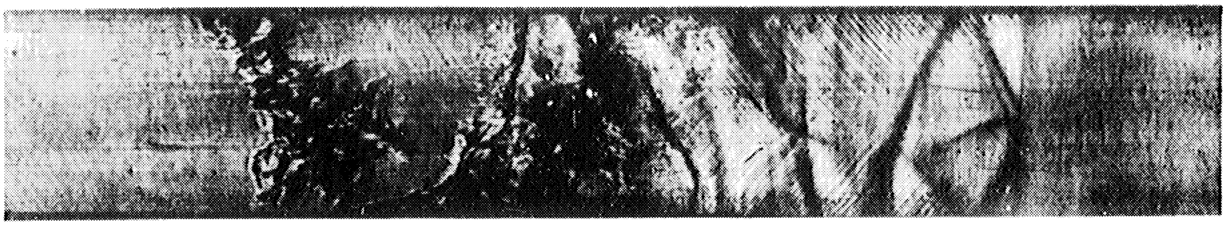


B - 19.5%

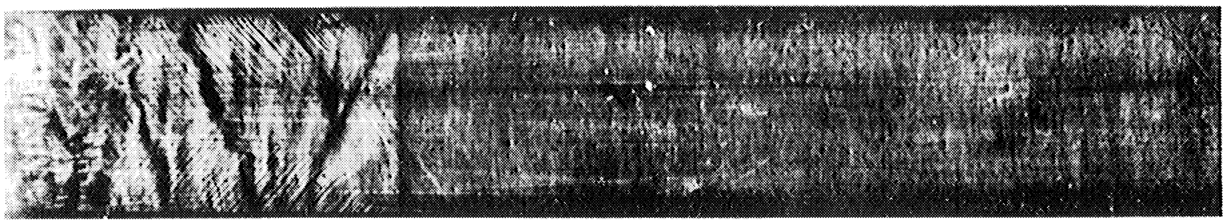
Fig. 7



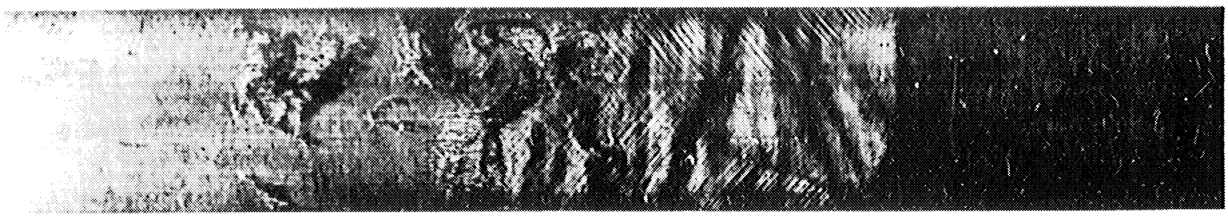
A - 24%



B - 24%

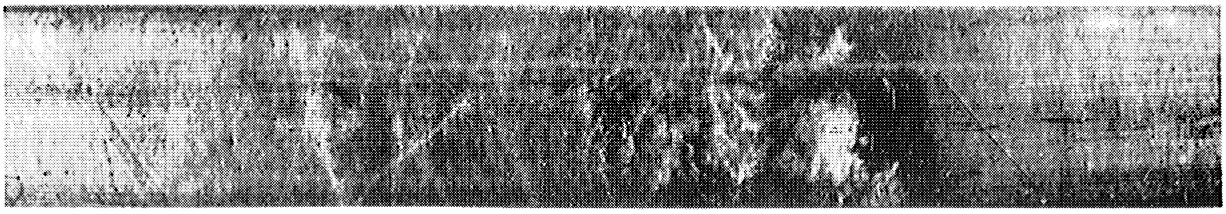


C - 31%

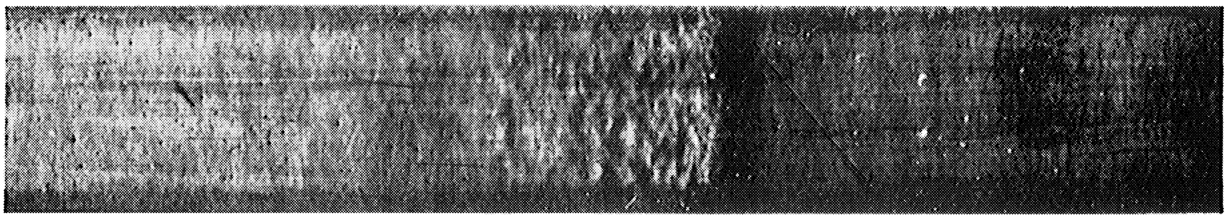


D - 40%

Fig. 8

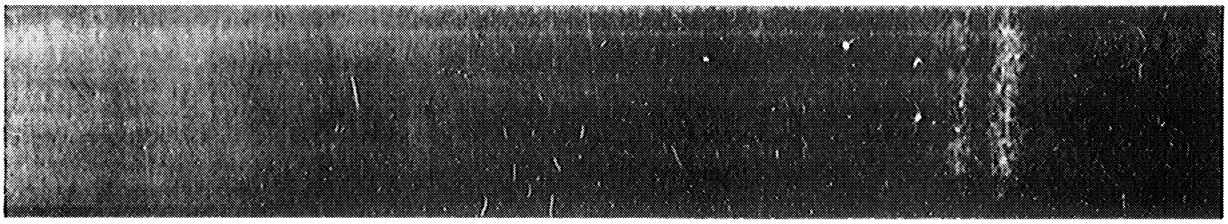


A - 50%



B - 60%

C - 72%



D - 72%

Fig. 9

In each case but the first, a vertical knife edge was used. The height of the visible phenomenon is 1/2-inch, so that the magnification on the photographs is close to two.

Figure 6-A is typical for a rich hydrogen-oxygen detonation where the knife edge is horizontal. In these cases the burning zone is evidently initiated in the initial shock front. Figure 6-B shows a 15% detonation where the shock front has already passed out of the picture to the right. It appears as though there may be a few weak shocks present on the extreme right end. The burning zone is seen to lag the front considerably. Apparently this lag increases as the mixture becomes leaner. This particular mixture is very close to the lower limit of detonation and at times was reluctant to react. For instance, Fig. 6-C shows the same mixture wherein detonation was evidently not initiated. The shape of the front is interesting in that it resembles neither the ordinary clean type of shock wave nor the type associated with detonation.

Figures 7-A and 7-B show the heterogeneous shock patterns distributed over the great lag distances for the leaner mixtures. Some of the shock pattern has evidently already passed out of the picture.

Two successive photographs of a 24% detonation are shown in Figs. 8-A and 8-B. The remarkable similarity is apparent and highly interesting. It is noteworthy that the two photographs, when superimposed with one negative turned 180° from the other, reveal practically identical patterns. Conceivably these photographs could correspond to two different phases of the phenomenon of spinning detonation. It is planned to explore this point a little further and see if different phases of a cycle can be detected.

Figure 9-D is included as a matter of interest. This is a double exposure of a 72% mixture which serves to show the reproducibility of the phenomenon as well as that of the time-delay circuit.

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