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INTERMITTENT DETONATION AS A THRUST-PRODUCING MECHANISM

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ABSTRACT

Tests were made on the pendulum detonation tube to determine the effect of spark-plug location on the impulse derived from a single detonation wave. These tests indicate a very slight effect although it is conceivable that in a cyclic detonation engine the effect could be much more pronounced.

A preliminary cyclic detonation tube was designed and assembled. The initial attempts at achieving intermittent detonation utilized hydrogen-oxygen mixtures. After the initial detonation, the fresh charge burned continuously well inside the tube. The fuel-oxygen injection system was modified in order to yield higher velocities throughout the tube. Again tests were run and the same results experienced.

Other fuels will be tested in the same tube and, if necessary, tests will be run in a glass-sided tube.

INTRODUCTION

The initial phase of this study,[1,2] was concerned with determining the influence of certain basic parameters. Toward this end, tests were conducted to measure the impulse received from a single detonation wave. This was done for a few different fuels. Some of the factors that were deemed influential in the success of such an engine were various end conditions on the detonation tube, delay in the initiation of detonation, and the effect of using a partial column of combustible gas where the detonation wave could transmit a shock wave through the inert gas. Tests were run in order to determine the effect of the above factors.

In this work period a few tests were conducted to measure the variation of impulse with spark-plug location. All of the earlier tests had utilized a spark plug at the closed end of the tube.

The tests outlined above were restricted to a single detonation wave and were in no way exhaustive. It was felt that valuable insight into the problem could be realized by noting the general trends. However, it is doubtful that these results would be realizable in an intermittent engine as the temperatures and unsteady flows would be so different. In view of the complex phenomena in a cyclic engine it was felt that it would be profitable to attempt tests on an actual intermittent engine at this time. Accordingly, two designs have been assembled and tried. Upon successful operation of such an engine, efforts will be channeled toward measuring thrust, pressure-time history, temperatures, and the effects of the parameters mentioned above, as well as others that would be readily apparent from the tests.

EFFECT OF SPARK-PLUG POSITION

So far as is known, only one person, Hoffman,[3] has ever successfully operated an intermittent detonation engine. Hoffman measured thrust for various operating conditions using acetylene-oxygen mixtures. Among the factors he found important were the distance from the fuel injection to the spark plug and the length of the diffuser beyond the spark plug. In order to obtain some evaluation of the spark-plug position, measurements were made on the impulse transmitted to the pendulum-type detonation tube by a single detonation. These results, along with a schematic of the tube, are shown in Fig. 1. It is apparent that the spark-plug location has very little effect. However, these tests were again on a single wave and there is a good possibility that the results would be entirely different in the case of cyclic detonation. It is anticipated that once an engine is successfully operated, the influence of the ignition location would be investigated.

INITIAL ATTEMPTS AT INTERMITTENT DETONATION

As mentioned earlier the philosophy of this study has been first to investigate some of the more obvious parameters that would conceivably affect the successful achievement of intermittent detonation. Realizing that the above effects could be appreciably different in an operating engine, no attempt was made to assess them too closely in a quantitative sense but mainly in a qualitative sense. Accordingly, it was deemed advisable to proceed directly toward establishing a cyclic detonation engine. It was intended that the first engine be as simple as possible in order that prime variables could be evaluated. The first design attempted is shown in Fig. 2. As seen, the detonation tube is immersed in a tank of water in order to provide cooling of the tube.

The cycle of operation is as follows. The fuel and oxidant flows are controlled by means of regulating valves which, by appropriate setting, determine the mixture ratio. Upon the establishment of flow the spark plug is energized and a detonation wave initiated. The resultant high pressures choke off the fresh gas supply and transmit a shock wave back through the inlet tubes. A check valve has been located in each of these lines in order to prevent back flow and also to weaken the shock wave.

Surge chambers were also provided to further attenuate the shocks. When the rarefaction wave which originates at the open end of the tube lowers the pressure to approximately atmospheric, the check valves open and a fresh charge is introduced. The spark is again energized and another cycle initiated. The cycle rate of the engine can be theoretically varied up to some maximum by appropriate control of the frequency of spark energization. Essentially then, the length of the column of fresh gas is controlled so that at the higher frequencies the fresh gas does not completely fill the tube. This case results in the detonation wave transmitting a shock through the burned gases of the previous cycle. This aspect was considered in the previous report[2] and might be a ready means of minimizing the fuel demands.

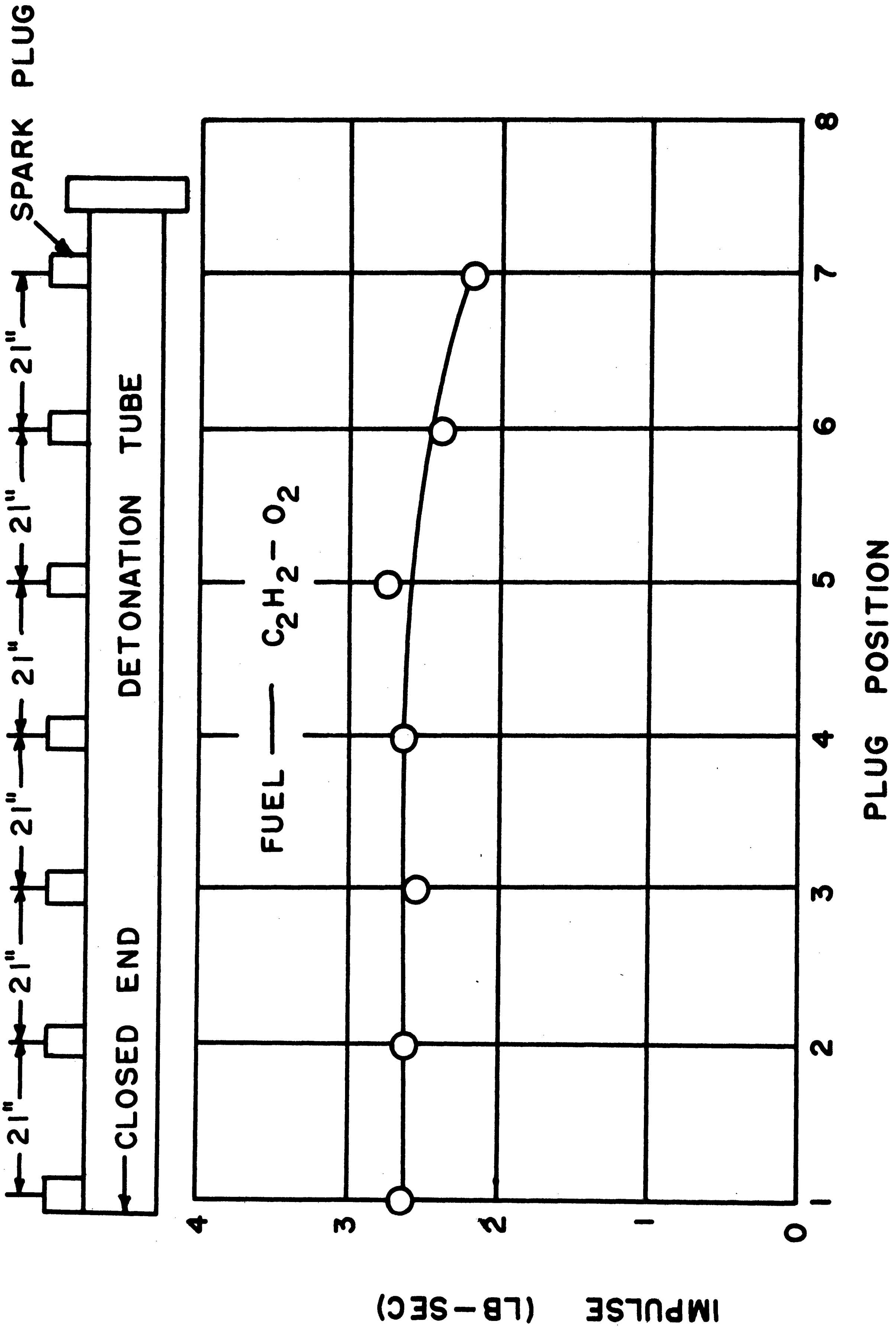

Fig. 1. Impulse vs Plug Position

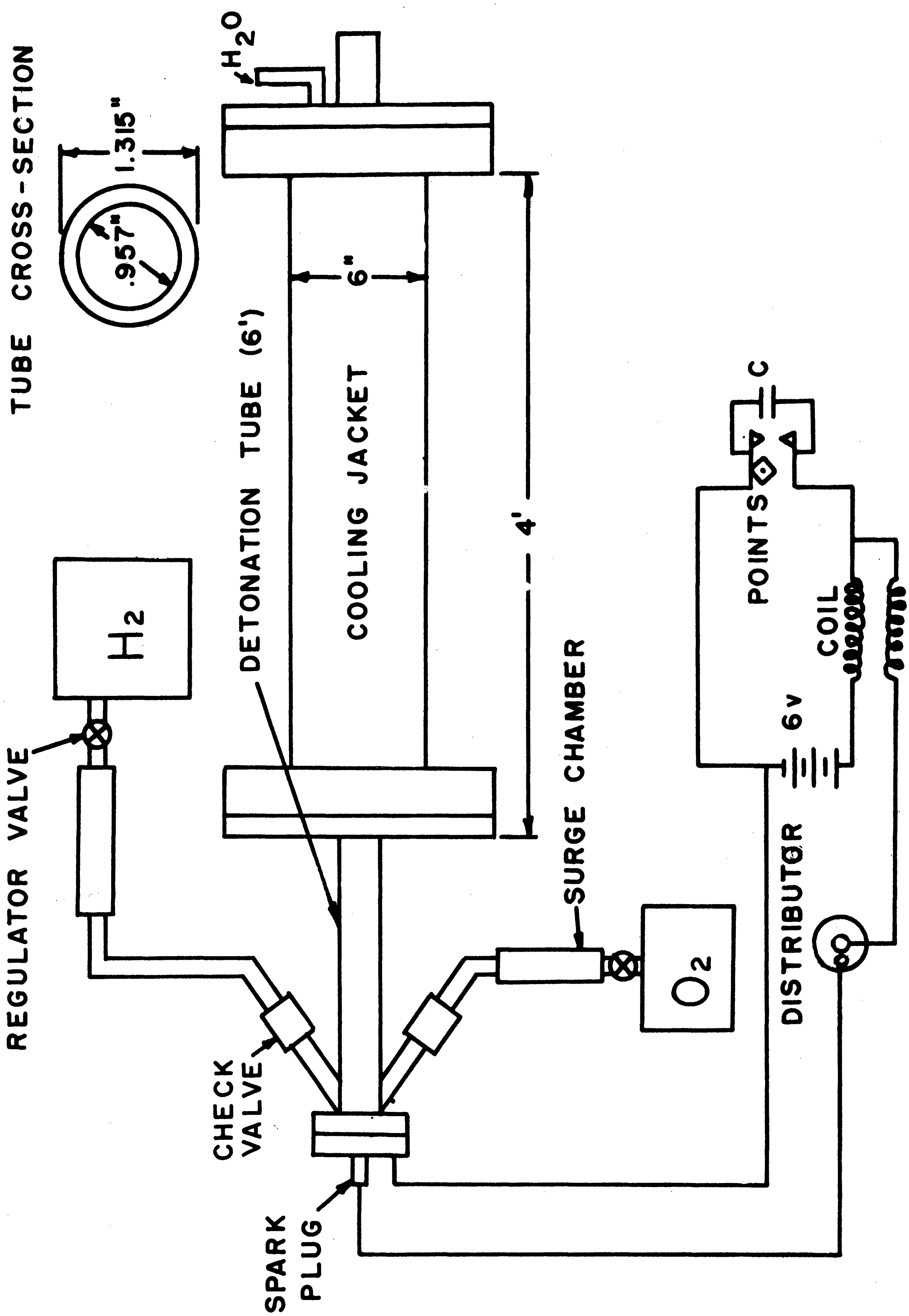

Fig. 2. Cyclic Detonation Tube

Attempts to operate this first cyclic detonation tube did not prove successful. The initial detonation was generated but then the fresh gases burned continuously and no length of unburned gas could be established. It appears somewhat unreasonable that the tube walls could become hot enough after one detonation to ignite the fresh mixture. Accordingly, it is assumed that the ignition has occurred by contact with the hot-burned gases. If the velocity of injection of the fresh gases were high enough this hot interface could be forced downstream and even out of the tube. This is probably a weakness of this initial design in that the fuel and oxygen mix too well and are essentially at zero velocity in the vicinity of the spark plug.

In view of the above difficulties it was decided to alter the fuel-injection system in order to insure that the combustible mixture was at high velocity and that no pockets of burned gas could be trapped in the vicinity of the fresh gases. The altered design is shown in Fig. 3. The area ratios were determined by assuming a mixture of 40 percent (by volume) hydrogen-oxygen and that the unburned mixture would travel down the tube at 150 feet per second. This resulted in an injection velocity of about 210 feet per second for the oxygen and about 180 for the hydrogen. The spark plug was located at 10 tube diameters downstream of the initial mixing cross section where it was felt that the mixing would be quite complete.

Velocity measurements were made on the above configuration in order to ascertain the regulated pressures required to yield the design injection velocities. These measurements indicated high losses in the charging lines but that the design conditions could be met.

The altered detonation tube was tested experimentally and met the same difficulty as the initial system. There is some doubt as to the responsible mechanism, for it is hard to conceive the flame burning at velocities in the order of 150 feet per second. Possibly the spark plug is acting as a flame holder. Tests were also run with the spark plug 2 inches and 5 inches from the initial mixing plane. Again the same results were experienced.

FUTURE PLANS

From the difficulties experienced to date, it would seem profitable to be able to attempt cyclic detonation in a glass-sided tube so that the flow phenomena could be visualized. This visualization could be either by eye or by schlieren photography. Such a tube is available at this laboratory and with little modification could be readily adapted to such a study. The high temperatures would be a problem but with runs of very short duration

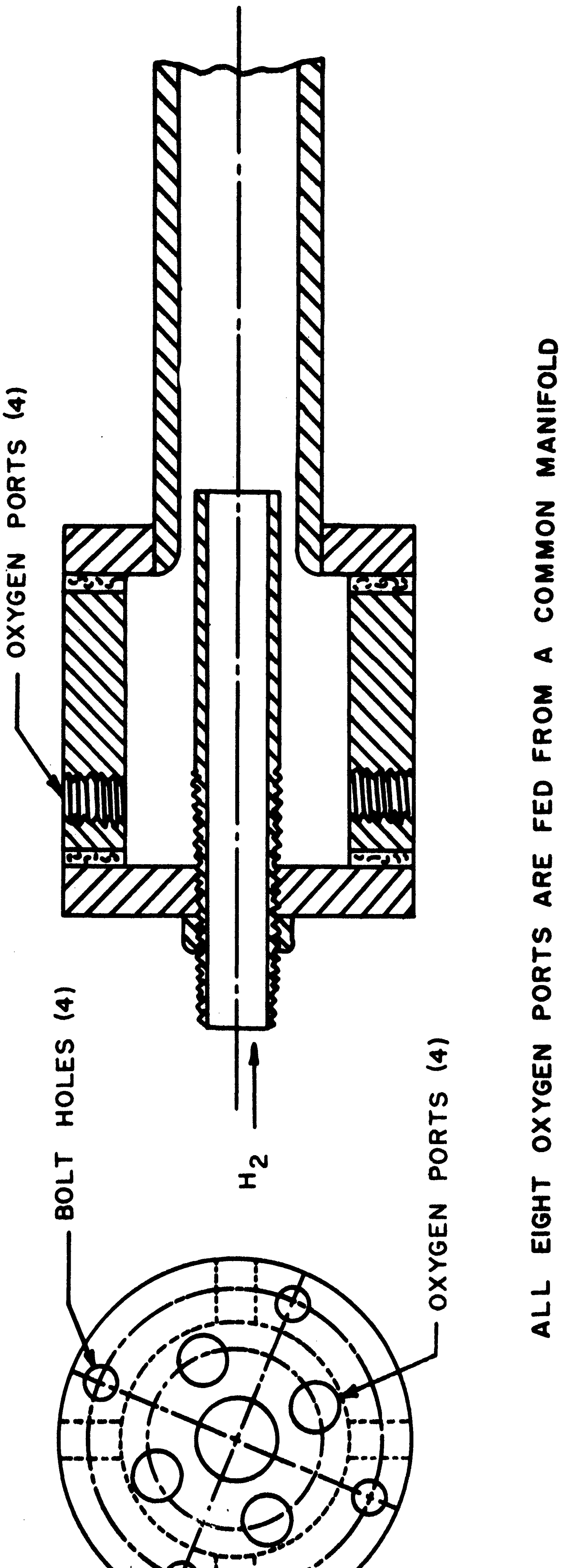

Fig. 3. Modified Cyclic Detonation Tube

this might be circumvented. Tests along these lines are planned in the near future.

Consideration will also be given to other fuels. For instance, Hoffman utilized acetylene and oxygen with water-vapor additions and managed to run an intermittent detonation engine. It is strongly felt, however, that with the correct design almost any detonable mixture should be successful.

REFERENCES

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