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INJECTION LAGS IN A COMMON-RAIL FUEL INJECTION SYSTEM

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Summary

Injection lags were determined for a common-rail fuel injection system for a compression-ignition engine. The system investigated consisted of a high-pressure reservoir, a timing valve, an injection valve tube, and an automatic injection valve. The injection lag was the time interval between the opening of the timing valve and the start of the fuel spray from the automatic injection valve. The range of the investigation included tube lengths from 10 to 70 in., tube bores from 1/16 to 5/32 in., valve opening pressures from 2000 to 5000 lb. per sq.in., injection pressures from 4000 to 10,000 lb. per sq.in., and initial pressures from 1000 to 3800 lb. per sq.in. The investigation was conducted at the Langley Memorial Aeronautical Laboratory, Langley Field, Virginia.

It was found that the injection lag increased linearly with increase in injection tube length, but was not affected by the bore of the tube. The lag increased slightly with an increase in valve opening pressure and decreased materially with an increase in injection pressure. The initial pressure in the injection valve tube before the opening of the timing valve did not

affect the injection lag, providing the injection pressure was considerably in excess of the valve opening pressure.

Injection Lags in a Common-Rail Fuel Injection System

Common-rail injection systems for compression-ignition engines can be divided into two classes. The first consists of those in which the injection valve is mechanically operated. The second consists of those systems employing an automatic injection valve to which the oil is released from the high pressure reservoir by means of a mechanically operated timing valve. In the second case there is an injection tube, often of considerable length, between the timing valve and the injection valve. There is a definite time interval or injection lag, therefore, between the opening of the timing valve and the start of the oil spray from the fuel injection valve. This injection lag is controlled by the design of the injection system and the oil pressures employed in its operation. The injection lag of a common-rail system operating from a constant source of pressure is independent of the engine speed, providing the timing valve operates with sufficient rapidity to permit uninterrupted oil flow through it. For this reason, the results presented in this report are given in seconds and not in crank degrees.

The purpose of this investigation was to determine the effects of tube length and bore, opening pressure of the injection valve, initial pressure in the tube before the start of injection, and the injection pressure on the injection lag of the system. The tube length was varied from 10 to 70 in., and the tube bore from 1/16 to 5/32 inch. The valve opening pressure was varied from 2000 to 5000 lb. per sq.in.; the pressure in the tube before injection from 1000 to 3800 lb. per sq.in.; and the injection pressure from 4000 to 10,000 lb. per sq.in. The investigation was conducted at the Langley Memorial Aeronautical Laboratory at Langley Field, Virginia.

Apparatus and Methods

The N.A.C.A. Spray Photography equipment (Reference 1) was employed for this investigation. With this apparatus it is possible to take high-speed motion pictures at the rate of 2000 to 4000 per second of the formation and development of single fuel sprays. The injection system investigated is shown in Figure 1. The timing valve cam is operated by a clutch which, when engaged, causes the cam to make a single revolution at a speed of 950 r.p.m. As the timing valve needle is lifted the oil under pressure in the high-pressure reservoir is released through the injection valve tube to the injection valve. The oil pressure acting on the annular area of the injection valve stem forces the stem against the stop and the oil is sprayed into the chamber. Approximately 0.003 second after the timing valve needle has lifted the by-pass valve is opened. Since the ratio of the area of the by-pass valve to the area of the orifice in the injection valve is large, the oil flows through the by-pass valve; the pressure drops below that required to hold the injection valve open; and the stem returns to the seat.

The oil pressure in the high-pressure reservoir is built up by means of a hydraulic hand pump. The pressure in the injection valve tube before the opening of the timing valve is obtained by opening the initial pressure control valve and building up the desired initial pressure by means of the hand pump. This valve is then closed and the oil forced into the reservoir until the desired injection pressure is obtained. The injection lag of the system is the time interval between the opening of the timing valve and the start of the spray from the injection valve.

The start of the motion of the timing valve was recorded by the method described by Gelalles and the author in N.A.C.A. Technical Report No. 330 (Reference 2). A beam of light from a point source was focused on a mirror which was rotated through a small angle by the motion of the timing valve stem. The motion of the reflected light beam was recorded on a moving film drum which had a peripheral speed of 1000 in. per sec. The timing valve record was synchronized with the spray photographic record by a small spark gap in series with the main spark gap used for taking the spray photographs. This small spark gap was placed in front of the timing valve film so that for each spray picture there was a line recorded on the timing valve film.

A photograph of the fuel spray is shown in Figure 2. A record of the timing valve stem motion is shown in Figure 3. The start of injection is obtained by extending the time penetration curve to zero penetration. The time interval between the appearance of the first photograph and the start of injection is added to the time interval between the start of opening of the timing valve and the appearance of the first photograph. This sum is the injection lag between the opening of the timing valve and the start of the fuel spray from the automatic injection valve. The lag of this particular record was 0.0021 second as designated on Figure 3.

Results

Variable Injection Valve Tube Length.- Figure 4 shows the effect of injection valve tube length on the injection lag for injection pressures of 4000 and 8000 lb. per sq.in. The curves are parallel and the variation of lag with tube length is seen to be virtually linear.

Variable Tube Diameter.- No appreciable change was found in the injection lag for injection valve tubes varying in bore from 1/16 in. to 5/32 in. Since the lag remains constant with varying tube diameter, the injection valve must be opened by a pressure wave.

Variable Valve Opening Pressure.- Figure 5 shows the effect of valve opening pressure on injection lag. The variation is small, being 13.5 per cent for a change in valve opening pressure from 1000 to 5000 lb. per sq.in.

Variable Injection Pressure.- Figure 6 shows the effect of injection pressure on injection lag for four different tube lengths. The curves have a negative slope as would be expected.

Variable Initial Pressure.- The effect of the initial pressure in the injection valve tube before the opening of the timing valve on the injection lag is shown in Figure 7. The curves for the four-tube lengths show a constant lag for the range of initial pressure investigated. That the lag does not vary with initial injection valve tube pressure indicates again that the valve is opened by a pressure wave and not by a pressure caused by compression of the oil in the tube from the inflow through the timing valve. The velocity of a pressure wave through the tube is not affected materially by the initial pressure in the tube. If the pressure increase at the injection valve was caused by direct compression of the oil from inflow through the timing valve, the injection lag would vary appreciably with initial pressure.

Conclusions

In the design of a common-rail injection system for the operation of automatic fuel injection valves, care must be taken to obtain the same injection valve tube lengths for all valves, otherwise the time at which injection starts will not be the same for each valve. A variation in the bore of the injection valve tube from 1/16 to 5/32 inch will not affect the injection lag. The valve opening pressures should agree closely for all the injection valves. The initial pressure in the injection valve tube preceding the opening of the timing valve has little effect on the injection lag, providing the injection pressure is considerably in excess of the static valve opening pressure.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 2, 1930.

References

1. Beardsley, E. G. : The N.A.C.A. Photographic Apparatus for Studying Fuel Sprays from Oil Injection Valves and Test Results from Several Researches. N.A.C.A. Technical Report No. 274, 1927.

2. Gelalles, A. G. and Rothrock, A. M. : Experimental and Analytical Determination of the Motion of Hydraulically Operated Valve Stems in Oil Engine Injection Systems. N.A.C.A. Technical Report No. 330, 1929.

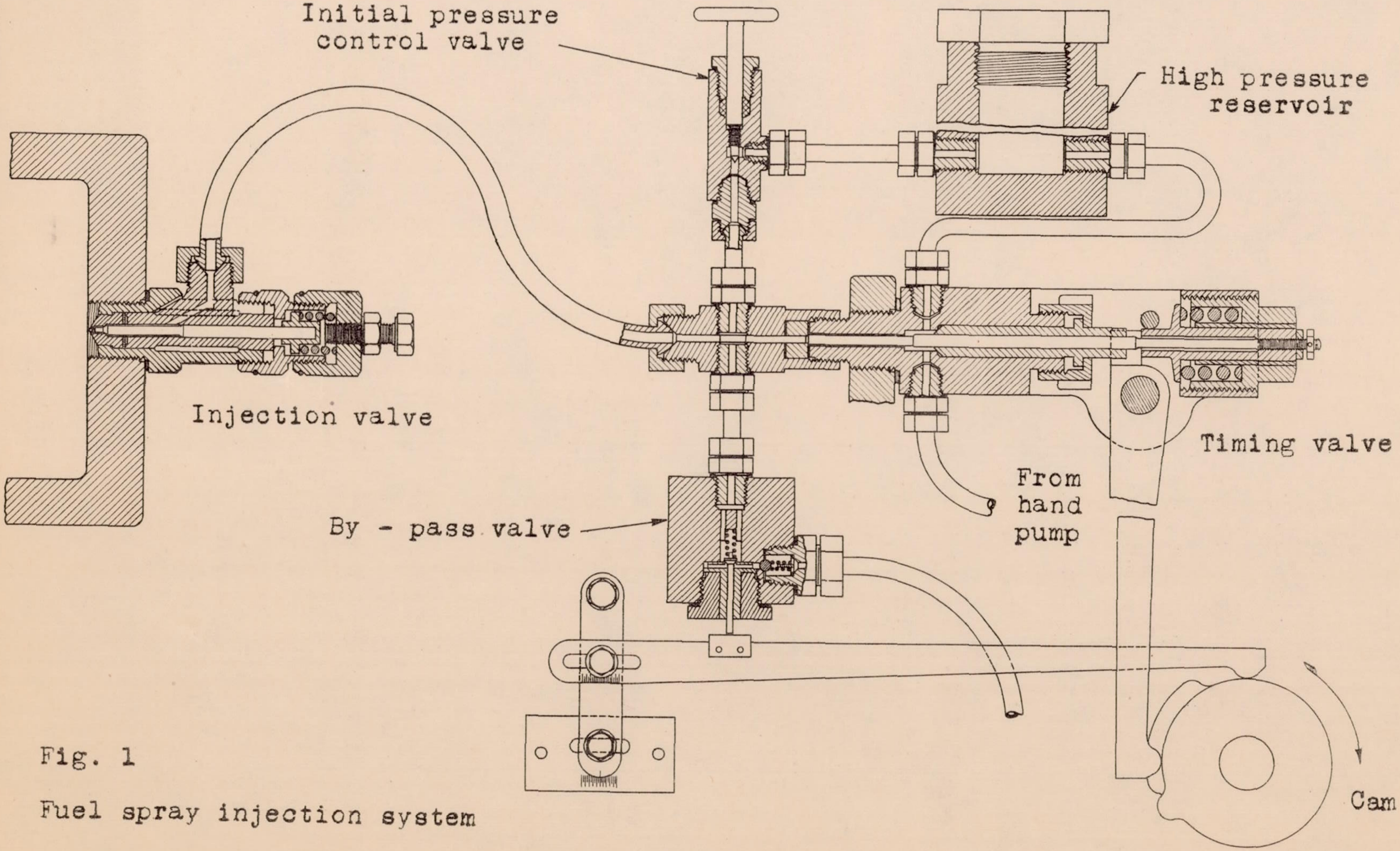

Fig. 1

Fuel spray injection system

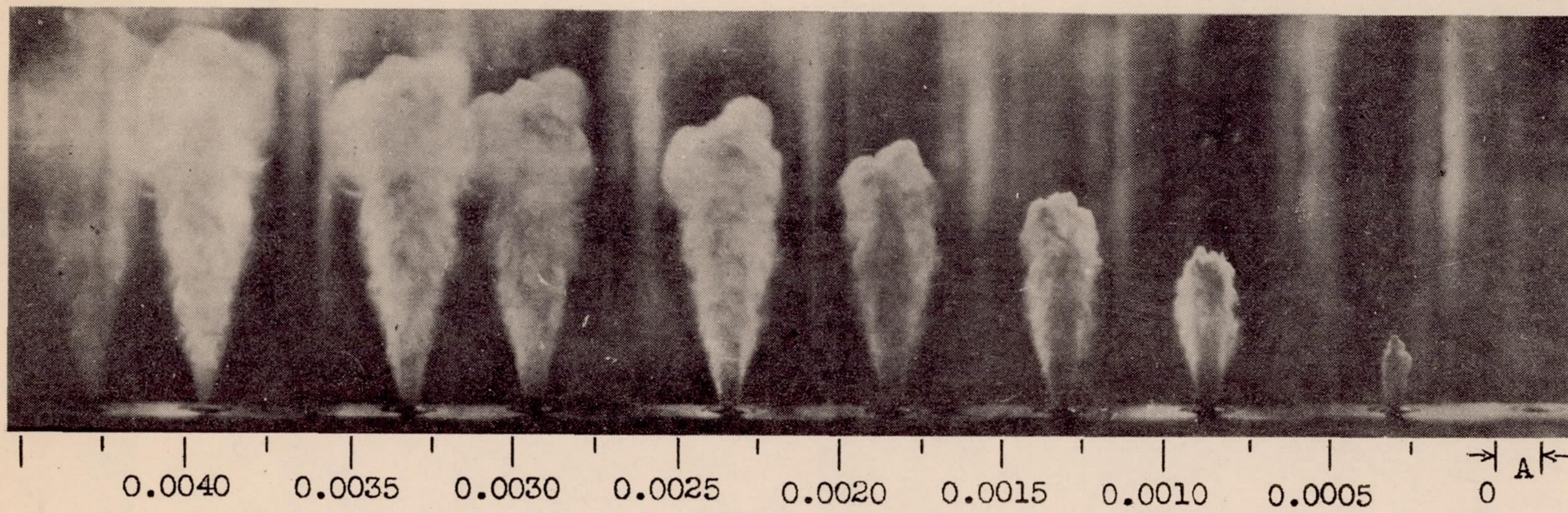

Fig.2 Fuel spray photographs. Injection pressure 8,000 lb./sq.in. A, time interval from first photograph to start of fuel spray.

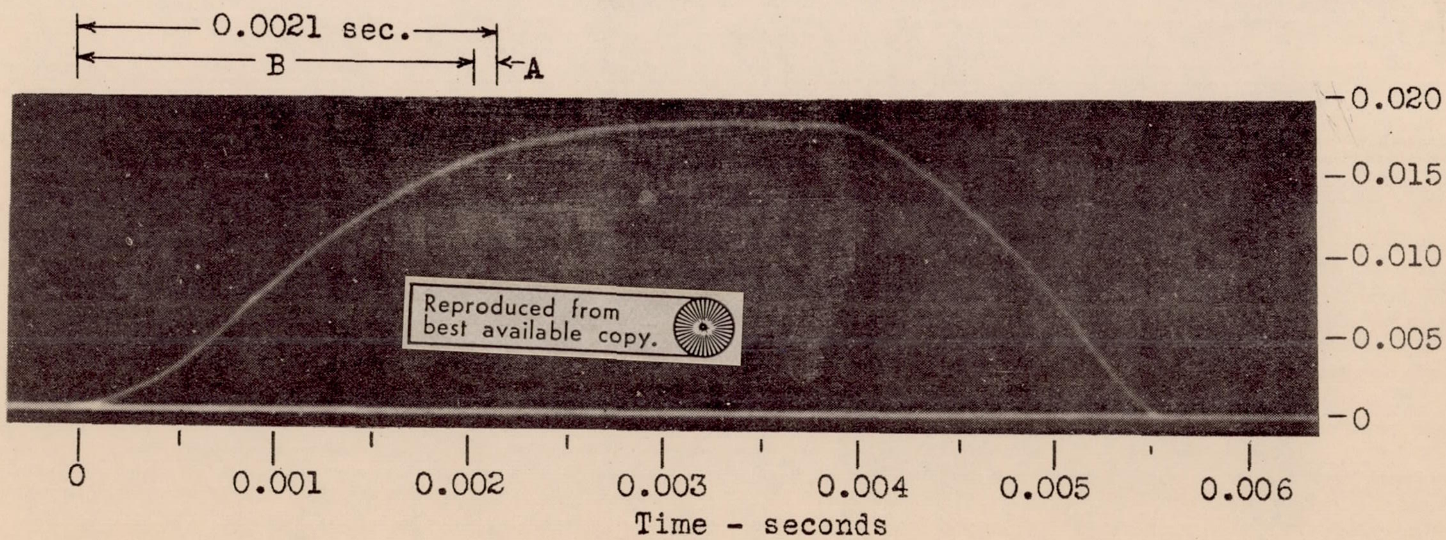

Fig.3 Record of motion of timing valve stem. B, time interval from start of timing valve motion to first photograph.

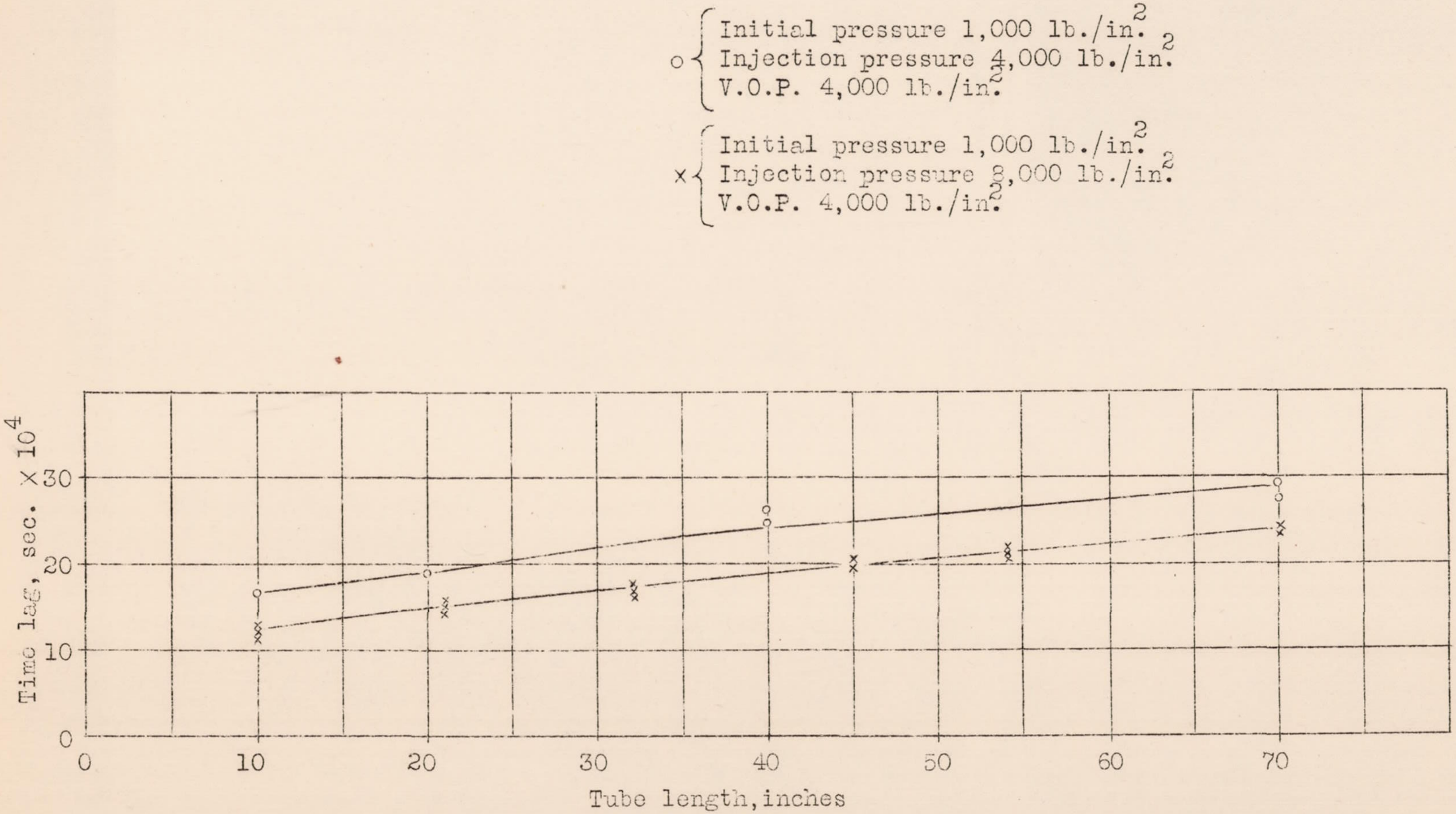

Fig. 4 Effect of tube length on time lag.

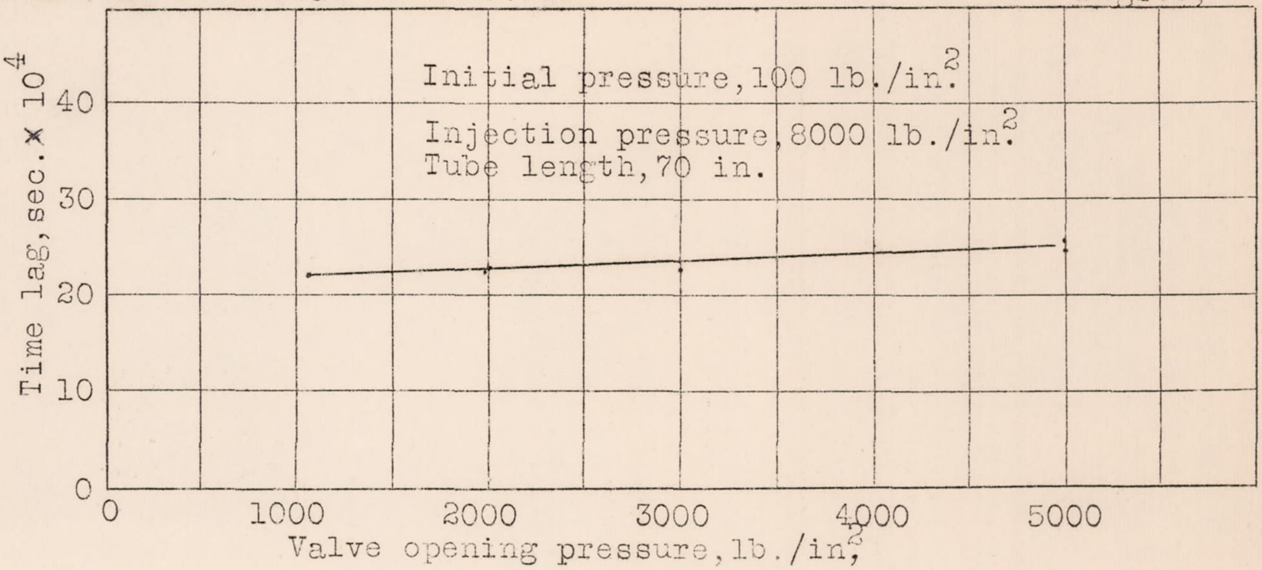

Fig.5 Effect of valve opening pressure on time lag.

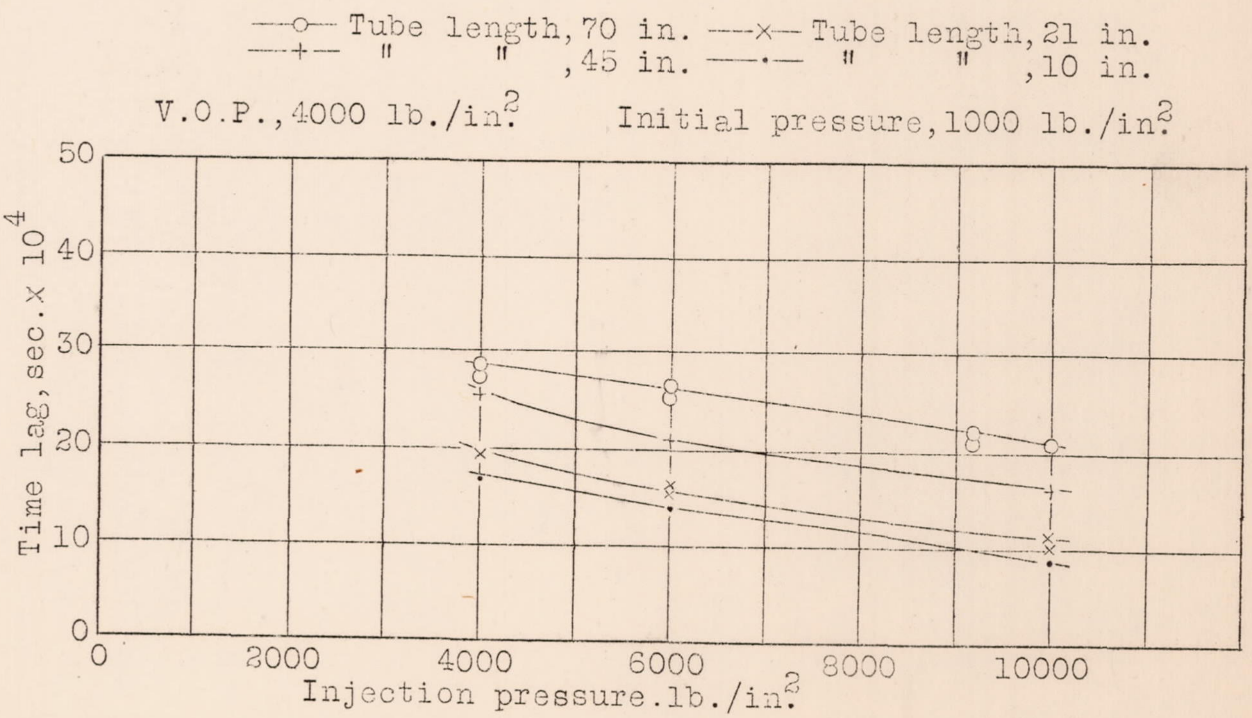

Fig.6 Effect of injection pressure on time lag.

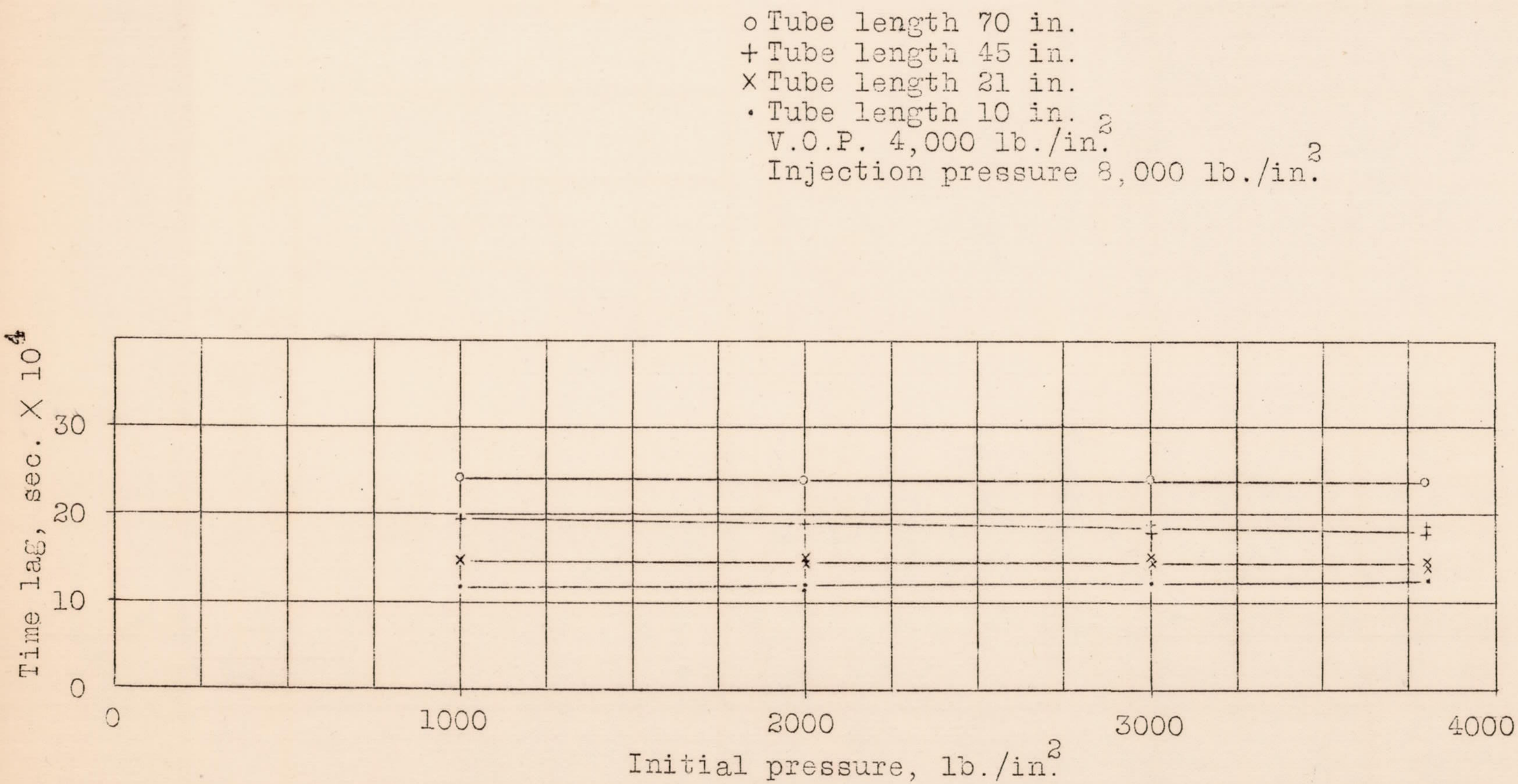

Fig. 7 Effect of initial pressure on time lag.