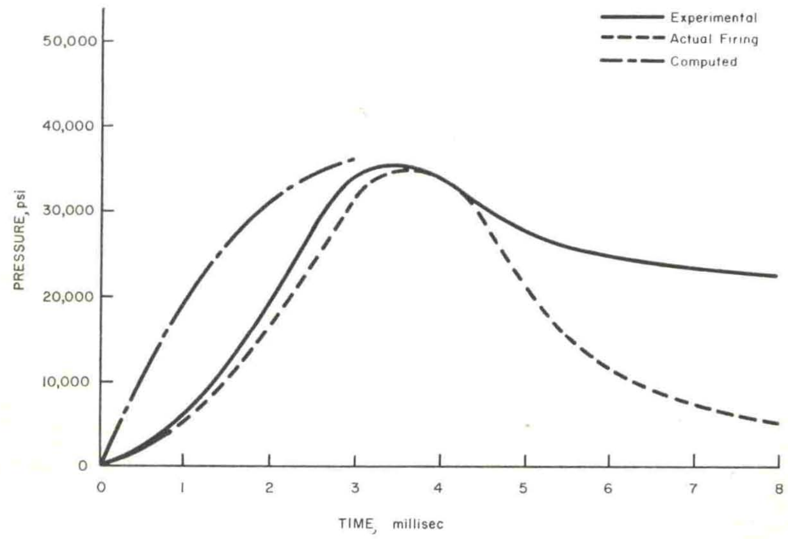

Fig. 2.—Experimental, actual firing, and computed pressure-time curves.

From Eqs 3, 6, and 9, the mass of fluid entering the pipes is given by

$$M = \rho_o C_s P_s \quad \text{.........(20)}$$

therefore, since $\rho = \rho_o(1 + kP_s)$

$$\frac{dP_s}{dt} = \frac{2A_p(1 + kP_s)}{C_s\sqrt{F}} \sqrt{P_{ao} - \left(1 + \frac{C_s}{C_a}\right) P_s} \quad \text{..(21)}$$

Again neglecting the kP_s term, separating variables and integrating from 0 to P_s and 0 to t gives the following equation for the pressure-time curve in the specimen:

$$t = \frac{\sqrt{P_{ao}} - \sqrt{P_{ao} - \left(1 + \frac{C_s}{C_a}\right) P_s}}{\frac{A_p}{C_s\sqrt{F}}\left(1 + \frac{C_s}{C_a}\right)} \quad \text{..(22)}$$

The constants in the above equation are determined as follows:

That part of C_s due to compression, assuming a combined specimen and pipe volume of 72 cu in., is equal to (2.22) (72) $\times 10^{-6}$.

That part of C_s due to dilation, assuming a straight, closed-end cylinder, is equal to 1.18×10^{-4} from the well-known Lamé equations.[3]

Therefore:

$$C_s = 0.278 \times 10^{-3} \text{ cu in. per psi}$$

Assuming an accumulator volume of 522 cu in., $C_a = 2.22 \times 522 \times 10^{-6}$

Therefore:

$$C_a = 1.16 \times 10^{-3} \text{ cu in. per psi}$$

An examination of the probable flow pattern through the feed valve indicates that most, but not all, of the kinetic energy of the fluid at the seat is lost passing through the valve. Based on this assumption, a value of F_v equal to 0.75 was used. Therefore:

$$F = \frac{0.0362}{773} \left[\frac{(0.024)(56)}{0.75} + 1 + (0.75)(4)\left(\frac{0.75}{0.5}\right)^4\right]$$

$$F = 8.42 \times 10^{-4} \text{ psi sec}^2 \text{ per in.}^2$$

Using these constants and an initial accumulator pressure of 44,000 psi in Eq 22 gives the computed pressure-time curve shown in Fig. 2. Also shown in Fig. 2 is the experimentally obtained pressure-time curve. The computed and experimental curves are in good agreement with respect to total rise time; the difference in the shape of the curves is probably due to the inertial forces involved with accelerating and decelerating the fluid, which were neglected in the above analysis.

High-Speed Valve

To release the energy stored in the accumulator into the test specimen in the required loading time, a valve having the following operating characteristics is required: (1) opening time must be less than 1 millisec, (2) time of opening must be controllable within $\frac{1}{2}$ millisec, (3) the valve must be capable of withstanding 50,000 psi pressure in the closed and open positions, and (4) it must have a volumetric flow capacity greater than 2000 gal per min.

To obtain these requirements, a pilot-operated valve using the differential-area principle was designed (Fig. 3). A pilot pressure of about 5000 psi, introduced into the area under the plunger, is sufficient to hold the valve closed against the seat with an accumulator pressure of 50,000 psi. The valve may now be opened either by releasing the pressure under the plunger or by introducing a pressure equal to or greater than the pilot pressure above the plunger through the trigger port. Either of these actions will cause the net force on the plunger to become downward. As the plunger begins to move, the high-pressure fluid at the seat will move into the area above the plunger and exert a large downward force on the plunger,

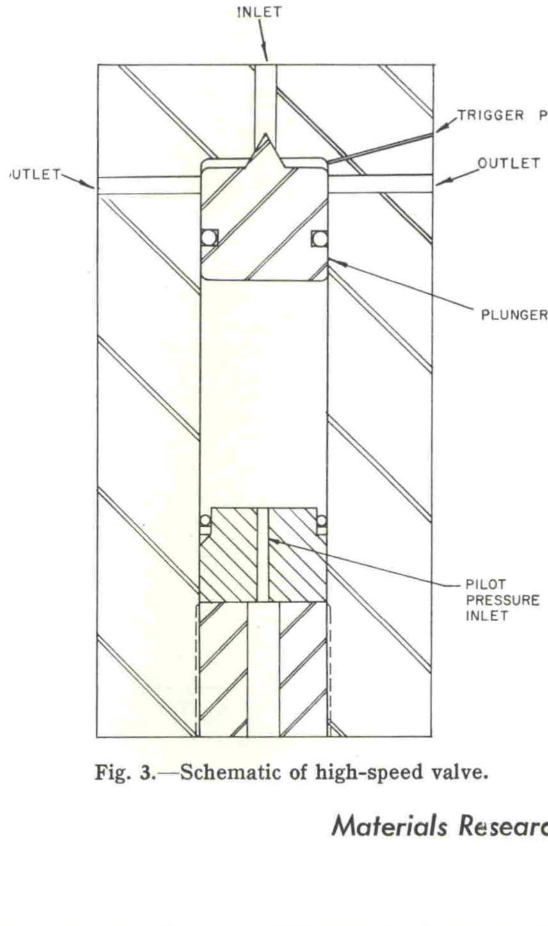

Fig. 3.—Schematic of high-speed valve.

[3] S. Timoshenko, "Strength of Materials, Part II," D. Van Nostrand, Inc., New York, (1942).

which will accelerate rapidly downward, compressing the fluid beneath it. The volume of fluid under the plunger is enough so that the compression of this fluid will allow the plunger to move far enough to uncover the outlet ports. Since a high flow rate out of the bottom of the valve is not required, small orifice tubing and valves may be used in the pilot pressure system. To prevent premature firing of the valve in case of leakage at the seat, the trigger port is vented to atmosphere through an air-operated dump valve which is closed just before the valve is fired.

Pressure-Release Valve

In addition to building up a maximum pressure in a given period of time, it is also necessary to relieve this pressure after a specified time and at a given rate. For this particular test, the time at pressure and decay rate should closely approximate that associated with the actual firing of the weapon involved near the maximum pressure.

The pressure-release valve is identical in principle and operation to the feed valve. It is opened by a hydraulic feedback circuit connecting its trigger port to the feed-valve trigger port. Owing to the fluid trapped under the plunger, the release valve will reclose at a pressure of approximately 10,000 psi in the system. Although this condition is not considered harmful, it is possible to drop the residual pressure to zero.

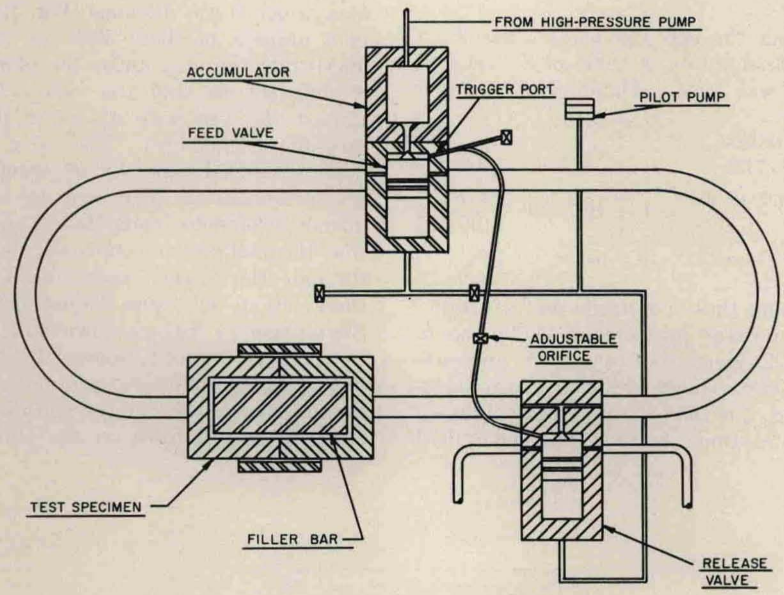

Fig. 4.—Schematic of test system.

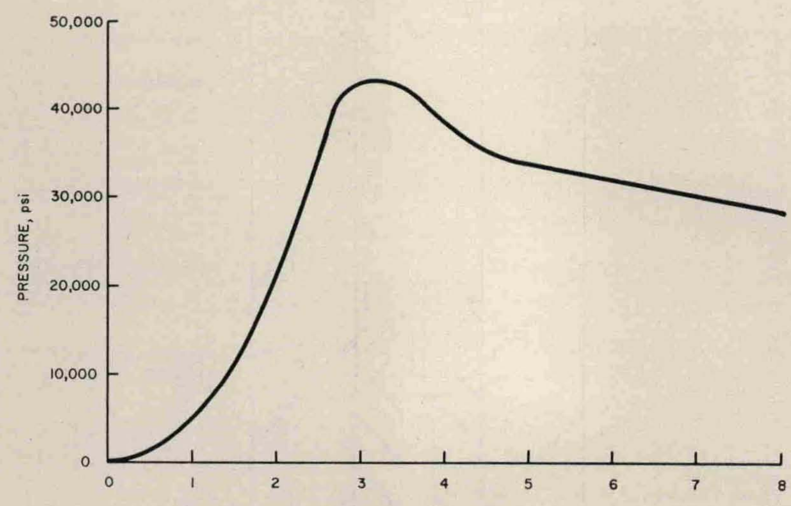

Fig. 5.—Pressure–time curve for 44,000 psi peak pressure.

Description of Operation

The system consists of three primary segments: (1) an accumulator with a high-speed valve, (2) piping for controlled fluid transfer to the specimen, and (3) a high-speed pressure-release valve. A schematic of these components assembled into the final system, along with the test specimen, is shown in Fig. 4.

Following is the sequence of events that occur when an attempt is made to simulate the pressure-time curve for firing in the test specimen. Initially, the accumulator is charged to a pressure of approximately 44,000 psi using an intensifier pumping system. The exact accumulator pressure, of course, is controlled by the desired maximum pressure in the specimen. The high-speed feed valve, located just below the accumulator and built integrally with it, is fired by releasing the pressure under the plunger. Fluid now flows out of both sides of the feed valve and into both ends of the test chamber until an equilibrium pressure, in this case about 35,000 psi, is attained. The volume of fluid transferred during this process is kept to a minimum by steel filler bars which occupy most of the volume of the test chamber. The remaining volume is pre-filled with fluid at atmospheric pressure. The fluid is piped into both ends of the specimen to assure uniform pressure distribution and to reduce external reaction forces produced by the acceleration of the fluid.

When the test pressure is reached in the chamber, the high-speed release valve is opened by pressure introduced above the plunger through the line connecting the trigger port of the feed valve with the trigger port of the release valve. The required time delay is obtained by throttling this flow with an adjustable orifice. The release valve will reclose at about 10,000 psi pressure in the chamber. This pressure will drop to zero when the valve connected to the trigger ports is opened due to leakage through the outlet ports of the feed valve, past the plunger, and out the trigger port.

Instrumentation

Initial pressure-time data were obtained from SR-4 strain gages mounted on the specimen. These gages were connected to an optical oscillograph with a 3300-cycle, fluid-damped, galvanometer. Amplification was provided by a d-c strain gage amplifier and a transistorized, cathode-follower type, driver amplifier. This measuring system was calibrated by building up a static pressure inside the specimen and calibrating the strain gages against a manganin wire pressure cell and Wheatstone bridge. The amplifier system was calibrated by shunting an accurate resist-