$$\sigma t = Pi\,\frac{c^2 + a^2}{c^2 - a^2} = 60{,}000\,\frac{1.75^2 + 0.375^2}{1.75^2 - 0.375^2} = 66{,}000 \text{ pounds per sq. inch}$$

The tangential stress at this section produced by the contact pressure is

$$\sigma t = -p\,\frac{2b^2}{b^2 - a^2} = -\,\frac{9050 \times 2 \times \overline{1.125^2}}{1.125^2 - 0.375^2} = -20{,}400 \text{ pounds per sq. inch}$$

Superposition of these stresses yields a resultant stress of

$$\sigma t = 66{,}000 - 20{,}400 = 45{,}600 \text{ pounds per sq. inch}$$

as compared to a stress of 75,000 pounds per sq. inch when composite design is not used.

The resultant safety factor based on the above calculation is 2.72 which represents an increase of approximately 53%. Actually, the safety factor is somewhat less than this, because of stress concentration, service, and surface finish factors. However, the design as such was adequate for the service intended.

Check Valve

Design of a check valve was perhaps the most difficult problem encountered in the design of the entire pump. The composite design theory was also used here. The outer ring was shrunk to the main body of the valve, thus reducing the peak stresses to valves similar to those already discussed.

Materials for this valve were selected carefully. More importantly, hardness of the various components affects success of the design. For strength to withstand stresses involved without failure from excessive brittleness, materials need to be hardened with heat. Mostly, this problem was solved with development tests.

For this valve, a poppet seemed most suitable for providing the sealing action required. For best sealing, small contact surfaces are indicated; but for longer operational life, larger contact surfaces are required to reduce high bearing stresses. The poppet design allows for practical adjustment of these stresses.

Using the poppet does, however, have one important requirement—surfaces sealed together must be accurately lapped together. The valve has been designed so that parts requiring lapping are easily removable to facilitate the lapping operation.

Performance and Tests

Newly designed equipment should be evaluated by test methods done under conditions as nearly like those encountered in laboratory operation as possible.

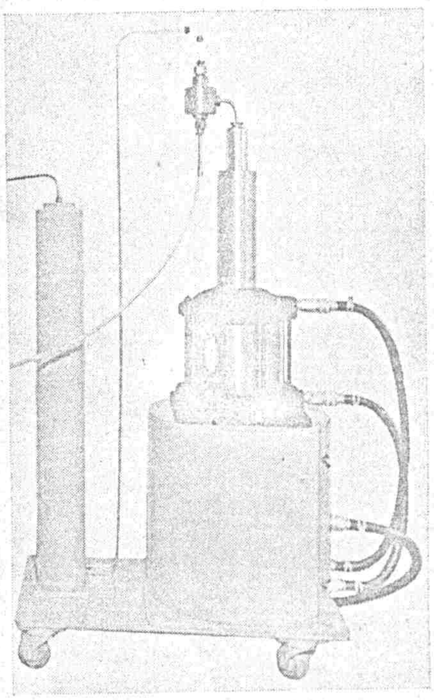
The high pressure apparatus is separated from the necessary control devices by a suitable barricade. To facilitate operation of the pump, the control apparatus has been placed on a panel which can be located on the exterior wall of a barricaded cell.

First it was necessary to have a constant supply of air to the pump air cylinder. This would not ordinarily be necessary during actual use of the pump; however, in determining performance curves it aided in accumulating data and facilitated reproducible results. The addition of the air accumulator as shown on the flow diagram assisted in this requirement and the maximum air pressure variation at any given setting was approximately ±2 pounds per sq. inch which occurred when the pump piston changed its direction of movement.

Several primary tests were conducted to determine suitable techniques to be used during operation of the test apparatus. These tests indicated that accurate results could be obtained by operating the pump for relatively short periods at any given set of conditions. The discharge pressure could be held constant by hand manipulation of a metering valve to adjust the volume of discharge for the duration of a test run. The average time required for a test run for any given setting was approximately 5 minutes. The maximum variation in discharge pressure ranged from 150 pounds per square inch below and above the desired setting. Higher discharge pressures were more easily controlled.

The fluid pumped was a 25 to 1 mixture of water and a suitable emulsifying oil. The oil was used to some extent for lubrication and for the most part to prevent oxidation of the alloy steel components in direct contact with the fluid being pumped.

All tests were made with a stroke length of 3.750 inches. It was determined during preliminary testing that a change in stroke length had a negligible effect on the amount of fluid pumped during a given period provided air pressure to the air cylinder was constant. It is possible, however, by adjustment of stroke and air pressure to control the volume discharge of the pump more accurately. A shortening of stroke length will provide a more even discharge flow, which will allow a finer adjustment of the total flow required during any given time.



The finished pump. Length of stroke and speed of operation can be varied without complicated and costly control devices

Test runs were made for discharge pressures ranging from 20,000 to 60,000 pounds per square inch. Curves were drawn from these data, plotting the delivery at the various discharge pressures against air pressure applied.

To provide additional versatility, two additional sets of cylinders and plungers were designed. The first was designed to produce a maximum discharge pressure of 30,000 pounds per sq. inch with an air pressure of 80 pounds per sq. inch applied to the air cylinder, and the second was to produce a maximum discharge pressure of 15,000 pounds per sq. inch with an applied air pressure of 80 pounds per sq. inch. Similar tests were completed with these components.

Conclusions

Design of high pressure apparatus requires subdivision into its essential elements which are then designed, keeping in mind the requirements of the complete apparatus. Development and test work must supplement theoretical considerations. The performance and tests indicate that this method was successful.

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