OPERATION AND CALIBRATION TESTS OF A 12-INCH INTERNAL DIFFERENTIAL NEEDLE VALVE FOR GRANBY DAM AUXILIARY OUTLET--COLORADO-BIG THOMPSON PROJECT, COLORADO

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RESEARCH AND GEOLOGY DIVISION

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DENVER, COLORADO

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Purpose

Hydraulic studies were made on a 12-inch internal differential needle valve to determine its discharge characteristics and to ascertain whether its hydraulic actuating mechanism would perform satisfactorily. The valve will be used to regulate releases from an auxiliary outlet at Granby Dam.

Conclusions

1. The modified hydraulic actuating mechanism (Figure 1) will operate satisfactorily provided sufficient pressure head is supplied to the mechanism. The required minimum pressure head \(H\), in feet of water, is given by the equation:

\[
H = 0,0468 \ Q^2 + 3.09
\]

where \(Q\) is the valve discharge in cubic feet per second (Figure 3).

2. When the source of the actuating pressure is from the outlet conduit, the minimum total head at which the actuating mechanism will function properly depends upon the pressure head in the conduit, which in turn depends upon the conduit size. The following table shows the minimum total head at which the hydraulic mechanism will function properly for various sizes of conduit leading to the valve. The table reflects the condition for the fully open valve.
A study of the requirements for an auxiliary outlet control valve at Granby Dam indicated that a 12-inch internal differential needle valve in storage at Hoover Dam could be utilized provided certain minor alterations were made. The valve was 1 of those intended to control the flow through the 12-inch bypasses around the 168-inch butterfly valves in the power penstocks at Hoover Dam. These valves had been removed when they failed to operate satisfactorily and the source of the trouble was not apparent.

A study of the details and history of the needle valves by members of the Mechanical Division disclosed that the operating difficulties might have resulted from the arrangement of water passages in the actuating mechanism and leakage between pressure chambers within the valve. They recommended that one of the valves be altered and placed in the Hydraulic Laboratory for tests to determine if satisfactory operation could
be obtained. The work was authorized and 1 of the valves modified as recommended (Figure 1). Tests were made to study the effect of the modifications and to obtain data from which discharge capacity and other valve characteristics could be determined.

THE STUDY

Laboratory Installation

The modified 12-inch needle valve was installed to operate under free discharge. A 20-foot length of 12-inch pipe was placed upstream to assure uniform flow at the valve. It was installed so that water could be supplied by any or all of the laboratory pumps, and the discharge could be measured by a venturi meter. The head to actuate the valve needle was originally supplied through a 1-inch pipe tapped into the 12-inch line 1 foot upstream from the valve; later, when the head at this point proved too small to operate the valve hydraulically, an auxiliary supply line was connected through a pressure regulating valve to the city water main.

Two piezometers, 1 in the 1-inch actuating supply line near the entrance port, and the other in the 12-inch conduit 1 diameter upstream from the valve, were used to measure the respective pressure heads. A point gage, utilizing a thin blade for measurements through the jet, was mounted on the downstream face of the valve (Figure 2) and calibrated against the movement of the needle so that the amount of valve opening could be measured at any time without interrupting the flow through the valve.

Valve Operation

When the actuating supply was drawn from the 12-inch conduit, and the full capacity of the laboratory pumps (about 20 cubic feet per second) passed through the valve, the hydraulic actuating mechanism operated satisfactorily only for valve openings below 80 percent. For total heads on the valve of less than 4 feet, the actuating mechanism would not move the needle from any position. The valve could be opened and closed manually however, by applying a large torque to the operating handwheel.

With the actuating supply taken from the city water main, tests were continued to find the minimum pressure head necessary to start the valve closing from the 100-percent open position since a pressure head sufficiently large to start the valve closing from this position would be satisfactory for the full range of valve openings. Computations and charts pertaining to the operating mechanism reflect the conditions with the valve fully opened.

Determination of the Minimum Actuating Head

The test procedure to determine the minimum actuating pressure head necessary to start closing of the valve consisted of:
1. Regulating and recording the discharge through the wide-open valve.
2. Decreasing the actuating pressure head until it was too small to move the needle hydraulically.
3. Turning the actuating handwheel toward "close.
4. Increasing the actuating pressure head until the needle just started to move.
5. Recording the actuating pressure head in the 1-inch line.

The minimum pressure head in the actuating supply line to operate the valve hydraulically was determined by the above procedure for each of several discharges up to 15.6 cubic feet per second.

If the valve is to operate hydraulically, the force against the needle in the pressure chamber (Figure 3) must be great enough to overcome both the force "F" on the needle due to the valve discharge and the friction between the needle and the tube. The pressure at any point on the exposed surface of the needle which produces the force "F" varies as the square of the velocity past that point, and the velocity varies directly as the discharge; therefore, the total force against the nose of the needle varies as the square of the discharge through the valve.

The force against the needle in the pressure chamber varies directly as the actuating pressure head; therefore, the actuating pressure head necessary to close the valve against the force caused by the valve discharge must vary as the square of this discharge. The friction between the moving needle and its housing must be overcome by an additional head.

It follows that the terms of an equation of the form:

\[ H = BQ^2 + D \]

which could enable determination of the required actuating pressure head, could be evaluated from the experimental data where:

- \( H \) = Pressure head, feet of water, in the actuating supply line
- \( B \) = A constant
- \( Q \) = Valve discharge, cubic feet per second
- \( D \) = Pressure head, feet of water, necessary to overcome the friction of the valve

Using the experimental data, a chart was made plotting the actuating pressure head versus the square of the valve discharge (Figure 3). The slope of the resultant line is the constant "B" and the intercept of the plotted line with the zero discharge ordinate is the value "D." Substituting these constants into the equation, the minimum actuating pressure head \( (H) \) to operate the valve hydraulically from the fully open position for any discharge \( (Q) \) is:

\[ H = 0.0468 Q^2 + 3.09 \]
Figure 4 shows the relation between the valve discharge \( (Q) \) and:

1. The total head immediately upstream from the valve
2. The minimum actuating pressure head to operate the valve hydraulically (determined by using the above equation)
3. The pressure head for a 12-inch, 14-inch, and 18-inch diameter conduit section upstream from the valve

**Actuating Mechanism Leakage**

Leakage through the actuating mechanism was measured volumetrically for pressure heads in the 1-inch line from 1.5 to 29.0 feet. Tests were made with the valve fully open, with and without flow through the valve; and the valve closed, with and without pressure on the upstream side of the valve. Assuming that the leakage through the actuating mechanism varied as the square root of the total head, a value \( "K" \) was determined for each test run where \( K = \frac{\text{leakage}}{\sqrt{h}} \). A plot of these values indicated that \( "K" \) became constant (about 0.0052) for total heads above 18 feet. Using this value of \( "K" \), a plot of leakage against total head was made for the actuating supply leakage up to a head of 185 feet (Figure 5). It was found that, for the same actuating pressure head, the actuating supply leakage was somewhat smaller when the needle was in the closed position than when it was wide open, and that the amount of head or flow in the conduit made little difference in this leakage.

**Valve Capacity**

Data necessary to compute the discharge coefficients of the valve consisted of the pressure head at the valve, the discharge, and the amount of valve opening. These data were obtained for 5 valve openings and for discharges which ranged from the smallest at which the valve would flow full to the maximum output of the laboratory pumps. Discharge coefficients for the valve were computed for various valve openings by using the formula, \( Q = C_d A \sqrt{gh} \), where:

\[
\begin{align*}
Q &= \text{Discharge, cubic feet per second} \\
C_d &= \text{Discharge coefficient} \\
A &= \text{Area of the 12-inch pipe, square feet} \\
h &= \text{Total head at the valve, feet of water, (pressure head + velocity head)}
\end{align*}
\]

Within the range of the laboratory pumps the coefficients were nearly constant for any 1 valve opening (Figure 6). Since \( C_d \) was constant for all practical purposes, a curve of \( C_d \) versus valve opening was plotted which was used in preparing a discharge chart covering the entire range of reservoir elevations at Granby Dam (Figure 7).

Tests were not made concerning pressures within the discharge passages of the valve; however, the valve's blunt downstream needle tip might be damaged by cavitation if the valve releases water for long periods at partial openings and under high heads.
SCHEDULE OF WORK TO BE DONE

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REFERENCE DRAWINGS

1/8" INTERNAL DIFFERENTIAL NEEDLE VALVE ASSEMBLY - 245-D-4338
1/8" NEEDLE VALVE DETAILS - 246-D-4338

United States Department of the Interior
COLORADO BUREAU OF RECLAMATION
GRANBY DAM
OUTLET WORK
1/8" NEEDLE VALVE REPAIR
12-Inch Internal Differential Needle Valve Operating Partially Opened Under a Head of About 60 Feet.

Key to numbers:
1. Gage for determining the position of the needle without interrupting the flow.
2. Operating hand wheel.

COLORADO-BIG THOMPSON PROJECT--COLORADO
GRANBY DAM OUTLET WORKS
12-INCH NEEDLE VALVE
**ACTUATING PRESSURE CHAMBER** (Schematically)

Plotted points are from experimental data.

Slope of line = 0.0468

"H" intercept = 3.09

Equation of line:

\[ H = 0.0468 Q^2 + 3.09 \]

COLORADO BIG THOMPSON PROJECT—COLO.

GRANBY DAM-OUTLET WORKS

12" NEEDLE VALVE

RELATION OF VALVE DISCHARGE SQUARED TO ACTUATING SUPPLY PRESSURE HEAD
**COLORADO BIG THOMPSON PROJECT-COLO.**

**GRANBY DAM-OUTLET WORKS**

**12" NEEDLE VALVE**

**RELATION OF VALVE DISCHARGE TO MINIMUM ACTUATING SUPPLY PRESSURE WHICH WILL OPERATE THE VALVE HYDRAULICALLY**

**FIGURE 4**

1. "Q" Vs Total head at the valve
2. " " Pressure head in 18" line
3. " " Pressure head in 14" line
4. " " Min pressure head req'd in actuating supply line
5. " " Pressure head in 12" line

Note: Valve fully open

Valve discharge for 200' head.
Figure 5

"K" becomes constant at 0.0052

\[ K = \frac{Q}{\sqrt{h}} \]

Plotted points are from experimental data

\[ Q = 0.0052\sqrt{h} \]

Note: Valve fully open

COLORADO BIG THOMPSON PROJECT-COLO.
GRANBY DAM-OUTLET WORKS
12" NEEDLE VALVE
RELATION OF ACTUATING SUPPLY LEAKAGE TO ACTUATING SUPPLY TOTAL HEAD
\[ Q = \text{Valve discharge, c.f.s.} \]
\[ A = \text{Area of 12-inch pipe.} \]
\[ h = \text{Total head in 12-inch pipe.} \]
\[ C_d = \frac{Q}{A \sqrt{2gh}} \]

COLORADO BIG THOMPSON PROJECT—COLO.
GRANBY DAM-OUTLET WORKS
12" NEEDLE VALVE
RELATION OF VALVE DISCHARGE TO COEFFICIENT OF DISCHARGE
\[ C_d = \frac{Q}{A \sqrt{2gh}} \]

- \( Q \): Valve discharge
- \( A \): Area of 12" pipe
- \( h \): Total head in pipe