INTERNATIONAL ASSOCIATION FOR HYDRAULIC RESEARCH

HORIZONTAL MULTIJET SLEEVE VALVE

(Subject D.c.)

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SYNOPSIS

Hydraulic laboratory tests were used to develop the design for a multijet sleeve valve and energy dissipation chamber to be used on municipal and industrial water supply systems. The valve design emphasizes effective energy dissipation for throttled flow conditions, but also incorporates capability to deliver maximum design discharges with minimum head loss at the control structure when considerable head is being dissipated due to friction in upstream lines. The stilling chamber dissipates the energy of numerous high-velocity jets. Cavitation forms but occurs within the body of the fluid away from any solid boundaries. The perforations are designed to avoid cavitation on the body of the valve. Two perforated sleeve designs were studied. The design selected consists of approximately one hundred 6-mm nozzles and eighteen 13- by 130-mm slots. The location of the nozzles and slots is based on a linear relationship between control sleeve travel and valve discharge. A computer program was developed to determine the location of the nozzles and slots as a function of upstream-pipe diameter and length, design discharge, and static pressure. This valve will eliminate the need for control stations using in-line butterfly valves and sudden enlargements for a municipal and industrial water supply system presently under construction.

Les essais laboratoire ont été utiliser pour developer le dessein d'une valve manche avec multijets et une chambre de dissipation d'energie pour les réseaus d'eau municipals et industrials. L'accent du dessein est la dissipation effective de l'energie pour un debit partial et aussi le pouvoir de décharger le debit maximal avec un perte de charge minimal quand le perte de charge par frottement en le tuyau amont est grand. La dissipation d'energie dans la chambre de la dissipation est effectué par les nombreux jets d'haute vitesse. La cavitation est situé dans le corps du fluide, loin de les parois. Les perforations sont dessiné d'éviter la cavitation sur le corps de la valve. Deux desseins de la manche perforée ont été etudier. Le dessein préféré consiste d'approximatifment cent buses de 6-mm diamètre et de dix-huit des fentes de 13- par 130 mm. La position des buses et des fentes est fondé par un rapport linéaire entre le déplacement de la manche et le debit de la valve. Un programme de calcul était developé de constater la position des buses et des fentes comme une fonction de la longuer et le diamétre du tuyau amont, du debit, et du pression statique. Cette valve peux éliminé le besoin pour les valves de papillon et les élargissements brusques en les stations du réglage dans un réseau d'eau municipal et industrial en construction.

INTRODUCTION

With the design and construction of long aqueducts to supply municipal and industrial water, the need arose to develop a valve and energy dissipator system which would be compatible with the aqueduct system. A system was needed that would (1) adequately dissipate high energy flow at small discharges and (2) pass design flows with a minimum energy loss. The aqueduct operating under design flow conditions would dissipate the majority of available energy in line losses, and when operating under a throttled condition would dissipate the majority of excess energy at the control valve and energy dissipator.

Flow control stations on long aqueducts have been limited to pressure head differentials of approximately 45 m. This restriction resulted from cavitation damage associated with the use of butterfly valves at higher head differentials. If a valve and associated energy dissipator could be developed to accommodate pressure head differentials exceeding 45 m the number of flow control stations required along an aqueduct could be reduced, resulting in significant cost savings.

It was with these needs in mind, that the Division of General Research and the Division of Design of the Bureau of Reclamation's Engineering and Research Center initiated a research program in 1972 to develop a suitable control valve and energy dissipator.

PREVIOUS DEVELOPMENTS

Earlier studies conducted by Burgi on a 50-mm model of a ported sleeve valve in a vertical stilling well, indicated that such a ported valve could fulfill the control requirements stated previously. In a study reported by Miller [1], Glenfield and Kennedy, Ltd., a submerged discharge valve (sleeve-type) was described similar to the Bureau of Reclamation's Wanship sleeve valve. Glenfield and Kennedy developed a new device which could be attached to their standard sleeve valve resulting in a ported sleeve valve. The advantage of the ported sleeve is that port shape and area can be designed to accommodate the specific hydraulic characteristics desired. Miller also noted an improvement in energy dissipation as a result of the small individual jets leaving the valve. The Metropolitan Water District of Southern California (MWD) [2] conducted tests on an improved submerged discharge valve (without ports) but found that at heads in excess of about 30 m cavitation damage occurred on the bottom plate of the valve and edge of the control sleeve. To develop a valve which could control high head

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1. Miller, E., "The Submerged Discharge Valve," Glenfield Gazette, No. 229, February 1969.
2. Johnson, D., "Sleeve Valves," Control of Flow in Closed Conduits, Colorado State University, August 9-14, 1970.

flows, the concept of flow nozzles was utilized. MWD engineers developed an outer sleeve containing a large number of small nozzles and attached it to the sleeve valve under study. The nozzles accelerate the flow through the outer sleeve, thus no cavitation can occur in the metal flow passages. As the jets exit from the valve, cavitation occurs in the water surrounding the valve and not against the flow surfaces. The multijet concept of valve control has permitted designers to consider controlling high energy flow in the range of 150 to 300 m in one step instead of several smaller steps.

HYDRAULIC CONSIDERATIONS

Two appealing flow characteristics of a valve utilizing the multijet concept are:

1. The flow energy is dissipated quite rapidly upon leaving the valve, thus requiring a relatively small energy dissipation structure.

2. The inevitable process of formation and collapse of cavitation, which occurs during throttling of high energy flow, can be controlled to occur in the water surrounding the valve and not against the flow surfaces of the valve or energy dissipation chamber.

The jet deceleration is related to port size. The location of the cavitation collapse zone is related to the multijet exit port shape and the relative location of the ports to each other. Albertson [3] describes the diffusion of a submerged jet in two stages: zone of flow establishment and zone of established flow. In the zone of flow establishment, the core of the submerged jet is penetrated by viscous shear until the centerline velocity begins to reduce. Thus, the fluid in the jet decelerates while the fluid surrounding the jet gradually accelerates. The zone of established flow is defined as that zone where the entire jet becomes turbulent and the centerline velocity begins to decelerate. The centerline velocity, V_m, is defined by Albertson as:

$$V_m = 2.28\ V_o \frac{B_o}{X} \quad \text{(slotted port)} \qquad (1)$$

$$V_m = 6.2\ V_o \frac{D_o}{X} \quad \text{(circular port)} \qquad (2)$$

where: V_m = jet centerline velocity at X

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3. Albertson, M. L., Dai, Y. B., Jensen, R. A., and Rouse, H., "Diffusion of Submerged Jets," Transactions ASCE, Vol 115, 1950.

V_o = jet exit velocity

B_o = slot width

D_o = circular port diameter

X = distance from port along jet centerline

From equation 2, it is evident that for a circular port, the distance X, from the port needed to reduce the jet centerline velocity, V_m, to a certain fraction of the jet exit velocity V_o, is directly related to the port diameter, D_o. Therefore a reduction in the port diameter by one-half would reduce the distance, X, required to produce the same centerline velocity, V_m by one-half. Ports as small as 3 mm have been used on some multijet valves. Therefore, for a head of 150 m, the jet velocity could be reduced from 50 m/s at the port to 1.2 m/s in 0.9 m, using a 3-mm diameter port.

TEST FACILITY

The laboratory facility (figure 1) consists of a seven-stage vertical turbine pump driven by a 187-kW (250-hp), direct current motor. A rectifying unit and motorspeed control converts alternating current into the direct current needed for the motor and provides speed selection from 200 to 1,800 r/min. Rate of flow is measured with a 200-mm by 113-mm Venturi meter permanently installed 3 m downstream from the pump outlet. A 200-mm motor-operated valve is used to control the downstream pressure on the test valve. The pump has the capability to deliver 0.13 m^3/s at 122 m of head.

The 200-mm laboratory test valve discharged into a 1370-mm-diameter, 1220-mm-long stilling chamber. The basic concept of the valve and stilling chamber is illustrated in figure 2. Flow enters the valve from the high-pressure side and is discharged through the perforated body of the valve into the stilling chamber. A cylindrical sleeve, located inside the valve body, travels over the perforated section of the valve, controlling the port area and thus the valve discharge. The flow enters the downstream pipeline at the lower end of the stilling chamber. Pressure heads were measured at pressure taps P_1, P_2, and P_3 and corrected for a pressure differential, ΔH, between the upstream flange of the sleeve valve, H_1, and the downstream 200-mm pipe flange, H_2.

INVESTIGATION OF THE HORIZONTAL MULTIJET SLEEVE VALVE

Previous multijet sleeve valve designs did not fully satisfy the performance criteria desired by the Bureau of Reclamation; that is a valve which will dissipate high energy flows at throttled discharges and deliver design flows with a minimum head loss at the valve. Although the designs function quite well as pressure reducing valves, most do not emphasize minimal head loss when delivering design flows. The concept of a nearly linear relationship between the control sleeve travel and valve discharge was another desired characteristic sought in the new design. Such a valve would provide better control characteristics on long aqueducts where water hammer presents a potential problem. Figure 3 illustrates ideal valve characteristics as a function of sleeve travel for a 200-mm pipeline where the static upstream pressure head is 137 m. As the valve is opened and the port area slowly increases, the valve discharge increases linearly with sleeve travel.

The increase in valve discharge with sleeve travel results in a reduced upstream pressure head due to friction losses in the long aqueduct. By the time the valve has opened about 230 mm, it has performed its function as a pressure reducing valve and assumes the role of a low head-loss control valve. At this point, the valve port area increases rapidly due to the large slots, but with little increase in discharge since the available pressure head across the valve is low. By the time the valve port area equals the 200-mm pipe area, the pressure head ΔH has reduced to 1.1 m across the valve, resulting in a discharge coefficient of approximately 0.68.

The key to the multijet design is the proper placement of the ports along the spiral length of the valve to produce a near linear relationship between the valve discharge and sleeve travel. A computer program was developed to calculate the flow passing through the nozzle ports in each successive spiral quadrant along the length of the helix. The program locates the ports in a manner to nearly equalize the flow through each quadrant. This results in a linear relationship between sleeve travel and valve discharge. When the required nozzle diameter is greater than the valve wall thickness, the program automatically changes the port configuration from nozzles to slots. Laboratory tests with the 200-mm valve were used to define the change in discharge coefficient for the nozzles and slots as the control sleeve varied the open port area.

The investigation included studies conducted on the two perforated valve sleeves shown in figure 4. The area for the slotted port configuration increases at a somewhat linear rate with sleeve travel, and the area for the sleeve with nozzles and slots increases very slowly at the start of the sleeve travel and then increases quite rapidly once the slots are exposed, yielding a linear relationship between sleeve travel and valve discharge, figure 3.

Figure 5 shows typical sections through nozzles and orifices. The use of nozzles or orifices for the discharge ports should be carefully considered. The present spiral arrangement of the ports results in the partial blockage of some of the ports when the valve is used to control the flow. Although the nozzle-port has the advantage of a higher discharge coefficient and structurally requires a smaller port cross section in the perforated sleeve, it has the disadvantage that during partial blockage, the control point for the nozzle could move from the exterior surface of the perforated sleeve to an internal control at the control sleeve. This change in control position could cause cavitation damage to the flow surface of the nozzle-port. Bureau of Reclamation laboratory tests with nozzle-ports up to 8 mm in diameter and studies conducted by the MWD of Southern California with nozzle-ports up to 13 mm in diameter showed no signs of cavitation damage to the nozzle flow surfaces. Further laboratory investigations should be conducted to determine the pressure head-nozzle diameter relationship where cavitation will occur in the nozzle flow passage.

Although the orifice port has a lower discharge coefficient, C_d, due to the vena contracta and requires a larger port area for the perforated sleeve, there is no change in the control point. The control for the jet is at the interior surface of the perforated sleeve when the orifice is completely open or partially blocked by the control sleeve. The 1.6-mm control surface and 45° taper provide a clean control point for the jet with adequate circulation.

The data for the head loss coefficient, K, are plotted with respect to percent valve opening (100 x port area/pipe area) in figure 6 for both port configurations shown in figure 4. The head loss coefficient is based on the pressure head differential, ΔH, between the upstream valve flange and the 200-mm pipe flange downstream of the stilling chamber. The loss coefficient, K, therefore, includes the total system loss for the control structure.

CONCLUSIONS

Results of laboratory tests conducted on the 200-mm horizontal multijet sleeve valve demonstrate capability to perform well as an energy dissipation device and also deliver design flows with minimum head loss. The computer program developed for the study effectively analyzes the valve flow characteristics and locates the multijet ports to produce a nearly linear relationship between control sleeve travel and valve discharge.

The perforated valve sleeve with nozzles and slots provided valve characteristics similar to those sought and was selected as the best design for a water supply aqueduct system.

The use of horizontal multijet sleeve valves on municipal and industrial water supply aqueducts can save hundreds of thousands of dollars for each large flow control station of conventional design eliminated. The first horizontal multijet sleeve valve installation is presently under construction on the Frederick Aqueduct in Oklahoma. It is a 356-mm valve which will deliver 0.23 m^3/s. The shutoff head is 70 m.

Fig. 1. - Laboratory test facility
- L'installation d'essais

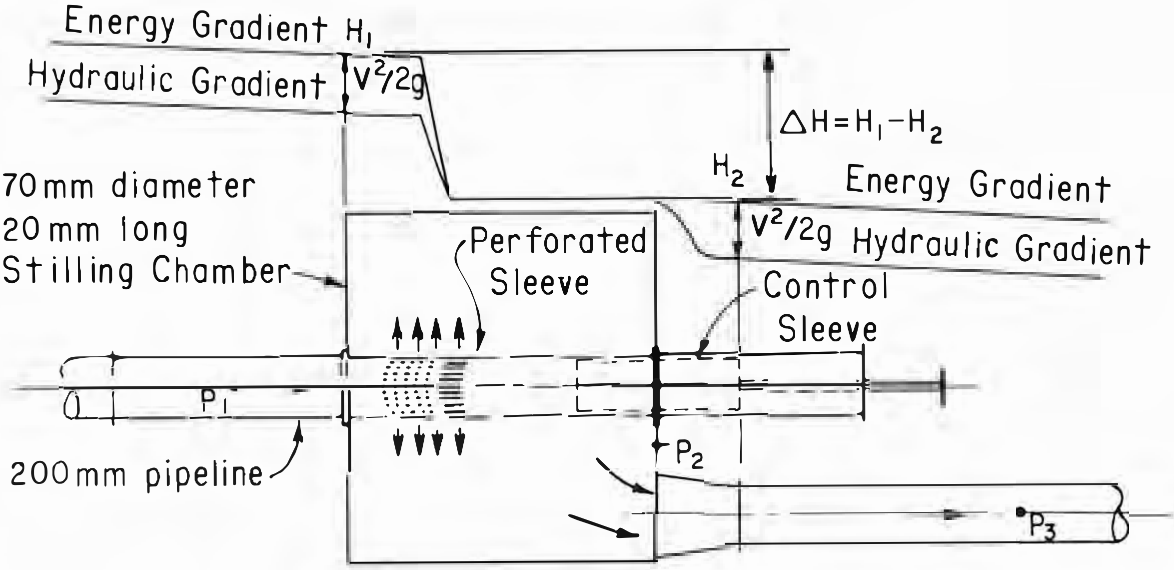


Fig. 2. - Basic concept of valve and stilling chamber
- Schéma de la valve et la chambre de la dissipation

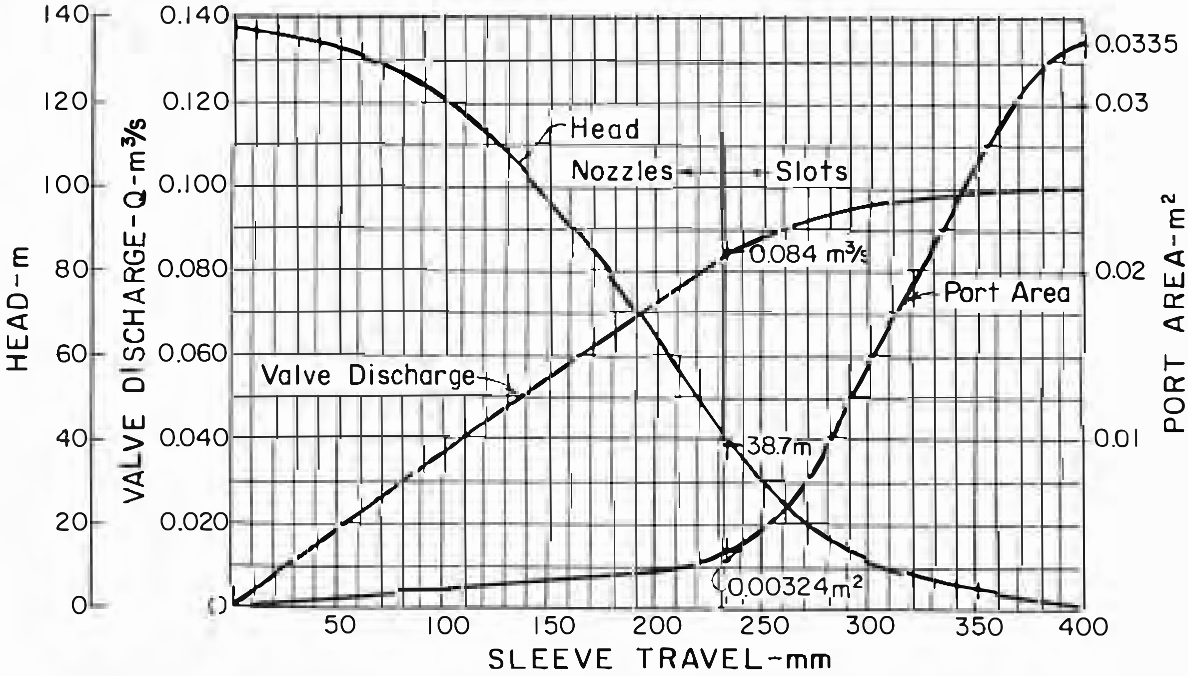
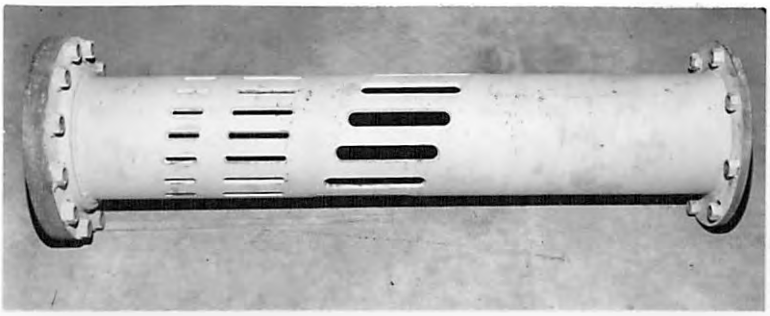
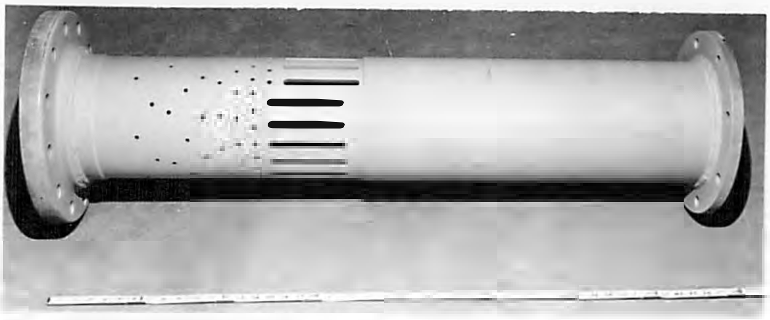


Fig. 3. - Ideal multijet sleeve valve characteristics
- Les traits idéals de la valve manche

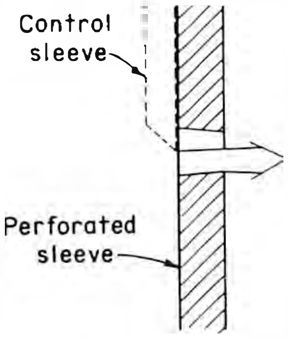


a. - Slotted ports
   - Des fentes

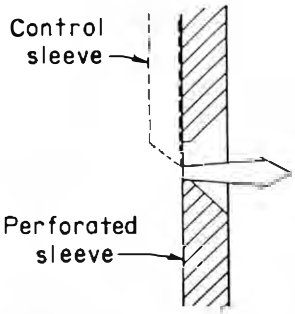


b. - Nozzles and slotted ports
   - Des buses et des fentes

Fig. 4. - Multijet sleeves
        - Les manches multijet



NOZZLE PORT



ORIFICE PORT

Fig. 5. - Nozzles and slot cross sections
        - Les coupes de la buse et de la fente

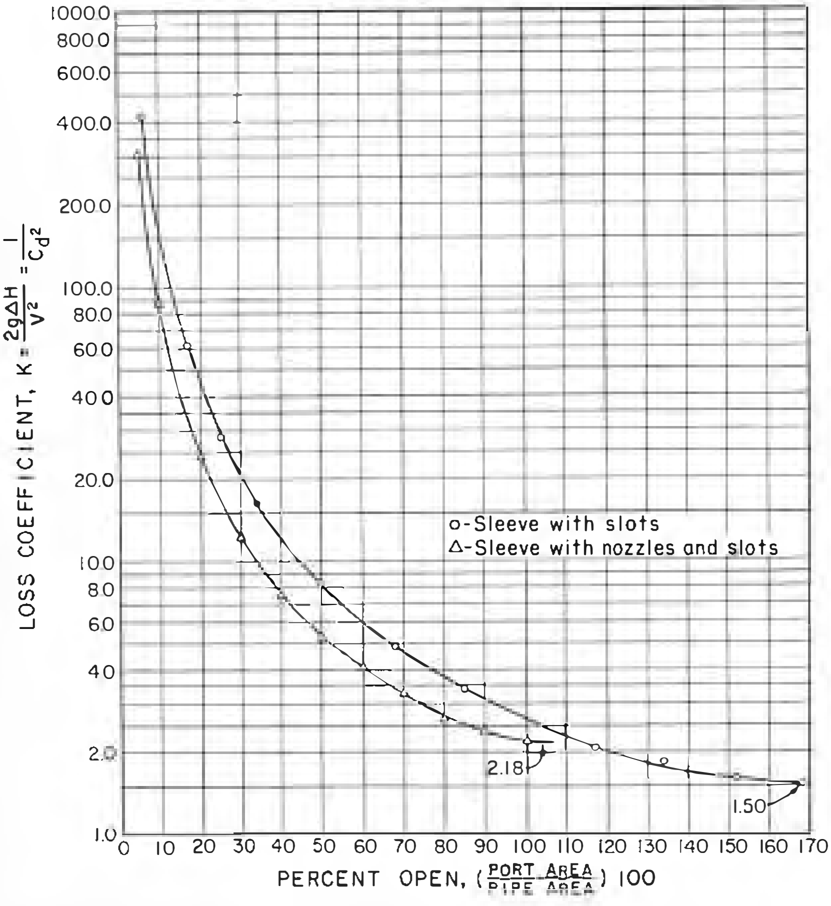


Fig. 6. - Head loss characteristics
        - Les traits du perte de charge

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3. Concentrate on the most important parts of your paper. Do not try to describe everything covered in the written version.

4. Please prepare 5 cm. x 5 cm. slides which show your principal photos, sketches, and graphs, etc. These are very helpful to the audience in understanding your work, and also will be useful to you in guiding you through your presentation.

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6. The allotted time for your presentation will be approximately 10 minutes, with an additional 5 minutes left for discussion of your paper. Please do not exceed your allotted time.

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