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AUTOMATED VALVES FOR SURFACE IRRIGATION PIPELINES^a

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INTRODUCTION

Both buried pipelines and gated pipe are being used more frequently for irrigation. Gated pipe has a number of advantages for delivering and controlling irrigation water to furrows and corrugates. It is a convenient way of distributing water to a field in an automated furrow irrigation system. To automate pipeline systems, valves and controls must automatically sequence irrigation from one turnout or irrigation set to another. Two types of pneumatic valves or closures for controlling the discharge from buried pipeline systems have been developed by Haise, et al. (2). Fischbach (1) extended the development and used a pneumatic bladder or diaphragm inflated with air to automate a surface irrigation pipeline valve. Haise and Payne (3) developed a self-closing valve which operates from water pressure in the distribution pipeline. The Snake River low pressure irrigation valves represent further modifications developed to control the discharge from a field pipeline turnout into either gated pipe or directly into irrigation borders. Three sizes of valves, 6 in. (150 mm), 8 in. (200 mm), and 10 in. (250 mm), have been developed and tested for use in systems operating at pressures up to about 12 psi (83 kN/m²). These are inflated with water from the pipeline and close with water pressure from within the pipe.

IRRIGATION VALVE DESIGN AND CONSTRUCTION

A Snake River valve and two types of water-inflatable bladders are shown in Fig. 1. Valve housing A having male (B) and female (C) pipe couplings

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encloses diaphragm or bladder D (Fig. 2). The bladder is the working part of the valve and consists of a modified small tire inner tube (E) supported on each side by a rubber membrane (F). Bladder D is positioned in the flow area between the front inside surface of valve body or housing A and reaction plate G. Seal rings H and I on these two parallel circular plane surfaces form



FIG. 1.—Snake River Automatic Irrigation Valve Showing Two Types of Water-Inflatable Bladders Used Inside Valve Body

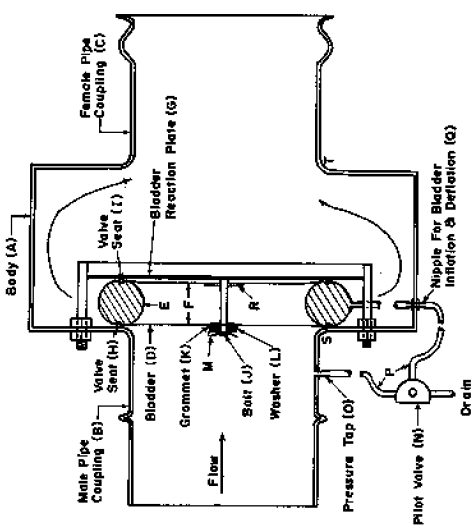


FIG. 2.—Cross-Sectional View of Snake River Low Pressure Irrigation Valve with Type A Bladder

the valve seats. Bladder D is held in place and centered in the flow area by center bolt J, which extends through grommet K in bladder membrane F and is fitted with retaining washer L and cotter key M at its outer end. When the bladder is filled with water from the pipeline, it expands and seals the flow area to close the valve. When the bladder drains, the momentum force

of the flowing water flattens it, and opens the valve. A small three-way pilot valve (N) controls the filling and emptying of the bladder. Water for inflation is supplied from pressure tap O on the upstream side of the valve and conveyed to the pilot valve and bladder through rubber tubing P and nipple Q.

Two types of diaphragms or bladders have been developed. Type A bladders were designed for irrigation systems where the water pressure does not exceed about 4 psi (28 kN/m²) or 9 ft (3 m) of head. The design details for this

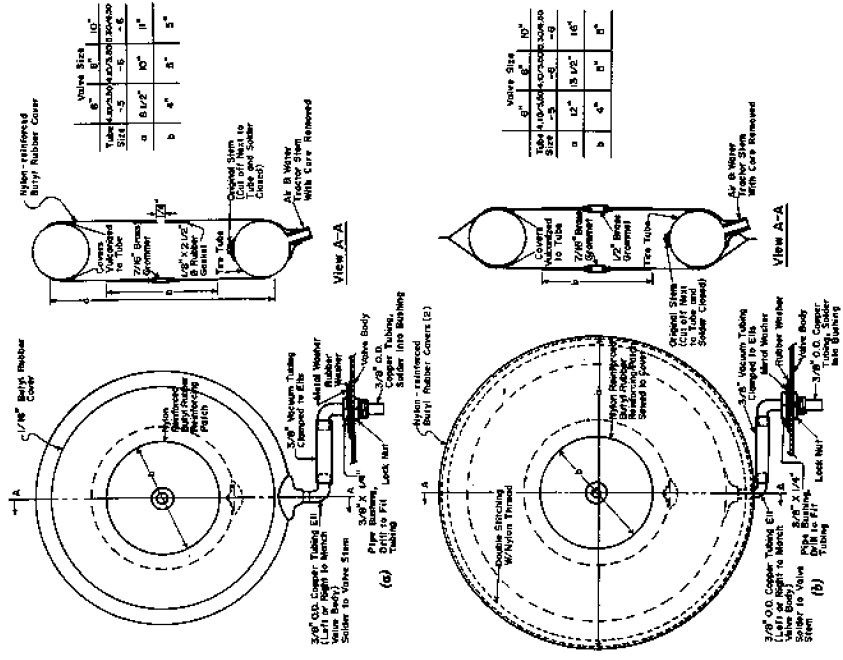


FIG. 3.—Design Information for 6-in. (150-mm), 8-in. (200-mm), and 10-in. (250-mm) Irrigation Valves: (a) Type A Bladders; (b) Type B Bladders

type of bladder for three valve sizes are given in Fig. 3(a) and Appendix I. These bladders have a 1/16-in. (1.6-mm) butyl rubber membrane vulcanized to the upstream side of the inner tube. This membrane has a 7/16-in. (11-mm) grommet (K) and a reinforcing patch in its center. A thin nylon-reinforced butyl rubber membrane is vulcanized to the downstream side of the tube. Rubber gasket R, which fits snugly around center bolt J, is cemented to the inside of this cover.

Type B bladders, designed for irrigation systems with pressures from 4 psi (28 kN/m²) to about 12 psi (83 kN/m²), are constructed with nylon-reinforced butyl membranes enclosing the inner tube. These support the inner tube to prevent it from bursting at the higher pressures. The covers are vulcanized to each side of the tube, have center grommets on both sides, and are sewn on the edges (Fig. 3(b) and Appendix I).

Since the valve is closed with a zero differential pressure between the pipeline and the bladder, the design requirements are different and more exacting than if an external pressure or energy source were used. The diaphragm is designed to allow water to enter the center or interior space of the tube annulus. Thus, the static pressure force of the water in the pipeline is transmitted to reaction plate G behind the bladder. If the static pressure force were supported by the bladder instead of the reaction plate, a seal could not be obtained because the bladder would tend to be compressed and pushed away from upstream valve seat H. The tube membrane covers are vulcanized to each side of the inner tube to prevent leakage between the tube and covers. Cementing the covers to the tube with a special rubber cement was not satisfactory. The type A bladders did not flatten as desired, and the cemented bonds on the type B bladders failed at pressures between 4 psi (28 kN/m²) and 12 psi (83 kN/m²). A laboratory procedure was used for vulcanizing the bladders for the test valves.

The 3/8-in. (9.5-mm) nonthreaded center bolt (J) is attached to the reaction plate. Grommet K on the upstream side of the bladder allows water to enter or exit the interior annular space. The flat retaining washer (L) over the grommet prevents pressure buildup within the interior space by the momentum of the flowing water when the valve is open. However, water can still flow around the washer, as needed, during valve closing and opening. Tests conducted with a crimped washer did not improve performance and indicated that water movement past the flat washer was sufficient.

The rubber gasket (R) on the downstream cover of the type A bladder fits tightly around the center bolt and prevents leakage from the bladder's interior space. Since the downstream valve seat (I) is thus not utilized, the valve is sealed only on the upstream side of the diaphragm, and the opportunity for valve leakage is minimized. Because the downstream cover on the type A bladder is not used for sealing, a smooth bladder surface is not needed. Therefore, this cover is made of nylon-reinforced butyl, which is stronger and less bulky than the 1/16-in. (1.6-mm) upstream cover. This material has a rough surface texture, and does not seal well at very low pressures. However, at pressures exceeding about 4 psi (28 kN/m²) good sealing is achieved with the type B bladder, which uses the nylon-reinforced butyl membrane covers. At lower pressures, the type B bladder may leak slightly, which may not be objectionable and can be minimized by light buffing to smooth the outside surfaces. Thin flat strips or rings of soft rubber also can be cemented or vulcanized on the outside covers where they contact the valve seats to improve sealing at very low pressures.

Obtaining a complete seal without leakage was one of the design problems. Sealing was attempted by providing a relatively wide contact area between the bladder and the smooth interior surfaces of the valve body. However, complete sealing could not be achieved when pump-related pressure surges or pulsations occurred in the pipe. Also, when a streamlined contour or curvature (S) was

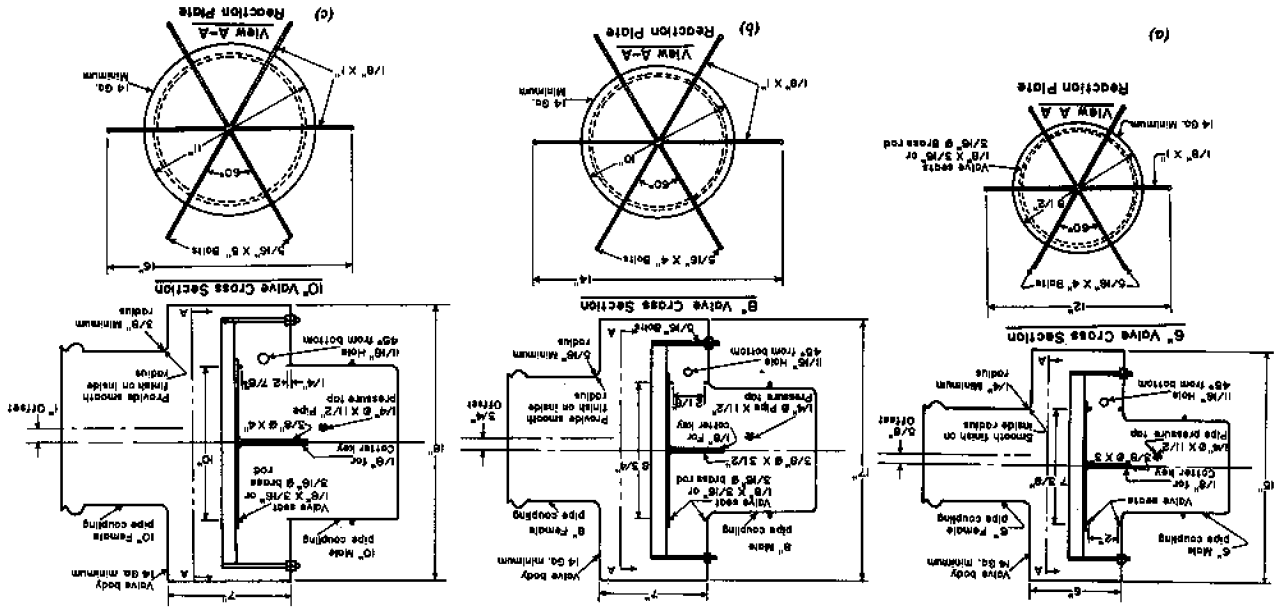


FIG. 4.—Design for Snake River Irrigation Valves: (a) 6 in. (150 mm); (b) 8 in. (200 mm); (c) 10 in. (250 mm)

used between the inlet coupling (B) and the valve housing to reduce the head loss, the contact area was too small and leakage occurred. Since the curvature



FIG. 5.—Automatic Irrigation Valve with 90° Elbow Outlet



FIG. 6.—Multioutlet Irrigation Valve of Alternate Design Configuration

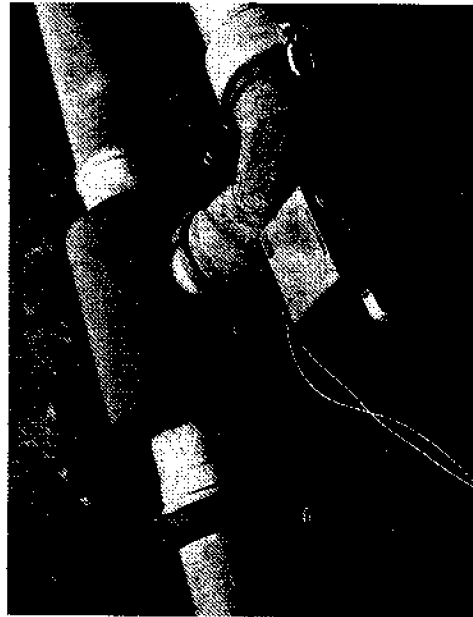


FIG. 7.—Dual Irrigation Tee Valve with Each Outlet Individually Controlled

was desired in the valve design, seal rings or valve seats were necessary to obtain a complete seal. Rubber seal rings cemented directly to the bladders, both on the outside of the cover and between the covers and the tubes, prevented

leakage, but were impractical. Therefore, the valves were made with metal seal rings or valve seats H and I.

A 1/8-in. (3.2-mm) wide steel ring and a 3/16-in. (4.8-mm) diam brass welding rod seal ring were both used to form the circular valve seats. The sharp edge of the 1/8-in. (3.2-mm) seal ring provided a slightly better seal than the round brass ring, but the steel seat was susceptible to rusting and corrosion. The 3/16-in. (4.8-mm) brass rod was used in most of the test valves. The valves were made with both upstream and downstream seats so that both types of bladders could be interchanged, even though the downstream seat is not needed for the type A bladders. The upstream seat on the 10-in. (250-mm) valve was formed by extending the inlet coupling approx 1/4 in. (6 mm) into the valve housing. The end of the coupling, which serves as the valve seat, was smoothed by filing or machining. This type of seat was used for the 10-in. (250-mm) valve because the diameter of the inlet coupling coincided with the mean diameter of the inner tube annulus, which is the required seat diameter. This was a convenient way to form the valve seat; however, a streamlining curvature cannot

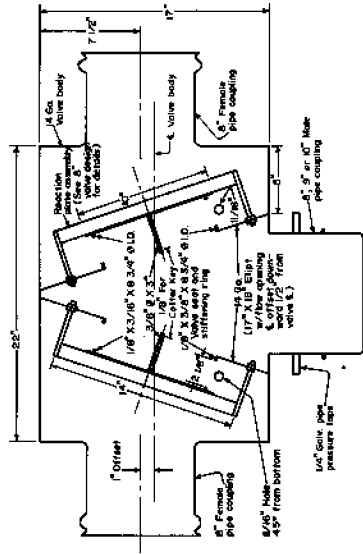


FIG. 8.—Design for 8-in. (200-mm) Dual-Control Irrigation Tee Valve

be used between the inlet coupling and valve body to reduce the head loss. The valve could be made with a curvature on the inlet side if a special diaphragm were used, however, the required size inner tube was not available commercially. The diameters of the 6-in. (150-mm) and 8-in. (200-mm) couplings are smaller than the corresponding mean tube diameters. Therefore, the inlet couplings were not used for valve seats and an inlet radius or curvature could be provided. Rings used for the downstream seat should not be more than about 1/4 in. (6 mm) high because they form a recess, which causes the bladder to become concave-shaped when flattened by the flowing water and increases the head loss.

Designs for 6-in. (150-mm), 8-in. (200-mm) and 10-in. (250-mm) valves are shown in Fig. 4(a), 4(b), and 4(c) (Appendix I). In-line valves with a straight-through flow are shown in the design drawings, however, other designs and configurations, with the outlet(s) oriented differently, were tested in the laboratory. For example, Fig. 5 shows a 90° elbow valve. A tee valve with two outlets can be made by adding another outlet. Fig. 6 shows a multioutlet valve which

has a higher head loss than the valve shown in Fig. 5. A tee valve could have a larger inlet than outlet, i.e., 8-in. (200-mm) inlet with 6-in. (150-mm) outlets, or 10-in. (250-mm) inlet and 6-in. (150-mm) or 8-in. (200-mm) outlets. Each outlet is individually controlled in the dual tee valve shown in Fig. 7. A design drawing for this valve is shown in Fig. 8 (Appendix I).

CONTROLS

The small brass three-way pilot or selector valve (N) is used to control the irrigation valve. It connects the bladder to either pressure tap O for filling or to the atmosphere for draining. A 3-v direct current motor powered by two D-cell batteries operates the pilot valve. The valve, driven by the motor with a stainless steel ladder chain on plastic sprockets rotates 90° from one position to the next. The motor direction is reversed by changing the battery polarity

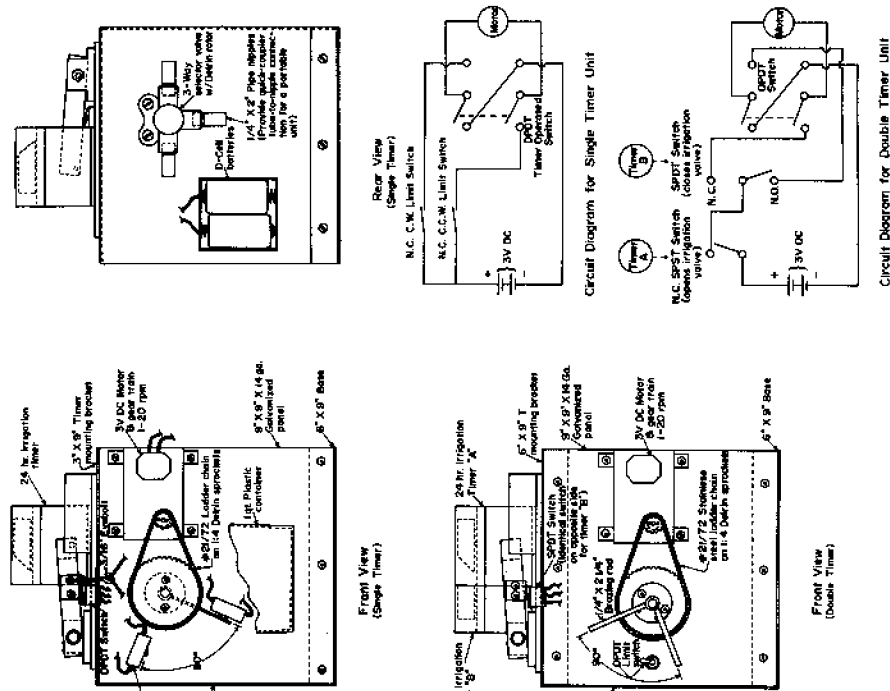


FIG. 9.—Design of Selector Valve Control Units with 24-hr Mechanical Timers (Provide Protective Covering or Coating for Electrical Components)

with a double-pole double-throw (DPDT) switch. The pilot-valve unit is versatile and easily controlled by either mechanical or electronic timers, programmable timer/controllers, or radio transmitters and receivers. The basic control unit using mechanical timers is shown in Fig. 9 (Appendix I). The pilot valve needs to be one that does not take a set or become difficult to rotate when not operated for a time, such as between irrigations.



FIG. 10.—Irrigation Valve and Control Unit with 24-hr Timer to Open Valve and Water-Filled Container to Close Valve

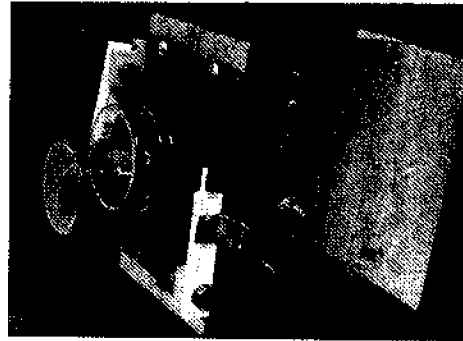


FIG. 11.—Automatic Irrigation Valve with Twin Timer Control Unit (One Timer Opens Valve and Other Closes It)

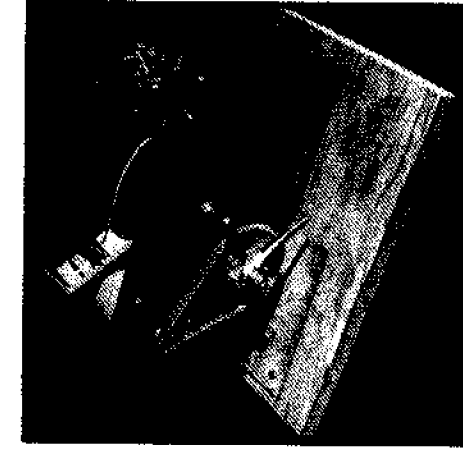


FIG. 12.—Pilot Valve Control Unit Designed for Use with Commercial Programmable Irrigation Controller

A pilot valve control unit with a 24-hr mechanical irrigation timer is shown in Fig. 10. (Obtained from the Brumley-Donaldson Company, Huntington Park, Calif. Reference to a company or product is included for the benefit of the reader and does not imply endorsement or preferential treatment of the product by the U.S. Department of Agriculture.) The irrigation valve is opened when

the timer activates a DPDT switch at the end of the timing cycle and is closed when water from the next irrigation set fills the water container shown. Filling the container activates the DPDT switch to reverse the drive motor. This arrangement can be used when the end of the gated pipe of the next set is adjacent to the valve of the preceding set, i.e., when irrigating in the upstream direction. To close the valve, water flows a short distance through a small tube from the pipe to the container. This eliminates one timer and assures that the next valve is open before the preceding one closes. Instead of using the water container, two timers can be used—one to open and the other to close the valve (Fig. 11).

A pilot valve control unit used with a commercial programmable timer/controller designed for sprinkler or turf irrigation is shown in Fig. 12. The valve control unit uses a 24-v DPDT relay to interface with the controllers which commonly use 24-v alternating current power for their control functions. An improved unit would be completely enclosed.

Laboratory Tests

Tests were conducted in the Irrigation and Drainage Laboratory to determine the valves' flow characteristics. The valves were tested in an open-channel flume with water supplied through a pipe from a constant-head box. Flow rates were measured with 6-in. (150-mm) and 12-in. (300-mm) Gentile flow meters. Pressure taps for measuring head loss were located on the side of the inlet and outlet couplings (B, C) 2 in. (51 mm) upstream and 2 in. (51 mm) downstream, respectively, from the face of the valve body on all valves. Head loss versus discharge curves for 6-in. (150-mm), 8-in. (200-mm), and 10-in. (250-mm) valves are shown in Fig. 13. Head loss is generally linear on a log-log plot except at some low flow rates when the diaphragm may not be completely flattened. Head loss-discharge relationships, with valves and diaphragms manufactured commercially to close tolerances, should be consistent enough for the valves to be used as flow-measuring devices.

The flow characteristics of the valves were greatly improved and the head loss reduced by providing streamlined contours or curvatures S and T (Fig. 2) where the inlet and outlet fittings join the valve body. The amount or radius of curvature that can be formed by cold-rolling the pipe fittings is limited. Flow would be further improved if a larger radius could be formed. A larger radius on the outlet would also reduce the flow contraction that occurs as water leaves the valve.

Flow contraction at the vena contracta in the valve outlet caused negative pressures at high flow rates when valves with straight-through flow were made with inlets and outlets symmetrical about the valve centerline. Only a portion of the resulting high velocity head can be recovered downstream unless a streamlined section of pipe is used. Offsetting the inlet and outlet caused nonsymmetry in the outlet flow, reduced the amount of contraction, and increased the pressure at the downstream manometer tap which reduced the differential head across the valves. When the valves discharged into a pipe where a portion of the velocity head was recovered, the total head loss increased proportional to the offset beyond approx $0.1 d$, in which d = the diameter of the valve coupling. However, when the valves discharged into the open with no velocity

head recovery, the total head loss decreased as the offset increased. As a result of these tests, the valves were designed with the outlet offset approx $0.1 d$ from the valve center line. With this offset, the total head loss was minimized for closed-pipe discharge. At open discharge with the inlet/outlet symmetrical, the contracted jet did not touch the sides of the outlet pipe. With a sufficiently large offset, the outlet pipe was self-priming and flowed full, and the upstream pressure head for a given flow decreased. At high open-discharge flow, the outlet pipe primed easier when the outlet was offset below the inlet. When the valves are used for open discharge, such as in border irrigation, they should be built with an inlet/outlet offset greater than $0.1 d$ which will reduce the required head and lower the exit velocity.

When type B bladders were used with a gasket around the center bolt on the downstream side like the type A bladders, the valves sometimes opened sluggishly and occasionally did not open when used in a pump system at relatively high pressures and low flows. The bladders tended to become self-inflating

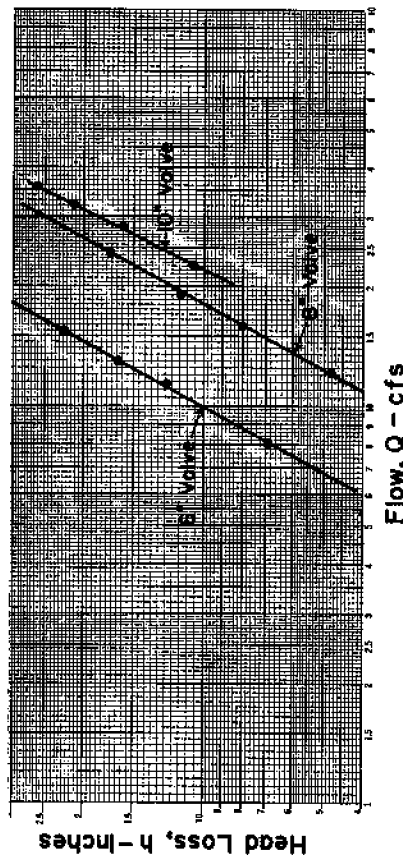


FIG. 13.—Typical Head Loss-Discharge Curves for 6-in. (150-mm), 8-in. (200-mm), and 10-in. (250-mm) Snake River Irrigation Valves with Type A Diaphragms

and did not drain. This problem was corrected by providing a relatively large open grommet on the downstream side of the bladder which allowed the bladder's interior annular space to drain faster. A flat washer with a good fit over the center bolt was needed on the upstream side to prevent water from entering the interior space faster than it could be exhausted through the grommet at the rear.

With clean water, the velocity head can be utilized to obtain a higher pressure for filling the bladder by using a pitot tube on the inlet pressure tap. This increases the pressure slightly and results in faster valve closing. The pitot does not help to make a more positive seal because, with the valve closed, the velocity is zero.

Endurance tests were conducted with water supplied by a pump having a maximum pressure of 12 psi (83 kN/m^2). The valves tested were automatically

opened and closed at approx 2-min intervals. Two of the valves were tested for over 5,000 cycles, while three valves were tested for 2,500 cycles. None of the inner tubes failed; however, a cemented cover on one tube and a vulcanized cover on another had failed at 2,500 cycles. The vulcanized cover failed because of a weakness in the bond, possibly as a result of inadequate surface preparation. Those tested for 5,000 cycles were still in good condition after the test.



FIG. 14.—Auxiliary Pressure Reservoir Used to Supply Water for Closing Irrigation Valves when Pipeline Pressure Is Too Low to Close Valves

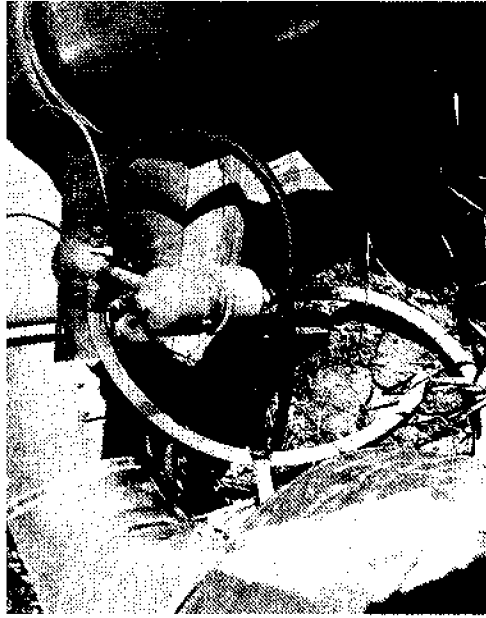


FIG. 15.—Air Collection Chamber Made from Plastic Pipe Used to Collect and Bleed Air from Water Lines

Two types of direct current electric motors used in the control units were also subjected to endurance tests. One unit with the motor completely enclosed in a plastic case failed after 3,500 cycles. The plastic case, which served as a bushing for a gear reduction shaft, became worn and caused the failure. The other unit with a metal case for the gear train, used to cycle the valves during the endurance tests, was still in good operating condition after 18,000

cycles. Thus, apparently the valve control units can have a long service life with normal irrigation use.

Although the valves were designed for an open/close operation, preliminary tests indicated that they can also be used for flow modulation and pressure control. However, for this purpose, controls must be developed and the flow range near the valve-closed position should be avoided because of vibrations that may occur in this range.

FIELD TESTS

Field tests, conducted on Snake River Conservation Research Center plots during 1972, were used to modify and improve the valves. The Snake River valves and gated pipe were used in 1973 to irrigate a field of corn with automatically cutback furrow streams. The field was divided so that each half could be irrigated in one irrigation set using every other row irrigation. Two automatic valves were used, one for each set. The valves were controlled by an experimental electronic timer developed at the Research Center. One-half of the field was irrigated until water in the furrows reached the end of the field and then the other half was irrigated until runoff occurred. The timer-controller then reopened the first valve so that the water supply was distributed evenly across the entire field, giving a cutback flow. After the first irrigation following planting or cultivation, the time required for the relatively large primary flows to advance to the end of the field was consistent enough so that a set time could be used on the timer. Both valves operated without any malfunction during the season, although some difficulty was experienced with the timer. The timer problem has since been corrected with a new design.

The valves were also used to irrigate beans with an experimental multiset system in 1973. A commercial irrigation controller was used to control the valves, using the pilot valve control unit shown in Fig. 12. The beans were irrigated 34 times with short frequent irrigations. Although the valves performed very well, some difficulty was experienced with the DPDT switches on the control units. They have since been replaced with a different type of switch.

Occasionally, with small flows, when two valves were both open at the same time or when one valve was opening while the other was closing, the pressure in the pipe dropped enough to prevent the valves from closing. Normally, the valves closed with the hydraulic grade line as low as 2 in. (51-mm) above the top of the valve. However, when the hydraulic grade line dropped below this elevation, the valves did not always close. This problem was corrected by using a small reservoir to supply the water needed to close the valves. A small container, placed on a block or stand adjacent to the valve (Fig. 14), was filled with water when the hydraulic grade line in the pipeline was at a higher elevation than the container. The top of the reservoir container was equipped with an air-bleed valve which permitted air to enter and leave the container but prevented water from escaping. Between valve operations the reservoir automatically filled and always maintained a pressure head sufficient to close the valves.

Air occasionally collected in the water lines during the field tests and blocked the flow of water to and from the bladder. This problem was corrected by using an air collection chamber (Fig. 15). A petcock at the top of the chamber was used to bleed air from the lines when they were first filled and also to periodically bleed air from the chamber.

SUMMARY AND CONCLUSIONS

Snake River automatic irrigation valves have been developed to control the discharge from a field pipeline turnout into either gated pipe or directly into irrigation borders. The low pressure valves are designed to operate with water from the irrigation pipeline at pressures up to approx 12 psi (83 kN/m²). Two types of water-inflatable bladders are used to open and close the valves. Design information for 6-in. (150-mm), 8-in. (200-mm) and 10-in. (250-mm) valves is presented. The valves can be built in different configurations, such as in-line with straight-through flow, elbow, or tee valves with multiple outlets.

Small three-way pilot or selector valves are used to control opening and closing of the irrigation valves. The pilot valve is operated by a 3-v d-c battery-powered motor. The motor/pilot-valve unit is versatile and can be used with mechanical and electronic timers, commercial irrigation controllers, or radio transmitter/receiver units.

The automatic valves, with an experimental electronic timer, were field tested using gated pipe to irrigate corn with automatically cutback furrow streams. They were also used with a commercial irrigation controller to irrigate beans with short frequent irrigations.

The valves and their associated controls can operate independently without an outside energy source. Their use can increase worker productivity and give better control of farm irrigation water, particularly when used with gated pipe in furrow irrigation systems. Use of automatic irrigation controls may be the most feasible way to achieve better on-farm water control without increasing labor input.

ACKNOWLEDGMENT

This is a contribution of the Western Region, Agricultural Research Service, U.S. Department of Agriculture; University of Idaho College of Agriculture Research and Extension Center, Kimberly, Idaho, cooperating.

APPENDIX I.—SUPPLEMENTAL DESIGN INFORMATION

Design details for the type A bladders for 6-in. (150-mm), 8-in. (200-mm) and 10-in. (250-mm) valves are shown in Fig. 3(a); those for the type B bladders are shown in Fig. 3(b). The large-core air-and-water tractor tire valve stem attached to the bottom of the tube, as shown in the drawings, is needed to allow rapid filling and draining of the bladders. When small conventional valve stems were used, the valve closed slower and, under certain conditions, did not open properly.

Designs for 6-in. (150-mm), 8-in. (200-mm) and 10-in. (250-mm) valves are shown in Figs. 4(a), 4(b), and 4(c). The spacings between the valve seats, as shown in the drawings, are the maximum recommended because sealing becomes more difficult with wider spacings. The housings or bodies for the test valves were made from 14-gage steel with a male pipe coupler on the inlet and a female coupler on the outlet. The valves can also be made from aluminum, plastic, or other suitable material. Steel valves should have a protective coating to prevent rusting and corrosion. The valves are installed in the field

with the bladder valve stem and drain positioned at the bottom to facilitate draining of the bladder.

An 8-in. (200-mm), dual-control, tee valve is shown in Fig. 8.

Drawings of pilot valve control units with 24-hr mechanical timers and the associated electrical wiring diagrams are shown in Fig. 9.

APPENDIX II.—REFERENCES

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