

# **Best Practice Catalog**

## *Shut-Off Valves*



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## 1.0 Scope and Purpose

### Major Valve Applications in Hydropower facilities [1]

There are various applications of valves in hydropower facilities. It is necessary to first describe different types of major valves to clarify the scope of this best practice document. Based on the functions and services that valves provide, the major valves in a hydropower facility can be categorized as shut-off valves, energy dissipating valves, flow control valves, pressure control valves, air/vacuum valves, and bypass valves. Their functions and major features are addressed as follows:

- (1) Shut-off valves (also known as closure valves) – They are often installed at the downstream end of a conduit or penstock, e.g., the inlet of the turbine scroll case. The turbine inlet valve is used to shut off water supply to the turbine, allowing turbine dewatering for inspection and maintenance without dewatering the penstock. This feature is desirable for long penstock and high-head cases, particularly when two or more units share a common penstock. This turbine inlet valve is also used to cut off the water flow and stop the unit when the wicket-gates fail to close; particularly at the emergency situation of load rejection and wicket-gate malfunction. Butterfly valves, spherical valves, and cone valves are the most commonly used turbine closure valves in medium-large scale hydro plants. Butterfly valves are used for the heads up to 122 meters (400 feet). Spherical valves are used for heads up to 1200 meters (4000 feet). Cone valves can be used for heads up to 1750 meters (5700 feet).
- (2) Energy dissipating valve – Water may be released from a reservoir through low level outlet(s) for reservoir level control, downstream water demands, or minimum stream flow requirements. Efficient energy dissipating valves were developed to improve the operating characteristics and lessen stringent stilling basin requirements. Fixed-cone dispersion valves are often used for controlling free discharge for heads up to 300 meters (1000 feet). Sleeve valves used to dissipate the head in a closed system without cavitation damage (for heads up to 30 meters).
- (3) Flow control valves – For large water conduits, energy-dissipating valves control the flow of water while simultaneously breaking the head in the releases. Fixed-cone dispersion and hollow-jet valves are used to control releases from low-level outlets, while sleeve valves are used for flow control in “in-line” piping systems. The flow control valves are also used to regulate the flow of water to the runner in impulse-type hydroelectric turbines (needle valves, as one part of Pelton turbine, are not discussed in this BP). Although shut-off valves may be used to throttle flow, they are normally not designed for continuous flow rate control.
- (4) Pressure control valves – Pressure control valves can be further categorized as pressure-relief, pressure-regulating and pressure-regulator valves. The pressure-relief valve opens

when the pressure acting on the valve reaches a preset value; it is often used as safety device on air pressure tanks and on governor pressure set accumulators. Pressure-regulating valves are often used to provide a regulated (constant) pressure source of air, oil, or water in hydro facilities, by reducing their openings as upstream pressure rises. For example, when the penstock or unit inlet is the source of the powerhouse cooling water, a pressure-regulating valve could be used to reduce the inlet pressure to the required cooling water system pressure. The pressure-regulator valve is applied for transient control, which opens to discharge the penstock flow simultaneously with rapid wicket gate closure. This permits the penstock flow to remain relatively constant during the load rejection. Flow control valves are commonly used for pressure-regulator service.

- (5) Air/Vacuum valves – They are provided in piping systems to exhaust air from a penstock system or spiral case, or to fill a vacuum to prevent conduit collapse.
- (6) Bypass valves – They are applied where water is conveyed around a turbine, powerhouse, or dam. Energy-dissipating and pressure-regulator valves are often used in bypass piping lines. Needle valves and other valve types are also used in bypass lines to balance the pressure across large butterfly or spherical valves before they are opened or closed.

### **Scope and Purpose of This Document**

As the smaller valves on common mechanical piping systems have no difference to other applications, this document focuses on the major valves typically applied in power water conveyance systems at conventional hydropower plants. Therefore, this best practice will only look at the shut-off valves installed at penstocks or power water conduits, including butterfly valves, spherical valves, cone valves, and knife gate valves. The document addresses their technology, condition assessment, operations, and maintenance best practices with the objective to maximize performance and reliability.

## **1.1 Hydropower Taxonomy Position**

Hydropower Facility → Water Conveyance → Control/Shut-off Valves

### **1.1.1 Butterfly Valve Components**

Butterfly valves use a disc that rotates ninety degrees to open and close the valve.

Performance and reliability related components of a butterfly valve consist of the valve body, valve seal, and the disc.



**Figure 1: Butterfly Valve Example**

Valve Body: The valve body's purpose is to house the disc and attach the valve to the piping system. Typically, the body has flanged connections to facilitate dismantling.

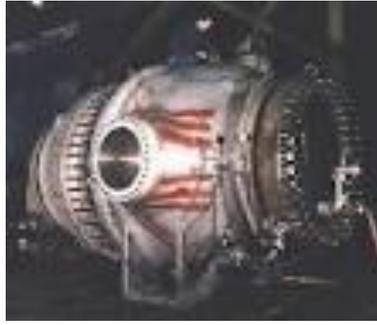
Valve Seat: The valve seat is on the contact portion of the valve body and is usually made of flexible materials such as rubber or nylon, or metals like bronze or stainless steel. The purpose of the seat is to seal the valve to prevent leakage through the valve when closed. In high performance butterfly valves, the seat is offset from the shaft, therefore not penetrated by the shaft. In triple-offset high performance butterfly valves, metal seats may be used. In the triple-offset design, the seal contacts the seat only at the fully closed position, without rubbing.

Disc: The function of the disc is to control the amount of water running through the pipe. Because the disc is always present in the flow, there will always be a head loss across the valve, even when the valve is fully open.

### **1.1.2 Spherical Valve Components**

Spherical valves are valves that use a rotor, shaped like a ball, to stop or start the flow of fluid. When the valve is opened, the ball rotates so the hole through the ball is in line with the valve body inlet and outlet. When the valve is shut the ball is rotated so the hole is perpendicular to the flow openings of the valve body, and flow stops.

Performance and reliability related components of a spherical valve consist of the body, rotor, and the seals.



**Figure 2: Spherical Valve Example**

Body: The function of the body is to house the rotor and connect the valve to the rest of the piping. The body is typically made of two or more flanged sections.

Rotor: The rotor has a cylindrical hole through it which controls the flow through the valve. When open, the rotor is parallel to the flow direction, leaving the flow completely unrestricted. To cut off the flow through the valve, the rotor is turned 90° perpendicular to the flow.

Seals: The seals reduce leakage through the valve. Spherical valves are recommended to have both upstream and downstream seals, where the downstream seal is the service seal. The upstream seal is used for maintenance, such as replacing the service seal. Typically, the seals are actuated with penstock water pressure.

### **1.1.3 Cone Valve Components**

Cone valves are similar to spherical valves in that they have a plug which contains a full-bore passage when open. The plug is cone shaped and is lifted from the seats and turned ninety degrees to actuate. Metal-to-metal seats are standard.



**Figure 3: Cone Valve Example**

Performance and reliability related components of a cone valve consist of the body, plug, and the seals.

Body: The function of the body is to house the plug and connect the valve to the rest of the piping. The body is typically cast of iron or steel. The body contains two seat rings.

Plug: The plug is cast in the shape of a frustrum of a cone and has a full bore passage with seats which mate to the body in either the open or closed position.

Operator: (not shown in Figure 3) The operator may be manual, electric powered, hydraulic powered, or pneumatic powered.

#### **1.1.4 Knife Gate Valve Components**

Knife gate valves use a plate which moves linearly into and out of the flow path to close and open the valve.



**Figure 4: Knife Gate Valve Example**

Performance and reliability related components of a knife gate valve consist of the body, gate, seats, packing, and operator.

Body: Valve bodies are typically cast stainless steel up to 24", and fabricated in larger sizes. Wafer and lugged (shown in Figure 4) bodies are available. End to end dimension is small compared to spherical and cone valves.

Gate: Fabricated from plate, with edges and surface finished for sealing at the packing and seats.

Seats: Where the gate meets the body when closed. Can be metal, which can leak a small amount, or resilient which are designed to be drip-tight.

Packing: Seals around the gate where the gate exits the body. Packing and packing gland are relatively large on a non-bonneted valve as shown in Figure 4. Bonneted valves are available which fully enclose the gate, including when the valve is open, and only the operating stem must be sealed. Rising stem and non-rising stem designs are available.

Operator: Manual, electric, hydraulic, and pneumatic actuation is typical.

## **1.2 Summary of Best Practices**

### **1.2.1 Performance/Efficiency & Capability-Oriented Best Practices**

- As an integral part of the penstock, routine monitoring of head loss through penstocks includes valves.
- Routine monitoring to ensure that valves are in the correct position, e.g., fully open when intended and fully closed when intended.
- Routine monitoring to ensure that valve actuators function, and time to open and close is as specified.
- Maintain documentation of Installed Performance Level (IPL) and update when modification to equipment is made.
- Include industry acknowledged “up to date” choices for valve components’ materials and maintenance practices.

### **1.2.2 Reliability/Operations & Maintenance-Oriented Best Practices**

- Develop a routine inspection and maintenance plan.
- Regularly inspect joints for leakage.
- Valves should be used within the specified pressure-temperature range. Spherical valves are capable of entrapping fluid in the internal cavity, which if heated can cause a rise in pressure. It must be ensured that in this condition, the pressure in the valve does not exceed the rated pressure for the attained temperature.

## **1.3 Best Practice Cross-references**

- I&C - Automation Best Practice
- Civil – Penstock/Tunnel/Surge Tank best Practice
- Mechanical - Lubrication Best Practice
- Mechanical - Generator Best Practice
- Mechanical – Governor Best Practice
- Mechanical – Raw Water System Best Practice

## 2.0 Technology Design Summary

### 2.1 Material and Design Technology Evolution

Butterfly valves are from a family of valves called quarter-turn valves and it derives its name from the way that a “butterfly-shape image” appears to form as it turns. The "butterfly" is a metal disc mounted on a shaft. When the valve is closed, the disc is turned so that it is tightly pressed against the seats, sealing off the passageway. When the valve is fully open, the disc is rotated a quarter turn so that it allows an almost unrestricted passage of the process fluid. The valve may also be opened incrementally to regulate flow. Unlike a ball valve, the disc is always present within the flow; therefore a pressure drop is always induced in the flow regardless of valve position [3].

Resilient seated butterfly valves were developed first. High performance butterfly valves, in which the shaft and seat are offset, were the next. Triple-offset high performance butterfly valves are the most advanced design. Triple-offset butterfly valves are utilized for high pressure and temperature conditions, and can have resilient or metal seats.

Spherical valves are specialty items, typically designed for the individual application. They are made for high pressure, high velocity, and large diameter applications found in hydroelectric facilities.

Spherical valves, on the other hand, have not been around nearly so long. A spherical ball-type, all-brass valve patented in 1871 led to the invention of the modern ball valve. Unfortunately, the valve was not successful and was not even mentioned in valve catalogs of the late 1800s. Nearly 75 years later, the first resilient seated ball valve patent was issued in April 1945. However, ball valves were not commercially available until the late 60s [6].

### 2.2 State of the Art Technology

In order to enhance the performance of valves, computer aided design (CAD) software is now used throughout the design process. Companies utilize top-of-the-line solid modeling software and finite element analysis programs to calculate stress and deflection of the valve components. With this information, developers can include proper relief and stress factors to assure a long valve life.

Another advantage to CAD software is that it can then be loaded onto a computer numerical controlled (CNC) machine. These machines can fabricate valves with tremendous precision and consistency.

### 3.0 Operation and Maintenance Practices

#### 3.1 Condition Assessment

After the commercial operation begins, how the valves are operated and maintained will have a huge impact on maintaining reliability. Condition assessment of the valves must address any past damage, location of damage, and repeat damage.

Typical valve distresses include the following:

- Shaft assembly wear, indicated by displacement between the shaft and bushing
- Seal condition
- Corrosion, usually caused by environmental factors, is suggested by loss of steel
- Cracking, found during dry inspection
- Abnormal noise/jumping/vibration, discovered during valve operation [7]

For spherical valves, close attention should be given to the condition of the seals.

#### 3.2 Operations

Butterfly valves cause a head loss in the flow through the valve. Head loss increases as design pressure or head increases because the disc and shaft size increase with pressure. Although head can be significantly reduced across partially open butterfly valves, prolonged throttling operation is not recommended as it can result in cavitation damage to the disc, seal, or body [1].

On spherical valves, moveable seals reduce leakage when the valve is closed. Valve opening and closing sequencing controls should preclude seal damage by valve rotation when seals are extended. It is recommended that spherical valves have both upstream and downstream seals. The upstream seal should be used as the maintenance/emergency seal and the downstream seal should be used as the service/working seal.

Rapid valve closure can result in damaging pressure transients. Opening/closing times and operating pressures should be recorded for future testing comparison.

During plant operations, it is important to routinely inspect the exterior surfaces of valves for signs of leakage while the valves are under hydrostatic pressure. If any leaks are discovered, the source should be promptly identified and repair performed.

#### 3.3 Maintenance

In order to avoid valve failure during operation, all valves should be periodically inspected to determine wear of the components and replace parts accordingly. The working conditions

and location of the valves should determine the frequency of the inspection and maintenance. The valve manufacturer should have information on how to best maintain their valves.

For spherical valves equipped with both upstream and downstream seals, the upstream maintenance seal allows replacement or maintenance of the working seal when the valve is closed under full pressure. However, the upstream seal should have a positive mechanical locking system on the seals to prevent accidental opening while working on the downstream seal [1].

#### **4.0 Metrics, Monitoring and Analysis**

##### **4.1 Measures of Performance, Condition, and Reliability**

For shut-off valves, the measure of performance is a direct result of their functionality. The purpose of the valves is to stop the flow of water and keep water away from the portions of the system being isolated. Each valve and its associated actuator must be able to fully open and close within the intended time.

Plant efficiency is not greatly affected by shut-off valves because the valves are normally a small fraction of the total water delivery system. It is important that these valves function properly not necessarily for efficiency, but for safety. Equipment and workers performing tasks in dewatered portions of the plant must be protected. Valve leakage can be tolerated as long as safety and equipment protection are not compromised.

Leakage rates should be measured and recorded. Large valves, even those designed to be drip tight when they are new, may leak after years of service.

##### **4.2 Data Analysis**

Leakage through shut-off valves can be tolerated as long as equipment protection and safety are not compromised. Relatively small amounts of leakage can be tolerated and handled by pumping water out of areas where maintenance will be performed. However, if pumping becomes excessive, the cost of new seals or other corrective actions may be justified.

##### **4.3 Integrated Improvements**

The field test results for leakage and actuator stroke time should be included when updating the plant's unit performance records. These records shall be made available to all involved personnel and distributed accordingly for upcoming inspections.

#### **5.0 Information Sources:**

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*It should be noted by the user that this document is intended only as a guide. Statements are of a general nature and therefore do not take into account special situations that can differ significantly from those discussed in this document.*

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