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HYDRO APPLICATIONS FOR THE THROTTLING KNIFE GATE VALVE

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The ancient Romans were renowned for their communal baths and the aqueducts that supplied them water. To control the flow of water in the latter, the first hydraulic engineers fashioned structures out of piled boards that spanned the channel. These first-generation water control devices came to be known as sluice gates.

Centuries later, in 1307, the first falling knife device was introduced to remove the head of Murcod Ballagh near Merton, Ireland (the French didn't stake a claim to the guillotine until 1789).

What do these two seemingly disparate inventions have in common? They led to the development of the modern-day throttling knife gate valve.

This article explores the history of the conventional wedge gate valve as an outlet valve on hydroelectric projects and why many are being replaced today. It also discusses how the throttling knife gate valve is being increasingly specified for use as an inlet valve, guard valve and regulating outlet valve on low- to medium-head dams, as well as a temperature-regulating valve on multi-level inlet works.

Gate Valves in Early Hydro Applications

When the first hydroelectric power station in the U.S. was constructed in 1882 near Appleton, Wis., the predominant valve specified for municipal and industrial applications was the conventional wedge gate valve, which was commonly used to control high-pressure steam and low-pressure water. It therefore stood to reason that when early hydropower engineers needed a valve to release water from the sluice outlets of reservoirs, they often chose this simple, proven valve.

The conventional wedge gate valve was a common outlet valve in the early days of hydro.

Although the conventional wedge gate valve appeared to perform adequately as an open-close sluice valve on low-head hydroelectric projects, as dams grew taller and as sluice outlets morphed into regulating low-level outlets (LLO), operators began hearing what sounded like gravel passing through the valve and a metal-against-metal clanging. What was causing this, and was it something to be concerned about? As it turned out, it was.

Discovering Cavitation

As the U.S. hydro industry was ramping up in the mid-1900s, operators at several major federal projects discovered a damaging water/air/pressure phenomenon known as cavitation. Large swaths of concrete were scoured from tunnel walls, and the surfaces of heavy steel slide gates appeared as if they had been shot-peened. Although the cavitation damage was found to primarily occur in the vicinity of slide gates or at discontinuities in tunnels and conduits, conventional wedge gate valves installed in the outlets of many smaller projects were also affected.

Cavitation occurs when high-velocity water is disrupted by a surface protruding into the flow stream. For a gate valve, the most common place for this to occur is immediately downstream of the gate leaf in a partially open, or throttling, position. At this location, the water has just passed the point of maximum velocity pressure within the flow stream, known as the vena contracta (see Figure 1).

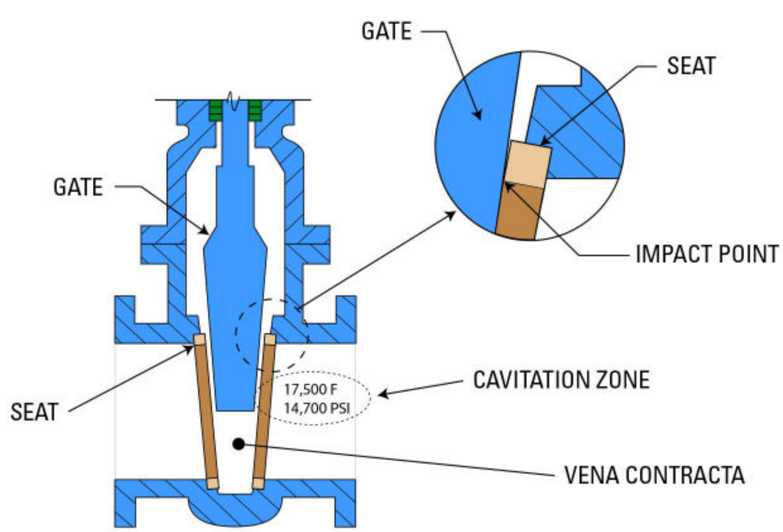

Figure 1: A conventional wedge gate valve makes a poor throttling valve

High-velocity pressure equates to low static pressure. If the static pressure falls low enough, the air entrained within the water comes out of solution in the form of micro bubbles. As the flow stream passes through the vena contracta, the static pressure instantly increases, forcing the bubbles to collapse violently. The temperature and pressure associated with the collapsing bubbles has been measured as high as 17,500 degrees Fahrenheit and 14,700 psi, eventually leading to failure of the valve and surrounding conduit surfaces.

Besides strain-hardening the valve and conduit surfaces to the point of failure, the pressure forces caused by the collapsing bubbles can cause the gate leaf to oscillate. The "gravel" early operators heard flowing through their sluice outlet valves was the sound of bubbles collapsing, and the metal hammering was the gate leaf bouncing against the seat.

These two damaging phenomena — cavitation and vibration — resulted in the understanding that the conventional wedge gate valve makes a poor throttling valve.

Conquering Cavitation

Faced with major, costly damage caused by cavitation at several of their large hydro facilities, engineers at the U.S. Department of Interior's Bureau of Reclamation got to work in the 1940s to develop an understanding of what was causing the damage and, more importantly, how to prevent it from occurring. Among the several remediating solutions developed, introducing air immediately downstream of the vena contracta proved to be one of the most simple and cost-effective. The introduction of air at atmospheric pressure prevents the formation of low static pressure (vacuum) that draws the entrained air out of solution. No bubbles, no damage.

Reclamation applied this new knowledge of cavitation in its development of the jet flow gate in the mid-1940s. The jet flow gate possessed a number of unique features that advanced outlet valve technology, including a floating bronze seal ring that was fully supported by the leaf throughout its travel and an oversized outlet and vent that allowed atmospheric air to reach the vena contracta. It also shared the rectangular, beveled leaf edge of a valve widely used in the pulp and paper industry: the knife gate valve.

The Poor Man's Jet Flow Gate

Beginning in the 1970s, dam operators found themselves increasingly being required to control the release of water from their reservoirs to comply with regulatory requirements to enhance fish habitat and recreational use downstream of the dam. This often resulted in the need to throttle the LLO valves, many of which were vintage wedge gate valves and not suitable for the reasons previously outlined. Around this same time, a manufacturer of knife gate valves in Redmond, Wash., Hilton Valves — which also designed and fabricated jet flow gates — noticed the design similarities between the two. Recognizing the need for an economical, lower-head alternative to the high-head jet flow gate, the chief engineer at Hilton, George Stevenson, joined forces with retired Reclamation engineer Lee Gerbig to conceive the throttling knife gate valve, a valve they initially dubbed "the poor man's jet flow gate."

The Hilton throttling knife gate valve shares the rectangular, beveled leaf edge of the jet flow gate, a gate that remains in contact with the seat over its complete travel. It also has an oversized outlet that, like the jet flow gate, allows atmospheric air to reach the vena contracta (see Figure 2).

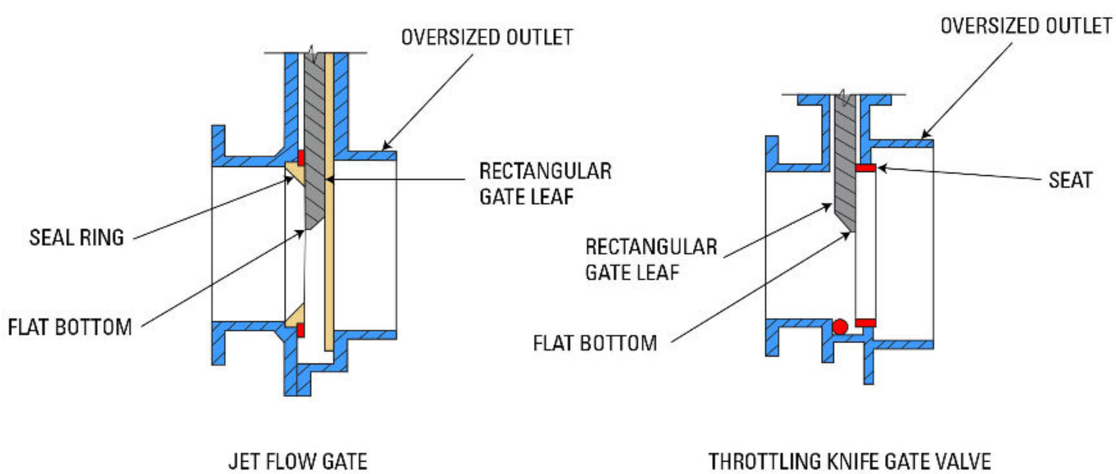

Figure 2: The throttling knife gate valve shares several design features of the jet flow gate.

Although early designs positioned the gate leaf downstream of the seat (to mimic the seat-to-leaf arrangement of a jet flow gate), later designs repositioned the leaf upstream of the seat to its conventional location in a knife gate valve. If the valve needs to be installed some distance upstream of the LLO outfall, a vent is installed within one pipe diameter of the gate leaf to admit air and prevent cavitation. To reduce the galling potential between the stainless-steel gate leaf and seat, the latter is fabricated from Nitronic 60 alloy.

The throttling knife gate valve is an economical outlet valve for low head dams. This 48-in throttling knife gate valve at Tiger Creek Afterbay Dam in northern California satisfies instream flow requirements.

Besides being more cost effective than the fixed cone valve and jet flow gate at heads less than 230 feet, other desirable features of the throttling knife gate valve include its high 0.95 coefficient of discharge (Cd), simple ruggedness and relatively compact face-to-face dimension of the valve. The throttling knife gate valve is not limited to use as an outlet valve. It can also serve as a guard valve in applications where the operating head is less than 230 feet if it needs to close against flow (higher if it will only be closed under a balanced head). It has even been submerged in the inlet works of a reservoir as an inlet valve.

There are other companies that offer similar valves to the Hilton throttling knife gate valve, but they can go by different names. Some have a square gate knife gate, which is one of the key features that allows the valve to throttle. Others' valves may or may not have the oversized discharge or vent. These are often custom-fabricated valves, so special construction options can be included based on customer application requirements.

Tempered Discharge Applications

Most recently, throttling knife gate valves are being specified for use as inlet valves in multi-level inlet works designed to temper the water discharged through the LLO by withdrawing water from different thermoclines within the reservoir (see Figure 3). In this case, the valve is fabricated from solid stainless steel and actuated with hydraulic cylinders supplied by a remote hydraulic pressure unit (HPU).

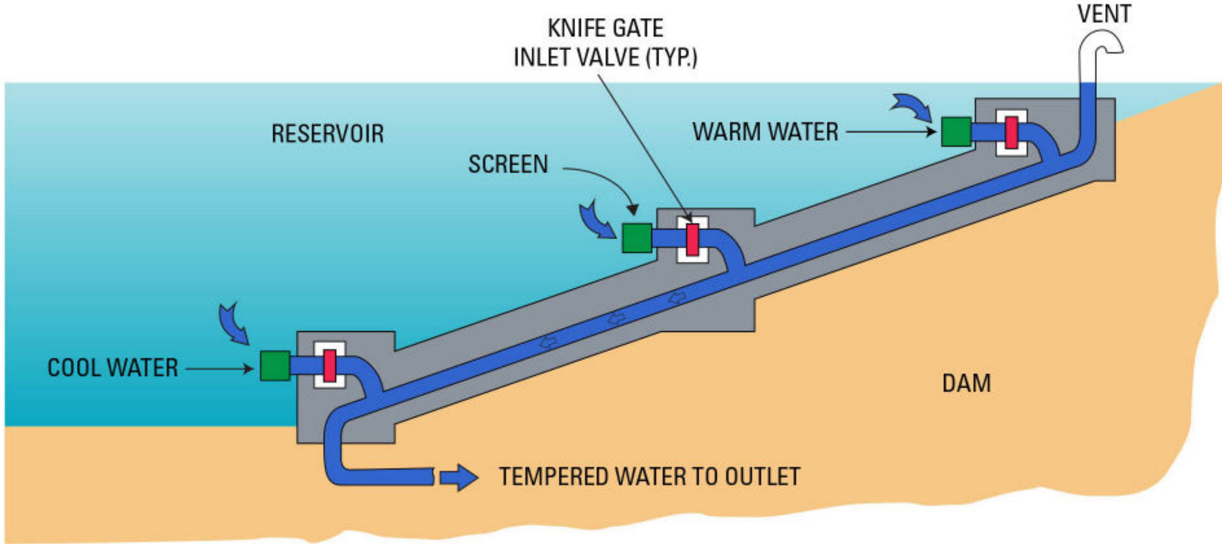

Figure 3: Knife gate valves make ideal inlet valves on multi-level inlet works to supply tempered water downstream

Case study at Ralston Dam

Denver Water's Ralston Dam was constructed in the mid-1930s. The reservoir's outlet works consisted of an upstream pivot valve, intermediate slide gate and downstream fixed cone valves. The pivot valve was submerged in 167 feet of water at the bottom of the embankment dam and protected by a trashrack structure. Operating the pivot valve became problematic in the 1970s, resulting in the valve being abandoned in the open position, with the intermediate slide gate being the sole inlet valve for over 40 years.

In 2020, Denver Water contracted with DeZURIK-Hilton to design and fabricate a 66-in hydraulically actuated throttling knife gate valve to replace the pivot valve. The new throttling knife gate valve provides the ability to drain the entire outlet works for inspections and maintenance and also serves as a guard valve for the downstream fixed cone valves. It is remotely powered from the top of the dam by an HPU also designed and fabricated by DeZURIK-Hilton.

Conclusion

Although conventional engineering wisdom holds that gate valves are not to be used to throttle flow, not all gate valves are the same. The throttling knife gate valve has a proven record in the hydro industry when installed in inlet and outlet works as a guard valve or intake valve, or as an economical alternative to the fixed cone valve or jet flow gate in low- to medium-head applications.

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