Valve Selection in Severe Abrasive Service









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A Note About the Authors

As the President of CGIS, Ross Waters has dedicated 35 years of his life to serving and improving the valve industry. Ross started CGIS, a valve distribution company, in 1980 in a small office in Vancouver, Canada. Thirtyfive years later, the business has grown internationally and now serves clients and industries worldwide. Ross is the driving force behind increasing awareness of Severe Service Valves and is part of a MSS task force writing its definition. He has attended numerous conferences around the world presenting his paper, "Defining Severe Service Valves" and is well onto establishing himself as the leading expert in Severe Service. Ross is also an avid member of ASTM International G04 and has served as an expert witness.

Malcolm Harrison was born and educated in the UK and received a bachelor's degree in mechanical engineering. After a successful career with major EPC's working as a mechanical and piping design engineer, Malcolm relocated to the USA in 1980 to work for Bechtel in San Francisco. He eventually entered the world of valves sales in the early 1990's. First with a specialist valve sales representative company and then as mining products industry manager with Houston based, ValvTechnologies. In late 2014 he retired started his own consulting company, Fluid Equipment Consulting. Malcolm now uses his vast experience to offer subject matter expert services related to all types of valve requirements.

Abstract

Severe abrasive service valves have become a critical component in the design and operation of varied industrial processing plants. Whether it be catalyst, harsh polymers, chemical slurries, waste materials in mining, or the transportation of mineral slurries at low and high pressure, all such applications need cutting edge technology compared to conventional liquid and vapour services. This advanced technology would not be possible if manufacturers were not able to design and provide equipment that can operate reliably in services where abrasive fluids exist. The modern design of such valves has become more complicated due to the use of highly sophisticated process controls, varying types of process media, increased sizes, higher pressures, and in some cases elevated temperatures. These complexities and variables have specifically challenged valve designers and manufacturers, who need to work closely with the engineering design companies and end-users alike, to find viable, cost-effective and more importantly, reliable solutions. Some process requirements could not be possible if the valve designers had not innovated existing designs to accommodate highly abrasive process environments. This paper examines how the application of severe abrasive service valves has become an important component in the successful design, construction and operations of processing plants throughout the world. Supporting data is provided by the use of actual working examples from existing applications. All cases involve slurry applications; i.e. those with a liquid carrier fluid.

Introduction

Abrasion, is the process of scraping or wearing away of a softer material by a harder material. Abrasion is one of the three main destructive agents that challenge the operation of valves used in slurry applications. Alone, it can be a devastating effect causing valve failure, but together with erosion and corrosion, it becomes a more significant challenge in valve selection and design.

The Science behind Valve Design Decisions

For abrasion to manifest itself in a valve contained within a slurry system, there must be at least two factors at work:

1. The abrasive fluid must be harder than the components of the valve (greater hardness is relative based upon the valve system pressure, velocity and solids size distribution and in some cases soft elastomeric materials are better than extremely hard ones).
2. There must be contact between the abrasive fluid and the valve components (friction, impingement, sliding, settlement, deflection).

The degree of abrasion is a function of its relative hardness and its energy state, or as is most commonly found, its flowing velocity. In addition, the slurry valve has several discrete stages of existence where its vulnerability can be substantially different from its other states of position.

Slurry isolation valves have at least three position states:

- Normally Open (N/O)
- Normally Closed (N/C)
- Transitioning between N/O and N/C

Assuming that continuous positive flow is occurring, there are differences in transitioning from N/O and N/C:

- N/O – N/C: increase in velocity until isolation
- N/C – N/O: decrease in velocity until fully open (except at initial opening)

There are several methods used for analysis and comparison of the severity of the slurry and these include:

- Hardness scales like Rockwell (B & C), Vickers, Shore, and Brinell
- Miller Number Test for Slurry Abrasivity (per ASTM G75-15)
- Slurry Abrasion Response of Materials (SAR) (per ASTM G75-15)
- Particle size and distribution (PSD)
- Velocity
- Specific rheological investigation

The study of flowing slurries, both in the laboratory and in the field, has revealed some important factors for the successful design of a slurry pipeline and since the Wasp model (1977) other work has been done to refine and better define successful operating regimes. These factors can also influence the design and selection of valves for use in such systems:

- The best flow regime is the one that maintains as much of the solids in suspension equally throughout the pipeline (Homogeneous Flow)
- Accurate definition of the critical velocity
- All voids, steps and abrupt changes within the piping system should be avoided

Considerations for Valve Design and Manufacture

To ensure reliable design and selection of valves for slurry service:

- Designs need to handle the deposition of fines and dewatered slurry throughout the non-flowing regions of the valve.
- Seats and seals should be made from materials that can withstand the nature of flowing slurry.
- Sealing seats should be capable of providing zero leakage under full design pressure and also with no pressure or low differential pressure.
- Valves should have ease of operation such that plant personnel can use safe methods for cycling.
- Internal components should be protected from the potential erosion of the slurry during normal operation and also during cycling of the valve.

- Actuators, both manual and automatic, should be sized generously to overcome high viscosity slurries and the potential for precipitation of solids (Normal safety factors may be increased by a factor of 1.5x – 3.0x depending upon fluid characteristics).
- Valve stems should be designed to accommodate very high torque (or thrust). MAST analysis with maximum actuator torque output is required.
- Design should account for reliability due to the need for continuous operation without the possibility of an unscheduled outage.
- Valves should be provided that become a valued asset of the plant, rather than a consumable.

Options for Low Pressure Systems

Definition of a low pressure system is very subjective from plant to plant, but typically any system operating below ~10MPa (ASME Class 600) is considered low pressure. The best choice for these systems would be knife gate valves with elastomeric or polymeric seats and hardened body, gate and wear rings.

Knife Gate Valves Types:

While there are five distinct styles of knife gates, two are the primary styles used in slurry piping systems:

- Push-Through Knife Gates - designs utilize two interference fit elastomeric sleeves that are deformed by the gate when cycled. During closing, the gate is pushed through the sleeve liners and exits the bottom of the valve forcing a discharge of the process media.
- Guided Shear Gate - closed body shear gate designs utilize a guided gate with a chisel edge that is contacted by an elastomeric or polymeric seat retained in the valve body.

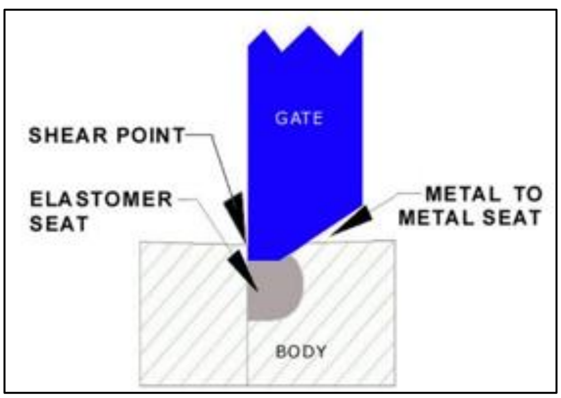

Figure 1: Shear Point and Bottom Sealing

Figure 2: Push-Through Knife Gate (left), Guided Shear Gate (right)

Figure 3: CGIS AITF Slurry Test Loop, May 2016, Devon, Canada

Application Examples in Low Pressure

Slurry service knife gates have been in service for over 60 years, starting on low pressure simple systems. Over the last twenty years, experience gained from the Canadian Oil Sands expanded the valve designs into more challenging and higher pressure systems, up to 10 MPa (1440-psig). Much of this design growth has been aimed at tailings applications.

The first 5MPa (Class 300) slurry knife gates were designed in the mid-nineties and provided to Suncor, in 1996, for their tailings lines. The oil sands tailings exhibit a greater challenge for the valve design as they are formed naturally (not ground by ball or rod mills). Thus they are far larger in particle size, are angular and have high silica content. Due to the large particle size and the higher pumping velocities (4.5 to 8 m/s) required, these tailings are considered the most abrasive in the world.

Examination of valves removed from service after their operational life had been reached led to modifications related to the basic design. The guided shear gate was now preferred based upon its ability to handle these higher pressures. The valves ability to provide secure containment of the process fluids, thus providing zero leakage was critical as any water based discharge would be subject to freezing for at least seven months in the northern location of the tailings plants.

Wear rings were used to strengthen the abrasion and erosion resistance of the bodies and gates made from 17-4 precipitation hardened stainless steel were supplied to provide the strength and resistance needed for the slurry system. The bore of the valve was lined with chrome or tungsten carbide, applied using special overlay techniques.

Figure 4: 6-month examination of tungsten carbide weld overlay and gate, showing no measurable wear.

Figure 5: 7 MPa Australian iron tailings system - Class 600 Guided Shear Gates

It is the opinion of the authors that Push-Through knife gate valves should be limited to 2MPa and limited cycles due to the required thickness of the gate and its tendency to create a loss of seat elasticity during each cycle.

Guided Shear Gates valves have been successfully supplied for 10MPa tailings systems and are available for uni or bi-directional applications. In order to provide longer service life, single or dual wear rings (inboard and outboard) are available in a number of materials including:

- Ni-Hard (Rc 59)
- Duplex SAF2507 and AISI 4140 with chrome or tungsten carbide coating (Rc 68-72)
- Ceramic (silicon nitride and partially stabilized zirconia (Rc>72)

The key design requirement of the Guided Shear Gate valve is to provide a shallow profile transition to reduce the effects of turbulence. The primary soft seat must be protected from the flowing slurry in order to provide zero leakage and prevent dewatering.

Guided Shear Gates valves have a design element that may cause some turbulence. When the gate is fully retracted in the open position, the area at the top of the waterway, within the chest and outside of the radius of the gate is a void.

Options for High Pressure Systems

High pressure systems typically operate above ~10MPa but owner's choice may dictate the use of common valve types in all systems, within the same plant. The best choice for these systems would be ball valves with metallic seats.

Metal Seated Ball Valve Types:

- Fixed seat design, where the seat is an integral part of the body.
- Fixed seat design, where the seat is welded in-place.
- Fixed seat design, where the seat is retained by a bolted ring.
- Loose seat design, where the seat is allowed to float in either direction depending upon pressure.
- Loose seat design where the fluid pressure is allowed to force the seat against the ball surface (trunnion mounted design).

All metallic seated ball valves must have a sealing seat and ball that is protected from the erosive (and in some cases corrosive) nature of the slurry. Most common for erosion resistance is a thermal spray hard coating technologies such as High Velocity Oxygen Fuel (HVOF). This method utilizes confined combustion and an extended nozzle to heat and accelerate the powdered coating material. Typical HVOF devices operate at hypersonic gas velocities, i.e. greater than MACH 5. The extreme velocities provide kinetic energy which help produce coatings that are very dense and very well adhered in the as-sprayed condition.

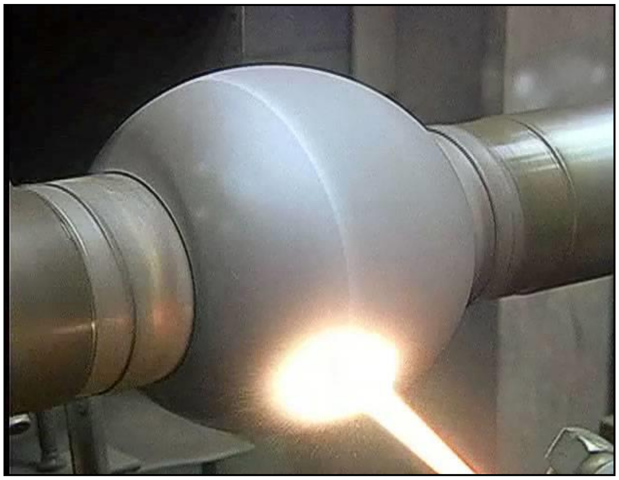

Figure 6: HVOF Coating of Ball Component

Another method used when there is potential corrosion capability of the slurry is Plasma Spray. The plasma spray process uses inert gases fed past an electrode inducing the "plasma" state of the gases. When the gases exit the nozzle of the gun apparatus and return to their normal state, a tremendous amount of heat is released. A powdered coating material is injected into the plasma "flame" and propelled onto the substrate. Ceramic Coatings are most often applied using plasma spray due to their high melting temperatures (Often > 1900 C). Several types of ceramic coatings can be applied using plasma spray.

For all thermal spray coatings, the coated parts are then lapped separately before mate lapping, where the contact surface becomes so highly polished that small particles cannot pass between these parts, in a fully assembled valve.

Figure 7: Plasma Spray of Ball Component

There are also variations on the basic thermal spray coating where nanostructured coatings are used to produce a highly dense coating that is almost totally impervious to corrosion.

In all cases the purpose of the coating is to protect the internal components of the valve from the process fluid. In some applications where abrasion is very high, even the bore of valve is coated for protection from erosion.

Figure 8: Coated and Mate Lapped Loose Seat Component

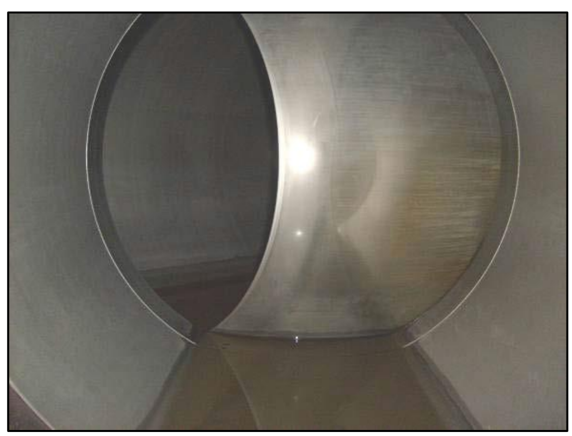

Figure 9: Internal View of Ball Valve Showing HVOF Bore Coating

Application Examples in High Pressure

Wear and Seal

In a "Wear and Seal" (also known as martyr and master) arrangement the downstream valve is cycled first taking the wear of the flowing slurry. After the valve is closed the upstream valve is then cycled with no differential pressure ensuring secure isolation of the pipeline.

Figure 10: Pipeline Station Isolation "Wear and Seal" Arrangement

Choke Stations

Particularly with gravity systems and also for pumped systems, accumulated pressure must be dissipated for safe pipeline operation. Choke stations are a method and apparatus for protecting against the abrasion of pipe walls in a slurry pipeline caused by slack flow, when the pipeline is operated in the batch mode (water or various slurries are delivered through the pipeline). Pressure transducers sense the pressure at each relatively high point of the pipeline as an interface between a water batch and a following slurry batch passes that point. When one of the sensed pressures falls below a predetermined low value of pressure, a control device actuates valves that divert the flow downstream in the pipeline through a staged choke containing flow restrictors, thus raising the fluid pressure in the water batch which then counteracts the effect of the static head of the slurry batch. The flow is redirected away from the staged choke when one of the sensed pressures exceeds a predetermined high value of pressure, thus lowering the fluid pressure and preventing pipe wall overpressure. The choke branch isolation valves need to operate under high differential slurry flow conditions and provide zero leakage when closed.

Figure 11: Typical Choke Station with Fixed and Variable Chokes

Valve Station Isolation (Bidirectional)

When a long distance slurry pipeline has extended portions of the line that may see pressure in either direction, valves are needed that can seal from either direction or should be installed such that when they are closed they see pressure on the preferred sealing end. These valves can see high cycling under conditions where the abrasive slurry may fall out of the preferred flow regime. Designing the valve internals for protection against erosion is critical in maintaining reliable operation.

Figure 12: Pipeline Isolation Valves for Bidirectional Operation

Conclusion

By selecting the correct severe abrasive service valve, maintenance can be virtually eliminated and installed costs can be drastically reduced. True full port valves ensure an unrestricted flow path, minimize pressure drops and limit premature wear. Most valves can be manually operated but more frequently, in modern projects, are automated with pneumatic, electric, hydraulic or electro-hydraulic actuators. In higher pressure applications automated ball valves can provide cycling speeds that can match that of most operational requirements.

Now, more than 50 years after the first significant commercial slurry pipeline, valve engineers have the advantage of many innovations that came from varying resources including the NASA space exploration program. Using the correct valves for slurry applications is not only attributed to the modern advances in the application of modern elastomers and hardened materials used in knife gate valves, but also extremely hard coatings used for the surfaces of balls and seats in slurry ball valves. Credit is also given to the advances of easy access to complex finite element analysis (FEA) modeling tools, used to design the valves for such high pressures (up to 28 MPa). Without such technological advances the options available may have been too unreliable and too maintenance intensive to allow developers the capital approval for projects to proceed.

Since the first commercial slurry pipeline was built, the effectiveness of transporting abrasive mineral slurries over long distances and at high pressure has become almost common-place. Projects transporting abrasive, erosive and corrosive slurries of iron, copper, zinc, phosphate, nickel, coal, as well as waste material (tailings) for many minerals, have been constructed and continue to operate reliably and profitably.

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- Compañía Minera Antamina – Perú (Figure 11)
- OCP – Morocco (Figure 12)

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