2.3.4

CENTRIFUGAL PUMP MINIMUM FLOW CONTROL SYSTEMS

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In designing centrifugal pumps, engineers strive to develop specific internal geometry that will produce head and flow with low energy loss. Each pump is designed for a specific head versus flowrate for the given impeller speed. The head and flowrate on this family of "characteristic" curves where the energy loss is minimum is known as the Best Efficiency Point (BEP).

In application, pumps spend a significant portion, if not all of their life, operating at conditions other than BEP. This is normal and is due to a combination of system design conditions (for example, static head, piping and valve impedances, and so on), available pump designs (that is, capacities and heads) and actual plant operating requirements. Low flow related problems occur when pumps continuously operate in or repetitively cycle into flow regions that are significantly below the BEP (for example, 50% of BEP). In these low-flow regions, pump and system component performance and longevity can be adversely affected.

Low flow problems are known to be worst for large high-energy pumps (for example, boiler feedwater), for pumps handling hot liquids, for pumps that handle liquids that have solid particles, and for pumps for low net positive suction head (*NPSH*) service. A well-designed minimum flow control system can establish an environment that will substantially improve pump and system performance. The following chapter will briefly review the topics that should be considered when designing a minimum flow system for a centrifugal pump.

FACTORS AFFECTING LOW FLOW RATE PUMP OPERATION

Collectively, the following broadly classed factors have been recognized as the major contributors to low flow pump problems.

Thermal Factors The increase in temperature of the liquid within the pump is directly related to the pump's efficiency. The energy that is available to heat the flowing liquid and the pump casing is basically the difference between the power input to the pump (brake horsepower) and the useful work done by the pump (liquid horsepower). At low flow conditions, centrifugal pumps are very inefficient and a significant amount of input energy is lost and heats the liquid and the pump assembly. Refer to Subsection 2.3.1 and Chapter 12 for more discussion on thermal effects.

Hydraulic Instabilities When the pump is operating significantly below the BEP, flow streamlines (that is, patterns) within the pump change considerably from the rated design streamlines. Fluid eddies are most likely to develop at the inlet and discharge of the impeller resulting in flashing, cavitation, and shock waves that often produce vibration and serious component erosion. This phenomenon is classically known as internal recirculation. It can occur at the pump inlet (suction) and discharge. Refer to Subsection 2.3.1 and 2.3.2 for a more in-depth discussion on this topic.

Mechanical Loads As the flowrate through the pump decreases, steady state loads increase and superimposed dynamic cyclic loads appear radially and axially on the impeller and shaft. The dynamic cyclic component increases significantly when recirculation within the pump occurs. Bearing damage, shaft and impeller breakage, and rubbing wear on casing, impeller and wear rings can occur. See Subsections 2.3.2 and 2.3.3 for discussion of this subject.

Axial-flow and mixed-flow pumps with high specific speed produce comparatively higher head and take comparatively more power at low flow. A bypass system may be necessary not only to reduce component loading and stress but also to prevent motor overload. See Subsection 2.3.1 and Section 8.1 for discussion.

Abrasive Fluids Liquids containing a large amount of abrasive particles, such as sand or ash, must flow continuously through the pump. If flow decreases, the particles can circulate inside the pump passages and quickly erode the impeller casing, wear rings, and shaft.

ESTABLISHING MINIMUM PUMP FLOW REQUIREMENTS

The bypass system designer must know the minimum pump flow specified by the pump manufacturer in order to properly design a bypass system. The four previously discussed topics should be evaluated in detail by the pump manufacturer to establish the minimum flowrate specification. Minimum flowrate specifications are generally established through a combination of analytical and experimental techniques coupled with field performance data.

Thermal Considerations The maximum allowable temperature rise of the pump is primarily based on two points: the permissible pump casing and shaft thermal growth and the flash point temperature of the pumpage. Pump manufacturers use analytical, laboratory and field data to validate their thermal analysis to ensure that pumps do not seize within the allowable temperature operating ranges. Refer to Subsection 2.3.1 for temperature rise calculations.

Applications involving extremely high or low temperature fluids may require more in-depth analysis to determine if individual component thermal growth is the limiting factor in determining minimum flowrate. Additionally, certain chemicals, which polymerize or solidify at particular temperatures, may establish the minimum flowrate specification. Chapter 12 and Subsection 2.3.1 provide more detail on this subject.

Hydraulic Considerations The minimum bypass flow requirement for most pumps is based on minimum continuous stable flowrate, a hydraulic criterion, rather than a temperature rise. Pump internal recirculation will occur at both the impeller inlet and impeller outlet as flowrates are reduced. Internal recirculation will occur at flowrates well above those that cause temperature concerns. Refer to Subsection 2.3.1 for a detailed evaluation of this topic.

Mechanical Considerations It is necessary to know how head, radial thrust, axial thrust and power vary with capacity before deciding on minimum allowable flow. Bearing capacity, motor rating, and stresses in drive and driven components are important influences.

Abrasive Wear Considerations Relatively high bypass flowrates may be required to protect the pump against abrasives in the liquid. Heavy wear can occur at flows below 85% of the best efficiency point. The designer must establish the minimum pump flow specification using the pump manufacturer's recommendation and his experience with comparable pumps and liquid/solid mixtures.

MINIMUM FLOW CONTROL SYSTEM DESIGN FACTORS

Pump Size Capacity, power, specific speed, and suction specific speed are all factors that must be examined when designing a bypass system. These factors have a direct impact on the cost of building and operating the bypass system. Use of a continuous bypass system will require an even larger pump and driver to supply both the process and bypass flow requirements simultaneously.

Discharge Pressure High discharge pressures result in high head loss in bypass valves, components, and lines. Liquids that can flash and cavitate demand special precautions to minimize damage in valving, orifices, and piping.

Available Heat Sink Bypass flow must be reintroduced into the system far enough upstream to prevent progressive temperature buildup or flow disturbance in the pump suction. This may mean a simple discharge back to an uninsulated inlet line or discharge to a receiving tank or cooler with enough area and enough inflow of cool liquid to handle the thermal load. Bypass flow can discharge into a deaerator storage tank, a condenser, a flash tank, or a cooling pond. Elevation, distance, and pressure inside the receiving tank are also factors, as is the fact that the interior must be available for inspection and for repair of spargers, spray or distribution pipes, orifices, and backpressure regulators.

Pump Design A pump's design and materials of construction often affect the minimum allowable percentage of flow. With thermal effects, pumps vary in the length of time that they will tolerate shut off or low flow. This is important in designing the bypass system valves, instrumentation, and controls.

Hydraulic effects at low flow are most apparent in high-energy pumps. The pump manufacturer should state the continuous minimum hydraulically acceptable flow for a given pump—and how it was determined. With axial-flow pumps, the shape of the pump head curve may be a factor in selecting the required bypass flow percentage. If feasible, a witness shop test of the pump should be specified to demonstrate and verify minimum flow recommendations.

Liquid Pumped Liquids that flash and cavitate generally required a high bypass flow percentage. Examples are liquids near the boiling point or at high pressure. Abrasives in the liquid may require more bypass than would be needed for thermal reasons alone.

Energy Costs A high energy cost to operate the pump requires careful consideration of bypass system design. The evaluation should compare equipment installation costs, maintenance, and energy costs for various bypass configurations. Figure 1 shows the annual pumping costs for a continuous bypass type system based on bypass flow, pressure and energy rates. The example shows a pump with a discharge head of 500 ft (152

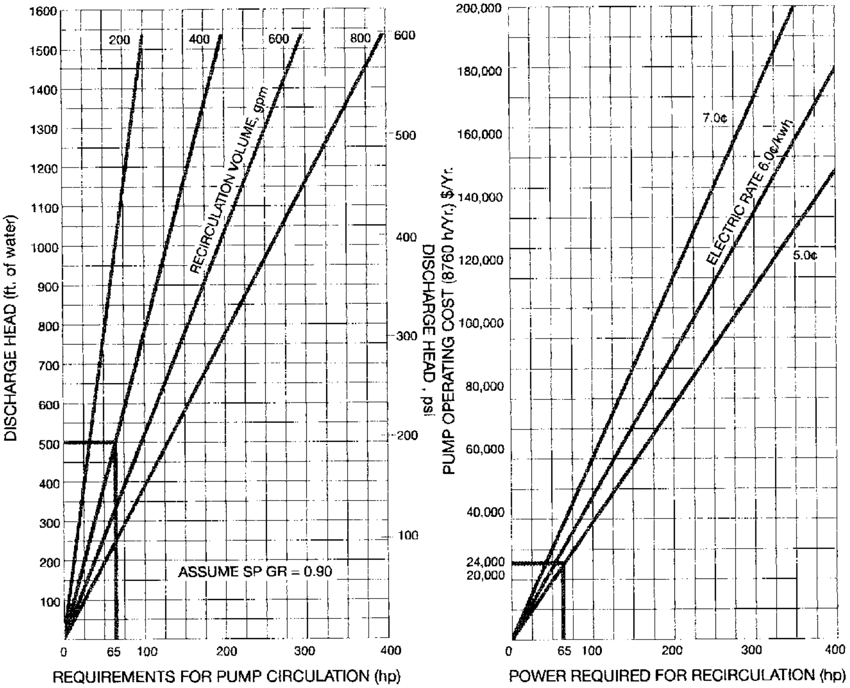

FIGURE 1 Annual pumping cost estimate for continuous bypass systems (metric conversions: ft × 0.3048 = m, gpm × 0.277 = m^3/h, hp × 0.746 = W)

m) and a bypass flow requirement of 400 gpm (91 m^3/h). Based on an energy cost of 5.0 cents/KWH, the annual cost for continuous bypass is $24,000. An automatic bypass system will only open the bypass when process flow demand is low. The total design life energy costs of a continuous bypass system can easily exceed the hardware costs of an automatic bypass system.

Noise Considerations Bypass systems can easily exceed OSHA requirements for occupied spaces if not designed properly. High pressure drops and high fluid velocity increase noise. Multi-stage pressure reduction, heavy wall pipe, insulation, and silencers will all combine to reduce noise to acceptable levels. See Section 8.4 for a further discussion of this topic.

Process System Design and Operational Expectations Bypass system design will depend on the plant design life and the expected process operational requirements. For example, a swing-loaded electric power plant will have far different pump operating requirements than a low-pressure emergency fire water system. The bypass system designer must evaluate installation, maintenance, and operating costs for the life of the process system with the expected utilization. If the actual operating conditions differ significantly from the design, the configuration of the bypass system should be reevaluated. For example, a process designed for normal operation with one pump at 75% of maximum capacity may put severe demands on the bypass system if the pump is operated continuously at 20% of maximum capacity.

LOW FLOW PROTECTION SYSTEMS

Bypass Systems—Types/Design Considerations

CONTINUOUS BYPASS SYSTEMS As the title implies, continuous bypass systems provide continuous flow whenever the pump is running, regardless of the process demand. Figure 2 illustrates a simple system, with a bypass line branching off the pump discharge upstream of the main line check valve and containing a fixed orifice dimensioned by analysis to provide minimum required pump flow. The bypass line discharges into a reservoir that is at a lower pressure than the pump discharge. The bypass line can also discharge directly into the pump supply line. However, the piping system design must ensure that the bypass liquid temperature does not increase to an unacceptable level. Additionally, vapor bubbles formed in the bypass by the pressure reduction process may be introduced into the pump. This will affect pump performance and longevity. Locating the bypass branch-off before the discharge check valve as shown keeps backflow from the process or from a parallel operating pump from going back to the receiving tank or back through the pump during a pump shutdown. Consideration should also be given to installing a check valve in the bypass line.

The size of the bypass pipe depends on flow and piping configuration. If the pressure drop through the orifice results in flashing flow, the orifice should be located at the end of the bypass piping and should discharge directly into the larger receiving tank or larger downstream piping. The discharge flow should be directed so it does not impinge on the walls of the receiving tank but rather into the liquid to absorb the force of cavitation implosion. Valves and fittings located immediately downstream of the orifice may be damaged by cavitation. Full ported gate or ball valves are less susceptible to damage. Waterhammer and erosion are not problems in well-designed continuous bypass systems.

The pump and prime mover must be sized to simultaneously supply both the bypass flow and the maximum process flow at the required pump discharge pressure.

AUTOMATIC BYPASS SYSTEMS Automatic recirculation systems control the bypass flow in relation to the process flow. The sum of the process and bypass flowrates will always exceed the minimum flowrate specified to protect the pump. Two essential elements of these systems are a device to measure the process flow and a device to control the bypass flow. Compared with continuous bypass, these systems reduce energy consumption and pump horsepower requirements.

The bypass flow can be regulated by either “Modulated” or “On-Off” control. When bypass flow is “Modulated,” the bypass flow is inversely proportional to the process flow.

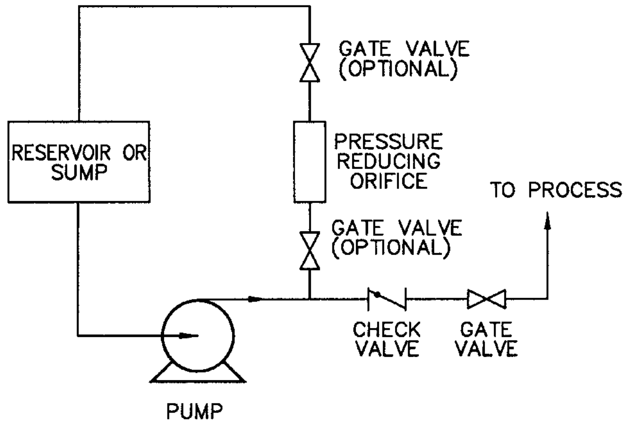

FIGURE 2 Typical continuous bypass system

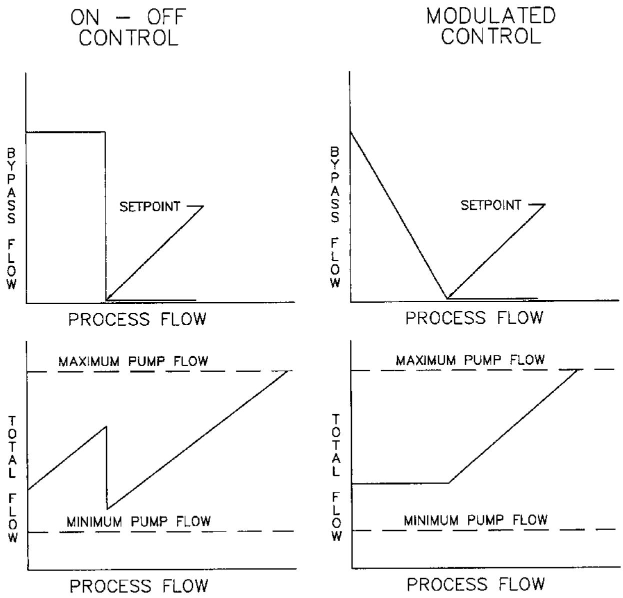

FIGURE 3 Comparison of On-Off versus Modulated automatic bypass flow control.

The bypass is shut when process flow is greater than the control setpoint (that is, minimum flowrate required), opens more as the process flow is reduced, and is full open when the process flow is zero. With "On-Off" bypass control, the bypass is open fully when process flow is below the setpoint and is shut when the process flow is above the setpoint.

Figure 3 illustrates these control methods and the effect on total pump flow. The total pump flow is the sum of the process and bypass flows; it is the flow that enters the pump suction. The "On-Off" control graph shows that there is a step change in the total flow when the bypass opens or closes. The "Modulated" control regulates the total flow smoothly when the process flow is below the setpoint. Either method will protect the pump from damage due to low flow. However, "On-Off" control may produce large pump discharge pressure variations depending on the shape of pump head curve. Rapid pump flow changes may produce damaging hydraulic or mechanical shocks. This will reduce pump life and increase maintenance. Modulated bypass control is required when the minimum flowrate specification exceeds approximately forty percent of the rated pump capacity. If "On-Off" bypass control is used above this point, the pump may exceed its capacity rating with resultant pressure pulsation and unsteady flow.

CONTROL LOOP SYSTEMS A typical automatic bypass system, based on an instrumented flow control loop, is shown in Figure 4. This system requires a flow meter, a check valve, a bypass control valve, a valve controller and a pressure-reducing orifice.

The flow meter can be placed at the pump inlet or discharge before the bypass tee (as opposed to it having to be placed after the bypass tee in an "On-Off" system). The controller compares the flow meter signal with the setpoint (minimum pump flow required) and operates the bypass control valve.

Single stage control valves are commonly used in low pressure systems with an orifice for pressure reduction located downstream. However, these are not suitable for high pressure differentials or for the controlling of cavitation or flashing. Pressure reducing valves with multi-stage trim, good seat tightness, and low pressure recovery characteristics are widely used in this service. Refer to Chapter 7 for a detailed discussion of control valve characteristics and selection.

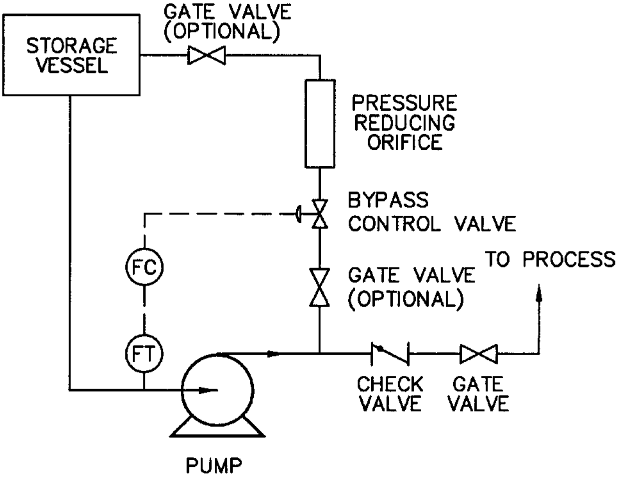

FIGURE 4 Typical automatic bypass system based on flow control

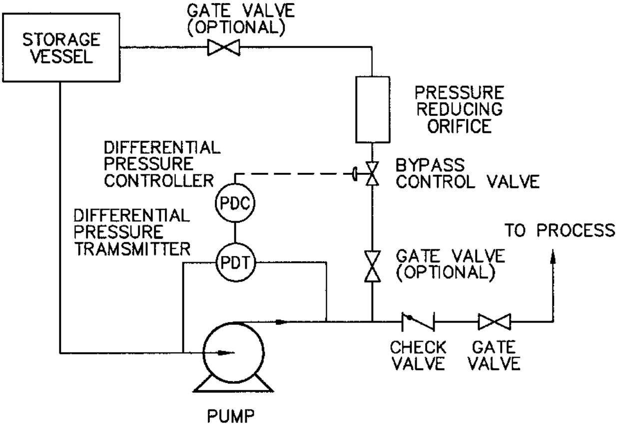

FIGURE 5 Typical automatic bypass system based on pump differential head

The bypass pressure reducing orifice handles the high velocity and erosive forces of the bypass flow. However, the handling of cavitation and flashing by this fixed restriction is limited. The orifice is sized to operate properly at one bypass flow condition. At low flows, the orifice does not provide the correct pressure reduction as designed.

The check valve is placed in the main line, as shown in Figure 4, to prevent reverse flow through the pump. The pump and motor bearings can be damaged if rotated in reverse. Pressure drop through the check valve must be considered in pump sizing in addition to other piping and valve pressure losses.

A typical automatic bypass system based on pump differential head is shown in Figure 5. This system is identical to the flow controlled bypass system except that pump differential head is measured instead of flow. This system can only be used with continuously rising pump head characteristic curves. The system will have to be adjusted for each individual pump characteristic and later adjusted if this characteristic changes over the life of the pump.

Depending on the bypass valve and control instrumentation selected, these systems can provide either “Modulating” or “On-Off” bypass control. Valves, instrumentation, and controls must be individually sized for the service conditions. All components must be integrated together to provide bypass flow control that meets the pump and process operational design criteria.

The Automatic Recirculation Control (ARC®) Valve This valve provides bypass flow control, pressure reduction, and reverse flow pump protection all within a single unit. This single valve combines the functions of the check valve, pressure reducing orifice, pipe tee, control instrumentation flow meter, and bypass control valve that are all required in the instrumented control loop bypass system. Valves can be designed to provide either “Modulated” or “On-Off” bypass control. The operation of all ARC valves is fundamentally the same. The flow sensing element (check valve disc) responds to the process flow demand and opens or closes the self-contained bypass control valve. Differences in ARC valve design center around bypass valve actuation method, repairability, serviceability, and adjustability. Figure 6 illustrates a typical ARC valve bypass system.

Pilotless Trim Design The simplest of ARC valve designs operate the bypass flow control valve directly by the flow sensing element. The construction of a typical ARC for low pressure service is shown in Figure 7. The basic operation of this valve is shown in Figure 8. At zero main flow (“A”), the bypass provides full recirculation flow. As main flow increases (“B”), the bypass modulates proportionally closed. At full main flow (“C”), the bypass is shut. The pressure reduction from the pump discharge to the bypass is accomplished by the characterized orifices in the bypass element that is attached to the disc. However, the differential pressure from inlet to bypass imposes static and dynamic forces on the disc assembly. These unbalanced forces interfere with the normal disc motion and limit the maximum differential pressure for pilotless trim. There is an upper differential pressure limit at which this design will not operate satisfactorily and pilot operated bypass control must be used.

Pilot Operated Trim Pilot operated bypass control valves utilize a combined hydraulic-mechanical force to control the bypass flow. Only a relatively small mechanical force is necessary to hydraulically generate the large forces required to operate a bypass flow control valve in a high-pressure system. Figure 9 illustrates a pilot-operated bypass that utilizes a lever connected to the check valve disc to actuate the pilot. Figure 10 illustrates a pilot operated multistage bypass operated by an in-line pilot valve. Pilot-operated valves require more components and seals than unbalanced valves and are therefore more costly.

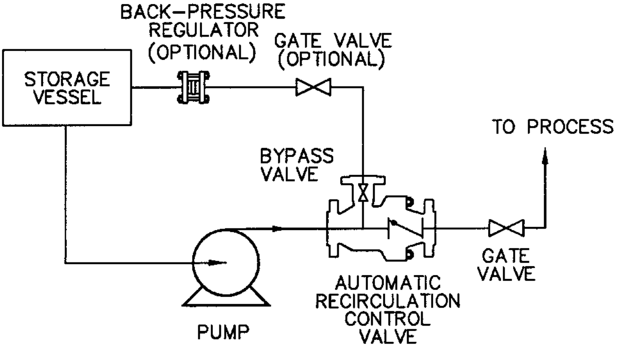

FIGURE 6 Typical ARC valve bypass system

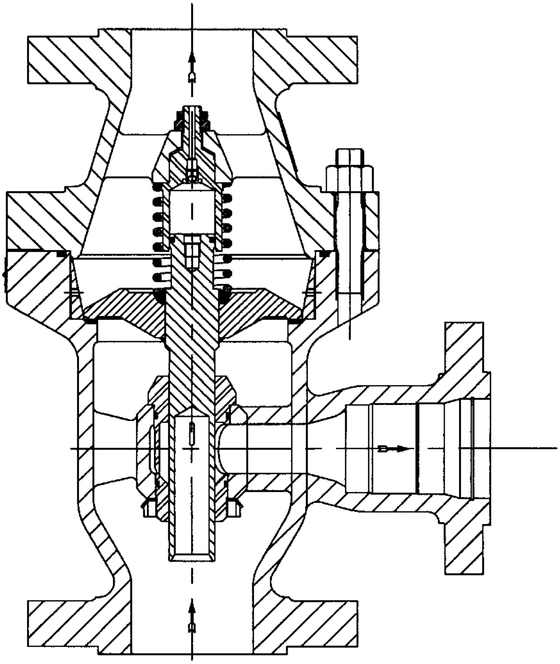

FIGURE 7 Construction of a typical ARC valve for low-pressure service

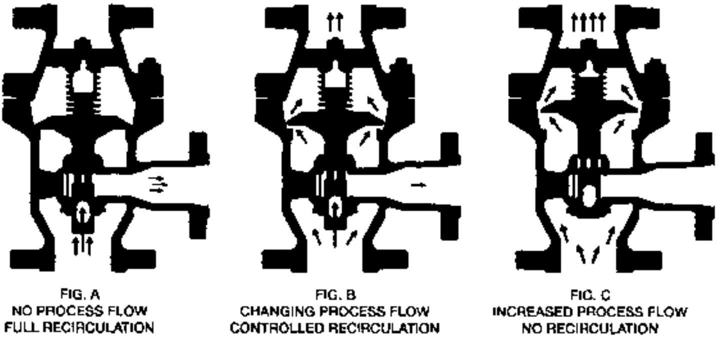

FIGURE 8A through C Basic ARC valve operation at three process flow conditions

Serviceability ARC valves can be designed for in-line serviceability. Access is provided to the valves internal components for inspection or repair without disturbing the process or bypass piping. Figure 11 illustrates a valve designed to be serviced in-line.

SAFETY SHUTDOWN SYSTEMS

These controls are normally provided as backup pump protection for the continuous bypass and automatic bypass control systems. They should only operate if the normal system fails due to mechanical or operator causes. In each case, the protection system trips the pump off.

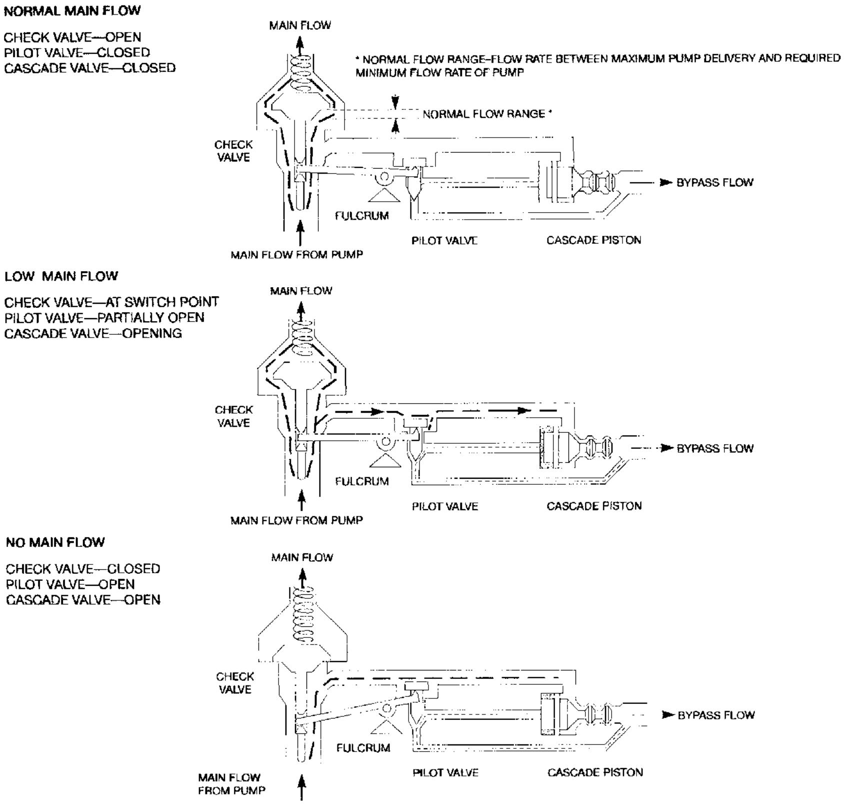

FIGURE 9 Operation of a typical pilot-operated ARC bypass valve actuated through a lever mechanism

Head This requires only an accurate pressure switch, set for a discharge pressure corresponding to the total pump head when the pump is close to the shutoff capacity. For conservative results, calculate based on minimum suction pressure. To use this method, the pump characteristic must rise continuously to shutoff. Control circuitry may require delays to reject spurious pressure surges.

Temperature A temperature sensor mounted on the pump casing or in the discharge and close to the pump can signal for a shutdown of all or some of the operating pumps. The trip can be on either a high temperature sensing or a high differential temperature sensing between inlet and discharge. This method can protect against large temperature rises (occurring at perhaps 5% or less of capacity) but is less sensitive to smaller rises at higher percentages of capacity where adverse hydraulic effects begin for large and high-power pumps.

Low-Flow Systems These protection systems can be configured in various ways. A low-flow switch can trip the pump off at a predetermined setpoint. A flow meter can signal a controller to shut down the pump. If this protection circuit is installed, the pump start circuit must temporarily bypass this trip in order to start the pump. This is normally accomplished by a spring-loaded switch that bypasses the low-flow trip when held in the "Start" position, but activates the trip protection in the "Run" position.

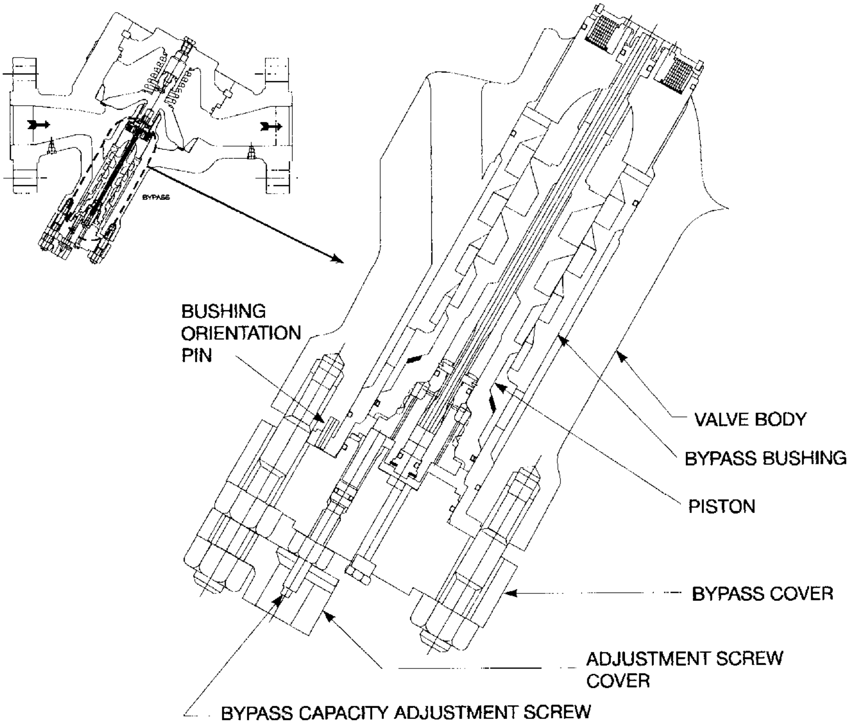

FIGURE 10 Pilot operated multistage bypass trim actuated by an in-line pilot valve

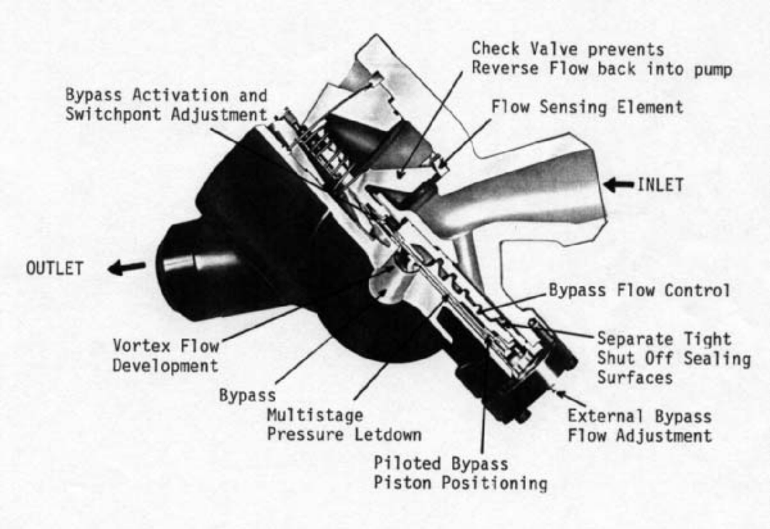

FIGURE 11 Typical in-line serviceable ARC valve

OTHER BYPASS SYSTEM HARDWARE

Orifices In high pressure applications, the system often does not provide adequate pressure in the bypass line to prevent cavitation or flashing. Either of these conditions is undesirable because it can cause damage to both valves and the pipe system or cause a reduction in flow below the minimum desired, jeopardizing the pump protection system. All pressure-reducing valves will experience a velocity-induced recovery effect that will limit the amount of pressure drop a valve can take and cause a reduction in flow capacity.

The requirement of backpressure is generic to all pressure-reducing applications. Pressure reduction even by multiple stage cascading can minimize the requirement; however, no valve design will redefine a fluid's physical properties. This becomes especially important in modulating systems. A fixed orifice will not provide the proper backpressure at all flow levels.

As the flow in the bypass line is reduced, the orifice becomes less effective. Proper system design should be used to optimize valve pressure reduction and consider all fluid dynamic effects downstream of any pressure-reducing device. When adequate backpressure is not available downstream of a pressure reducing valve, vapor bubbles will form in the zone just downstream of the valve last stage control surface. This zone is defined as the "Vena Contracta" and represents the point of highest fluid velocity and lowest pressure.

The potential for 1) damage to downstream piping components and 2) flow reduction exists from this point. When line pressure remains below the fluid vapor pressure, any existing bubbles will remain and expand as piping friction further reduces line pressure. This can be defined as *"flashing condition"* and is characterized by a polished appearance on affected surfaces. When the line pressure drops below the fluid vapor pressure and then recovers, any entrapped vapor bubbles will collapse (implode). This is defined as a *"cavitating condition"* and is characterized by a cinder-like appearance on affected surfaces. The resolution of either condition is best addressed by eliminating vapor formation. This can be assured by the provision of adequate back pressure through the use of a fixed or variable orifice.

Fixed Orifice Simple, easily replaced orifices that reduce the pressure are an effective way to reduce bypass head and provide adequate backpressure in bypass systems. Several stages may be necessary, however, to break down high-pressure drops without flashing. For calculations of flow through standard-shaped orifices, see Section 8.1 and 8.2.

Coefficients of discharge for oddly shaped multistage orifices are difficult to calculate. However, manufacturers of these specialties can furnish curves of delivery as a function of pressure.

Variable Orifice In modulating systems, a fixed orifice will not provide the proper backpressure over a wide flow range. A backpressure regulator (BPR) has a variable orifice with a spring-loaded plunger that is designed to open at a specified differential pressure. If flow and differential pressure increase, it opens further to maintain the differential pressure and backpressure constant. Figure 12 illustrates a typical BPR construction. Figure 13 shows a standard BPR installation. The BPR is normally located as close to the receiver vessel as possible so that the correct backpressure is maintained in the entire bypass line.

Valves, Piping, and Fittings For cold water at low pressure, a simple power-actuated globe-type bypass valve is often adequate. In modulating bypass systems, the bypass valve must resist throttling damage, particularly if the water is hot. Staging the pressure drop in the valve is the most common way to reduce or eliminate flashing and cavitation damage to the valve trim or body. Figure 14 illustrates a typical multi-stage pressure reducing valve (PRV).

Pressure is reduced in stages to ensure that the pressure never decreases below the fluid vapor pressure. This prevents cavitation and the resultant valve damage and noise. Figure 15 illustrates typical calculations for reducing pressure in sequential stages. Refer to Chapter 7 for detailed information regarding valve sizing and selection.

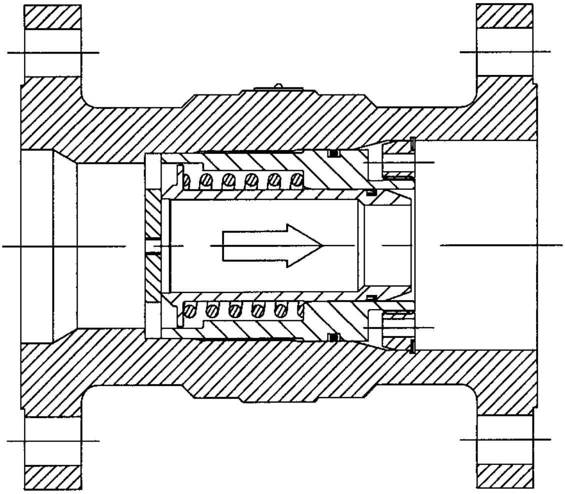

FIGURE 12 Construction of a typical backpressure regulator

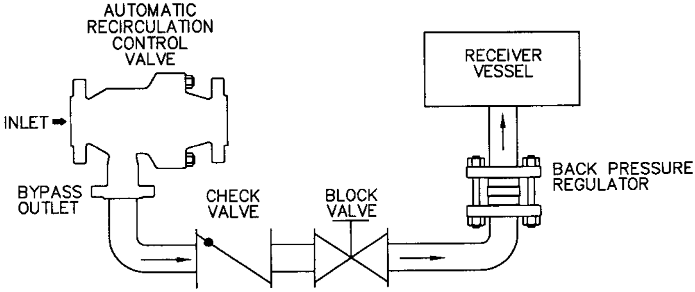

FIGURE 13 Backpressure regulator installation

Pipe material like that used for the main discharge is adequate for nearly all of the bypass line. Near the orifice and control valve outlets, however, heavier wall or higher chrome content will lengthen life. Welded piping is common for high pressures. To prevent erosion, pipe fittings (especially elbows) should not immediately follow an orifice.

Flow Meters Flow rate is the variable that must be measured for most automatic bypass multi-component control systems. The meter may have any type of primary element that will produce an accurate signal at the process flow for which the bypass must be controlled.

A simple orifice meter or venturi tube is commonly used. The user must have the required straight upstream and downstream pipe lengths or use flow straighteners to obtain an accurate reading. The device must be properly sized to provide both accurate indication at relatively low process flows and satisfactory pressure drop at maximum process flow conditions.

Flow meters can be located either upstream or downstream of the pump. Meters located upstream are at lower internal pressure but are larger in diameter with larger flanges. In addition, pressure drop at rated flow is important to avoid low pump *NPSH*. Meters located downstream are normally smaller but must be rated for the maximum pump discharge pressure.

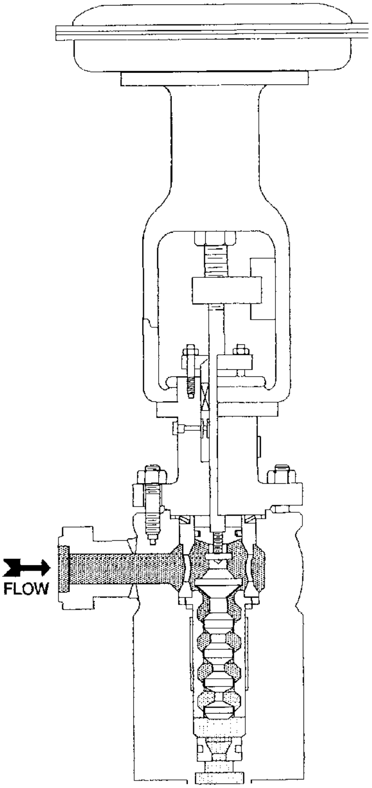

FIGURE 14 Construction of a typical multistage pressure-reducing valve

Controls Controls range in complexity from a simple pressure switch that stops a pump drive motor to modulating systems that meter flow and maintain a selected minimum flow through the pump. The control system may have to provide a deadband near the opening point and be sufficiently stable to hold bypass flow nearly constant in spite of erratic flow during upsets and startup.

For example, when the primary flow-measuring element is upstream of the bypass branch off, sufficient decease in flow will cause the bypass control to open in an "On-Off" bypass system. The main control valve, farther downstream, will then also open to maintain flow to the boiler or process. The primary element will sense the added flow and, in a simple bypass control system, close the bypass valve, initiating hunting in flow and valve action. To prevent this, the setpoint for bypass valve closing must be greater than twice the minimum bypass flow. If minimum flow is in the 30–50% range, this wastes energy during bypass. This control problem is avoided if a modulating system is installed.

SPECIAL BYPASS SYSTEMS

Pumps in Parallel It is possible to provide a single bypass valve for two or more pumps, as shown in Figure 16. The bypass line and valve must be able to handle simultaneously

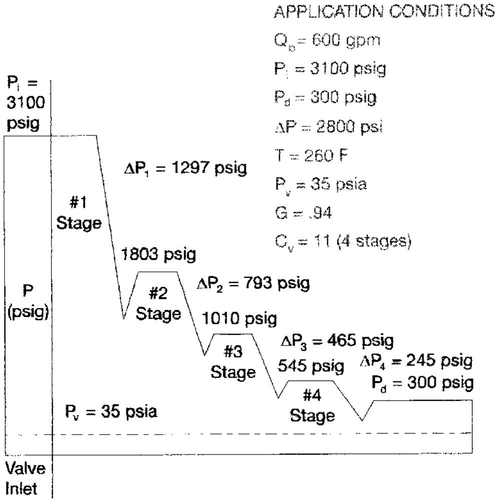

FIGURE 15 Calculations for pressure reduction through a multistage valve

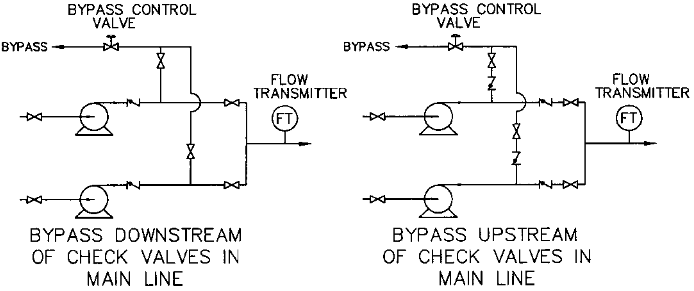

FIGURE 16 Examples of a single bypass valve that provides minimum flow control for two parallel pumps

the total bypass flow of all pumps. The pumps must operate together and they must have identical head-capacity curves. If they do not, the bypass flow will differ between pumps. The pump with the lower head may have insufficient bypass flow or could be completely shut off.

In the system of Figure 16 (left), the main line check valve prevents backflow through an idle pump. If the branch off were installed as shown in Figure 16 (right), an additional check valve in each bypass connection would be necessary to stop the backflow. Therefore, this latter configuration is not recommended.

An alternative arrangement that provides better operational flexibility and pump protection is illustrated in Figure 17. Each pump is individually protected by its own automatic recirculation control (ARC) valve. Pumps can be operated individually or in any combination and the pump head characteristic curves do not have to be identical.

Pumps in Series A single bypass line and valve can protect two pumps in series (see Figure 18). The designer must provide for the larger of the two separately evaluated bypass flows and must take into account the heating effect of the upstream pump. The pumps cannot operate singly unless additional piping and controls are installed.

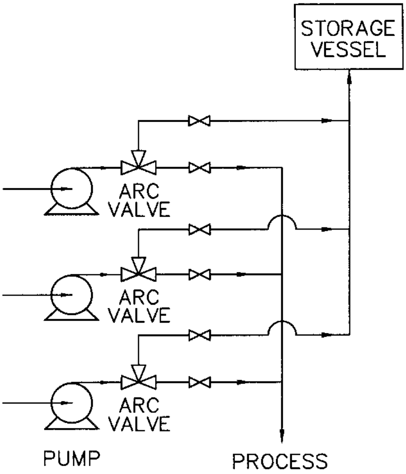

FIGURE 17 Multiple parallel pumps individually protected by ARC valves

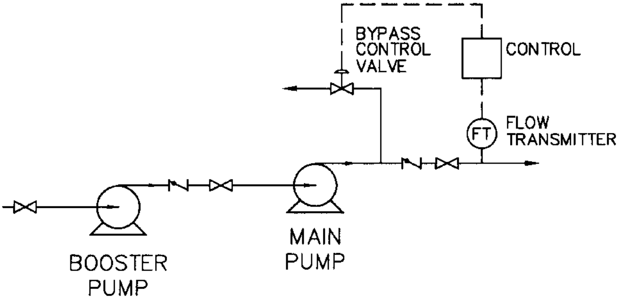

FIGURE 18 Example of a single bypass line that protects two pumps in series

VARIABLE SPEED PUMP BYPASS CONSIDERATIONS

Large horsepower pumps are often powered by steam turbines or with motors connected through a variable speed coupling. The effect of decreased speed and discharge head is to reduce the minimum flow requirement for the pump. Therefore, if the minimum required bypass flow is calculated and sized with the pump at normal operating speed and pressure, the bypass flow will be adequate when the pump is operated at lower speeds.

Warning If a constant backpressure device such as a backpressure regulator is used to control bypass pressure, precautions must be taken to ensure that the pump is never operated at pressures below the BPR setting. If the pump is operated below the BPR setting, the pump will have no bypass flow and may be damaged in a short time.

In a typical boiler system, a constant speed booster pump, requiring less minimum flow than the boiler-feed pump, could be protected by the bypass flow for the variable speed boiler feed pump. The designer must determine if the booster pump bypass flow is sufficient when the high pressure feed pump is running at minimum discharge pressure.

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