BOILER FEEDPUMP RECIRCULATION VALVE AND SYSTEM REQUIREMENTS

In this paper, continuous, on-off and modulating recirculation systems are discussed. Complete descriptions of each system are given with control, piping, and valve requirements. Primary emphasis is given to on-off and modulating systems as these designs are the most common in modern power generating stations.

An in-depth comparison of on-off and modulating systems is presented, detailing anticipated problems and possible solutions.

A four-part criteria is presented for evaluating recirculating valve designs. Various valve designs are presented and investigated against this criteria, including one novel design is shown as one of the few designs that can meet the needs of this arduous service.

INTRODUCTION

When a motor or turbine-driven boiler feedpump discharge flow, some of the energy generated from the pumping action is converted to heat. If the pump discharge flow falls below a set minimum level there is a rapid increase in both temperature and Pressure within the pump. This increase can cause mechanical pump damage due to cavitation or excessive pressures. To guard against this, a minimum flow line is used downstream of the pump discharge. (See Figure 1.) This minimum flow line takes the full discharge pressure from the pump and passes a set minimum flow to the deaerator, deaerator storage tank, or the condenser. The feedwater valve cannot serve this purpose as the full head of the boiler is on the feedwater valve outlet at start-up.

On some older, small units there is merely an orifice in the minimum flow line and the line is left open at all times. Substantial loss of energy will be noticed in this Arrangement as this minimum flow line is leaking off flow that should be going to the boiler or reactor for generating steam. Therefore, it is much more cost effective to install a boiler feedpump recirculation valve in this minimum flow line. Once the pump flow is above a set minimum level the recirculation valve is closed and full pump flow is supplied to the boiler.

For discussion purposes we will call this an on-off recirculating system. The typical operating sequence for this valve is as follows: When the boiler feedpump is first started, the recirculation valve will be opened and the feedwater valve will be slowly opened as the planned comes on line. Once the feedwater valve reaches 10% to 25% of pump capacity, the recirculation valve will go closed. This recirculation valve will remain closed until the pump flow falls below the 10% to 25% level, at which time the recirculation valve will automatically open to guard against the rapid heat and pressure rises.
Therefore, the boiler feedpump recirculation valve will be in the closed position for 90% to 95% of the time in most power plants. This valve will also have the highest differential pressure across the seat of any other valve in the plant. This makes the recirculation valve one of the most severe duty valves in a generating plant.

A slight modification of the on-off recirculation system is the modulating system. This valve operates through the same basic sequence except the recirculation valve is modulated open or closed off of thermal, pressure, or flow transducers in the pump discharge line. This gives a less abrupt transient in system flow when the plant goes on or off recirculation and will meter recirculation flow based on pump need thereby increasing efficiency.

LIQUID PRESSURE REDUCTION

At this point it is necessary to discuss the effects of reducing the pressure of a liquid. In the case of the recirculation valve, inlet pressures between 1,500 and 6,000 psig must be reduced to outlet pressures between a vacuum and 200 psig.

As liquid travels through a restriction it can be observed that as the pressure drop increases so does velocity until it reaches a maximum level in the vena contracta area immediately downstream of the restriction. Beyond the vena contracta the pressure recovers and the velocity decreases.

Figure 2 shows the relationship between pressure and velocity in a single point-throttling valve. From this figure you will note that there is an overshoot of the pressure before it recovers to the exit pressure. The amount of overshoot is a function of the required pressure drop.

It is during this overshoot period that the temperature of the liquid comes into effect. If the temperature of the liquid is such that at no time during pressure reduction is the vapour pressure of the fluid approached, then no adverse effects will be noted. When the final pressure is close to the saturated vapour pressure, problems can arise. Referring to Figure 3, the following three aspects of liquid pressure reduction indicate the significance of liquid temperature:
A) Normal Pressure Reduction

Curve 1 of Figure 3 illustrates the pressure drop through a valve where the vapour pressure is not approached during the pressure reduction. No change in state occurs and the fluid remains liquid.

B) Flashing In

Curve 2 it can be noted that during the throttling the pressure profile falls below the vapour pressure line. Immediately, a portion of the liquid will vaporize and vapour bubbles will be formed in the liquid flow, giving rise to two-phase flow. When this occurs a mixture of liquid and vapour exists, and the vapour portion results in an increased volume, which, in a confined space, will result in an increase in velocity.

C) Cavitation

From Curve 3 it will be seen that during the pressure recovery the pressure profile rises through the vapour pressure line. At this point, vapour bubbles that were formed in the liquid stream in the low-pressure vena contracta area cannot exist at a higher pressure and will collapse and implode back into a liquid state. When the vapour bubbles collapse the cavitation process is complete. As the vapour turns back into liquid, voids will occur in the flow stream and liquid rushing into these voids will set up high-pressure shock waves. Some investigations into this phenomenon have recorded pressures as high as 10,000 psia.
Having considered the three stages of liquid pressure reduction, it will be seen that cavitation is most likely to occur with a recirculation valve discharging to a deaerator tank or cavitation and flashing with a recirculation valve discharging to a condenser. One or more of the following will generally accompany the occurrence of cavitation within a valve: noise, vibration, and material damage.

Incipient cavitation is usually detectable as a hissing noise emanating from the downstream nozzle of the valve. As the intensity of the cavitation increases, the noise will increase until in the fully developed stage of cavitation the noise can best be described as a crackling, rattling sound giving the impression that gravel is passing through the valve.

Vibration due to cavitation will depend on several factors, including the mass of the system and how well it is anchored. In addition, actuator stiffness can go quite a ways to control the vibration. With severely cavitating conditions, vibration can reach dangerous proportions.

Both cavitation and flashing can result in trim oscillation, particularly on pressure-balanced, flow-over-the-seat plug designs. The effect of the vapour bubbles forming and collapsing, specifically beneath the plug, can result in pressure fluctuations beneath the plug, which are not matched by static pressure above the plug.

The most serious effect of cavitation is the material damage, which can occur. Under severely cavitating conditions, implosions occur as the vapour bubbles collapse. If these implosions occur near a solid boundary, such as the valve trim or valve body, the shock waves that occur result in mechanical damage.

Under severely cavitating conditions even extremely hard components will fall in a short period of time.

The example above shows the sort of damage that cavitation is capable of. This shows a Plug and Cage that has been in cavitating service for only a few Months. As is obvious the plug, cage and seating material have been completely destroyed and a full replacement trim set would be needed every two or three months to keep this valve in service.

A material’s resistance to cavitation increases with its hardness, but at present no material exists that will give reasonable life under severely cavitating conditions.
3) THE ON-OFF RECIRCULATION SYSTEM

The on-off recirculation system can be further divided into two subclasses, full pressure reduction within the valve or a valve plus orifice plate arrangement. For full pressure reduction within the valve a pressure-staging or profiling trim will be required to prevent cavitation damage downstream of the valve trim vena contracta. (See Section 7.) For a valve plus orifice plate arrangement the valve will take only enough pressure drop such that cavitation will not occur. The remainder of the pressure drop must be taken, usually in stages, across the outlet piping. This is normally achieved through orifice plates, diffuser plates, capillary tubes, or spargers installed in the outlet piping.

The major drawback of this second system is that the valve must be opened or closed quite rapidly in order to establish backpressure in the outlet piping since the outlet piping pressure drop increases from zero to its maximum as the flow through the recirculation loop increases. This means that the first part of the recirculation valve's travel will be a severely cavitating condition and thus the duration must be minimised. When using full pressure reduction within the valve the duration of severe cavitation/flashing coming on or off of the valve seat is minimized.

The main drawback of the on-off system is the effect of opening or closing the recirculation valve on the rest of the system. If opening or closing is too rapid, significant changes in main feedwater flow and pressure may cause fluctuations in the net flow to the boiler or reactor. Therefore, the key to success with an on-off recirculation system is to limit opening and closing times such that less rapid adjustments are required to maintain a continuous feedwater flow.

This can be done in two ways with pneumatic actuators. The first method is to run the valve opened or closed on a gradual ramp with the plant computer feeding a gradually increasing or decreasing signal to the positioner mounted on the recirculation valve. A second and possibly more simple method is to use a solenoid valve actuator with needle valves or orifices installed in the feed and exhaust ports. By throttling down the air flow to and from the actuator the valve will open or close more slowly.

4) THE MODULATING RECIRCULATION SYSTEM

A slight variation of the on-off system is the modulating system. In this system, instead of opening or closing the valve at a fixed point, a proportional control scheme is used where the amount of recirculation flow is regulated in proportion to the amount of feedwater flow decreases, recirculation flow must increase. In using this system one would not expect to see rapid variations in feedwater flow as the recirculation valve opens. Significant energy savings will also be attained since the valve will pass only enough flow to meet the pump's needs and not a set minimum flow.

There is, however, one keep drawback to this type of operating scheme. The problem arises if the proportional control is such as the valve is positioned at low lifts for any significant period. This problem could arise with a 500-mw during the evening hours. During this period the valve could be continuously throttling across the valve seating surfaces, and wear, wire-drawing or cavitating of the seats can be expected. As will be presented in a later section, valve seating and zero seat leakage are imperative and thus every measure must be taken to protect the valve seats. In order to avoid this problem it is imperative that the valve be ramped closed quite rapidly below 10% to 20% of valve stroke. This can be done with a programming step in a computer control scheme or by using a limit switch and solenoid valve in a direct proportional control scheme. In addition, some characterizable positioners will allow this bi-stable step in the cam programming.
5. THE DOWNSTREAM RECEIVING VESSEL AND PIPING

Two basic choices are present when considering where the recirculation flow should be discharged. The first but less desirable from a performance viewpoint would be to allow the recirculation valve to discharge directly to the condenser. The basic problem with this type of system is that the outlet pressure will fall below the vapour pressure, as condensers in general operate at a slight vacuum, and flashing off the recirculation flow will occur. Generally, if outlet piping pressure reduction devices are not used, the valve will be continually flashing at the outlet. At first opening and closing flashing will occur across the valve seat. In the event that a backpressure device is used, it is important that the valve must open and close quite rapidly. Once the recirculation flow drops off, the backpressure generated in the downstream piping will fall off proportionally and flashing will again occur.

This implies that one should only consider on-off systems with quite rapid opening and closing times to minimize the effects of flashing. This in general will be the case as the amount of turndown on the outlet piping backpressure devices is quite limited, and, unless the valve operates within a very narrow flow range, back pressure devices will not be able to provide outlet pressures at the valve greater than the vapour pressure at all flows. The problem basically reduces to the fact that valve designers are able to control cavitation from most feedpump pressures (as high as 6,000 psig) all of the way to outlet pressures greater than the vapour pressure (see section 2). However, to reduce the valve outlet pressure below the vapour pressure, many other problems are encountered if done within the valve.

If flashing must occur in this type of recirculation system, the most desirable location would be across an outlet diffuser or sparger mounted in the condenser. If located away from the condenser wall or piping, the flashing will occur inside the relatively large volume within the condenser and damage will not occur within the recirculation valve, outlet piping, or condenser.

A recent development in the backpressure device industry is the constant backpressure device. This device, usually mounted within the condenser, will effectively maintain a fixed backpressure within a certain range of flows and will flash the outlet flow into the condenser.

The second, most common, and preferred downstream sink is the deaerator or deaerator storage tank. Since deaerators generally operate within the 50-to 200-psig ranges, the outlet pressure at the valve will automatically be above the vapour pressure and flashing will not occur. This, in general, will eliminate the need for outlet piping backpressure device. Furthermore, if the valve is located close to the pump, there will be a significant amount of backpressure due to the difference in elevation of the valve relative to the deaerator. Degaerators in general are located about midway up the boiler in elevation, and the pump will generally be located on or below the turbine floor.

When considering costs, condenser discharge may at first seem the way to go as the actual amount of piping is very small. The cost difference compared to systems discharging to a deaerator storage tank will easily be offset by the cost of backpressure devices and a much more severe duty valve for condenser discharge. In the event that one has selected to discharge the recirculation flow to the deaerator or storage tank, consideration should be given to placing the recirculation discharge pipe below the water level in the deaerator. This would keep the outlet-piping full of water and minimize adverse effects during initial recirculation valve opening or closing as the outlet piping would charge more rapidly.
6) VALVE REQUIREMENTS

For a valve to be successful in this service with differential pressures in excess of 1,800 psig, it must be able to deal with four general problems.

First, the valve must be able to protect its trim from cavitation damage between initial valve opening and full valve opening. (See Section 2.)

Next, the valve must be able to deal with foreign matter and pipe scale entrained in the flow stream. Foreign matter will cause problems in two basic ways. If foreign matter gets into the plug-to-cage clearances, galling will occur if the hardness of the foreign matter exceeds that of the trim. Or, if the valve seat closes on foreign material, full valve closure will be impaired and wire-drawing/cavitation will occur across the seat.

Third, the valve must be able to provide zero seat leakage as any leakage in this service will cause wire-drawing across the seat and trim failure will occur. One very important fact to be considered here is the effect of recirculation valve leakage. Referring back to Figure 1, it can be seen that the recirculation leakage flow will be passed back to the deaerator or condenser instead of going to the boiler or reactor to generate steam. Two different results will occur. On a sub critical unit generally the pump is oversized by a sufficient amount to make up for the recirculation leakage; however, the pump will have to generate more horsepower to make up for the lost capacity. On a supercritical unit there will be a direct relationship between recirculation leakage and generating capacity at peak load. For example on a 500-mw supercritical unit, 80,000-pph leakage is not unheard of with a wire-drawn trim. This, if viewed in proportion to total plant flow, would indicate 4-mw leakage at peak load.

The final and most difficult requirement is that the valve must be able to maintain zero seat leakage throughout a normal service life. In the past, valve designers have been able to provide zero leakage initially, but maintaining that leakage throughout a number of opening and closing cycles has been the key problem. The main concern is that the area of minimum cross-section upon initial valve opening and closing will be across the seat in most valve designs. This implies that the seating surfaces will be the initial throttle point in the valve upon opening or closing. This throttling action on the valve’s primary seat will be detrimental to the ability of the valve to provide zero leakage. Metal seats will be much more resistant to this throttling action; however, zero leakage is quite difficult to obtain with a metal seat.
7) CAVITATION PROTECTION

Two basic approaches exist for eliminating cavitation within the valve, pressure-staging and pressure-profiling trims.

Figure 4 illustrates a pressure-staging trim design. Liquid enters at the bottom of the trim and reaches a maximum velocity before discharging into the first groove, where its velocity is reduced. This process is repeated over the entire length of the plug, and the liquid is subjected to velocity changes as it passes through each stage of the trim. A pressure drop occurs at each increase in velocity such that the pressure drop is broken down in a series of fixed increments. A very slight taper is employed so that the change in area through the valve trim is gradual, and this introduces a friction drag effect to the fluid. In this design the pressure is reduced in a number of stages, and quantifying the pressure drop per stage is generally not considered. This implies that there may be cavitation on certain individual stages.

The most successful and technically advanced cavitation control solution is to adopt the principle of pressure-profiling. The formula for determining the incidence of incipient cavitation is:

\[ P_{cav} = K_d (P - P_v) \]

Where:

- \( P_{cav} \) = pressure drop likely to result in cavitation
- \( K_d \) = coefficient of incipient cavitation
- \( P_1 \) = inlet pressure
- \( P_v \) = vapor pressure at flowing temperature

From this it will be seen that the pressure drop at which cavitation will occur is linked to the inlet pressure and the vapor pressure of the fluid. Therefore, at a high inlet pressure, quite a high-pressure drop can be taken before cavitation will occur. As the inlet pressure reduces a lower pressure drop will give rise to cavitation. In the pressure-profiling concept the pressure drop is varied at different stages of the trim, so that at no point in the fluid's passage will cavitation occur, as shown in Figure 5.
One design employing this approach is shown in Figure 6, from which it can be seen that the trim consists of a series of cylindrical sleeves that are provided with a multiplicity of drilled holes. These holes are arranged in a series of rising spirals so that a gradual increase in flow is achieved as the plug, located within the center sleeve, is raised. The sleeves are rotated relative to one another, such that the holes in successive sleeves are overlapping. The overlap between successive sleeves provides a restriction to the flow path and the holes themselves provide the expansion chamber following the restriction.

Fluid is admitted into the central sleeve where the mass flow is broken down into a series of jets. As these jets pass through successive sleeves they undergo an increase and subsequent decrease in velocity as well as a change in direction. At each successive increase in velocity a pressure drop is created in the fluid’s path, and, by correctly sizing the amount of hole overlap between each sleeve, a controlled pressure drop is assured at each stage. In this manner, the pressure drop can be guaranteed not to exceed the limit set in order to avoid cavitation. This design is limited to a maximum of 5 or 6 Pressure reduction stages. In some cases, where more stages are needed an alternative design, such as the RAVEN must be used.
RAVEN TRIM TECHNOLOGY IN BOILER FEEDPUMP RECIRCULATION

To effectively eliminate cavitation the recirculation valve must perform two functions:

1. It must control the fluid during the large pressure letdown
2. It must ensure that no leakage occurs when the valve is closed.

The RAVEN trim consists of a number of individual discs bonded together to form a disc stack. Each Disc in the stack has a multitude of tortuous channels etched onto the disc surface. The RAVEN trim incorporates the next generation of development in velocity control trims. The RAVEN Trim consists of:

- **Multiple Inlets** - Regardless of flow direction (i.e. over or under the web), multiple inlets feed one path. Therefore, the path capacity will not be reduced if one inlet happens to get blocked. For flow from under the web, the multiple inlets uniformly distribute the fluid around the plug, therefore, insuring complete plug stability and control.

- **Thin Wall Design** - The thin wall design incorporated with the Raven disc, maximises the tortuous path by forcing the fluid to ‘turn back on itself’ then assures uniform velocity control by directing the fluid through long straight sections, which streamline the fluid.

- **Open Flow Pattern** - The Raven flow path pattern is a symmetrical design that distributes the fluid evenly through out the disc. The open flow path pattern allows for an evenly redistribution of fluid if one or more of the paths are blocked.

- **Multiple Outlets** - The multiple outlets for the disc design are extended in length in order to streamline the fluid. This prevents turbulent interaction between outlet jets down stream of the trim, which in turn minimises exit velocity, noise and plug or body erosion.

In the recirculation valve each disc pattern is the same so that the disk is working equally for all flows. If necessary the trim can be characterised by using smaller Cv discs at the bottom of valve stroke, and increasing this “Cv per Disk” as the stroke increases. This allows full flexibility and an invariable number of characteristics that can be match to virtually any requirement.
A Typical disc is shown on the left. Each flow channel consists on a number of sharp right angle turns (or Stages), each of which account for more than one velocity head of pressure. By using a thin wall design it is easy to see that a large number of turns (or stages) can be performed within a single disc. RAVEN, through the use of narrow wall design is typically more efficient at passing flow or allowing more turns or stages of drop in a given valve size.

We shall look at the individual design features of this trim and discuss how and why these are important in a recirculation valve.

1. Multiple Inlets.

These serve a number of key features. Firstly they inhibit the introduction of any foreign matter into the trim, which may pass through the valve and damage the seating surface. Due to the open flow path design any blockage that does take place does NOT affect the flow characteristic of the trim. On other similar design the individual flow paths are separate from each other - hence if the inlet to the channel becomes blocked the entire channel is effectively rendered useless. Most RAVEN trims contain multiple relief points in the flow path as a standard feature. These relief points allow entrained debris to clear the main fluid flow, or in the case of severe blockage, they provide a bypass route.

With the benefits of relief point being obvious, the actual fluid flow streams still remain virtually separate or discrete from each other for best velocity control. Note the flow pictures above and left. Above shows the RAVEN in full flow. The Picture on the left shows a very obvious blockage - however note that all the exit ports are still in use - hence the flow has been bypassed around the blockage causing minimal capacity loss.
2. Expanding Flow Channels
The Flow Channels are increasingly expanding as the fluid pressure decreases. From disc 1 shown previously you will see that this is a Flow UNDER the web disc as the flow area increases from inside to outside. As the pressure drop takes place the internal trim velocity is controlled by the disc design – therefore there are no local pressure recovery points for cavitation to take place as you would find in a single pressure drop trim.

3. Turns or Stages designed per application
Because of the large number of stages the pressure drop takes place at much lower velocities. In many recirculation valves the liquid velocities can reach up to 600 feet per second (180 m/sec). In this type of trim the liquid velocity is limited to around 200 feet per second (60 m/sec) and this will only occur for a very short period of time as the first turns begin to take effect and reduces this to the acceptable limit.

4. Pressure Equalizing Ring.
A Pressure Balanced groove ring around the I.D of each disc allows the plug to be completely balanced around its circumference, and provides a landing area for entrained debris, thus precluding plug galling. Additionally, bypasses in the flow path allow for entrained debris to clear the main fluid path.

The second essential function as mentioned previously is to maintain a ZERO leakage valve.

Two basic approaches have been employed in valve seating, metal and soft seat designs.

In the metal seat design, as shown in Figure 7, a differential bevel is used between the plug and seat to achieve a line contact surface between the seats.

In this manner, the actuating thrust is developed over a fairly narrow band, thus focusing the stress in a very small area.

As can be seen in Figure 8, the inherent surface microstructure is such that various peaks and valleys occur between the seat joint. In order for the seat to provide zero leakage the actuator thrust must be sufficient to yield the peaks in the seat surfaces such that perfect contact is achieved for 360 degrees about the plug's contact area.

Figure 7: Metal Seat Concept
This kind of contact, although obtainable, remains fairly inconsistent, and repeatability is very questionable. In the event that leakage occurs in this service, it is easily seen that cavitation and/or wire-drawing across the seat will follow. Once leakage commences it will increase quite rapidly to astounding proportions due to the severe differential. By using Stellite or hardened metal seats, resistance to wire-drawing is increased, yet in services where shut-off differentials exist in excess of 1,800 psig, there is no existing seat material that can survive the continuous leakage of a metal seat design.

One further problem with a metal seat design is that nearly perfect plug-to-seat alignment is required to provide zero leakage. Perfect plug-to-seat alignment is almost impossible to maintain due to machining tolerances.

It is not being proposed that metal seats never be used in any service but that, within the scope of feedpump recirculation, metal seats in general will not be serviceable and Class VI leakage rates should always be specified.

With a soft seat design, a soft, resilient seating material is used to mate with the plug, as shown in Figure 9. By embedding the smooth surface of the plug into the resilient seat material, perfect plug-to-seat conformance will be obtained, with reasonable actuating thrusts on the valve’s stem. In general, only enough stress to provide zero leakage need be applied to the soft seat, making it very critical that the resilient seat be able to support this load for extended durations. Repeatability is assured as the soft seat surface is not permanently deformed (yielded) and perfect plug-to-seat conformance can be repeated. Seat-to-plug alignment is not nearly so critical as with a metal seat since the resilient seat will correct for minor variations in the alignment.
9) PLUG BALANCE

Due to the excessive differential pressures with recirculating service, plug balance becomes very critical. The area of exposure to the inlet pressure must be nearly in balance above and below the plug. Figure 11 illustrates the balanced concept with the standard metal seat design. A series of holes is drilled through the plug to allow the inlet pressure above the plug. A u-cup seal is then used to inhibit leakage through the plug-to-cage clearance from above.

![Figure 11: Balanced Trim](image)

By analyzing this drawing, it can be seen that only two very small, out-of-balance areas exist. The first is the area of the valve stem, which will have atmospheric pressure above and the inlet pressure below. The second occurs when the valve is seated due to the differential angles of the seat.

To further illustrate this concept, consider a 3-in. diameter plug with an inlet pressure of 5,000 psig and an outlet pressure of 100 psig, with frictions neglected. If an unbalanced design were used, an actuator thrust of nearly 35,325 lbs would be required to shut the valve as compared to an actuator thrust of 3,926 lbs for a balanced design.

One added aspect to consider when analyzing trim balance is to be careful not to have drastic changes in balance at different plug lifts or extreme instability may be observed.

10) ENTRAINED SOLIDS

Probable one of the more common failures of recirculation valves is leakage of a soft or metal seat due to the plug's shutting off on a piece of entrained solid. If this occurs, wire-drawing/cavitation of the seats will occur. Most soft seat designs are able to deal with solids of .60-in. diameter and smaller if the concentration is low. Metal seats, on the other hand, will encounter problems if the entrained solid is harder than the plug or seat ring, thus impairing full valve closure and providing a leak path.

Two basic methods exist for filtering the flow stream of particles larger than .060-in. diameter. The first, and most common, is to rely on the suction strainer installed with the pump. The main drawback of this approach is that pipe scale, weld slag, and pump debris could still be received into the recirculation valve due to the piping between the suction stainer and the valve. The most common time for this occurrence is during cold, initial start-up or start-up after an overhaul.

Referring back to Figure 1, it can be seen that when the pump is first started all flow from the pump is through the recirculation valve as the feedwater valve is closed. Therefore, any debris in the pump or in the pipeworks between the pump and the valve will wind up in the valve.
11) CONCLUSION

As presented in the previous sections, it can easily be seen that the feedpump recirculation valve, although simple in function, is normally the most severe duty valve in the plant. Valve manufacturers have certainly responded to the needs of this system and are finally able to deal with all of the four general problem areas:

1) Protecting the valve from cavitation damage
2) Providing zero leakage
3) Maintaining zero leakage
4) Protection from entrained solids.

Technically advanced designs such as the RAVEN Trim fitted with a ZERO Leakage seat are easily able to survive this service. With the advent of pressure-profiling trims, there is no longer the need for expensive downstream equipment.