CONTROLLING CENTRIFUGAL PUMPS

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INTRODUCTION. The centrifugal pump is one of the simplest pieces of equipment from the automation point of view. It is a two port device with a well defined characteristic. Its purpose is to provide the necessary pressure to move liquid at the desired rate from point A to point B of the process. Figure 1-1 shows a 'generic' process with a centrifugal pump connected to deliver liquid from A to B.

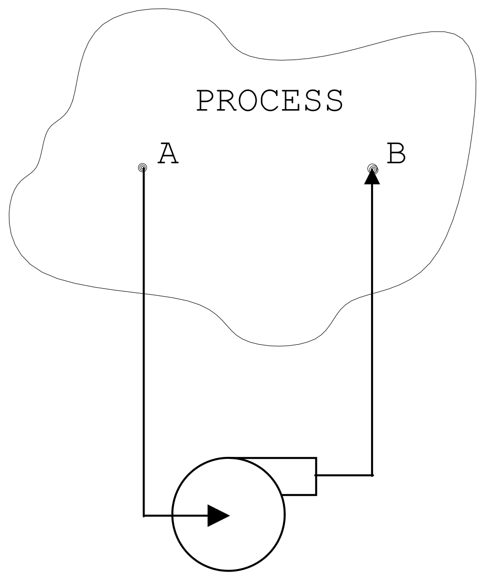

Fig. 1-1. A Centrifugal Pump and a Process

Figure 1-2 shows the characteristic curve of an actual pump (a single stage vertical turbine pump) together with the characteristic curve of the process, known as the system curve. The intersection of the two curves defines the operating point of both pump and process. It would be fortunate indeed if this operating point is the one actually specified for the process. It is impossible for one operating point to meet all desired operating conditions since the operating point is, by definition, exactly one of an infinity of possible operating points. In fact the entire point of controlling the pump is to modify its characteristic so that its actual operating point is the one that is required at every instance in time.

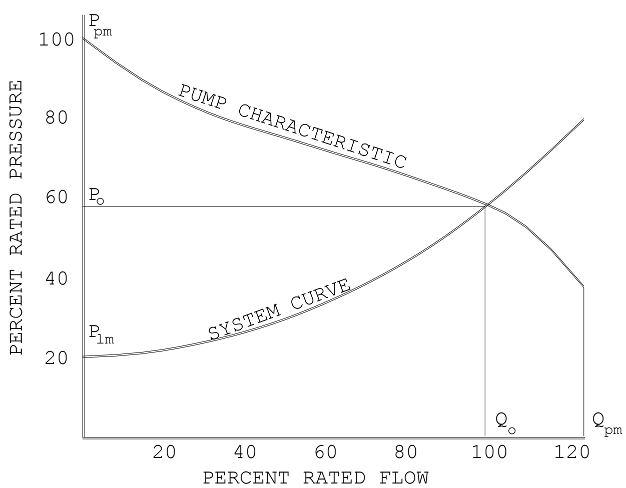

Fig. 1-2. Pump Characteristics and System Curve

Several definitions are presented in order to discuss the diagram:

- P_o = Differential pressure, or head, at the operating point of the pump and also of the process.
- Q_o = Flow rate, at operating point, of the pump and also of the process.
- P_{pm} = Maximum differential pressure across the pump (at shutoff).
- Q_{pm} = Maximum discharge flow of the pump.
- P_{lm} = Static (Minimum) differential pressure between points B and A of the process.

The minimum static differential pressure of the process is frequently zero, as in a closed, circulating system. If the pump is in parallel with other pumps that are maintaining the system pressure, then P_{lm} is greater than zero. It is clear from the outset that if P_{lm} is greater than P_{pm}, no amount of process control can force the two curves to intersect. The pump is simply inadequate. How is process control like cutting off a rope? You can always cut off more, but you can't cut off less.

Assuming the pump is more than adequate for the process requirements at the moment, what is the best way to trim it back to the desired operating point, P_1, Q_1? There are three possible locations to place a valve: At the discharge, at the suction, and as a recycle valve. Each will be discussed in turn.

DISCHARGE THROTTLING. Since the pump exists to serve the requirements of the process, and one of the primary purposes of instrumentation is to adapt the equipment to the process, let us consider the pump from the point of view of the process. It can be viewed as a constant pressure device with an internal restriction. It is the restriction that gives it the "curve". It seems natural to put a valve on the discharge to further restrict the pump. This has the effect of rotating the curve of the pump/valve system clockwise around P_{pm}, as can be seen in Figure 1-3.

At this point I must warn the reader that we are about to encounter a paradigm shift(!) The combination of pump and valve will be presented as a "black box" with a single characteristic curve which I shall term the "modified" pump curve.

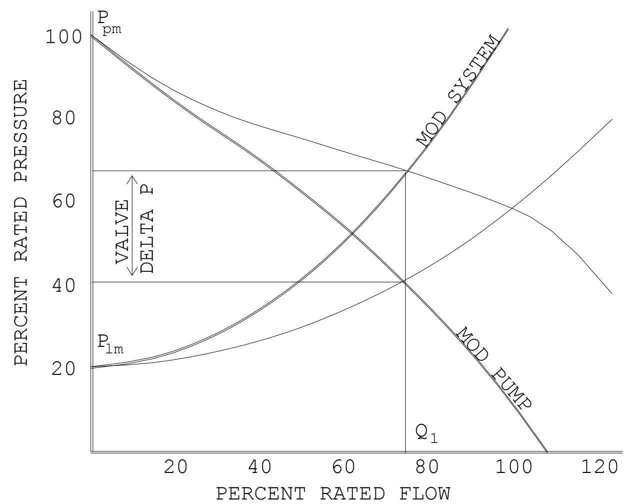

Fig. 1-3. Modified Curves: Discharge Throttling

The more traditional way of looking at the situation is from the point of view of the pump. It sees the process system curve as having rotated counter clockwise around P_{lm}. Figure 1-3 shows that the flow, Q_1, is the same for both cases. The difference between the two pressures is the Delta P across the valve. Since the purpose of the pump is to serve the process requirements, and the purpose of the valve is to adapt the pump to the process, it makes sense to consider the valve to be part of the pump system and to use the modified pump curve rather than the modified system curve in our discussion. In any case it can be seen that a discharge valve can be used to achieve any operating point on the system curve so long as that point is below the pump curve.

SUCTION THROTTLING. The second possibility for control using valves is to place the valve in the pump suction line. This would have an identical effect on the characteristic curve, but the method has a fatal flaw – cavitation. Cavitation is a phenomenon that occurs when the pressure of a liquid is reduced below its vapour pressure and brought back up above the vapour pressure again. Bubbles of vapour form in the liquid and then collapse upon arriving at the higher pressure region. The collapse occurs at sonic speed ejecting minute jets of extremely high velocity liquid. Wherever these jets impinge on a solid surface extreme erosion occurs. Over time even the hardest materials will be destroyed. Therefore it is of utmost importance that this pressure reduction never occurs. It is prevented by having sufficient pressure available at the pump suction so that the pressure drops that occur as the liquid is drawn into the eye of the impeller are at **all** times above the vapour pressure of the liquid at its current temperature.

An explanation of the term Net Positive Suction Head (NPSH) is in order. This is the pressure of the liquid at the pump suction in terms of feet or meters of liquid head above the vapour pressure of the liquid. The actual NPSH under operating conditions is called NPSHA and the minimum required by the pump to prevent cavitation is called NPSHR. Clearly NPSHA must be greater than NPSHR to avoid cavitation. It is safe to leave a margin of about one meter.

These peculiar definitions are very reasonable in terms of the pumps actual characteristic but they cause some problems to the controls engineer. It means that the gauge pressure equivalent of a given NPSHA is proportional to the density of the liquid and is also affected by its temperature. The vapour pressure can rise dramatically as the temperature rises. This means that the NPSHA can fall without a noticeable change in pressure.

Anything that would reduce the net positive pressure at the pump inlet below the NPSHR must be absolutely avoided. Thus suction throttling is never used to control pump flow.

RECYCLE CONTROL. The third remaining possibility for pump control with valves is to bleed some of the discharge flow back to the pump suction or to some other point on the supply side. Once again we can view the result as a modified system curve or as a modified pump characteristic. Figure 1-4 shows both. Each curve is a rotation of the original: The modified system curve as a clockwise rotation around P_{lm}. Note the little "tail" at the left of the modified system curve. This represents the flow through the recycle valve before the discharge check valve opens to the process. The modified pump curve has a counter clockwise rotation around the hypothetical intersection of the pump curve with the flow axis.

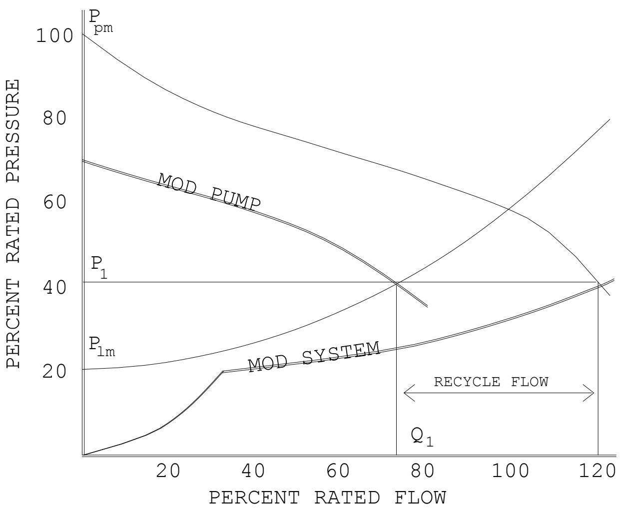

Fig. 1-4. Modified Curves: Recycle Valve

This family of curves shows several problems with recycle control. Firstly, the pump is not rated to discharge more than the flow rate at the end of the curve. It is **possible**, of course, to run the pump with a wide open discharge, minimum ΔP, but it is unhealthy for this particular pump to run at such a high rate. Excessive flow may cause cavitation damage. (Excess flow cavitation is not caused by NPSH problems but by high velocity within the internal passages of the pump.) This restriction means that the minimum discharge pressure may not be lower than the one corresponding to the maximum flow. In other words, the modified pump curve cannot reach all points on the system curve.

Secondly, although many pumps are capable of operating near zero discharge pressure, the very flat pressure vs. flow curve for much of the lower range for most pumps means a change of flow has very little effect on the discharge pressure. Thus it would take a very large amount of flow to produce a small drop in pressure. In control terms this means that control would be very 'sloppy'. Discharge throttling on the other hand, allows the pump to develop the head that 'suits' it. The unwanted pressure is dropped across the valve. (Note that the curve for this particular pump rises rather steeply. It will be more easily controlled than most.)

Thirdly, this method is often inefficient. Figure 1-5 shows a system curve, a pump characteristic, a discharge modified characteristic, and a recycle modified characteristic. Above these is a pump power requirement curve. In the case of discharge control, the pump is adapted to the process by dropping its discharge pressure. If one follows the flow line vertically to the actual pump curve and then beyond to the power requirement curve one arrives at its power requirement. In the case of recycle control, the pump is adapted by reducing the discharge flow. Following the pressure line to the right to the actual pump curve and then upwards to the power requirement curve one arrives at the power requirement for recycle control. Note that the power requirement curve tends to slope upward as flow increases. Therefore recycle control consumes more pump horsepower than discharge throttling when both achieve the same operating point. This is not always so. If the power requirement curve were flat, there would be no difference. Notice on the curve that there is a slight drop in horsepower near the right hand end. If circumstances were such that the operating point corresponded to a downward sloping power curve, recycle control would be more efficient. This is rare.

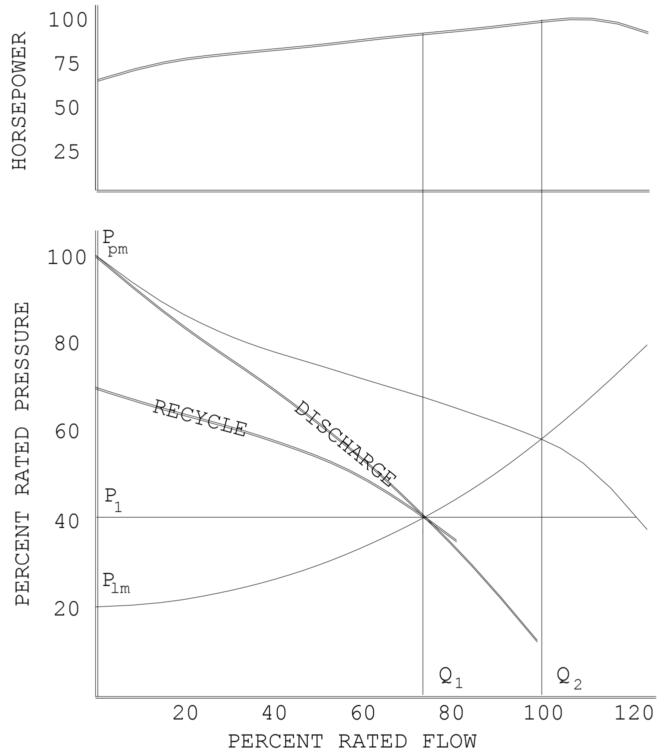

Fig. 1-5. Discharge Throttling

SPEED CONTROL. There is, of course, one other means of adapting a pump to the changing demands of the process: Speed control. The virtue of this method is that it reduces the energy input to the system instead of dumping the excess. Figure 1-6 shows a system curve superimposed on a family of curves for a variable speed pump. The curves reach all parts of the system curve below the full speed curve. Therefore this is an effective means of control. Note, however, that these curves have one feature in common with recycle control: At the far left end of the system curve the pump curve and the system curve are almost parallel. (The particular pump chosen for this example has a rather steeply

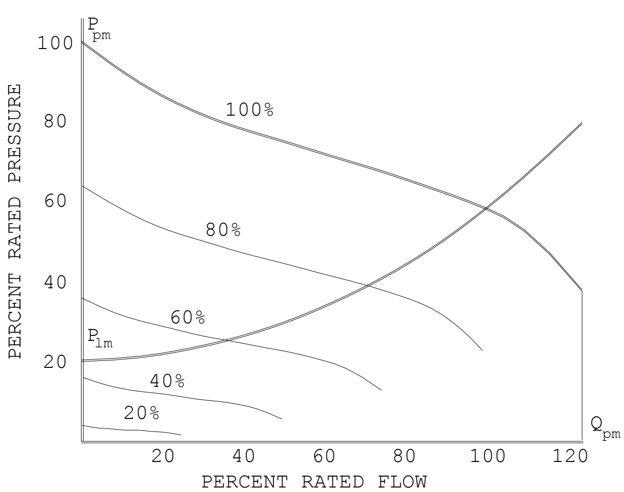

Fig. 1-6. Variable Speed

rising curve near shutoff. Most are considerably flatter.) In mathematical terms this means that the intersection is poorly defined. In practical terms this means that it is difficult to maintain a precise operating point and that control is 'loose' at high turndown.

In practice, variable speed drives for centrifugal pumps are still relatively uncommon. For small pumps the power savings are not significant and for large pumps the associated electronics become very expensive. Also, they do not have the high reliability of valves. Variable speed steam turbine drives are quite common in the larger horsepower ranges. Electric variable speed drives are used in certain specialized applications such as pumps that are embedded inside a high pressure vessel. In such cases there are no alternatives.

RIDING ON THE CURVE. Last but not least: No control at all! The fact is that the majority of pumps in the world run with no control at all. The exact flows and pressures are not critical and the pump has been reasonably well selected. The discharge pressure will rise to partially compensate for increased back pressure. It falls as the back pressure decreases so that the flow does not increase as much as it otherwise might. The pump is allowed to "ride on its curve". When this situation is acceptable, leave well enough alone and don't try to fix what ain't broke. (Be careful though, the machine may still require minimum flow and other protections as detailed in the section on Machine Protection.)

MEASUREMENT. The appropriate measurement for the controller depends on the demands of the process. Flow control is a frequent requirement. Two rules guide the location of the flow measurement: Make sure that side streams are included or not, as required, by the measurement and make the measurement at the highest convenient pressure. The latter requirement is to avoid any possibility of flashing or cavitation within the measuring device. In general the best place to measure flow from a centrifugal pump is between the recycle Tee and the discharge throttling valve. The exception is when the discharge is at an extremely high pressure and the suction has adequate NPSHA. In that case a suction measurement may be best.

Level control of a vessel is one of the most common requirements[1]. The vessel may be either upstream or downstream. It is quite possible to connect the Level Controller directly to the discharge valve. Frequently, however, the vessel serves to buffer a downstream process from upstream flow variations. In that case it is not desirable for level control to be precise. Perfect level control implies that the flow out is exactly equal to flow in at all times. Often it is desired that the downstream flow remain as uniform as possible while keeping the level within bounds. In simple terms, it is desired that the flow out is the average of the flow in. The vessel absorbs the instantaneous differences. This simple requirement is more difficult to accomplish than it may seem and deserves a discussion entirely of its own. A simple arrangement that is often satisfactory and is widely used is to have the Level Controller cascade to a Flow Controller on the pump discharge. The flow loop keeps the discharge “constant” while the Level Controller *gradually* raises or lowers the setpoint as the level in the vessel rises or falls.

Another common requirement is to control the pressure of either upstream or downstream equipment. The tap for the pressure transmitter should be connected at the point where it is desired to control the pressure. Note that a pressure tap between the pump and a discharge throttling valve is probably meaningless. A careful look at many pump curves will show that the characteristic near shutoff is quite flat and may even slope downward. Pressure control cannot be accomplished when the pressure curve is flat. If the slope is the 'wrong' way, control will work backwards and drive the valve away from the set point. In this case the minimum flow should be set so that the pump cannot operate in the positive slope region of the curve. (It is, of course, possible to reverse the action of the controller so that it can operate to the left of the peak. But in that case, what will happen if the operating point moves to the right? It is extremely difficult to design control systems that can operate continuously along a characteristic curve that has a local minimum or a maximum in it.)

There is a second, more serious, problem with pressure control. Centrifugal pumps are essentially constant head machines. The discharge pressure for a given pump rotating at a fixed speed is proportional to the density of the liquid. This means that if the liquid has a constant density, the discharge pressure is constant. The "curve" of the pump curve is produced by losses and the dynamic affects of flow. Unless there is a flow through the system, there is only one pressure and that is the shutoff pressure. If it is desired to control the pressure of a vessel being charged by a pump, it is best to pressure control a valve at the outlet of the vessel and let the pump ride on its curve. If the vessel must be dead ended, only recycle flow at the pump can control pressure to a setpoint.

ON / OFF CONTROL. On/off control is used in many situations where the object is simply to move a liquid from point A to point B and the exact pressure or flow rate is unimportant. A typical example is the sump pump. The simplest arrangement employs a level switch with a very broad deadband. This is used together with a Hand/Off/Auto switch to turn the pump on and off. The schematic is shown in Figure 1-7. The LSHL contact opens when the level is below its setpoints. "M" represents the motor contactor which energizes the motor whenever the contactor is energized. "M" also represents the auxiliary contact that is closed whenever the contactor is energized.

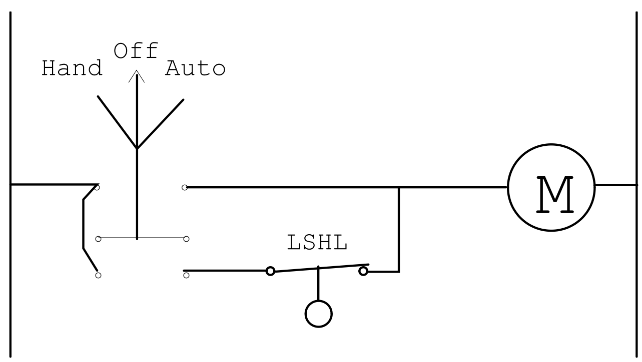

Fig. 1-7. Hand / Off / Auto Schematic

If it is important that the level never goes beyond the upper or lower setpoints, the Start/Stop arrangement is preferred. It is illustrated in Figure 1-8. The process sensing switch has a separate output for the upper setpoint (On) and the lower setpoint (Off). (Two switches may be required.) The manual switch consists of a Start and a Stop button or a combined Start/Run/Stop selector with a spring return to centre. The operator may start or stop the pump whenever the level is between the two setpoints. He cannot stop it when the level exceeds the high setpoint unless he locks it out. He cannot start the pump below the low setpoint. A variation of the circuit places the left connection of the start button to the left of the low

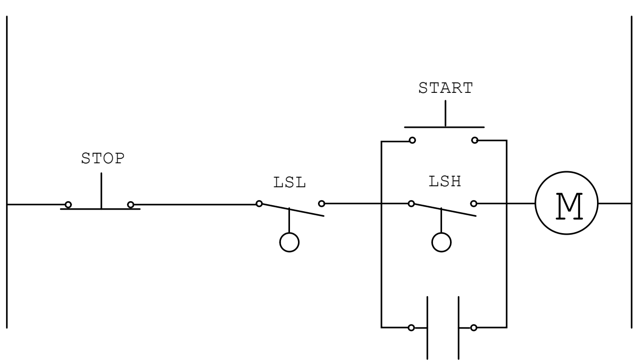

Fig. 1-8. Start / Stop Schematic

level switch. With this arrangement it is possible to drain a vessel below the low set point by holding the start button on. The pump will stop as soon as the button is released.

With both of these arrangements, there must be sufficient deadband between the high and low setpoints to make certain that the pump does not cycle on and off too rapidly. Excessive wear of both the motor and its starter will result if this occurs. Rapid cycling is a sign of an over-sized pump.

MACHINE PROTECTION. Once the process requirements have been met, the attention of the process control engineer turns to protecting the equipment. Centrifugal pumps are fairly undemanding. In general they have only two requirements: that the NPSHR is met at all times and that a certain minimum flow is maintained. To meet the first requirement is generally a piping design problem. In cases of doubt, a low pressure shutdown switch may be added to the suction line. A second look at the explanations of NPSH, above, shows that determining the setpoint of the switch is not necessarily a simple matter if there is any possibility of the liquid density changing. Things get even more complicated if the vapour pressure is very sensitive to temperature. A rise in temperature that causes the liquid to boil will cause the net positive pressure to fall to zero even though there is an increase in actual pressure. LPG and LNG pumps are notorious for NPSHA problems. Fortunately most pumps can tolerate brief periods of cavitation without noticeable damage.

When a pump is taking suction from a vessel, a low level shutdown switch is essential. The switch, or transmitter, must be separate from any level control devices.

To meet the second requirement, minimum flow, is somewhat more difficult. A centrifugal pump adds energy to the liquid that the moving liquid carries away. If flow is blocked, the temperature within the pump will rise steadily until the liquid boils (net positive pressure is now zero). Damage to the pump is quite likely. For this reason some form of minimum flow is almost always included on larger machines. The simplest arrangement is a fixed restriction orifice on a line leading back to the supply side of the pump. The preferred destination of the recycle flow is back to the vessel from which it came. This allows the heat to dissipate before it is recycled back into the machine. Restriction orifices have two drawbacks: They waste energy when the process demand is sufficiently high to meet all minimum flow requirements and also they limit the maximum pump output.

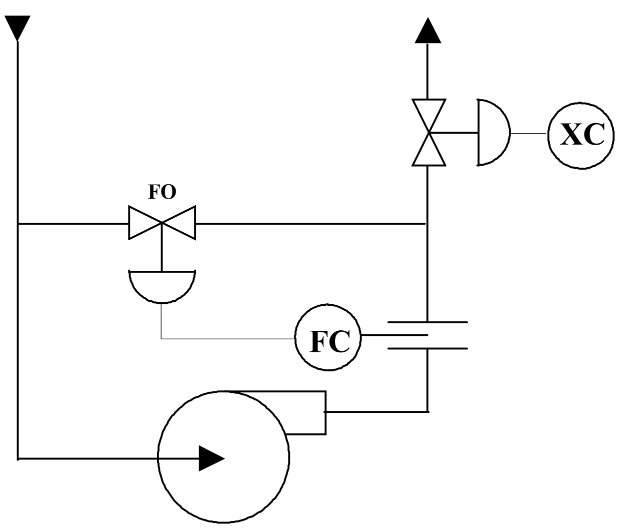

Fig. 1-9. Minimum Flow Control

A more efficient method of recycle control requires that the discharge flow of the pump itself is measured, and that a valve in the recycle line is opened when the process does not draw the required minimum flow. The most straightforward way to accomplish this is shown in Figure 1-9. Note that the recycle line tees off upstream of the control valve. It is precisely when the control valve is closed that the recycle is needed. There is a small problem with controlling the minimum flow in this way: The measurement orifice in the discharge consumes energy and also slightly reduces pump capacity. A second problem is that the actual signal being measured is the ΔP across the orifice plate. Since flow varies as the square root of ΔP, a minimum flow of 40% of maximum flow implies a controller whose set point is only 16% of the measurement range. A typical instrument accuracy is 1%. Therefore an error of 7% of the setpoint can be expected. Fortunately the minimum flow need not be held very accurately. **Always** use a fail-open valve.

Various schemes have been devised to infer the required valve setting from the net discharge flow measurement. These require the flow downstream of the recycle Tee to be subtracted from the required minimum flow. The recycle valve is then opened in proportion to the difference, if it is positive. To do this accurately one must know the valve and actuator characteristics. There is no feedback to confirm that the correct flow is occurring. Since the flow is usually above the minimum flow, the valve is usually closed. This will cause the controller to wind up and be slow in responding when a low flow condition suddenly arises. Fortunately pumps can tolerate short periods of low flow so this is not a problem.

One method of minimum flow control that is occasionally proposed is to put a flow control loop on the recycle line with the set point equal to the minimum flow. This solution is worse than a fixed restriction. When discharge flow is high, the discharge pressure falls. Flow through a fixed orifice will reduce somewhat. A flow control loop will open the valve further to maintain constant flow precisely when it is not needed. At this point the operator will be tempted to manually close the valve. Then, when a discharge blockage occurs, there will be no minimum flow at all!

There are a number of devices available called Automatic Recirculation Valves, or ARC valves, that combine the functions of net discharge measurement, recycle control, recycle valve and discharge check valve all in one device. These devices can be very effective but they suffer from one drawback: lack of flexibility. In cases where the pump and process characteristics are well known, they can be an ideal solution. Pipelines, for example, have many identical pumps operating under steady conditions. Once the correct components are known, application is routine. It must be kept in mind, however, that both the process and pump data provided to the controls engineer for a new facility are often tentative. ARC valves have very little margin for error when the reality turns out differently from the theory. One particular problem that can occur with the older style ARC valves that operate in an open/close mode, and even with some that modulate, is instability. It occurs as follows:

- The discharge valve begins to close due to a reduced process demand.
- The ARC valve senses the reduced flow and opens the recycle valve.
- The pump discharge pressure drops.
- The discharge Flow Controller senses that it is being starved of flow and opens the discharge valve.
- The ARC valve senses the increased flow and closes.
- The pump pressure rises.
- The discharge valve closes.
- The cycle repeats itself.

Note that ARC valves are not positioned by conventional actuators. They are positioned by the process liquid itself and are capable of very rapid action. Instability results in violent slamming of the recycle valve, scaring the operators and severely damaging the reputation of the controls engineer. Very little can be done at this stage other than to remove the ARC valve and to attempt to modify its characteristic by changing the spring or boring out the recycle ports. The latter spoils the hardened seats required in high pressure drop applications and leakage is inevitable. Boiler feed pumps seem to be especially **prone** to these problems. Note that ARC valves are quite expensive and often cost more that a complete flow control loop. They are, however, extremely effective and simple under the right circumstances. Their use often simplifies the piping arrangement and essentially eliminates routine valve maintenance.

ARC valves are best bought as part of the pump package. In this way the responsibility for ensuring that they match the pump rests with the party that is most familiar with it.

The pump curves used in this article represent an actual pump but are by no means typical of all pumps. Multistage pumps, in particular, may have little quirks in the curves that can complicate controls. If the characteristic curve droops as it approaches the zero flow axis, (the shutoff pressure is less than their peak pressure) the minimum flow setting must be well to the right of the peak or severe instability can result. Boiler feed pumps discharge into a compressible volume. If they have a reverse slope near shutoff, they may experience surge much like a centrifugal compressor does. Note that API STD 610[2], the American Petroleum Institute standard for centrifugal pumps, explicitly bans a drooping characteristic.

SEAL FLUSHING and COOLING. Pumps in certain services require flushing and / or cooling fluids to be injected into the seals. The details are provided in API STD 610[2], Appendix D. In general, the instrumentation is rather simple consisting of rotameters, pressure gauges and thermometers.

In certain hazardous services, sealing becomes a more complex issue. If the danger of a seal leak is sufficiently serious, specialized leak detection may be required. One simple method is the installation of a pressure switch, or better yet, a transmitter, between the tandem seals. This can then be connected to the plant alarm system.

SAFETY. Centrifugal pumps are not generally hazardous pieces of equipment. However, there is one special safety consideration whenever a pump is drawing volatile hydrocarbons or other flammable liquids from a vessel with significant capacity. (API RP-750[3], defines this as five tons.) Volatile liquids have a low viscosity and seal leaks are not uncommon. The leaked liquid often catches fire and it is absolutely essential that the pump be shut down to prevent feeding the flames further. In such situations it is desirable to have a remotely controlled block valve between the pump suction and the source vessel. This valve and its actuator should be fire safe. Since closing the valve can cause low flow damage to the pump, it must have a limit switch to shut down the pump whenever the valve is not fully open. It should also have both opened and closed status indication in the control room so the operator can be fully confident that the valve is open when the pump is running and that the valve is closed when a hazardous situation exists. If the block valve has an electric actuator, it is a good idea to have an alarm on the main panel to indicate if there is a power failure, if the local switch is not in the 'Remote' position, or if there is any other reason the valve might not work when called upon to do so. In extremely critical processes, one may wish to interlock the pump so that it cannot start unless the valve is in working condition.

Any indoor pump in flammable service should have adequate fire detection in the building. Ultraviolet detectors are preferred because they are sensitive to flame. They are extremely fast acting since they do not depend on heat buildup or the generation of smoke. (There is an exception to this rule: If the flammable material produces a lot of smoke, it may obscure the vision of the UV detector. In such a case one might be advised to install both smoke and UV detectors.) A certain amount of care must be taken when UV detectors are installed. They are sensitive to sunlight and to welders. The sensitivity to welders is probably a good thing since it forces all welding to be co-ordinated with the control room. The sensitivity to sunlight means that they must be positioned so that they are unlikely to 'see' the sun. The usual position is high up under the eaves of the building in diagonally opposite corners. This is not always fool proof. The author is aware of one case where a pipeline compressor was shut down because a UV detector saw a welder working out in the parking lot. The welder was directly in line with a gap around a pipe that went through the building wall. "Smart" combined UV/IR detectors are becoming available that are able discriminate between sunlight, welding arcs and fire. This type is also suitable for outdoor use.

Fusible link sprinkler systems are extremely reliable and can contribute greatly in cooling down a fire that is too hot to approach. Their drawback is that they only become active once considerable heat has been developed. In critical applications they are best used together with a faster detection system.

It may be worthwhile installing flammable vapour detectors near the base of large pumps if leakage is a possibility.

Never overlook the placement of check valves. This is a safety related issue that should not be left to other disciplines as check valves are an integral part of the functioning of many control schemes. It is generally self-evident that parallel pumps need check valves on each individual discharge. This check is also needed downstream of the control valve on single pumps. When the pump is not running, the discharge valve will most probably go wide open. A reverse flow could have some peculiar effects on the upstream process. A check valve is also required downstream of the recycle valve if a fire safe valve is necessary. Any time the fire safe valve isolates the pump from the supply vessel, the recycle valve will open wide. ARC valves should be checked to make sure all necessary check functions are included.

ACCESSORY INSTRUMENTS. Centrifugal pumps require few accessory instruments. Since the purpose of the pump is to develop pressure, it is a good idea to have a pressure gauge on the discharge. If the application requires a low suction pressure interlock, a pressure gauge should also be provided at the suction. It would be nice to have a local flow indicator but they are invariably expensive and inconvenient to install so they are rarely used. A thermometer on the suction may serve to warn of cavitation if the vapour pressure is temperature sensitive.

PARALLEL PUMP INSTALLATIONS. Centrifugal pumps are frequently operated in parallel. Their smooth operating curve allows this to be done without complication. If it is intended that the pumps are usually operated individually and not simultaneously, it is sufficient to have a common discharge throttling valve and suction block fire safety valve. However it is essential that each have its own recycle arrangements. Do not be swayed by the argument that the two pumps will never be run simultaneously. The most obvious reason for simultaneous operation is to switch from one to the other so that maintenance can be done without shutting down the process. In this case the pump that is being started will be operating against a blocked discharge check valve and is in no position to make use of a common recycle valve. Remember that the throttling valve is there to serve the process but the recycle is there to protect the machine. You don't share seat belts do you?

Parallel variable speed pumps obviously have individual controls. The most effective arrangement is to provide constant flow controls to the majority of the pumps. The setpoints should be at the peak efficiency for each individual pump. The remaining pump should have its controller set to handle the swings. Actually this an example of the complex subject of Supply and Demand Control and deserves a discussion of its own. Note that is meaningless to have two pumps each on pressure control pumping into the same header. They will **not** share the load.

SERIES PUMP INSTALLATIONS. Sometimes centrifugal pumps are operated in series. The usual situation is when a multistage pump has an NPSHR greater than what is available. In such a case, a single-stage pump with a low NPSHR is used as a booster. This is common with boiler feed pumps especially if the pump is drawing hot water whose vapour pressure is already elevated.

Process demand control is applied to the high pressure pump. The booster pump should be on discharge pressure control. The author was involved in one situation where oil field injection water was drawn from a cistern connected directly to a river. In this case the booster pumps were pressure controlled by recycle back to the cistern. This allowed the recycle water to keep the water in the cistern agitated, preventing an accumulation of silt.

It is not unusual for a group of booster pumps in parallel to supply a group of high pressure pumps in parallel. In such cases care must be taken to ensure that the various operating combinations are matched in capacity.

Every individual pump in a series installation must have its own minimum flow arrangement.

SUMMARY. Figure 1-10 shows a complete set of instrumentation for a typical centrifugal pump application. The drawing illustrates a pump drawing volatile hydrocarbons from a large surge vessel. The following features are illustrated:

- A level / flow cascade loop on the pump discharge to provide process control.
- A check valve on the discharge downstream of the control valve to prevent reverse flow when the pump is shut down.
- A fire safe motor operated valve (MOV) in case of seal leakage and fires.
- An interlock from the MOV to stop the pump if the valve is not fully opened.
- A low level interlock from the vessel to stop the pump if the vessel loses its liquid seal.
- A pressure gauge on the suction to indicate adequate NPSHA.
- A thermometer on the suction to indicate potentially high vapour pressure.
- A minimum flow recycle loop back to the vessel.
- A check valve on the recycle line to prevent reverse flow when the pump is shut down,

especially when the fire valve is closed.

- A pressure gauge on the pump discharge to indicate that the pump is working.

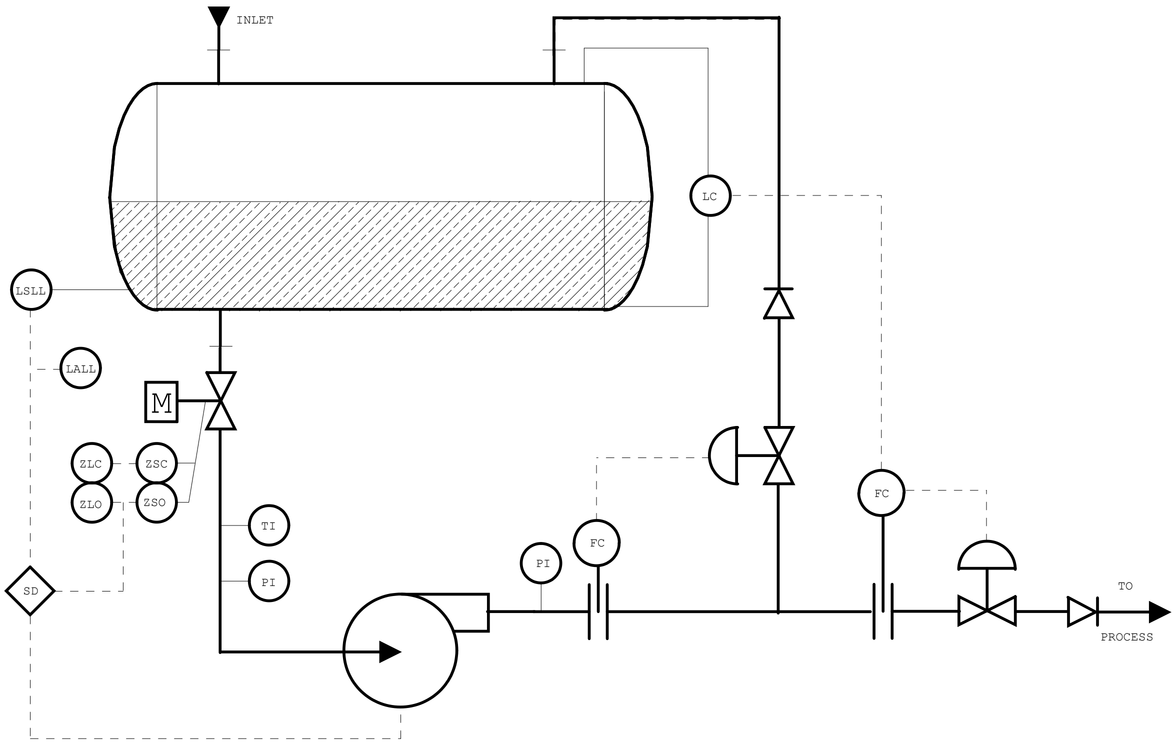

Fig. 1-10. A Complete Centrifugal Pump System

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