Session Six:

Pump Minimum Flow Protection Using Automatic Recirculation Valves

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Abstract

A major cause of pump damage is incorrect operation and specifically operation below minimum flow. Operating pumps below minimum flow leads to overheating, cavitation and loss of hydraulic balance. There are multiple ways of keeping a pump above its minimum flow rate these include using orifice plates in minimum flow lines and complex control valve systems. This paper will outline the operation of the Automatic Recirculation valve and compare with other traditional minimum flow techniques. The paper will show why the use of the Automatic Recirculation Valve is the best industry practice for pump minimum flow protection.

Introduction

Centrifugal pumps require a certain flowrate to be passed at all times this is referred to as the pump's minimum stable flow. As stated by Sterling Sihi 2003;

> *'As a result of recirculation flow disturbances, this can lead to unstable flow conditions which are manifested by increased vibration and noise levels and can lead to increased bearing loads. In continuous operation, to prevent pump operating problems and damage, operation below the manufacturer's minimum permissible flowrate* $Q_{min\ stable}$*, which is known as the "minimum stable flowrate" should be avoided'*

Aside from the unbalanced thrust loads leading to noise and vibration stated above pumps operating below minimum flow can experience;

- Cavitation due to higher NPSH values close to shut off
- Overheating due to loss of cooling circulation flow
- High shaft deflections

Pumps running below their minimum stable flow will see damage to;

- Bearings
- Seals
- Internal thrust components
- Wear rings
- Shafts

Examples of such damage can be seen in Figure 1 and Figure 2 below.

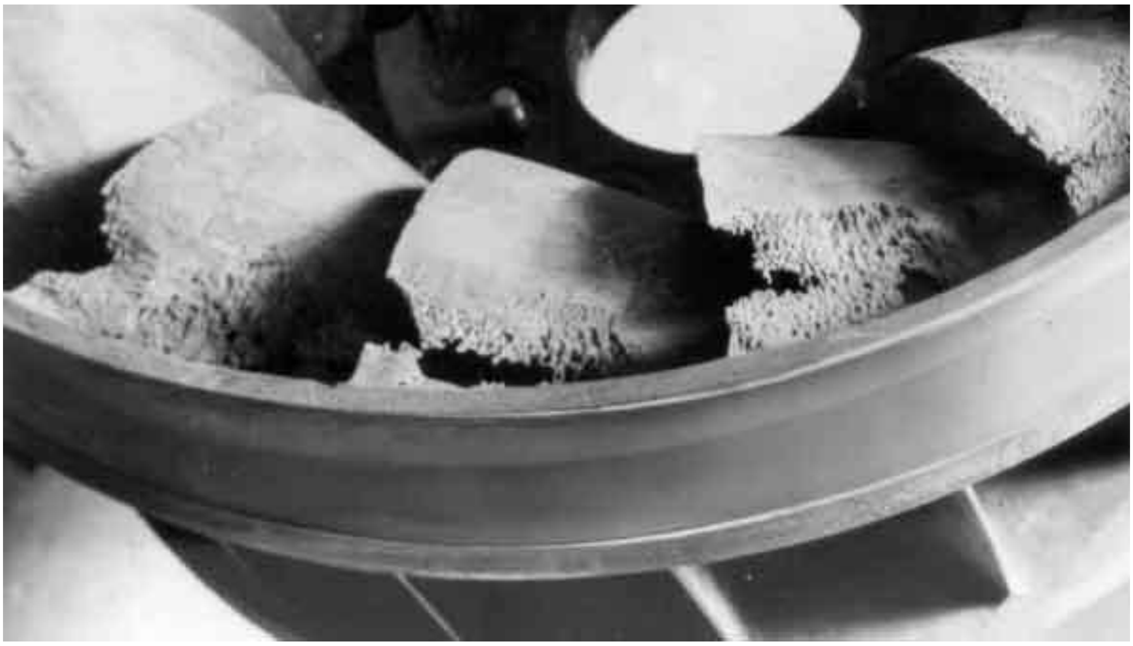

Figure 1: Cavitation damage to impeller blades (Image courtesy of California Institute of Technology)

Figure 2: Damaged pump shaft after pump overheated due to lack of liquid

Operation below minimum flow can occur due to process upsets, operator error, downstream failures or other pipeline blockages.

For these reasons and to achieve maximum mean time between failures (MTBF), minimum flow protection should be considered on all critical centrifugal pumps.

There are multiple ways in which to protect pumps which will be discussed in the following paragraphs.

Traditional orifice plate bypass

The oldest and most common form of minimum flow protection is through the use of a bypass line and minimum flow orifice plate. Arrangements can be a single orifice or multiple stages depending on pressure drop required and susceptibility of fluid to cavitation. This arrangement is shown in Figure 3;

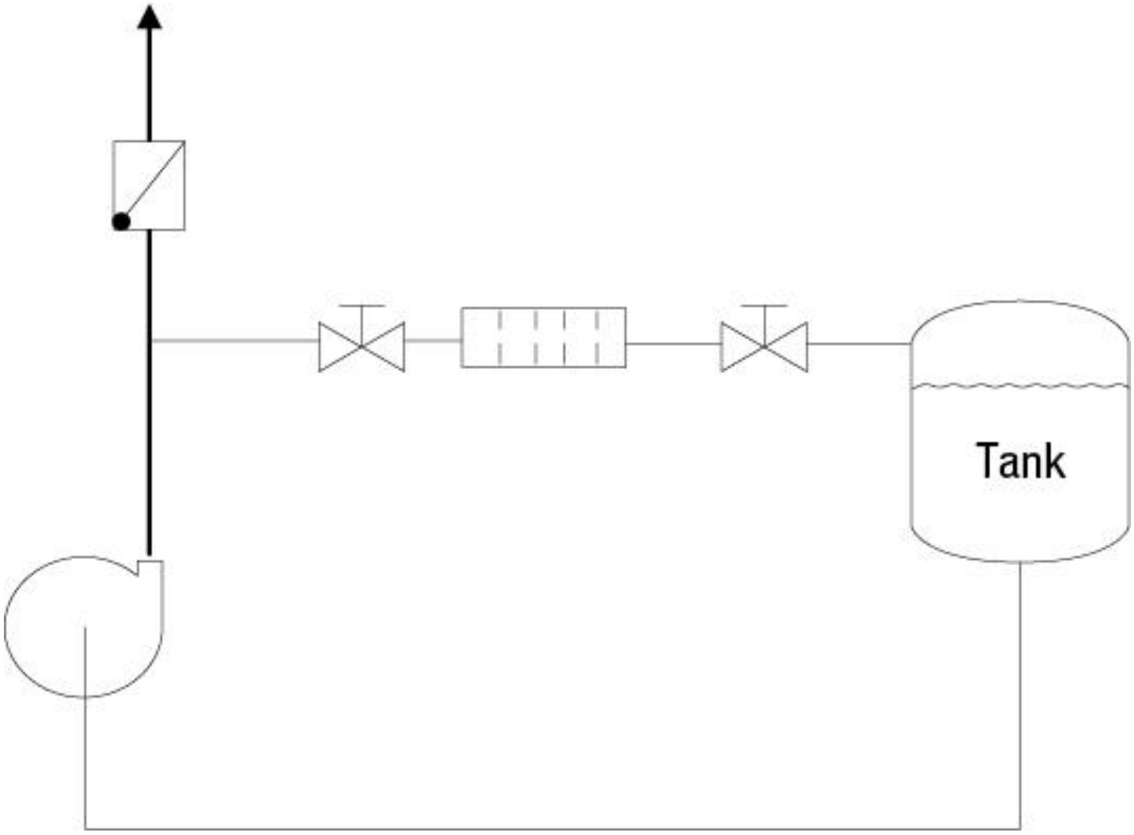

Figure 3: Traditional bypass line with orifice (Image courtesy of Schroedahl – ARAPP)

With this system the orifice plate is sized to pass the minimum flow at all times through the bypass line and back to the tank.

This arrangement is very easy and economical to implement for the system alone, however other costs must be considered. Operating in this configuration the pump will bypass the minimum flowrate at all times even at full system flow when this is unnecessary. This means pumps and motors are larger than required giving higher capital outlay.

The major costs associated with running this arrangement are the ongoing energy costs. Even only adding an extra 2m^3/hr at pressures of 100m head can add 1kW or more to pump absorbed power for every kW added to the pump power this is an extra 8760kWh per year for continuous running.

Based on current electricity prices of 22c/kWh this is $1,927 per kW per annum in energy costs per kW. Add to this the environmental cost of CO_2 produced at 1.1kg/kWh (assumption for coal power generation) and you add 9.6 tonnes of CO_2 per kW per annum. When you consider the number of pumps contained on sites and the push for energy efficiency and environmental control these avoidable losses are becoming unacceptable.

Controlled Bypass System with control valves

This system uses a control valve and instrumentation to divert flow to the bypass only when required. A flow sensor in the suction line is used to determine low flow which will open the valve using an actuator to control flow back to the suction tank.

The control valve will be placed in bypass line and open as flow drops and close as the flow increases.

This system is quite complex and requires many parts to work together which is both difficult to commission and has a higher chance of failure. These systems are often high capital cost and higher maintenance cost as all individual components require periodic maintenance.

Schroedahl Automatic Recirculation Valve

The Schroedahl Valve is designed to keep the pump operating on its pump curve. The Schroedahl ARC Valve provides the most economical and reliable form of pump protection. The valve combines the following 4 components in one;

- Flow sensing – The check valve is machined to in such a way that it senses process flow and opens accordingly. This check valve then operates the bypass line as it rises and falls.
- Check valve – The ARC is also a check valve eliminating the need for a separate valve
- Modulating function – The check valve will open or close based on process flow
- Pressure reduction without cavitation – Pump pressure is broken down over the bypass insert without cavitation.

The Schroedahl ARC valve is fully mechanical and activates by flow sensing and reacting to the system flow controlled by a downstream process valve.

When no flow to the system is required the check valve will close opening the bypass (position shown in Figure 4), this is fully flow controlled based on shaping surfaces of the check valve correctly. As the system opens and draws flow the check valve will unseat and move vertically sending flow to the system while closing the bypass line (position shown in Figure 5).

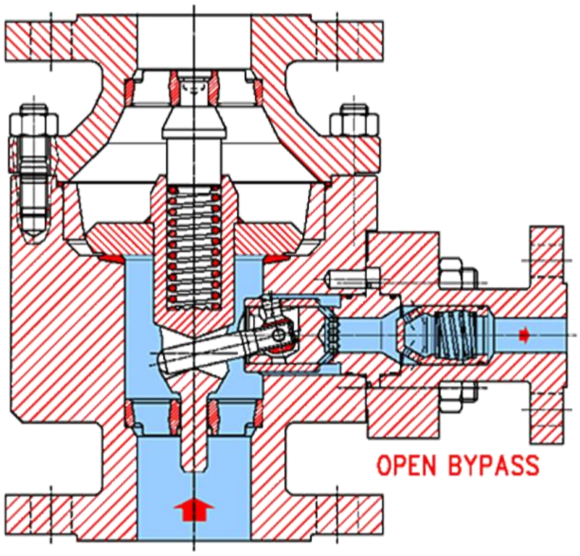

Figure 4: ARC Valve in bypass open position to pass minimum flow rate. In this case the check valve is seated with no flow to the system. (Image courtesy of Schroedahl ARAPP)

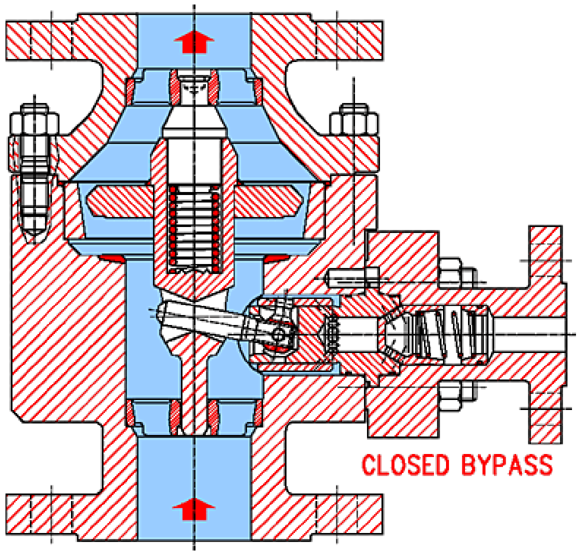

Figure 5: ARC Valve in closed bypass position. In this case the check valve is unseated and flow goes to the system. (Image courtesy of Schroedahl ARAPP)

Schroedahl ARC valves are fail safe, in the unlikely event of a failure of the internals the valve will fail in a bypass open position insuring the pump is protected at all times.

Sizing the valve

When sizing the valve the following information is required;

- Fluid
- Temperature
- Specific Gravity / Density
- Pump duty flow and pump head at this condition
- Pump minimum flow and pump head at this condition

- The pump curve is always desirable
- The flange size and rating of the pump outlet (Ideally the valve should be installed direct on the pump discharge and will be matched to this flange)
- Material for body (Typically the body material is matched to the pump casing, valve internals are various stainless steels with a minimum 12% Chr)
- Installation (Vertical is the standard and preferred orientation for the valve, horizontal can be supplied upon request)

When sizing the valve it must be noted that there must be a difference of 150% between the minimum flow and duty flow. As the valve is fully mechanical this is required to insure the valve can operate correctly.

Valve installation

It is recommended valves should be installed directly on the pump discharge flange. Where this is not possible it shall not be further than 3m downstream and be first fitting (no elbow allowed on valve inlet). Valves can be installed in either horizontal or vertical configuration.

On the bypass line there should be a straight run of pipe at least 3 pipe diameters. Also in some cases to avoid flashing a back pressure or orifice plate may be used to maintain line pressure, this should be installed as close as possible to the tank.

Conclusions

The Schroedahl ARC Valve is designed specifically for process conditions to give a reliable fully mechanical check valve/bypass valve. It is best engineering practice for maintaining pump minimum flow giving the most efficient system and best protection.

References

1. Basic Principles for the Design of Centrifugal Pump Installations, Sterling Sihi 7th edition 2003
2. Schroedahl-ARAPP, Engineering Letter Pump Protection
3. California Institute of Technology, *Bubble Dynamics, Damage and Noise*, digital image, California Institute of Technology, accessed 12 June 2013, <http://authors.library.caltech.edu/25019/1/chap6.htm>.