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Using Variable Frequency Drives with Steam

Understanding Variable Frequency Drive (VFD) Applications for Centrifugal Boiler Feed Pumps

This bulletin is intended a brief overview for steam system applications where variable frequency drives (VFDs) are used for controlling centrifugal volute style boiler feed pumps. It is important to note that a turbine pump, by its inherent design, and operational characteristics would not fit into this discussion.

Over the past few years, Shipco began coupling the use of a VFD with the use of an automatic flow control valve to maintain a flow at a constant pumping rate, while varying the speed of the pump motor to satisfy varying boiler operating pressures, and simultaneously meet the ASME (American Society of Mechanical Engineering) code. These various operating pressures are part of a growing trend in our industry with respect to efforts surrounding "net zero" energy building designs and reduced energy operation procedures (e.g., weekend shutdowns and night setbacks).

Simply stated, boiler feed pumps are sized to meet the flow requirements of boiler design loads and overcome the internal operating pressure of the boiler, in addition to overcoming all the pressure drops of the feed piping and feed control valves. Modern boilers are manufactured to ASME standards and this has resulted in standardization of specific boiler design pressures. The specific design pressure that seems to continually be of concern to feed pump manufacturers is the *150 PSIG design boiler*. Boilers of this design pressure are typically fitted with a pressure relief valve that is set for 150 PSIG. Consequently, this is not the typical operating pressure of most boilers, even when they are designed to operate at 150 PSIG. Boilers operate over a wide range of pressures. It's when a boiler is designed to operate at one pressure, and then operates at a significantly different pressures, that causes centrifugal pump manufacturers major headaches (an lots of warranty claims). This article will not go into an in-depth discussion of steam space or steam quality. It is relevant to point out that any changes in boiler operating pressure can adversely affect the operation of other components in a steam system such as: traps, regulators, pipe sizing.

A basic understanding of centrifugal pump flow characteristics and centrifugal pump curves is assumed for this discussion. Pumps perform at specific conditions based on pump curves and flow characteristics required for steam system performance. An example following the outlined characteristics is described as follows:

- 100 BHP boiler
- Operating pressure = 100 PSIG
- Pressure drop of piping and valves in the feed system = 15 PSIG
- Pressure drop of automatic flow control valve = 5 PSIG
- Boiler relief valve set from factory at = 150 PSIG

From the information given, we know that the evaporation rate of a 100 HP boiler is .069 GPM/HP, hence 100 times .069 or 7 GPM. Doubling the evaporation rate to determine a pumping rate for on/off pumps is an accepted industry standard for most boilers. Based on this formula, the recommended boiler feed pump pumping rate would be 14 GPM.

Furthermore, the ASME code dictates that the pump discharge pressure must exceed the boiler relief valve set point by at least 3%. Using the 150 PSIG relief valve setting, plus the 3%, we get 154.5 PSIG. Depending on actual operating pressure, we may need to add in a safety cushion for any piping pressure drop (i.e., friction loss) and flow control valve pressure drop to arrive at the total pump discharge pressure required.

Additionally, the pump HP requirement is determined by reading the pump curve, typically available from the pump manufacturers' catalog or website.

For our example, let's assume the manufacturers' pump curve at the selected condition points places the HP at 5. In other words, the pump required HP at the condition point of 14 GPM at 155 PSIG is 5 HP. During normal 100 PSIG boiler operation, we require the pump to provide 14 GPM at 120 PSIG. What is critical to understand in this scenario is that this is 35 PSIG lower than the pump design pressure at 155 PSIG.

Pumps perform based upon the pump curve and the resistance pressure (sometimes referred to as "back pressure" or "head resistance"). In our example, the pump would have a flow condition much greater than the 14 GPM required inherent to the manufacturers' recommended impeller trim, which can be found on the manufacturers' published impeller / pump curve. A negative consequence and the primary focus of this article is this lack of resistance may lead to motor short cycling and excessive wear on the pump internals (also referred to as "cavitation").

In order to avoid this, Shipco, as a standard feature on pumps 75 PSIG and above, provides an automatic flow control valve that restricts the flow to the desired GPM. This eliminates the possibility of short cycling and the pump cavitation. On certain applications, we now provide the auto flow control valve along with VFDs.

The pump discharge pressure (PSIG) is based on the pump design speed and the diameter of the impeller. In our example, at 3500 RPM pump motor speed, our pump discharge pressure is 155 PSIG. According to the Pump Affinity Laws, reducing the motor speed will lower the pump discharge pressure. Therefore, with a VFD, we can electronically signal the motor speed to directly correspond to the desired pump discharge pressure of 120 PSIG.

The key difference to how we are controlling VFDs when compared to hydronic systems or circulating pump loops is that we are placing the **pressure transducer in the steam main header** to sense the actual boiler operating pressure and control the motor speed accordingly, NOT in the pump discharge manifold. The reason for this is so that the pumps will not only pump water into the boiler under normal operation, but they will simultaneously also satisfy the ASME pumping requirement of exceeding the relief valve setting by 3% under emergency operating conditions.

The Affinity Laws dictate that our centrifugal pump will follow the manufacturers' curve based upon motor speed to the relative point on the curve that correlates to 120 PSIG pressure. **When reducing the speed of a pump, the flow is directly proportional to the pump motor speed, the discharge pressure is directly proportional to the square of the pump motor speed and the motor horsepower is directly proportional to the cube of the pump motor speed.** According to the hypothetical manufacturers' curve, we agreed earlier that a 5 HP motor will produce the power required at 14 GPM at 155 PSIG. At our new condition point of 14 GPM at 120 PSIG, the 5 HP motor will also work, but if we slow down the motor speed, we can significantly reduce the actual operating HP and save energy.

Therefore, when selecting a centrifugal feed pump, we have to consider the pump curve in conjunction with the Pump Affinity Laws. Due to the inherent characteristics of the manufacturers' centrifugal pump curve, the pump we selected is capable of pumping considerably more flow than 14 GPM required to satisfy the boiler load capacity, which can also be the downfall of even the most accurately sized boiler feed pump.

Steam system pumps handle water that is near saturation temperatures. The NPSHr (Net Positive Suction Head Required) of the pump should be incorporated into an effective pump selection. Pump selection is based upon "NPSHr" vs. "NPSHa" (Net Positive Suction Head Available), in addition to boiler capacity and boiler operating pressure requirements discussed previously. Typically, it is recommended that boiler feed pumps operate on the left of the manufacturers' published pump performance curve. A manufacturer that designs their pumps specifically for steam system operations should publish their curves with the NPSHr marks clearly labeled. For purposes of this article, a corresponding benefit of reducing the motor speed of a centrifugal pump is the NPSHr of a pump decreases as well. It is equally as important to note that for pumps in these applications, efficiency is not a selection criteria, and due to inherent design parameters to provide low NPSHr pumps, efficiency is low.

Keeping NPSHr in mind, we can effectively use pump Affinity Laws to calculate the pump operating speed required to produce 120 PSIG. When the pump moves right on the centrifugal pump curve, we can utilize the VFD in conjunction with the auto flow control valve to adjust the motor speed accordingly to maintain our pumping rate of 14 GPM, as well as maintaining a condition point that prevents the NPSHr of the pump from exceeding the NPSHa.

To recap the main points of this bulletin:

- ✓ Boilers come in standard sizes, and typically with safety relief valve sizes that are also directly correlated to the boiler design.
- ✓ Pumps must be sized properly to meet the load demands of the boiler(s), as well as be sized to pump water at a pressure that exceeds the operating pressure of the boiler(s), and meets the ASME boiler safety code requirements.
- ✓ We furnish pumps that come with auto flow control valves if the discharge pressure exceeds 75 PSIG.
- ✓ When using VFDs, we provide a pressure transducer that must be installed in the boiler steam main header to vary the motor speed based on the operating pressure of the boiler, while also providing the option for the pumps to ramp up speed to increase pump discharge PSIG in the event the boiler goes into a low-water emergency situation.
- ✓ Pumps have NPSHr design characteristics. The NPSHr design of a pump must be less than the NPSHa from the pumped liquid. (Please refer to Shipco Technical Bulletin on NPSH for in depth discussion on NPSHa vs. NSPHr.)