Pump ED 101

Pump Selection for VFD Operation

Part 2 – ΔQ / ΔH - Circulation

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Introduction

In Part 1 we took a look at the pump selection process for VFD operation in constant pressure applications. In those applications pressure is held constant as flow varies. In this section we will review a very different type of application – one where both flow and pressure can vary depending upon demand. Constant pressure (with the exception of certain industrial applications) is a relative new comer to variable speed operation but, pump down applications have used variable speed drivers for decades. Some were as simple as two speed motors while others involved adjustable belt and fluid drives. Some, such as the liquid rheostat, were quite complex. This device, despite it's "Rube Goldberg" appearance, controlled a wound rotor AC motor and was still popular into 1990's.

A major reason that variable flow applications took advantage of this technology early on, was simple. Large motors, used on pumps in sewage (and other) lift applications, were often limited to two or three starts per hour, even if current limiting, starting techniques were employed. By varying the speed of these large pumps the wet well could be maintained at some predetermined level and thus frequent starting became a non-issue. Also, you will see that the potential power savings in some variable flow applications is huge!

Variable Flow / Variable Pressure

As the name implies, Variable Flow / Variable Pressure (often referred to as system curve flow or just variable flow) applications experience moderate to large changes in flow without the need to maintain a constant pressure. This ability to undergo flow changes without maintaining some predetermined pressure is what separates them from constant pressure applications where changes in flow also occur but pressure must remain constant.

One of the most common variable flow applications is circulation. Although there are others, this one represents a significant portion of centrifugal pump, VFD installations in the USA. We will discuss two different circulation applications as they require pumps with slightly different characteristics.

Circulation – Closed Loop

Circulation applications are found in two configurations – closed loop and open loop. Hydronic applications (chilled water circulation in large air conditioning systems and hot water circulation in heating systems) are examples of closed loop applications. Chiller cooling tower flow and swimming pool filtration are examples of open loop systems. We will address pool applications in another tutorial.

Once water is flowing in a closed loop, the head required to maintain circulation is that which is required to over come the friction that is generated by the water flowing in the loop. This remains true regardless of the elevation difference between the upper and lower portions of the loop. (See the Hot & Cold Puzzler for a more detailed discussion on this subject.) As you might expect, the head required to maintain flow in a closed loop decreases as flow decreases and becomes greater when flow increases. In a well designed system (one with properly sized pipe and fittings) friction will decrease proportionally with a decrease in flow. This proportion is greater than one to one and roughly follows Poiseuille's Law as long as flow is laminar. In a typical VFD controlled chilled water system, a temperature sensor (and possibly a flow sensor) will monitor the change in temperature of the water returning to the chiller and adjust pump speed accordingly. (In applications that use centrifugal chillers, a separate VFD is often used to control the chiller output.) As demand on the system increases (as indicated by a greater than normal increase in the return water temperature) flow (and possibly chiller output) is increased. As demand recedes, the reverse occurs. Cooling tower (open loop) applications are similar except that some static elevation must also be overcome.

The simplest and most accurate method for pump selection in closed loop applications is to use the system curve generated by the system designer. If one does not exist, it can be regenerated by calculating the total friction in the loop at maximum flow. Once this point has been calculated several other, reduced flow, points can be calculated. Figure 1 shows a simple system curve for a closed loop consisting of 1000' of 8" steel pipe and a maximum flow of 1600 gpm. Unlike the constant pressure system curves seen in Part 1, this curve rises as flow increases. The curve indicates the amount of friction, in feet, generated at any point on the X axis (GPM). Please understand that this is a simplified curve. Many closed loop applications contain multiple branch lines and thus create a more complex friction component.

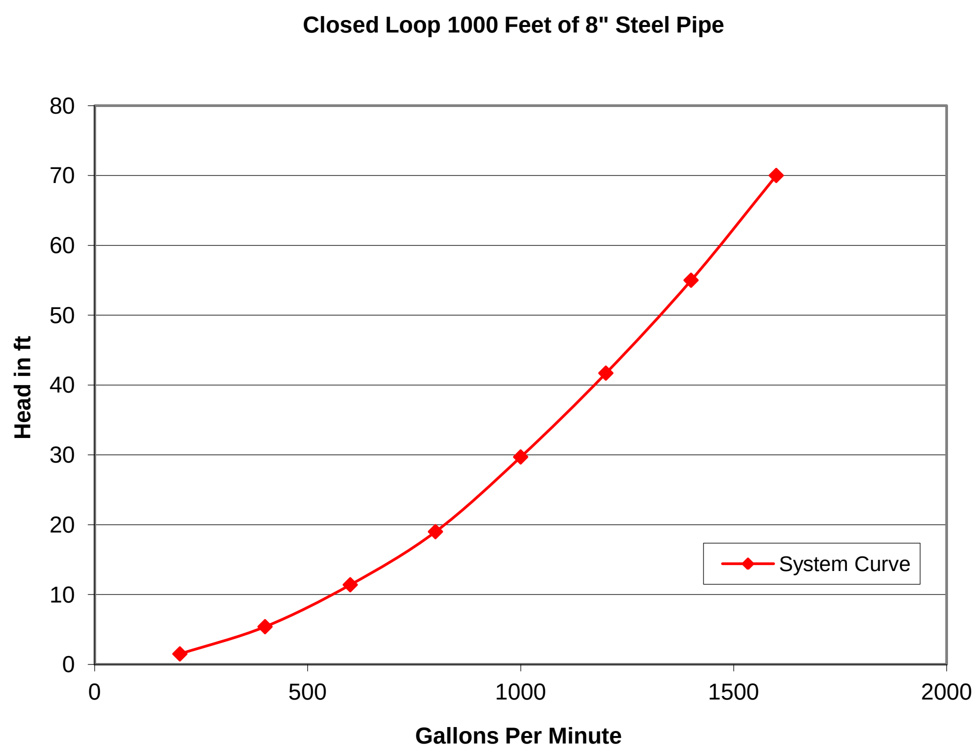

Figure 1

The application that gave birth to this curve requires flows of 700 to 1400 gpm. Flow, at any point in time, is based on the demand of the system. The system curve illustrates that a pump, running at 60hz, must be able to provide 1400 gpm at a TDH of 55′. When selecting a constant speed pump that will meet these conditions, its BEP should fall in the area between minimum and maximum flow points. This allows an evening out of efficiency across the spectrum of flow. Later we will see that this BEP guideline does not apply to VFD operation. (It is also a good idea to add a small error factor (5-10%) to the TDH calculation to accommodate potential errors in friction calculations.) Since friction (and therefore the pressure required to maintain flow) decreases with decreasing flow, a "steep" curve with some minimum rise to shut off will not be required to meet the head requirements at lower flows. Therefore, unlike constant pressure applications, pumps with flat or slightly rising curves may be used and, are often preferred because of the additional power savings they can offer at lower flows. An example of a constant speed pump is seen in Figure 2. It is probably not the best selection because its BEP located at maximum flow rather than in between but, I want to compare its operation at constant speed with that of VFD control.

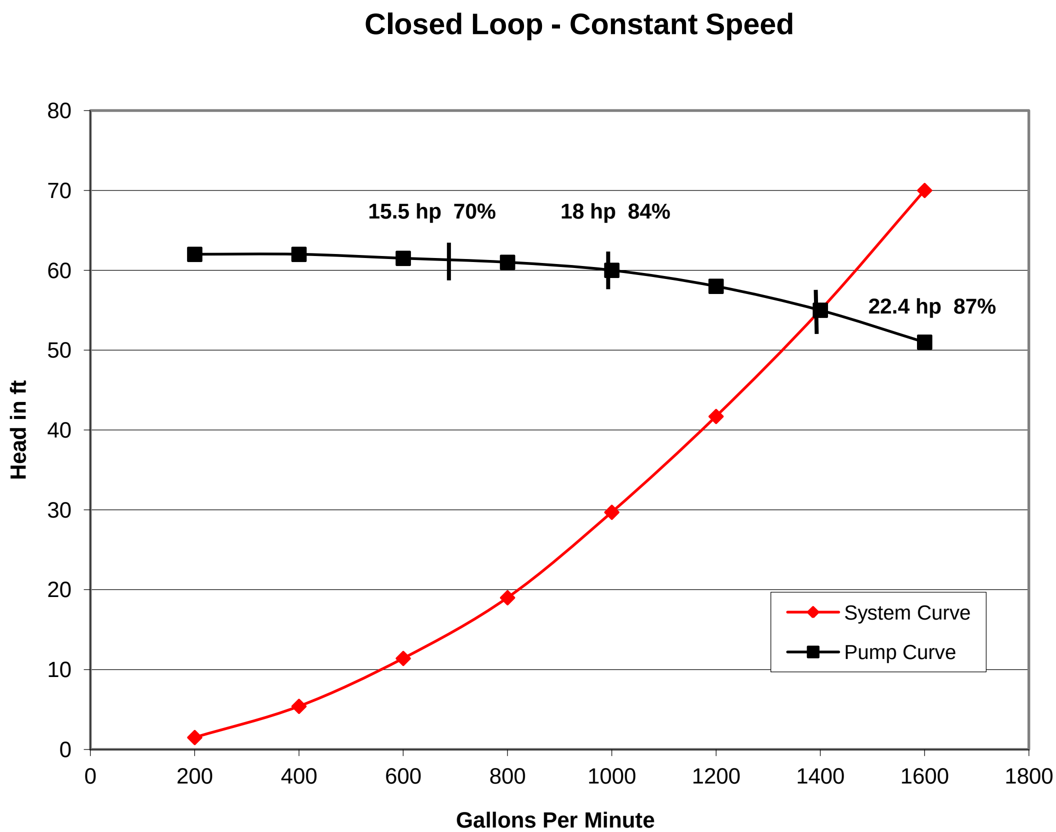

Figure 2

The curve shown is that of a 6X6X12 end suction pump running at 1200 rpm. It meets the maximum flow point perfectly (1400 gpm @ 55′ TDH) and rises less that 7′ at minimum flow (700 gpm @ 61′ TDH). The power required at minimum flow is about 69% of that required at maximum flow. Brake HP can be calculated at any point on the head / capacity curve by using the following equation:

BHP = (GPM x Head) / (3960 x Pump Efficiency)

The equation states that BHP is directly proportional to both head and flow. It is for this reason that a flat curve is preferred for variable flow applications.

Even though BEP is a bit too far to the right, this pump is still a pretty good fit as efficiency at minimum flow is still 70%. But, if you want to see a "great" fit, take a look at Figure 3. Here we see the same pump under VFD control. Because the system curve falls steadily from maximum to minimum flow we are able to utilize a control frequency range of 29 hz. This translates into a power requirement of just 13.8% or 3.1 HP at 700 gpm compared to 15.5 HP for the constant speed installation.

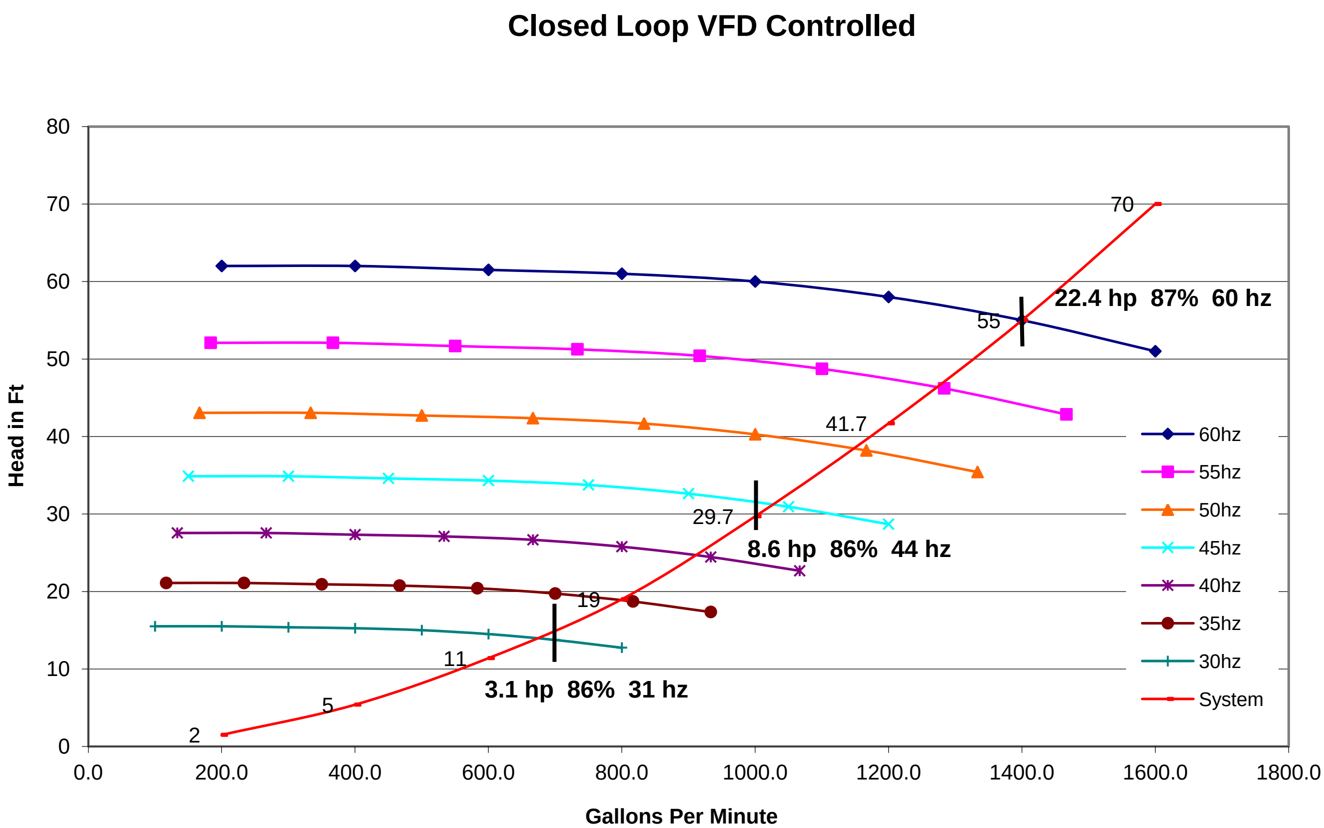

Figure 3

There are two reasons we see such a major reduction in power. First we are able to effect a large reduction in pump speed and second, the BEP efficiency isomer closely follows the system curve (See Part 1 for an explanation of efficiency isomers). Therefore, at 700 GPM, the control frequency point of 31 hz has almost the same efficiency as the 60 hz point. This was not the case in constant pressure applications.

When evaluating pumps for VFD control in closed loop applications, follow these guidelines. Select the highest efficiency pump with a BEP that falls at, or just to the left of maximum flow. Head rise to minimum flow should as small as the application will allow. Test your selections using "Hertz" or a similar program. Hertz allows entry of a system curve so that you can evaluate the performance of your selection against the curve.

Circulation – Open Loop

Cooling tower and most other open loop applications are similar to closed loop systems in that friction in the loop varies with flow. The difference between the two is that the static heads of the supply and return lines are not in balance in open loop systems. Simply stated, the discharge elevation is different than that of the return elevation. Figure 4 is an example of a typical single pump, cooling tower loop.

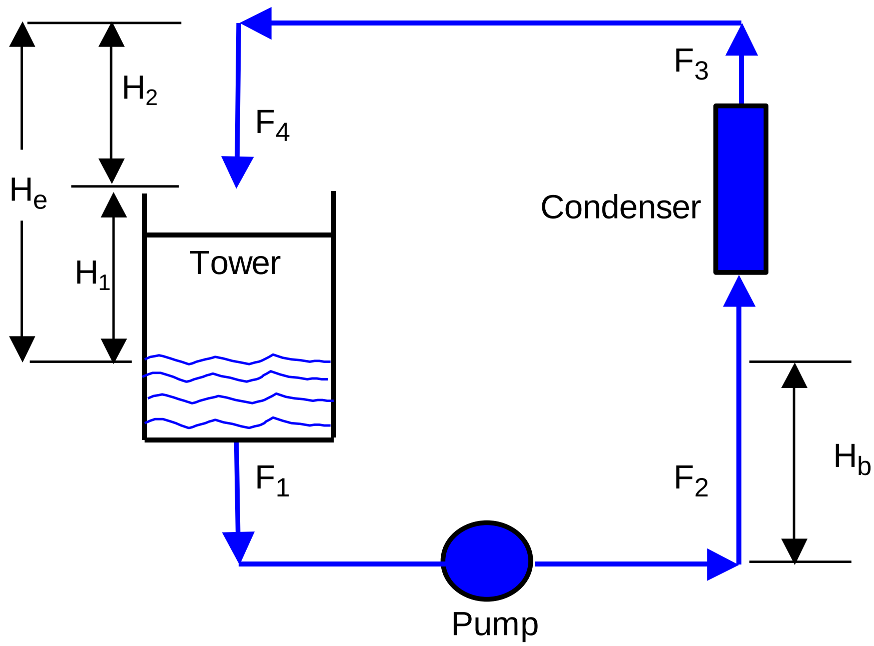

Figure 4

Hb is the balanced head of the system - i.e. the water level in the cooling tower pan produces the same level on the other side of the loop. He is the total elevation head required to reach the highest point in the system above balanced head (we will talk about H1 and H2 a little later). F1 through F4 (Hf) are the friction components of the system and include the piping, condenser, and the discharge device in the upper level of the tower. Therefore the total dynamic head required to operate the open loop is:

TDH = He + Hf

There are various cooling tower designs, however, their purpose is the same - - to provide maximum exposure of the circulating water to air so that heat can be removed. Some use spray nozzles while others direct the water flow to a splash pan or some other object designed to dissipate the stream. Some older designs incorporate a relatively long, vertical pipe, known as a "down comer", to direct flow into the tower. It's length is represented by H2 in Figure 4. Under certain conditions, it can create a siphon and the negative head it develops is subtracted from Hp. We will not address down comers in this tutorial.

Figure 5 shows the system curve for an open loop circulation application consisting of 500' of 6" steel pipe and flows of 100 – 800 gpm. I have included two friction components and a static head of 20'. Once the system curve is generated open loop, pump selection is the same as that used in closed loop applications.

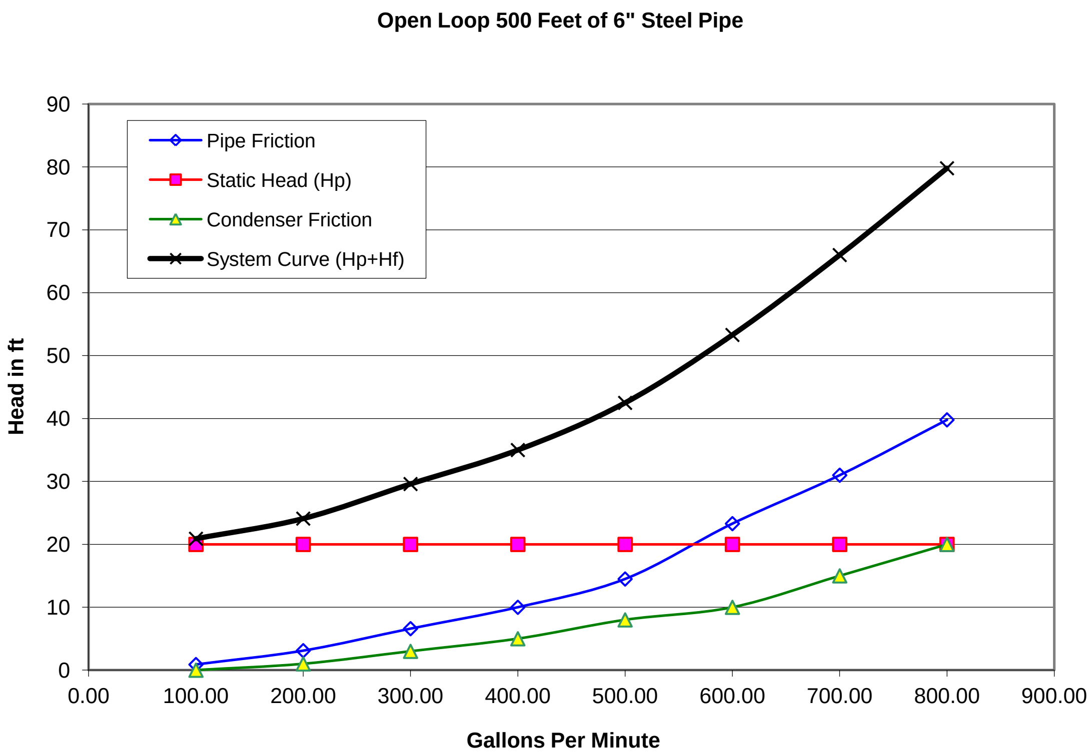

Figure 5