Using an SMC-50 Solid-State Smart Motor Controller for Pump Protection

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Pump system protection comes in many methods, from preventing water hammer to detecting potential pump blockage. You need this protection to help prevent further damage or to keep damage from occurring at all. The damage in a pumping application can cause a critical operation to stop and cause flooding or no water supply.

Prevention of water hammer during starting and stopping of a pump motor can easily be fixed by controlling the ramp and deceleration of the motor. The use of a properly set soft starter or a variable frequency drive can assist greatly with water hammer.

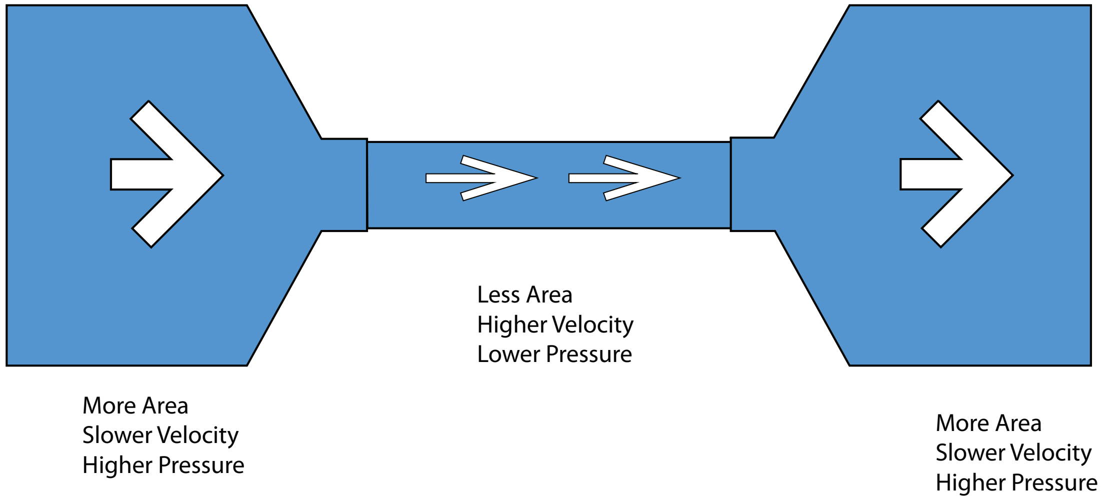
But what about damage to pumps caused by partial blockage or absence of fluid? Partial or complete blockage is costly and time consuming to repair. Some of the damage can cause immediate erosion of parts such as pump impellers. Other damage could take time and lead to costly repairs and downtime in the future. Without some form of detection, a maintenance person, seeing the system is not working properly, has to go out and see what the issue is. Trying to figure out what is going on may also mean taking the system apart. This paper discusses the use of technology to warn of damage or to stop a process from damage.

Pump Issues

A by-product of partial blockage on the inlet side of a pump is cavitation. Cavitation could be very damaging to a pump and other components in a system. Cavitation and flashing (see page 2) can cause pitting or erosion of metal parts within a pump, or other metal components in the system. Blockage frequently adds vibration and noise to the pumping system.

Cavitation is typically a result of restriction of liquid flow (oil, water, etc) in the pump system. From Bernoulli's principle, a decrease in area will have an increase in velocity, which will in turn have a decrease in pressure. The arrows in Figure 1 show the direction of water flow in a pump system.

Figure 1 - Bernoulli's Principle Illustration

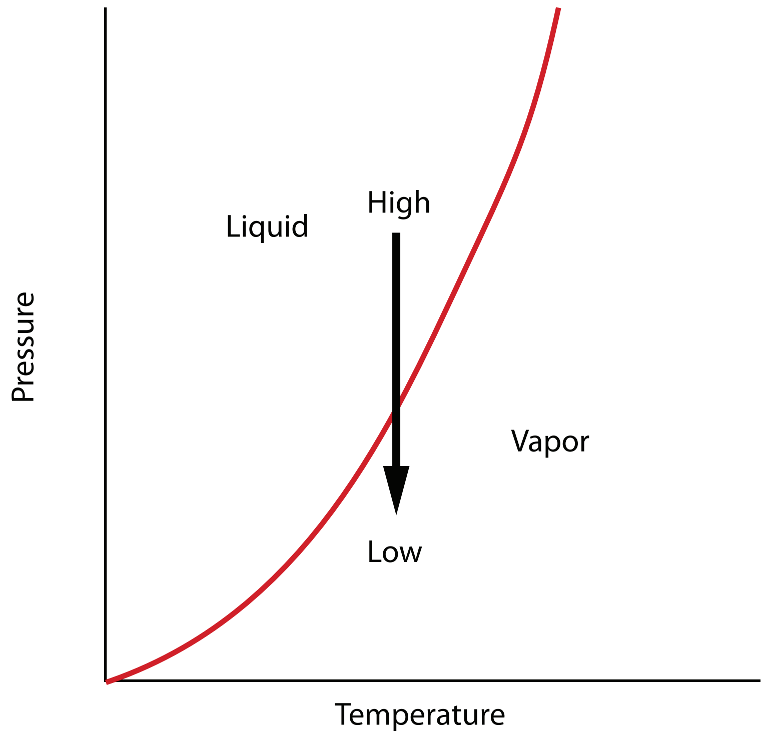


When the pressure in the line feed drops due to a restriction or a partially closed valve, the velocity of the fluid increases and vaporization occurs if the pressure drops below the vapor point, forming bubbles. If the pressure continues to drop downstream from the *vena contracta* (narrowest point or diameter of the flow restriction), the bubbles get bigger. When the bubbles flow to a larger volume area, the velocity slows and the pressure increases. The bubbles have an internal pressure less than the surrounding volume pressure at this point. The bubbles now collapse and the surge of energy causes pressure waves with possible levels as high as 60,000…100,000 psi. There is noise and possible vibration associated with the collapse back to liquid. This collapse of bubbles and the resulting pressure surge, along with the associated noise and vibration, is called cavitation. Damage from cavitation can be very quick, very destructive, and very costly.

Flashing occurs when the pressure of a fluid falls below its vapor pressure. At this point, the fluid begins to change from a liquid to a vapor that may still have small droplets of fluid in it, both of which have the same chemical makeup. Flashing damage is slower and results in smoother damage to components like smooth river rocks. The damage from flashing takes longer to occur than the damage caused by cavitation.

Graphically, if pressure falls below the vapor pressure curve, and temperature stays the same, there is the possibility of reaching the vapor state of the liquid. The same thing happens in the opposite direction if you raise the temperature and the pressure stays the same as in commonly seen in boiling water.

Figure 2 - Cavitation Curve



Signs of Cavitation in the Power System

From a motor performance perspective, a drop in current, low power factor (PF), and drop in real power could all be warning signs of cavitation. Current measurement by itself is not necessarily the most accurate method as explained further in this paper. The more power information a device can collect, the better its ability to indicate signs of cavitation. Vibration is another byproduct of cavitation as the vapor returns to a solid and the pressure expands. In most cases, you can clearly hear the vibration caused by cavitation.

Dry Runs

Similar to and possibly partly caused by cavitation, a dry run is a situation in which a pump is run without liquid. It could be caused by a closed suction valve or other blockage in the suction line. Running dry can cause thermal and mechanical failures within the pumping system.

Low or No Flow Discharge

Blockage or partial blockage on the discharge side can cause vibration and may reduce the minimum required flow rate of a given pump. The reduction in flow rate may cause damage thermally and mechanically to the system, because most pumps have recommended operational range. Operating outside of the range may cause damage to the pump.

Overload Conditions

Jammed impellers, oversized impeller, improper fitting of system components, bearing failures, and improper head pressure for the pump size are just a few examples of situations that can cause overload conditions on a pump. An overload can cause thermal and mechanical damage.

What are some available preventive options?

Some options available are relays marketed as being suitable to detect cavitation and prevent dry running. Some of these only monitor a single phase and have to work in conjunction with an externally mounted Current Transformer (CT). In some cases, a toroid is also used in conjunction with a CT to bring current feedback in the case of larger motors. Other components, such as resistors, may also be needed. These add up to extra components and wiring needed to do the job of measuring the current.

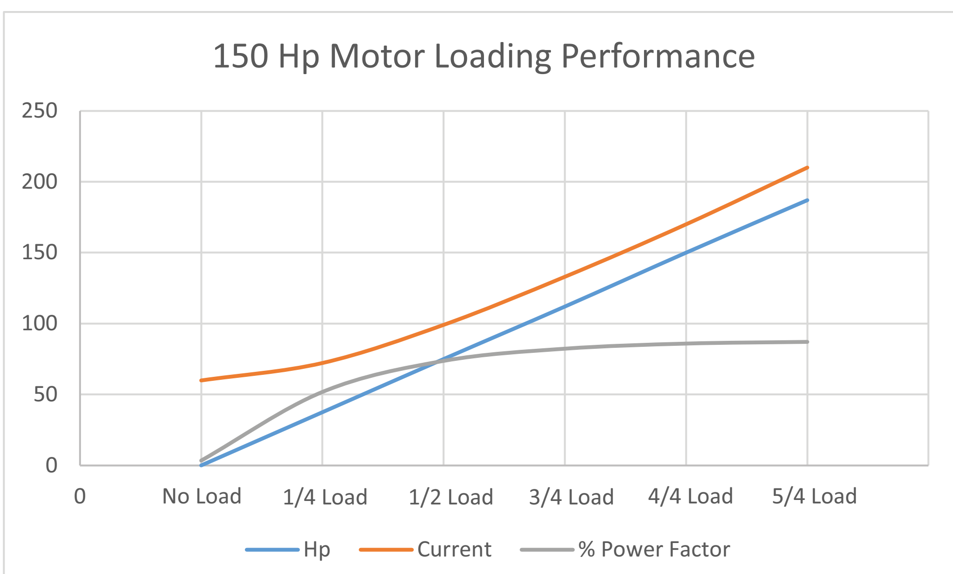
While it appears most devices use current to help diagnose cavitation and prevent a dry running pump, some use power measurements.

You can use power measurements such as power factor and real power. Figure 3 shows the motor performance from no load to approximately ¼ load; the current rise is very slight, almost flat. At this load, using current only as a monitoring metric has very limited usefulness, outside of monitoring for overload. Above ¼ load, the current begins to increase substantially.

Properly sizing the motor for the application benefits the protection of the pump system. Oversizing the motor too much will reduce the range of opportunity to detect an issue with the system. For example if the motor is 50% loaded nominally, current has barely changed in Figure 3.

Power factor and horsepower rise significantly for the same duration starting at no load. The combination of the power factor and horsepower may be a better indication of cavitation or some other issue going on with a pump application.

Figure 3 - Motor Load Performance



Horsepower (or Watts) would range from zero, where no work is done, to the rating of the motor, or slightly higher, depending on the load. This would appear as almost a straight line.

The equations for 3-phase power are as follows:

$$kW = \frac{\text{Volts x Amperes x Power Factor x } \sqrt{3}}{1000} \qquad Hp = \frac{\text{Volts x Amperes x Efficiency x Power Factor x } \sqrt{3}}{746}$$

Current level is the amount drawn on the given portion of work performed from the motor. Many factors are taken into account to produce the no-load current, including the number of poles of the motor and reactive power. Maintaining the magnetic field of the motor is the main reason why current does not drop to zero with no load.

Power Factor ranges from 0.0 to 1.0. A 1.0 power factor is a purely resistive load. 0.0 is usually inductive. The lower the PF, the lower the efficiency of the system. Real power (kW) performs the actual work of the motor. In the case of a PF value of 0, no real power is present.

Reactive power (kVAR) is the power that is needed to magnetize the motors

$$\text{Apparent Power x } \sin \Theta = VI\sin \Theta$$

Apparent power (kVA) is the combination of real and reactive power. For typical loads with reactance, the equation is:

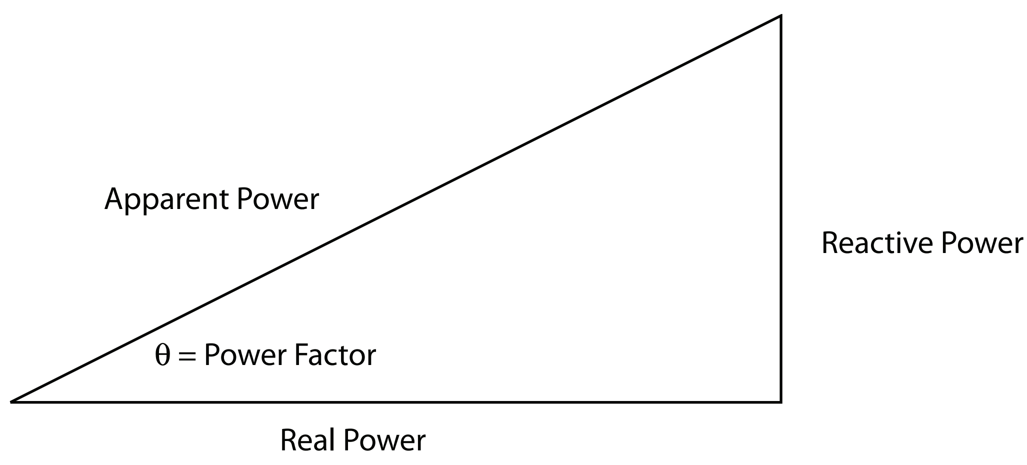
$$\sqrt{(\text{Real Power}^2 + \text{Reactive Power}^2)}$$

Power Factor is the ratio of real power to apparent power.

$$PF = \frac{\text{Real Power}}{\text{Apparent Power}} = \cos \theta$$

Figure 4 illustrates this graphically and geometrically in the power triangle.

Figure 4 - Power Triangle



For overload conditions, different types of standalone devices are used based mainly on an increase in current. Devices like soft starters may have the overload functionality built in.

Rockwell Automation Solution

The SMC™-50 solid-state smart motor controller is a solid-state soft starter that has vast starting, stopping and power measuring capabilities with the ability to add more functionality with option cards for communication and expansion I/O. The ability to smoothly start or stop a pump without water hammer using a linear acceleration, pump start, or soft start (or soft stop) is only a matter of a parameter setting.

What enhances and sets the SMC-50 soft starter apart from competitors is the ability to actively monitor valuable power information that can be used to assist in detect damaging cavitation and assist in preventing dry runs in pumping applications. Easily programmable alarm and fault levels assist in indicating the system issues.

The SMC-50 soft starter has the ability to monitor power factor in all three phases in addition to providing a total average. With the ability to monitor over and under power factor, also comes the ability to monitor whether it is leading or lagging. A lagging PF is when load current lags voltage. Lagging PF is indicative of an inductive (motor) load. Leading PF indicates a capacitive load when load current leads voltage.

To assist with eliminating false trips, you can program delays from 0.1 to 99 seconds before an enunciation of the fault is performed. As the power factor drops below a settable value, that value could be used to indicate cavitation and provide feedback (alarm) or stop the soft starter (fault).

Any time the SMC-50 soft starter faults, a snap shot is taken of the following parameters.

- Phase Voltage (A-B, B-C and C-A)
- Phase Current (A,B and C)
- Power Factor
- Motor Thermal Usage
- Motor Speed
- THD Voltage Average
- THD Current Average
- Product Status
- Board Temp
- Line Frequency

This aids in the troubleshooting of the issue with the system.

Real, reactive, and apparent power for each phase with alarms and faults for each is part of the SMC-50 parameter structure. Since reactive power doesn't change much when changing loads to the motor, real power is a better method of detecting cavitation or low loading conditions.

Remembering Figure 3, the best indication of an issue with underload conditions is monitoring and using these values, especially when cavitation or a dry run is possible. Using current alone is not accurate enough.

With the pump application detection methods inherent to the SMC-50 soft starter, it may be possible to use the slow speed reversing function to unclog a blockage when something has been pulled into the pipes, for example, a blockage in a sewage influent pump. Once the blockage is detected by the appropriate power parameters, the slow speed function could be used to reverse the flow for a short period of time with the hope of unplugging the intake and not requiring manual intervention.

Additionally, using option cards such as the 150-SM3 Analog I/O Module would allow feedback from a flow meter to the SMC-50. You could possibly use the analog data with the included DeviceLogix capabilities programming for control. You can download free Connected Components Workbench™ software to create the DeviceLogix™ program in addition to programming the SMC-50 soft starter.

Overload protection is also standard with the SMC-50 soft starter, which covers the overloading issues the pump may have. An adjustable overload trip class is used to dial in the appropriate setting for the given pump system, potentially preventing further damage to the motor, pump and system.

Conclusion

Pumping applications can be very dynamic and, being so, using dynamic protection is the best way to protect the system. Proper protection could prevent, or at least limit, damage to equipment such as impellers and pumps themselves. Proper protection can include notification of changes in the system. After something is damaged, not only is there the cost of the item itself, but down time, troubleshooting, uninstalling, and reinstalling the new part. Prevention is much more cost effective.

The SMC-50 soft starter successfully starts the pump system with a choice of starting options, and offers broad power monitoring capability to monitor how the pump system performs. It also has the ability to indicate if an issue is beginning to take place.

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