Control of Sprinkler System Pressure utilizing Variable Pump Speed

Problem Definition

The selection of the most economical components, that meet the requirements of the sprinklers and standpipes, comprise the fire pump sprinkler system and establish the system maximum allowable working pressure. Variations in the suction supply pressure, variations in pump shut-off pressure for a given rated flow and pressure, and variations in the driver speed change from full load to part load can result in a well-designed system becoming over-pressurized. Historically the solution has been to install an amply sized main relief valve (mrv), to “dump” a sufficient amount of water such that the system maximum pressure is not exceeded. In the 1999 edition of NFPA 20, pressure relief valves are not allowed to compensate for any other over-pressure conditions. (Section 2-2.4* The net pump shutoff (churn) pressure plus the maximum static suction pressure, adjusted for elevation, shall not exceed the pressure for which the system components are rated.)

The current design options presented below are expensive and / or introduce potential reliability issues. Options a. and b. meet current code requirements as a way to avoid over-pressurization. Option c. has been proposed for the 2003 edition of NFPA 20.

a. Install a break tank to use as the suction supply for the fire pump. The break tank requires an automatic fill arrangement. This solution adds to the cost of the installation, and introduces an automatic fill arrangement, which may reduce the overall reliability of the system.

b. Install a tank sized to meet the total fire flow requirement. This solution adds significantly to the cost of the installation, and requires space to locate the tank.

c. Install a pressure control valve in the pump suction piping to maintain a constant suction pressure. This solution introduces another device and may reduce the overall reliability of the system.

This paper will present another method of limiting sprinkler system pressure.

Factors that can result in sprinkler system over-pressurization

Factors that can result in sprinkler system over-pressurization and they are being ranked here in terms of having the greatest affect to having the least affect:

1. Variations in Suction Pressure
2. Variations in pressure rise at shut-off from one manufacturer’s pump curve to another for all pump models that produce the same rated flow and pressure
3. Variations in driver speed from maximum pump bhp demand to minimum pump bhp demand at shut-off
Each of these, by themselves or in any combination, could cause system over-pressurization. Every system design has to be analyzed based upon knowledge of the dynamics of the suction supply and the particular pump and driver selected.

Let us first address some basic principals of pumps and pump systems:

System pressure is the sum of suction pressure and pump total developed pressure including the increase in pump total developed pressure due to variations in driver speed from maximum pump bhp to shut-off bhp. Suction pressure varies with flow, with the highest pressures being at the static or no-flow condition. In most sprinkler systems, a check valve is installed downstream of the fire pump to maintain system pressure in the piping. It is a drop in this system pressure that calls the fire pump into action.

For a centrifugal pump, pressure is highest at shut-off or no-flow. The Affinity Laws govern the changes in pump flow, pressure and bhp as a function of changes in pump speed. Also, the Affinity Laws state that the pump pressure varies with the square of the speed ratio.

From the basic principles presented above, it can be readily determined that the highest system pressures occur at or near shut-off or no-flow.

Let us now consider each factor that can cause system over-pressurization:

#1 Variations in Suction Pressure
Most fire pump installations take suction pressure from a city main. NFPA-20 requires that suction pressure (measured at the pump suction flange) must always be positive when pumping 150% of rated capacity. Typically, good design practice would require a minimum of 20 psi residual pressure (measured at the pump suction flange) when pumping 150% of rated capacity. From a static, or no-flow situation, the suction supply, being part of the municipal water supply is not only subject to variations over each 24 hour time period (as demand for water fluctuates), but also is subject to variations over time as new feeder branches are either added or removed or additional water pumps are added or pumps are removed from the municipal system. It is not uncommon to see a suction supply that has a static pressure of 60 psi (no-flow) with a residual pressure of 20 psi at 150% of rated fire pump capacity during the day time hours, and has a static pressure of 100 psi with a residual of 60 psi during the evening hours. Being that a fire could occur at any time, the increased suction pressure in the evening may result in system over-pressurization that would not normally be a factor during the day.

#2 Variations in pump curves
For a given rated flow and pressure, it is the pump maximum bhp demand that determines, above anything else, the equipment cost. Each pump manufacturer’s quest for the lowest bhp demand pump design has resulted in shut-off pressures going higher. Although the standard has, for many
years, allowed a 140% rise in pump pressure from rated pressure, it has been only recently (last 10 to 12 years) where more pump manufacturers have designed up to this limit in an attempt to minimize pump maximum bhp demand. This pressure rise to shut-off varies from one pump to another. Pumps with a low pressure rise to shut-off add little to system over-pressurization, but pumps that approach the 140% pressure rise limit could, by themselves, result in system over-pressurization.

#3 Variations in driver speed from maximum pump bhp demand to minimum bhp demand at shut-off

The two basic types of fire pump drivers are electric motor and diesel engine. Both types of drivers have the same characteristic: as the load or bhp demand is reduced, the driver speed increases.

For an electric motor, this characteristic is called “slip”. The design of the motor has a lot to do with its “slip”, but typically most motors produce from only about .5% “slip” to a maximum of 2.5% from maximum pump bhp demand to shut-off bhp demand.

For a diesel engine, this characteristic is called “droop”. “Droop” is probably one of the most mis-understood terms for those more familiar with pumps and pump systems than diesel engines. NFPA 20 allows for a maximum 10% “droop”. Applying the Affinity Laws for pressure for a worst-case scenario using an engine that possesses 10% “droop” would result in a significant increase in pump pressure. In reality, typical diesel engines that meet the certification requirements for NFPA-20 have a “droop” at shut-off of approximately 4%, which is not that much different than an electric motor’s “slip”.

In either case, be it an electric motor, or a diesel engine, the increase in speed at shut-off or no-flow (due to a reduction in pump bhp demand) needs to be factored into the determination of maximum pump pressure which is part of determining the maximum system pressure and the potential for system over-pressurization.

In closing this section, one must remember that these 3 factors are additive in calculating the maximum system pressure and there-by determining if there is a possibility of system over-pressurization:

\[ \text{Factor #1} + \text{Factor #2} + \text{Factor #3} = \text{Maximum System Pressure} \]

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**A new solution to an age-old problem**

By language accepted, during the ROP phase of the 2003 cycle, to be added to NFPA-20 to allow the use of variable pump speed, it now becomes possible to limit system pressure regardless of the magnitude of Factors #1, #2 and #3 presented above. The sprinkler system pressure “control” occurs by the constant sensing of system pressure and by employing a speed control device that can react to an increase in pressure above a set point pressure by reducing the pump speed.

This can be somewhat compared to the pressure sensing line, that is part of every sprinkler system, which feeds the system pressure into the pump controller. This line constantly senses system pressure, and a decrease in system pressure, below the set point pressure, results in the controller reacting, with its designed-in logic, by starting the
pump. The difference here is that this additional sensing line also is constantly sensing system pressure, and an increase in system pressure, above the set point pressure, results in the speed control device reacting by slowing down the pump.

Because the speed control device has a set point pressure, which would typically be set no higher than 90% of the system working pressure limitation, speed reductions only occur once pressures go above this set point pressure. Also, the magnitude of the speed decrease is proportional to the amount of over-pressurization of the system, and therefore, the maximum speed reductions occur at shut-off. However, since the speed control device works off of a set point pressure, speed reductions can occur even out to 150% of rated capacity if the factors presented above result in system over-pressurization even out to these higher flow rates. However, since the set point pressure is always greater than the original sprinkler system design pressure, there is never a case where pump performance is compromised.

To explain further what the speed control device does to system performance, two performance curves are presented here. The first curve (Figure 1) shows performance with 35 psi of suction pressure (at all flow rates) where only a portion of the system curve is above the speed control device set point pressure, and the second curve (Figure 2) is with 85 psi suction pressure (at all flow rates) where the entire system pressure is above the speed control device set point pressure. In both cases, the speed control device behaves as intended, keeping system pressure below its limit.

**Figure 1**

**Typical System Performance - 500gpm, 160psi**

including 35psi Suction Pressure

![Graph showing system performance with 35 psi suction pressure](image)
**Figure 2**

**Typical System Performance - 500gpm, 160psi**

including 85psi Suction Pressure
Since the speed control device only reacts to an increase in pressure above a set point pressure, it deals with system variations. It does not affect the originally selected constant speed pump performance. What this means is that the fire pump industry would go about its methods of pump selection and flow ratings and pressures in the same fashion that it always has. This speed control device only keeps pressures from rising above an established system pressure limit, which would always be above the sprinkler system design pressure.

Implementation

An electric motor would require a variable frequency drive used in conjunction with a single point, set point P-I-D (proportional-integral-differential) controller in order to provide variable pump speed that reacts to system pressure. All of this technology is currently available.

A diesel engine would require a speed control device used in conjunction with a single point, set point pressure controller in order to provide variable pump speed that reacts to system pressure. This technology has been developed and would be production ready in 3 to 6 months pending the NFPA-20 committee actions.

Conclusion

The most reliable and economical sprinkler system design (that meets all current Standards) is what drives the acceptance of sprinkler systems for life safety and property protection. The sprinkler system fire pump market has not championed significant changes in many years, and justifiability so. However, utilizing variable speed drive technology (developed for diesel fire pump engine speed control or electric motor variable frequency drives currently being used successfully in other non-fire pump applications), that can control the sprinkler system pressure utilizing variable pump speed, has the potential to bring with it an entirely new set of economics, life safety and property protection benefits.

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