SMC PLUS™ and Medium Voltage SMC PLUS™ Controller Pump Control

ALLEN-BRADLEY
A ROCKWELL INTERNATIONAL COMPANY

A Unique, Cost-Effective Approach to Reducing Fluid "Surges" or "Hammering" in a Pipe System

An Innovative Motor Control Solution to a Fluid Problem

I. Industry Overview

Surges or pressure transients occur in centrifugal pumping systems when any sudden change of flow is introduced. These surges can result from starting and stopping a pump, opening or closing valves and many other sources in a particular system. There are a number of mechanical surge reduction techniques, but these tend to be costly and complex. Electronic starting and stopping of the pump motor will be explored as a cost–effective solution that reduces surges or hammering problems.

From the Affinity Laws for Pumps we see:

$$\frac{Q2}{Q1} \propto \frac{N2}{N1}$$

Where N = Pump Speed
Q = Flow (CFM)

Therefore, we can directly relate the percentage of change in pump speed to the percentage of change in flow output from the pump.

Centrifugal pumps are generally coupled directly to the shaft of an electric motor. When the motor is started by applying full line voltage, the pump is accelerated from zero speed to full speed very quickly. Less than 1/4 second is not uncommon. This means that the flow out of the pump also increases from zero to total capacity in less than 1/4 second. Due to the fact that fluids are only slightly compressible and have momentum, this large change in flow over such a short period of time results in high and low pressure surges and cavitation as the system seeks equilibrium. This results in many undesirable effects.

Pressure surges stress the walls of the pipe and cause an audible noise. The sound is as if the pipe was struck with a mallet repeatedly. The noise is responsible for the term "Water Hammering" or just plain "Hammering" being applied to this phenomena. But the sound created is trivial when compared to the physical damage that pressure surges can cause. Extremely high pressure transients can cause the pipe to burst while extremely low transients can cause pipes to collapse. Cavitation produces zones of highly agitated liquid and partial vacuums whereby the pipe lining may be eroded and the liquid may be boiled off. These effects also damage the valves and fittings. All of these effects are objectionable.

Since hammering is caused by rapid changes in flow, the hammering caused by starting and stopping the pump can be minimized by controlling the acceleration and deceleration of the pump motor. To understand how fluid flow is affected during the starting and stopping of a pump motor, a review of the various starting and stopping methods is necessary.

The three methods of starting and stopping a pump motor to be reviewed are as follows:

- Direct On Line (closing a contactor and applying full voltage to the motor)
- Solid state reduced voltage starting
- Allen–Bradley's SMC PLUS™ and MV SMC PLUS™ Controllers with Pump Control Option

Before comparing the three methods of starting, it is necessary to establish the relationship between the pump system and pump motor.

II. Pump System and Pump Motor Relationship

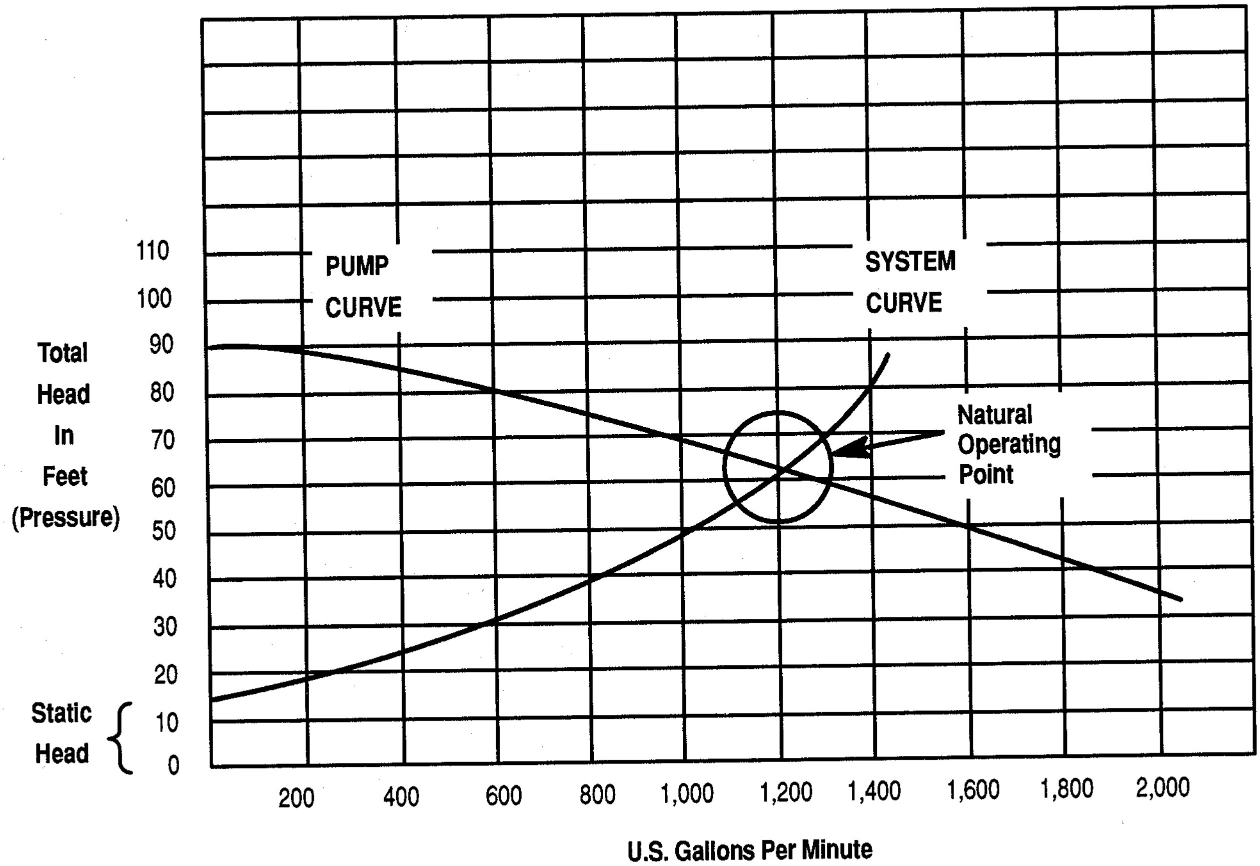

Figure 1. Pump Curve Versus System Curve.

Figure 1 shows two independent curves. One is the pump curve, which is solely a function of the physical characteristics of the pump.

The other is the system curve which is dependent on the pipe diameter and length, the number and location of elbows, and many other factors. The intersection of these two curves is called the natural operating point.

Another Affinity Law states:

$$\frac{P2}{P1} \propto \left(\frac{N2}{N1}\right)^2$$

Where N = Pump Speed
P = Pressure (Feet of Head)

Therefore, we can say that the change in pressure is proportional to the square of the speed.

For a pump motor (AC induction motor) driving a variable torque load, such as a centrifugal pump, the following is true:

$$\frac{T2}{T1} \propto \left(\frac{N2}{N1}\right)^2$$

Where N = Motor speed
T = Motor Torque

Since the pump is directly coupled to the shaft of the motor:

$$\left(\frac{N2}{N1}\right)^2 \propto \frac{P2}{P1} \propto \frac{T2}{T1}$$

Therefore, change in pressure is directly proportional to change in motor torque.

Motor characteristics are described in terms of Speed/Torque curves. Since we have determined that flow is proportional to speed, and pressure is proportional to torque, we can plot the pump torque requirement and the motor torque curve on the same graph.

III. Direct on Line Starting

Figure 2 on page 4 shows the speed torque characteristics of a pump (AC induction) motor started Direct On Line (DOL) with the load requirements of a centrifugal pump superimposed. Note that at 100% speed the two curves intersect. The motor meets the full load requirements of the pump system. Motors are selected to meet the pump load requirements based on this single point in the two curves.

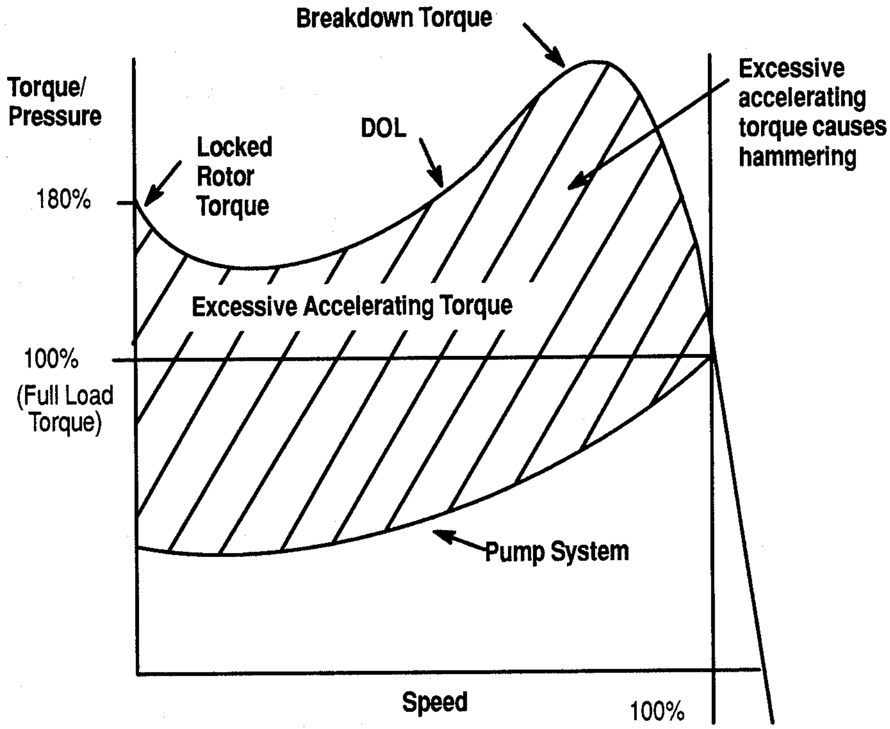

Figure 2. Direct on Line / Pump Speed Torque Curve.

Unfortunately, the motor torque output more than exceeds the requirement of the pump during the start cycle. Locked rotor torque (LRT) is the torque developed by the motor the instant full voltage is seen at the motor terminals at zero speed. LRT can be as high as 180% of the torque the motor produces at full speed. Breakdown torque (BT) is the highest amount of torque the motor can develop. BT can be as high as 250% of full load torque. The difference between the torque produced by the motor and that required by the load is called Accelerating Torque.

Accelerating Torque is the torque that causes the motor to rotate the connected load. In the case of the pump, the excessive accelerating torque produced by starting the motor Direct On Line causes the pump to come up to speed very quickly, typically in less than 1/4 second. The result of this sudden change in speed (and therefore flow) is "surges" or "hammering" in the pipe system.

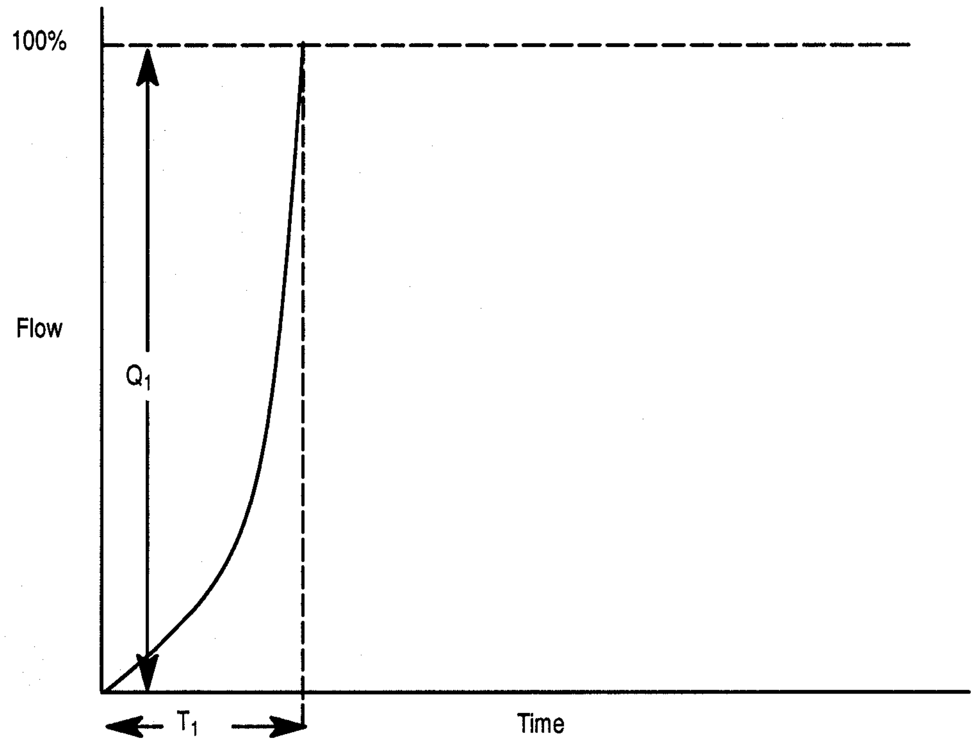

Figure 3. Change in Flow Versus Time – Direct On Line Starting.

To look at the problem another way, as shown in Figure 3, there is a very large change in flow (Q_1) in a very short period of time (T_1). This is due to the large acceleration torque shown in Figure 2 on page 4, resulting in system hammering during starting of the pump motor.

IV. Solid-State Reduced Voltage Starting

If the period of time in which the flow goes from zero to 100% can be increased, hammering can be reduced. This can be achieved by reducing the amount of accelerating torque delivered by the motor. Less accelerating torque means less force to turn the load and therefore more time required to change the speed of the pump. This can be done using a solid state reduced voltage starter to slowly ramp the voltage applied to the motor from zero to full voltage over some preset time (adjustable from 2 – 30 seconds).

The Formula for torque in an induction motor is:

$T \propto V^2$ Where T = Motor Torque
V = Voltage

From this equation we can see that the torque produced by a motor will vary by the square of the voltage. Therefore reducing the voltage by 50% will reduce the torque to:

.5 x .5 = .25 or 25%

Twenty-five percent of the initial torque is now available. If the locked rotor torque was 180% then:

180% x .25 = 45%

The new value of initial torque is 45% of the full load torque.

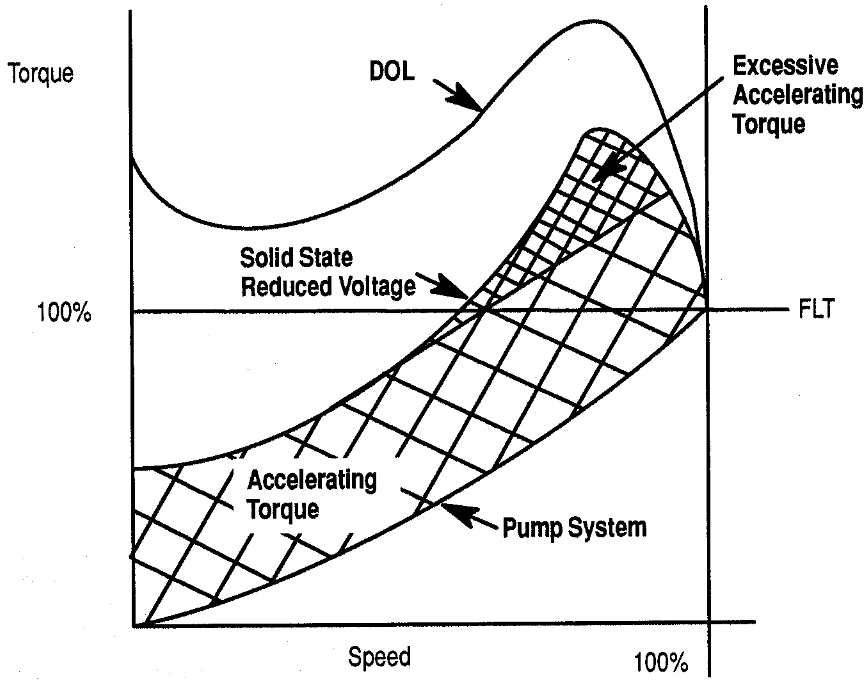

Figure 4. Solid-State Reduced Voltage / Pump Speed Torque Curve.

Figure 4 compares the Speed Torque characteristics for DOL starting and solid state reduced voltage starting of an induction motor. Note that the accelerating torque has been greatly reduced versus the direct on line method of starting the pump motor. This is caused by the solid state motor controller's ability to start at a lower value of initial voltage and to "ramp" up to the full voltage value over an adjustable time period. The torque applied to the motor also "ramps" up.

At the end of the "ramp," however, there is an excessive acceleration torque as shown in Figure 4. This sudden change in torque generates a corresponding burst of speed (flow) at the end of the start cycle and results in hammering.

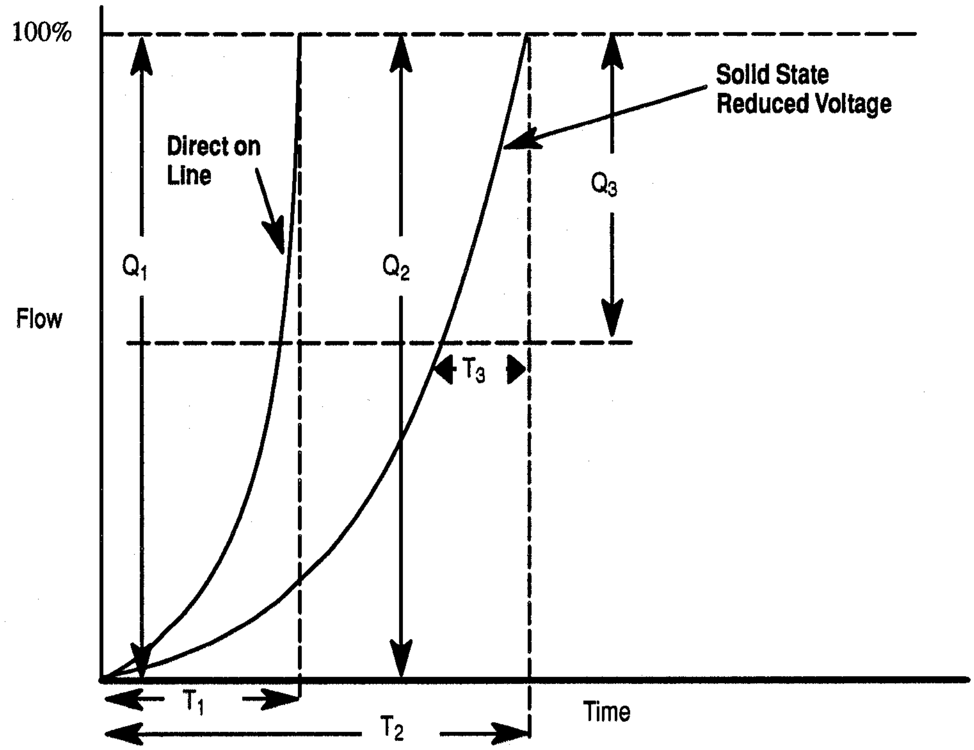

Figure 5. Change in Flow Versus Time.

Again the nature of fluids comes into play. In Figure 5, flow (speed) versus time is compared for the two methods. Note the ultimate flows (Q_1 and Q_2) are the same, but the time varies. T_2 is longer than T_1 so there has not been a sudden surge on the system. However, when observing Q_3 versus T_3 there is still a rapid change in flow (Q_3) versus time (T_3). There is still excessive acceleration torque as the pump motor rapidly approaches 100% speed. This is a result of the breakdown torque which is still present when using a solid state reduced voltage starter. This sudden surge in pump motor torque at the end of the start cycle results in a flow surge.

The sudden surge in torque is due to the characteristics of the motor. It occurs because solid state reduced voltage starting ramps the voltage up without regard to the motor's performance. In centrifugal pumping applications the result is hammering.

As shown, solid state reduced voltage starting improves starting torque characteristics of the pump motor, but cannot control breakdown torque which causes surges.

This is where Allen–Bradley's innovative Pump Control Option resolves this problem.

V. SMC PLUS and MV SMC PLUS Controllers with Pump Control for Starting Pump Motors

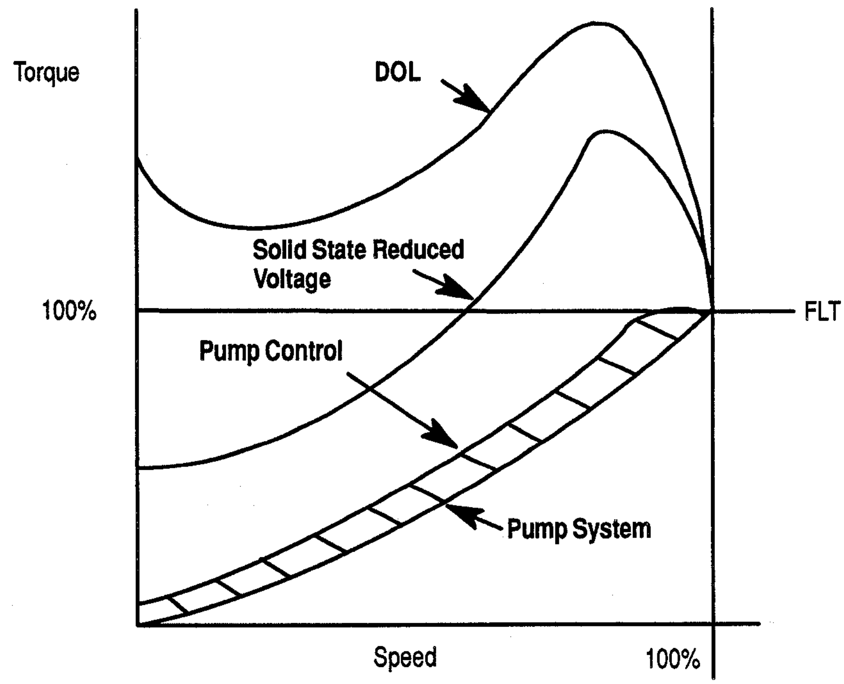

Figure 6. SMC PLUS Controller with Pump Control / Pump Speed Torque Curve.

Figure 6 compares Direct On Line starting, Solid State Reduced Voltage, and Pump Control starting speed torque curves.

With Pump Control, the surge produced during DOL and Solid State Reduced Voltage is greatly reduced. This is done by using the microprocessor in the SMC PLUS Controller or Medium Voltage (MV) SMC PLUS Controller to carefully control the torque output of the motor.

Since there are no sudden changes in torque, this translates into a smooth acceleration of the motor minimizing surges or hammering in the system.

In Figure 7, Flow versus Time is compared for the three starting methods.

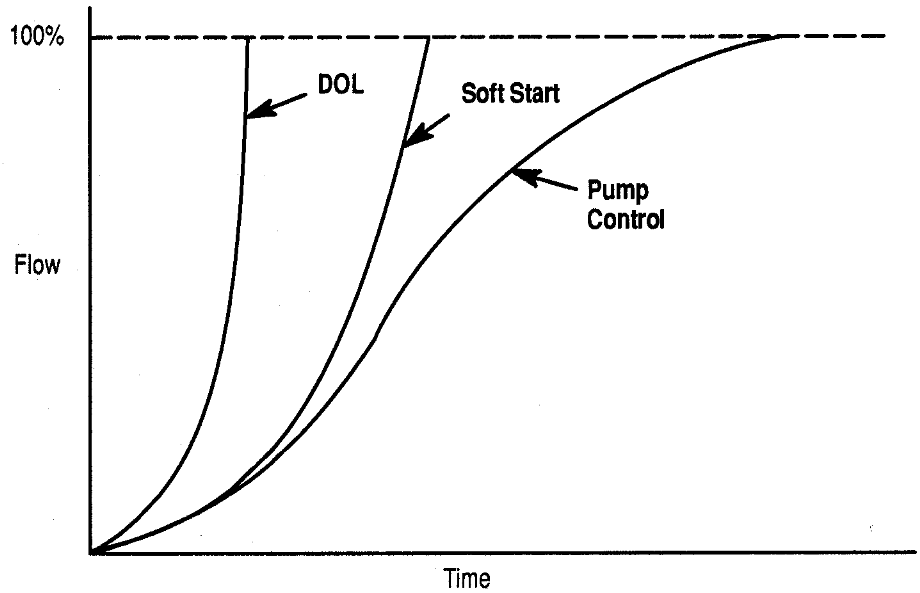

Figure 7. Change in Flow Versus Time.

Pump Control reduces sudden change in flow by controlling the accelerating torque of the pump motor and extending the time to produce a 100% flow, thus minimizing "hammering." This is the desired effect and is the key to the Pump Control Option: there are no sudden changes in torque. This is what is needed to reduce surges. Therefore, hammering is reduced in the pumping system.

VI. SMC PLUS and MV SMC PLUS Controllers with Pump Control for Stopping Pump Motors

So far, we have only discussed starting techniques. Stopping the pump is as critical in reducing surges and hammer as starting. In this discussion we will limit the examples to speed (flow) versus time. Refer to Figure 8.

When a Direct On Line starter is applied, the pump motor will coast when a stop command is initiated (see DOL Coast Stop in Figure 8).

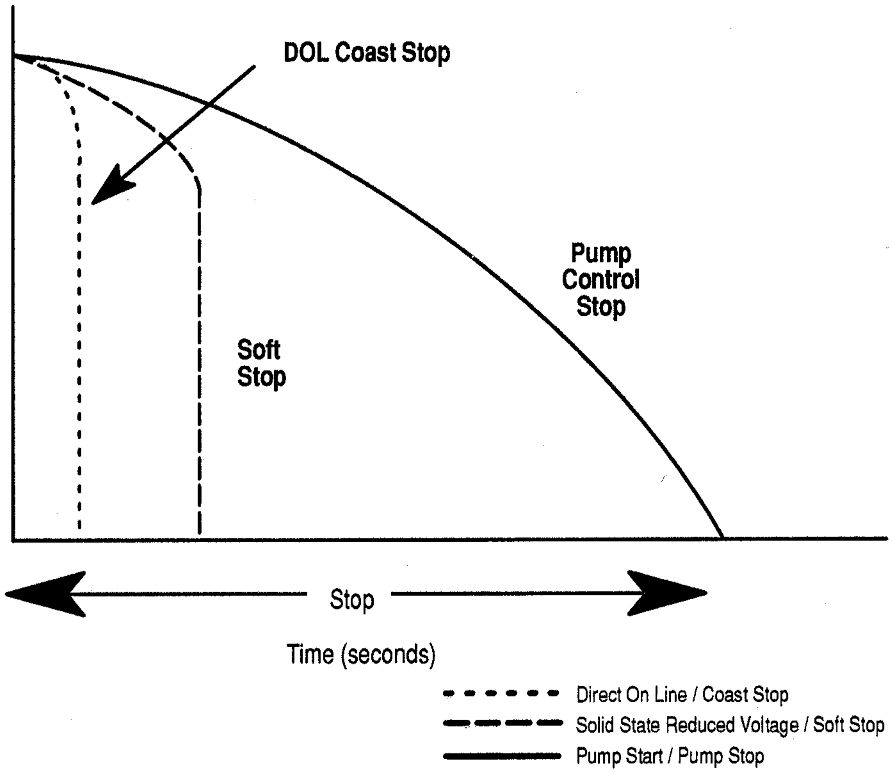

Figure 8. Allen–Bradley Pump Control for Stopping Pump Motors.

The system head will quickly overcome the motor inertia and the pump will come to a rapid stop. The fluid, which is in motion and has momentum, must come to a complete halt as well. This action causes pressure surges on the pipes and valves. This is undesirable due to the damage caused in the system.

Many control manufacturers are promoting a solid state reduced voltage starter with a soft or extended stop as a solution to surge or hammering problems. In most applications Soft Stop cannot prevent sudden changes in motor torque required on pumping applications. When a Soft Stop is initiated, the voltage is ramped from full voltage to zero volts over a time selected by the user (see Soft Stop in Figure 8 on page 10). As shown before, reduction in voltage results in reduction of torque and the pump begins to slow down. However, a point is quickly reached where the load torque demand exceeds the motor torque supply and the motor stalls. The effect, though not as severe, is the same as slamming a valve closed, and hammering occurs.

The SMC PLUS and MV SMC PLUS Controllers with Pump Control Option will control the deceleration of the pump motor in a method similar to the control of the acceleration. When a stop command is initiated, the controller reduces the motor speed to prevent any sudden changes in torque, minimizing surges in the system. The SMC PLUS and MV SMC PLUS Controllers continue to reduce the torque of the pump motor resulting in a speed characteristic as illustrated in Figure 8. This type of pump motor deceleration curve results in minimal surges or hammering in the system as there will not be sudden changes in flow.

VII. SMC PLUS and MV SMC PLUS Controllers with Pump Control for Starting and Stopping Pump Motors

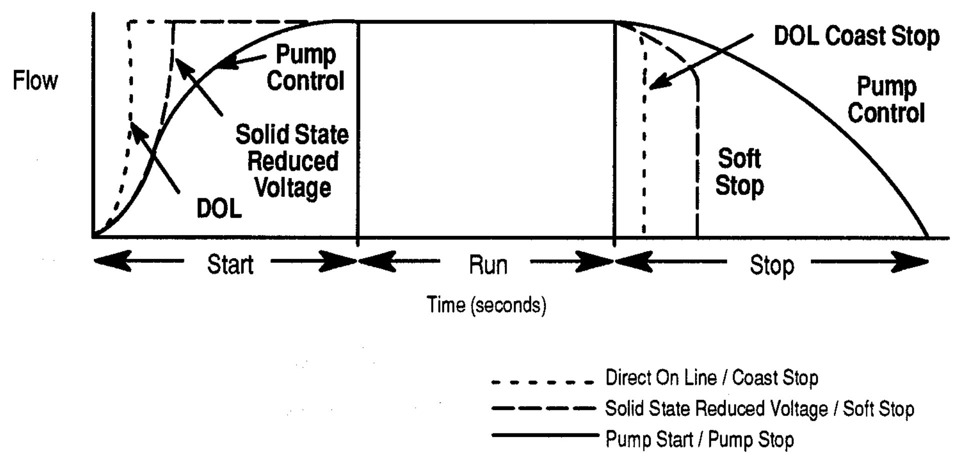

Figure 9. Allen–Bradley SMC PLUS and MV SMC PLUS Controllers with Pump Control for Starting and Stopping Pump Motors.

To summarize, Figure 9 compares flow versus time when different starting/stopping techniques are employed. The Allen–Bradley SMC PLUS and MV SMC PLUS Controllers with Pump Control Option produce the most desirable flow characteristics when starting and stopping centrifugal pump motors. There are no sudden peaks or breaks in flow which result in surges or hammering in the system.

When analyzing what is to be done about a hammering problem, an electrical solution should be considered before a mechanical solution. The initial cost for the electrical solution tends to be less than that of a specialized control valve, and less complex. In addition, the frequent maintenance/ system shutdown that would be required with the specialized valve is not required with an electrical solution.

Allen–Bradley's SMC PLUS or MV SMC PLUS Controllers with Pump Control Option is the preferred starting and stopping method for centrifugal pump systems.

VIII. Allen–Bradley's SMC PLUS Controller and MV SMC PLUS Controller Features

Allen–Bradley's SMC PLUS and MV SMC PLUS Controllers are used on applications other than pumps for controlling the starting and stopping of AC induction motors. During starting, the SMC PLUS and MV SMC PLUS Controllers minimize mechanical shocks to the system. They can also be applied to minimize line disturbances that occur on the power system when a motor is started direct on line.

The SMC PLUS and MV SMC PLUS Controllers provide microcomputer controlled starting for standard three–phase squirrel cage induction motors. The following starting modes of operation are available within the standard unit:

- Soft Start with Kickstart
- Current Limit
- Full Voltage

The built–in **energy saver** feature allows the controller to save energy on applications where the motor is lightly loaded or unloaded for long periods of time.

Optional features include:

- Soft Stop
- Preset Slow Speed
- Pump Control
- SMB™ Smart Motor Braking
- Accu–Stop™
- Slow Speed with Braking

The SMC PLUS controller is available for AC motors with Full Load Amp ratings of 1–1000A; 200 through 480 volts or 200 through 600 volts, 50 and 60 Hz. This device is available as open type, non–combination and combination controllers. In addition to motors, the controller can be used to control resistive loads.

The Medium Voltage SMC PLUS Controller is available for AC motors with Full Load Amp ratings of 20 – 800A; 2400 through 4200 volts, 50 and 60 Hz. This device is available as a non–combination and combination controller.

World Headquarters, Allen-Bradley, 1201 South Second Street, Milwaukee, WI 53204 USA, Tel: (1) 414 382-2000 Fax: (1) 414 382-4444

Publication 150–911 March 1994
Supersedes Publication 150–911 Dated August 1989