

Toshiba VLP Drive Software

Kurt Bihler
Bihlertech, Inc.

Dana Dominiak, Ph.D.
(Illinois Institute of Technology, Chicago, IL)
Automate the World, Inc.

Abstract / Executive Summary

Process control via traditional Adjustable Speed Drives (ASD) with centrifugal devices has an inherent problem of attempting to use a linear equation to solve a non-linear problem. The traditional Proportional Integral Derivative (PID) method controls frequency directly. Controlling frequency directly produces flows and pressures along a non-linear curve and an individual machine's impeller design. By contrast, Virtual Linear Pump (VLP) indirectly solves for power (P) in the Pump Affinity Laws. The new VLP algorithm for the Toshiba P9 drive provides enhanced control, expanded configuration options, and improved energy efficiency over the conventional PID method.

Introduction

The purpose of this paper is to compare and contrast the new Toshiba Virtual Linear Pump (VLP) drive software with the traditional Proportional Integral Derivative (PID) software. The new VLP algorithm provides enhanced control, expanded configuration options, and improved energy efficiency over the conventional method. Various tests were conducted that qualitatively demonstrate the improvements. These tests will be discussed in detail.

Over time, the pump industry has drastically improved the mechanical aspects of pump design through increasingly sophisticated computer CAD/CAM modeling and improved machining. The use of standard Adjustable Speed Drives (ASD) has also achieved better energy efficiency as the kilowatt (kW) usage drops off along a voltage/frequency ratio.

The aspect that has been missing from the conventional method, which the Toshiba VLP software addresses, is the ability to solve indirectly for power (P) in the Pump Affinity Laws for each machine individually, whether the machine(s) operate alone, in series, or in parallel.

This paper describes why solving for power (P) and indirectly solving for speed (N) is important to overall energy savings and how Toshiba's VLP software accomplishes this task. Problems will be defined with a standard frequency change as applied to process control with machines that follow centrifugal law. The deficiencies of simple speed control algorithms will be addressed. In addition, the use of VLP software to balance loads on centrifugal machines and the benefits derived will be discussed.

Results will be analyzed from extensive testing done at state-of-the-art facilities. Tests will utilize Toshiba P9 ASDs and two pumps lined up in parallel and series, using both standard ASD control and Toshiba VLP. A summary of advantages will be presented that can be obtained using Toshiba VLP software to achieve the optimal amount of useful work, and the minimal heat and mechanical stress per kW of energy used.

Problem Definition

Process control via traditional ASDs with centrifugal devices has an inherent problem of attempting to use a linear equation to solve a non-linear problem.

The common PID software used in ASDs provides an estimated speed to achieve a desired set-point. However, when the target speed is reached using this method, the answer is not available. This is because the answer is on an unknown non-linear curve for the pump. The PID software must again guess the speed, and hopefully decrease the error. This process continues until a reasonable deviation from set-point is met. If an aspect of the system curve changes, the whole process must be restarted. This process of searching for the speed costs energy, even on a single machine.

On a system with multiple machines operating either in series or in parallel, a second and more serious problem occurs. This problem is balancing the load. Even if the machines in a multi-machine setup

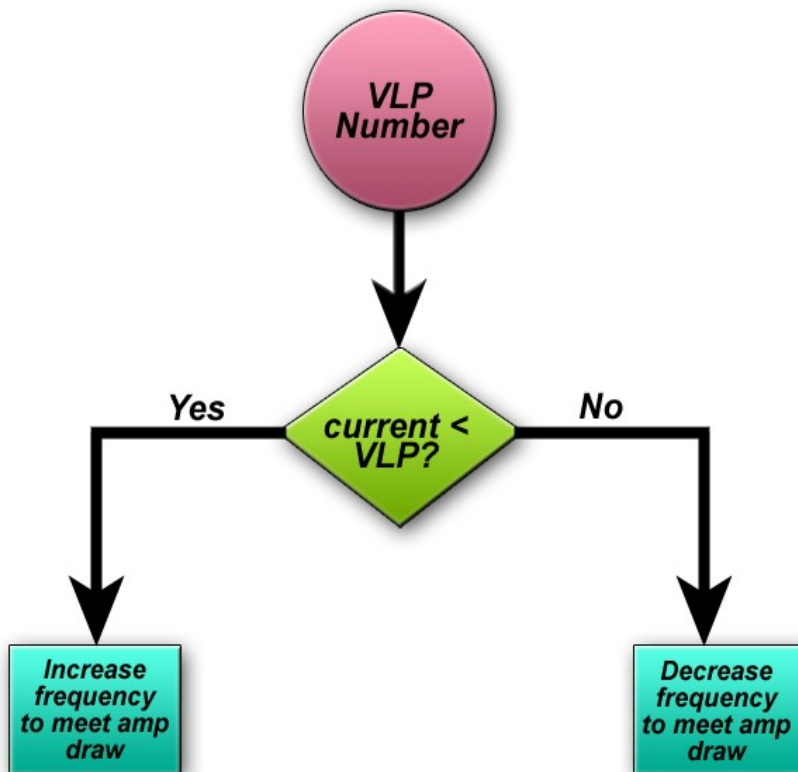
are built to the same specifications, there will be differences in motor performance, impeller clearances, and other mechanical design issues that change a specific pump's speed.

Using conventional frequency control, multiple devices are operated at the same speed when running together. This produces different flows and pressures from each machine. The result is that while in parallel operation, the pump with the greatest pressure will capture most of the output and corresponding amperage, while the other pumps will use a fairly high amount of power and add very little to the total output. There is no way to balance a load using frequency directly, because the smallest of physical differences will cause a shift in power to the device with the highest pressure.

Solution Details

This section describes how Toshiba's VLP software can balance loads and eliminate the process of searching for a set-point.

The new VLP algorithm starts with a fixed VLP number. If the output electrical current is less than the VLP number, then the frequency is increased. Otherwise, if the output current is greater than the VLP number, the frequency is decreased. The frequency (in Hz) turns into rpm to meet the amp draw. This is true on centrifugal devices. Amp draw is linear to both pressure and flow, and non-linear to N. This is in contrast to the VLP algorithm which controls power directly to meet pressure or flow.



Consider the Pump Affinity Laws where the diameter of the impeller is held constant and:

Q = flow

H = pressure

P = power

N = speed of impeller

Flow	Pressure	Power
$\frac{Q_1}{Q_2} = \left(\frac{N_1}{N_2}\right)$	$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2$	$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$

The VLP number is a percentage of available amps of power of a specific ASD. When a motor/pump is first setup in the VLP wizard, the user is instructed to enter the motor full load amps into the drive. The ASD temporarily sets the VLP Max variable to the entered motor amps divided by the ASD full output amps. The operator can then adjust the MAX VLP number to achieve the maximum desired set-point for flow, pressure, etc. Once this is done, the operator will set the MIN VLP to find the lower limit, or motor stall point. At this point, the ASD has stored the limits of where the pump can operate. On multiple pump systems this is repeated so each machine has the same operational set-points. The VLP numbers, which also effect the corresponding amp draw and frequencies of operation at any given point, will be different because of mechanical differences in piping, impeller wear or trim, and motor efficiency. Next, a Virtual Linear Pump curve is created in software, where a percentage each pump will run at the required power in order to precisely match the other pumps' set-points.

If controlled from a common external analog signal, a VLP MIN of 0% will cause all the pumps to run at the MIN VLP set-point. The same is true at 100% where all pumps will be running at their individual MAX VLP. What is important is that for each change in set-point, the resulting flow or pressure will be linear, whereas the frequencies and amp draws will be non-linear.

The reason this is important on a single machine is that when the frequency is changed as in standard ASDs, the output is non-linear and energy is wasted searching to find the appropriate speed needed to satisfy the control loop. *Because VLP produces a virtual linear performance curve, the first calculation from an external PID controller will most likely be the most accurate calculation.* The VLP software changes the power of the motor to produce the desired pressure or flow. No time or energy is wasted accelerating and decelerating past the needed frequency. When the internal VLP process hold loop is used with an external feedback signal from a pressure transducer or flow meter, the control loop process is greatly enhanced because there is no lag in communication and the variables can be tested and satisfied at CPU clock speed.

Another relevant characteristic of VLP is that each ASD running VLP software can calculate what speed to run at in order to hold the VLP number independently. This would be impossible for separate drives running speed control PID because each drive would be fighting the other with hunting errors until the whole system became unbalanced. Because VLP software provides a virtual line of performance, each ASD can simply select an individual point that represents exactly the same pressure

at flow point as every other ASD. This means the overall control system is greatly simplified. Therefore, an external PLC or DCS system needs only to tell each VLP ASD when to run, what set-point to hold and provide the feedback reference signal. The heavy lifting of calculating the specific power requirements to maintain set-point is distributed across all the individual machines that are online.

In this scenario, each VLP ASD that is online, whether it is running or not, is continuously calculating what power it needs to be running to maintain the desired set-point based on its initial stored setup values. When called for, the next drive will ramp up and recalculate the feedback to find its point on the performance line. At the same time the lead pump will be backing down because the additional flow will be changing its reference signal. Eventually all pumps will reach the needed frequency to meet the virtual pump performance set-point, while the VLP software runs in the background to find the required power. This process occurs very quickly because each estimate finds a known performance point. It generally happens faster than the mechanical forces can cause any pressure or flow change.

This leads to the most important function of Toshiba VLP software, and that is balancing the load between multiple pumps.

Each pump is tuned during commissioning to produce a specific result, such as a flow rate or pressure at both VLP MIN and VLP MAX. Each motor/pump combination is unique and requires slightly different frequencies and power requirements at both end points and every point in-between. As a percentage, they are all same. Since all the ASDs share the same common reference signal, they can independently calculate the power needed to match the flow/pressure of all the pumps online.

In a series operation this effect is even more pronounced. If series pumps are run at the same speed, they have different velocities. This is analogous to a traffic jam on an expressway where the cars are stopping and starting. Using VLP, the “cars” are all moving at exactly the same velocity. Without VLP, this difference in velocities between pumps can result in over pressure waves that amplify and resonate. This causes mechanical stress, which in-turn costs power.

With VLP, the frequency can range to satisfy changes in the system curve. An example of this may be found in a common lift station connected to a force main that is shared by other pumping stations. In this case, a transducer would provide feedback to keep the wet well at a constant level. As the flow rate changes, VLP would increase and decrease power to achieve this, just as a standard VFD would range the frequency. By contrast, the different VLP machines resolve for the P variable of the power affinity laws simultaneously. At a given power setting on a pump with an increasing power curve, VLP increases the frequency to maintain the specified power when the force main pressure increases as other stations come online. When running in VLP "Process Hold Mode", the VLP software will do this independently, each time the the feedback changes the VLP output number.

The result is that unlike a simple speed control system, the VLP software corrects the frequency based on power needed before any change comes from the feedback loop. This has a two-fold advantage: more accurate process control, and consequently, less power is used by the pump.

VLP Testing at Hydro, Inc.

The following tests were conducted at the Hydro, Inc. facilities in Chicago, IL. These facilities were designed in compliance with Hydraulic Institute standard and API 610 and employ a LabView data collection system with electronic flow meters, torque meter and remote valve controls.

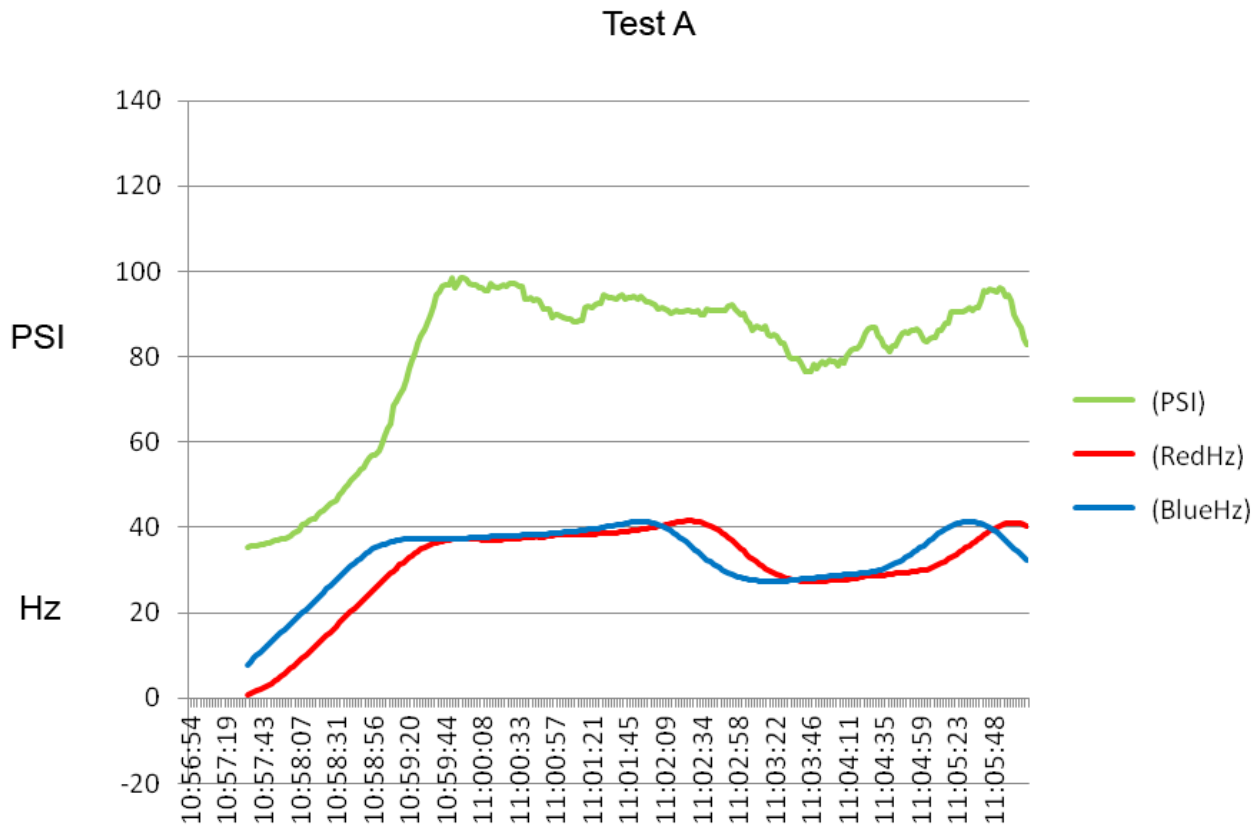
Test A "PID Lead Pump"

95 PSI Set-point (Blue Pump)

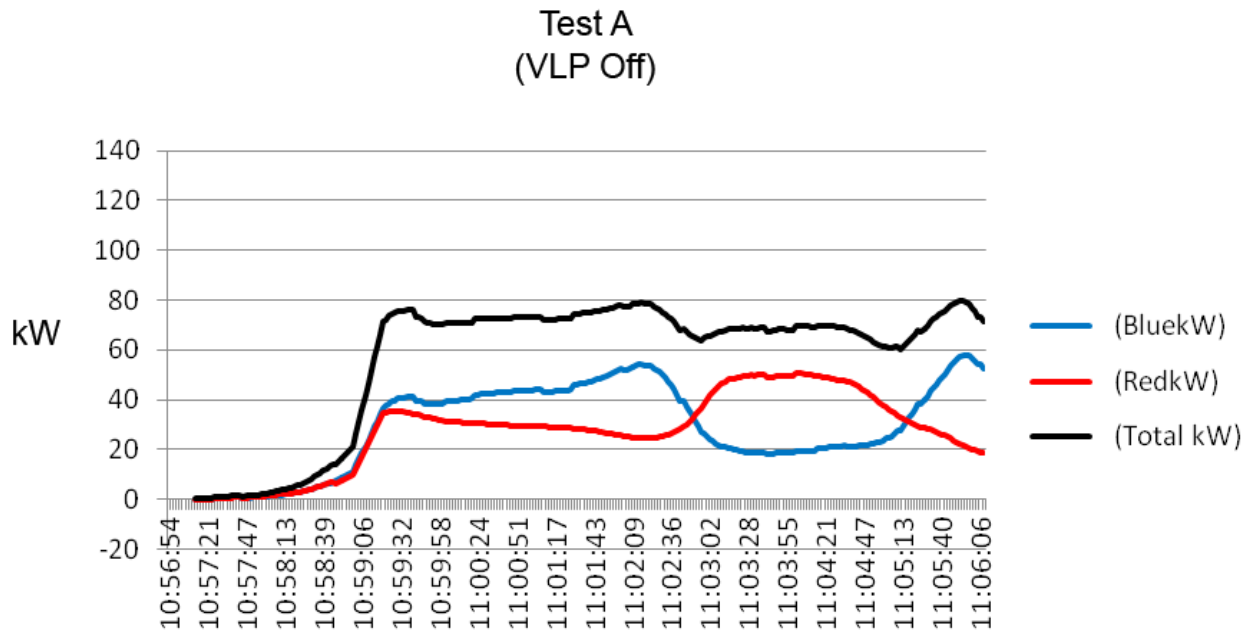
Speed Follower Lag Pump (Red Pump)

Average kW Usage from 10:59:32 to 11:05:49 = 70.88

This test shows the traditional method of using two pumps on a common header. A PID algorithm with feedback is used on the first pump (PID cannot be used on more than one pump in a system) and the second pump is set to follow the speed reference from the lead. The lag in response is due to the acceleration time.



With traditional PID, a significant amount of energy is wasted in unbalanced systems. In parallel systems, one pump will take over and produce the majority of the flow when all pumps are running at the same speed. This occurs whether on a ASD or across the line. All the other pumps will draw a considerable amount of power, but contribute little to the total flow. By contrast, in a VLP system, each machine will precisely produce its portion of the flow and use the same amount of energy. With VLP, all of the pumps on the system become one "virtual" machine.

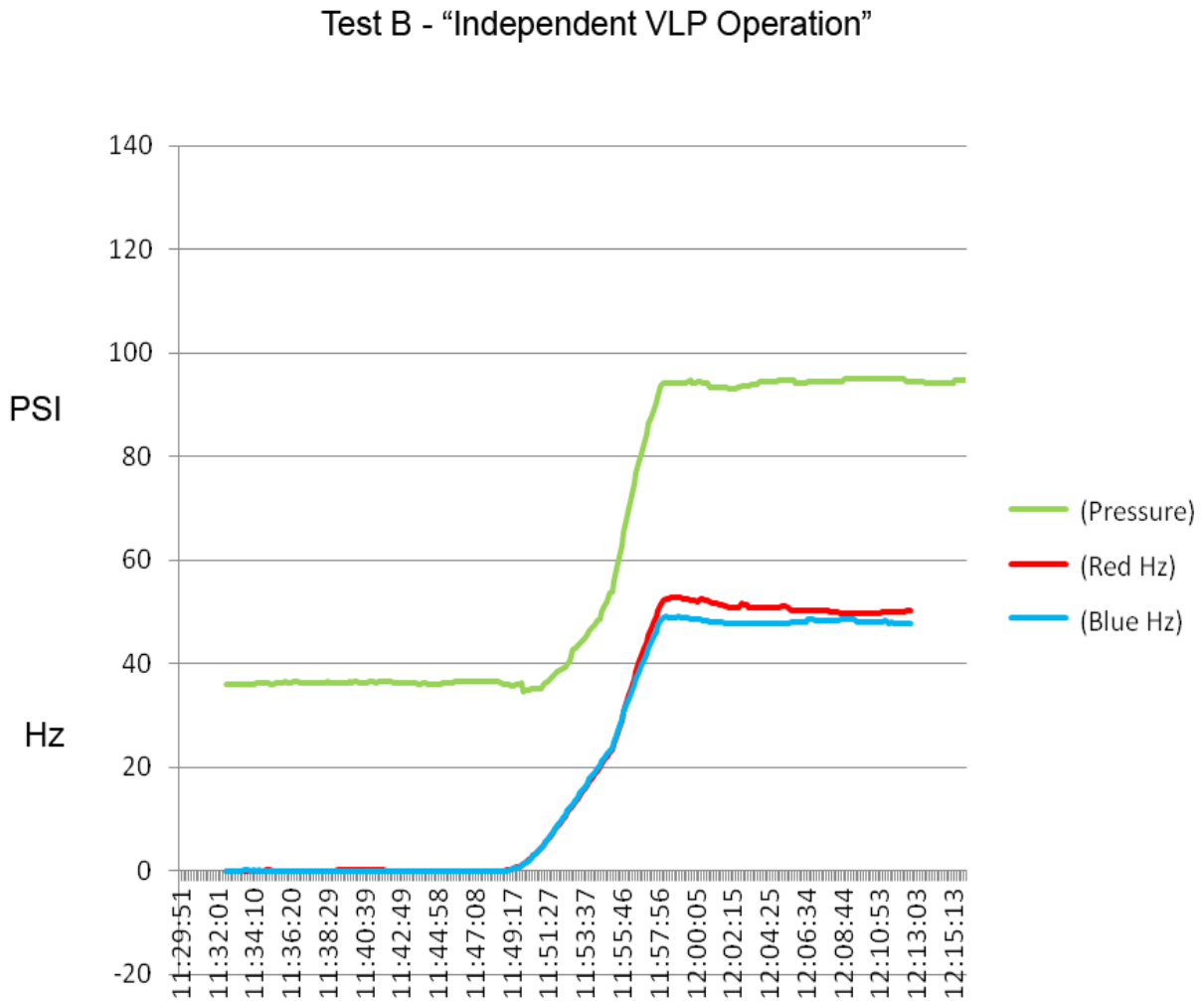


Test B "Independent VLP Operation"

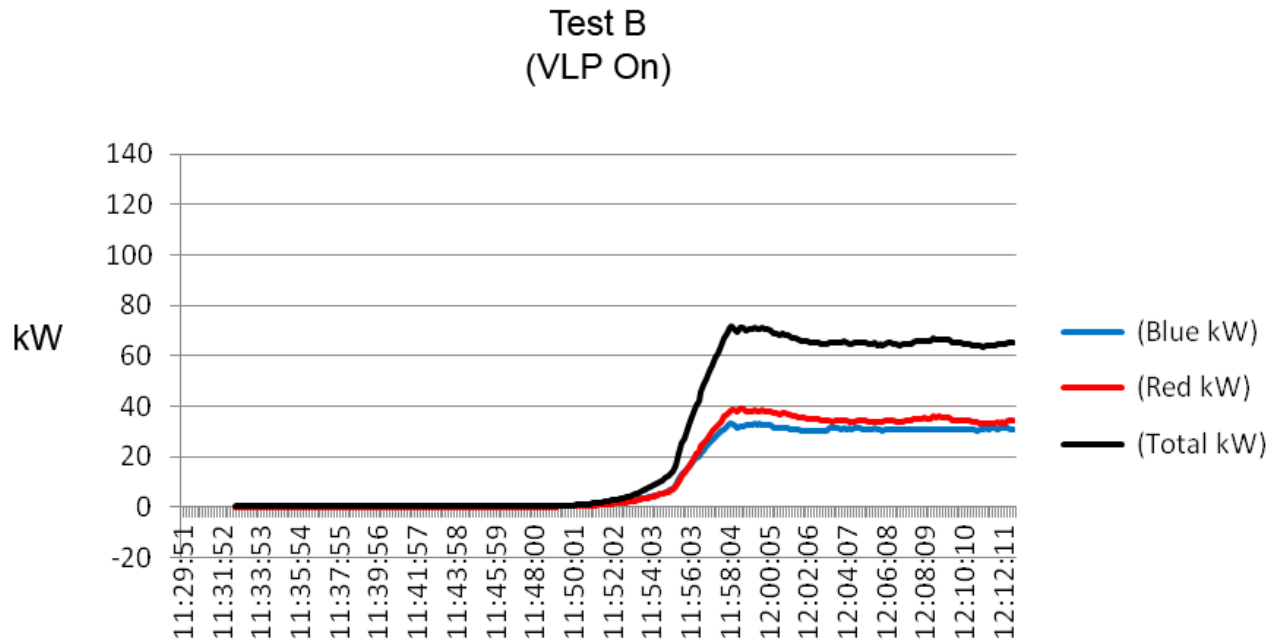
95 PSI Set-point

Average kW Usage from 11:57:30 to 12:11:19 = 65.93

This test performs the same set-points as Test A above, but uses both drives in independent VLP process hold mode. Of note is the smoothness in pressure and flow, and that the drives do not get out of sync and fight each other as shown in Test A. One additional point of interest is that in Test A the PID loop was tuned by a professional application engineer. By contrast, in Test B the Toshiba P9 drives were simply run through the VLP setup wizard and no tuning was performed. Instead, all the values were the drive defaults.



Looking at the chart below and comparing it to Test A, this clearly shows the cause of VLPs energy savings. Precise control of the process and balancing of the load reduces energy that is otherwise converted into heat and mechanical stress.

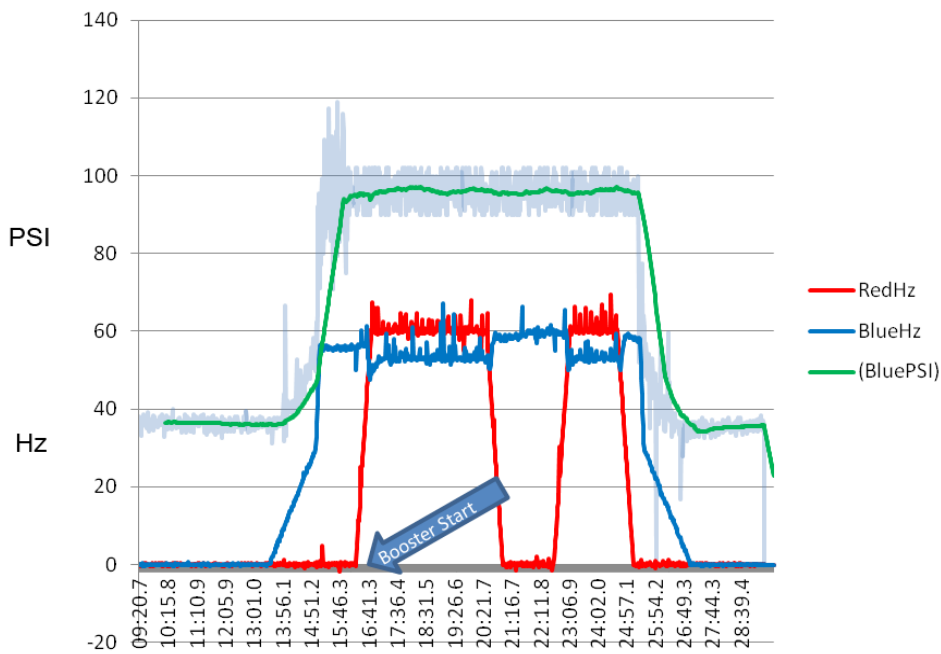


VLP with "Across the line" Booster

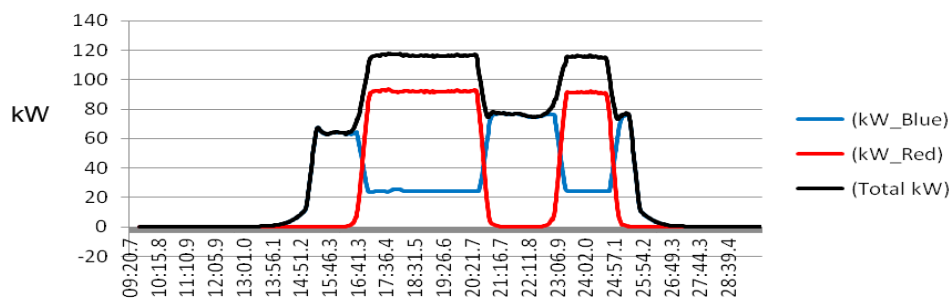
The blue pump drive was configured for VLP operation to control pressure at a set-point of 95 PSI. The pressure set-point was chosen as it was obtainable by the 100Hp pump and motor but would cause the pump to operate at an undesirable efficiency level. The red pump drive was configured to emulate a soft-start device - accelerating to 60 Hz using a 7.5 second acceleration rate. On the top chart, the green trace shows the pressure on the common header while the blue and red traces show output frequency on the respective drives. The lower chart indicates kW consumed for each drive as well as the total kW. Total kW (with both pumps running) is 118kW.

This chart confirms that using across the line starters with multiple pumps verses using a drive for every pump can not be cost justified. The difference in cost of having a drive for every pump is quickly diminished by, in this case, a 36% lower kW usage. VLP software will be more energy efficient than traditional speed control PID by about 5% in this case. That still leaves 31% less electrical usage using VFDs with standard PID software. 31% is lost due to heat, vibration, and mechanical stress. By any measure, one drive for each pump costs less.

VLP with "Across the Line" Booster

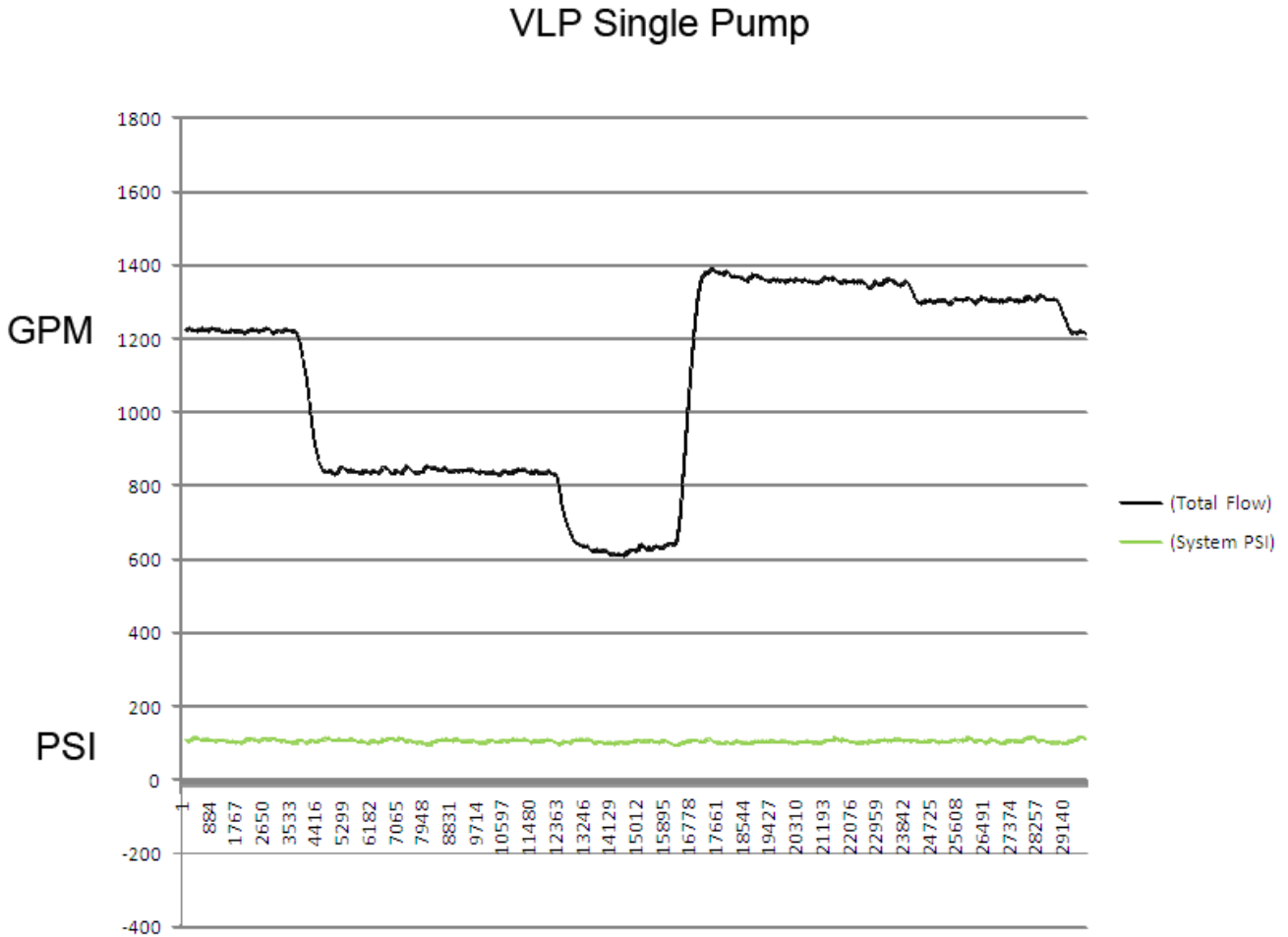


VLP with "Across the Line" Booster



VLP Single Pump

During this test the VLP number was held constant. This chart shows that in Direct Mode, the VLP software will maintain a constant power usage corresponding to the VLP number by altering the frequency in response to external changes in flow and pressure.

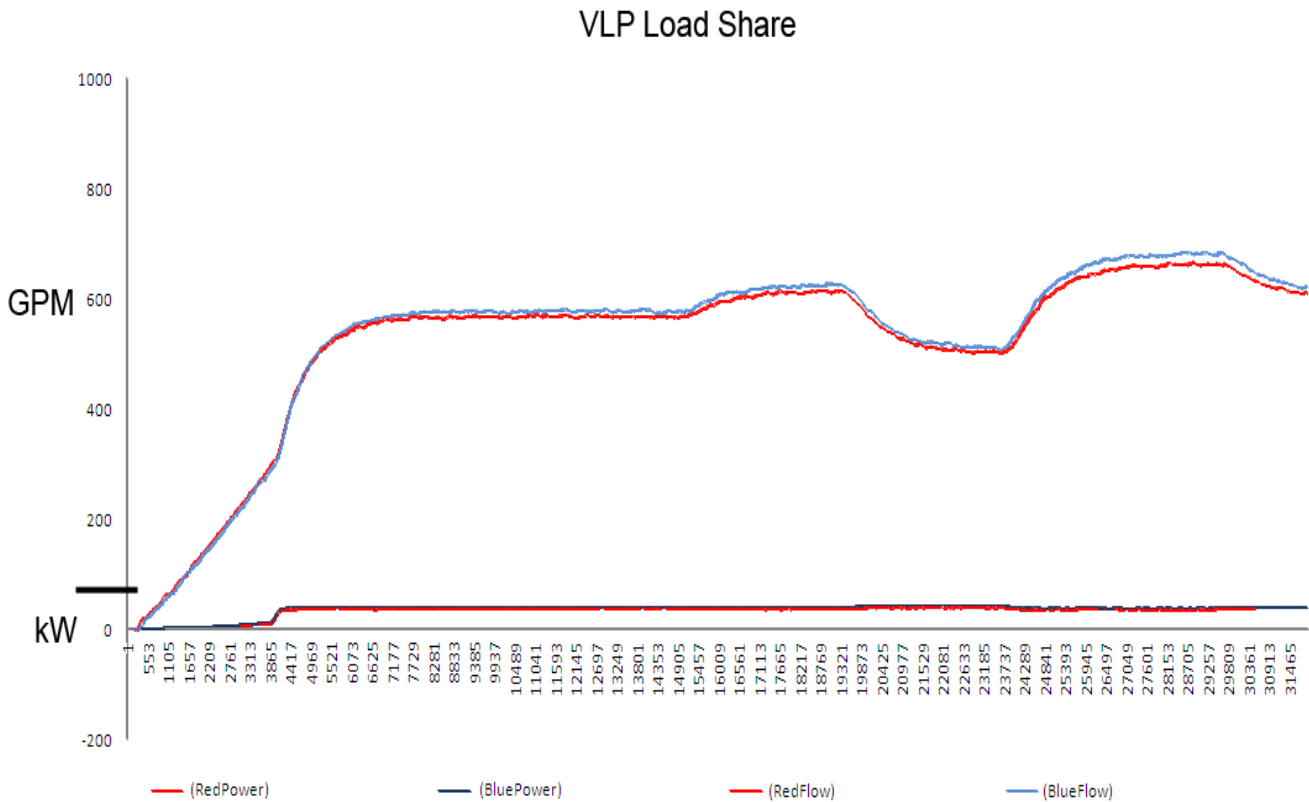


VLP Load Share

The chart demonstrates both pumps in VLP Direct mode reacting to changes in the main valve to increased and decreased system pressure.

Notice the power does not change, and the loads are balanced in flow. In operations like this without VLP, one pump would use most of the power and produce the majority of the flow, and the second pump would use somewhat less electricity but contribute very little. The power changes between both pumps are not subtle. Power usage and flow violently change from one pump to another.

The chart (60 Hz on one pump and trim with the other) indicates that in this case 36% more power is needed to produce the same results. This is an extreme, as would be the case with an across the line starter and a VFD trim. When compared to VFD PID and Speed Follower, it still takes 5 or 6 percent less energy to meet the set-point using VLP. This energy loss causes heat and mechanical stress, which is significant not only to direct energy savings, but also costs related to increased wear and mechanical damage.

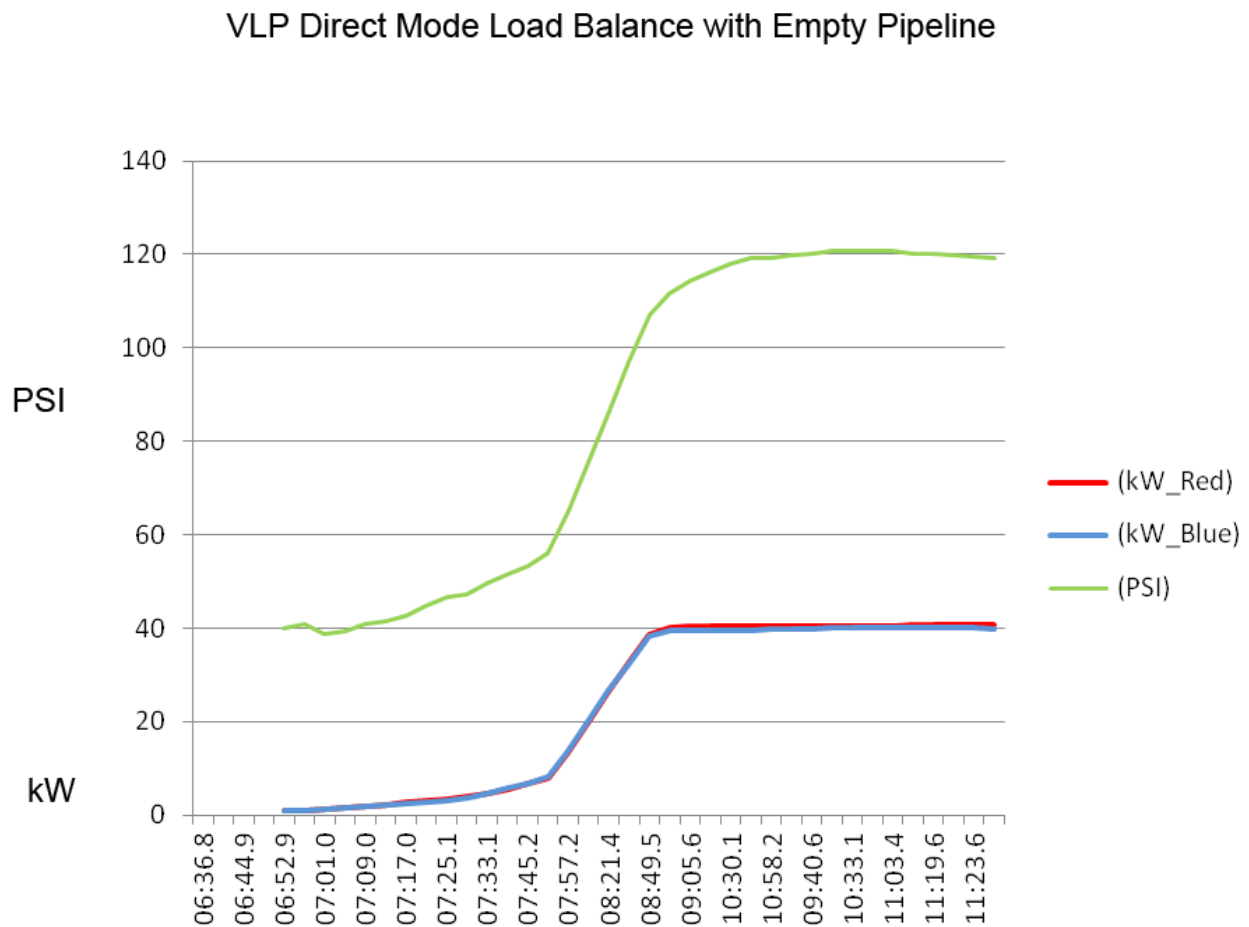


VLP Direct Mode Load Balance with Empty Pipeline

This chart shows two key issues that VLP software addresses. First, VLP will limit pump overload that normally occurs when starting a pump on an empty pipeline. Normally, the pump having no restriction on flow would electrically overload. The VLP algorithm will limit the output frequency in order to limit the output amperage.

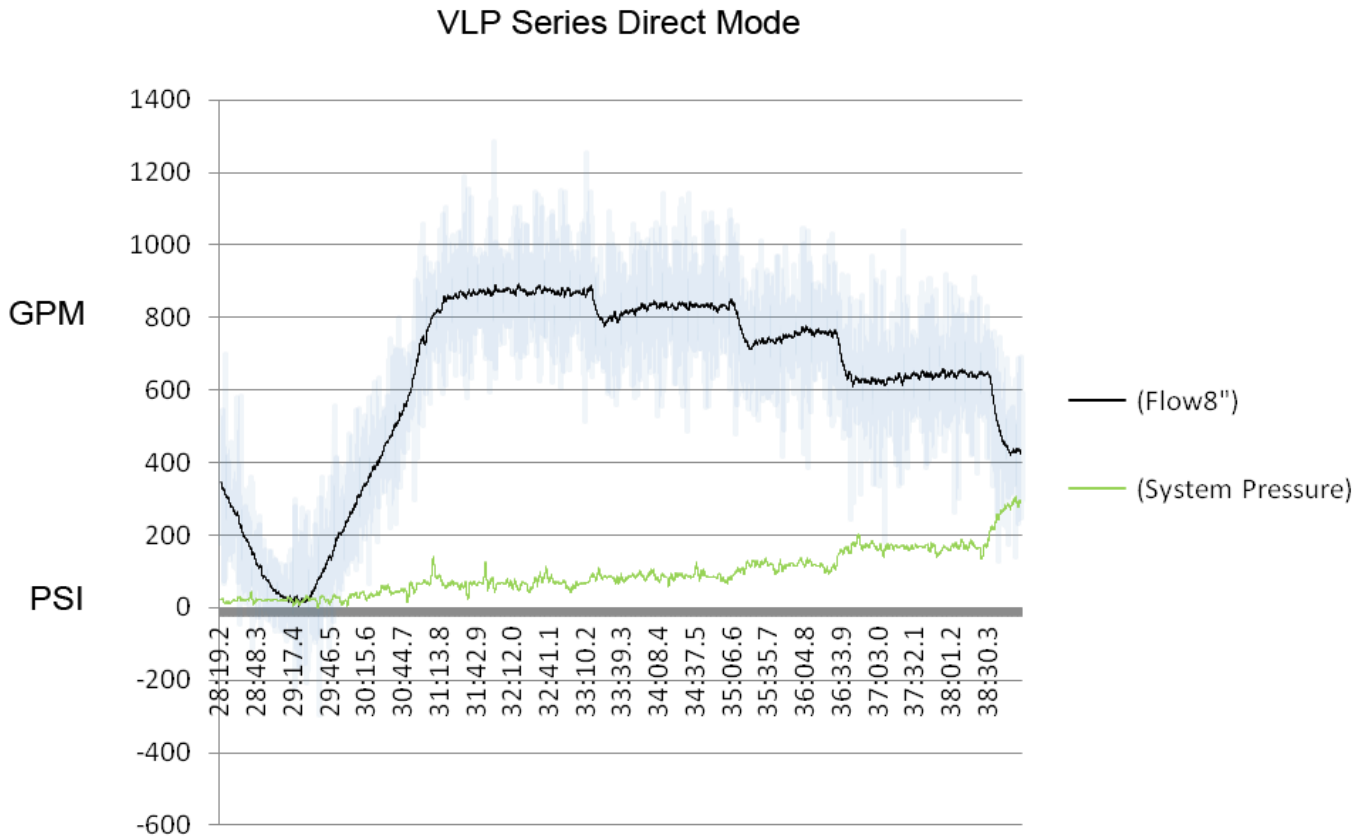
Also, precise process control eliminates wasted energy. This is the key to VLP's energy savings. VLP can not change pump efficiency or process piping. VLP can limit wasted power because of mistakes in process control introduced by traditional speed control.

This test also demonstrates that the VLP software is also capable of achieving a balanced mode.

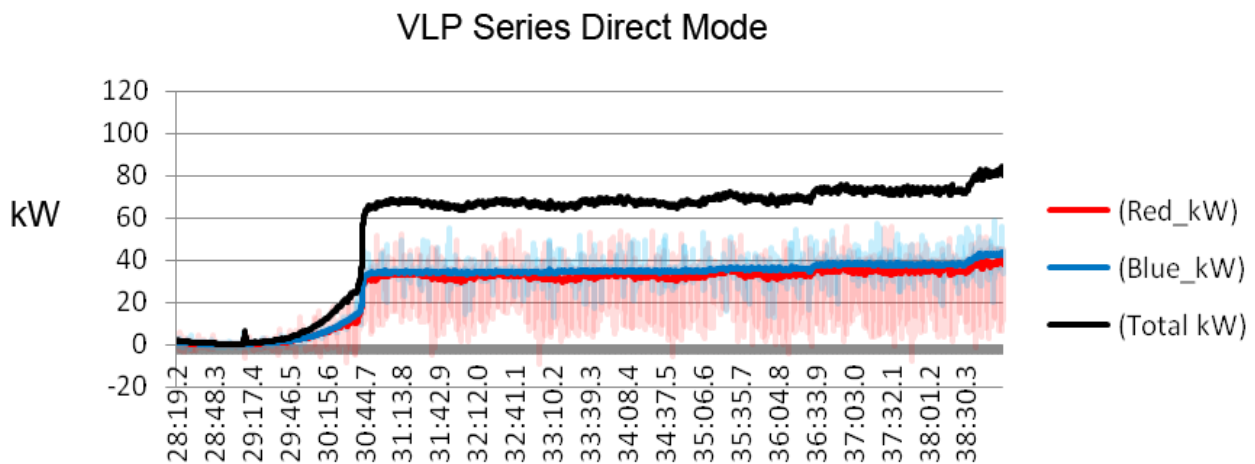


VLP Series Direct Mode

The VLP Series Direct Mode test shows that with VLP, as pressure goes up, the power remains balanced. Pressure is represented as the bottom green line on the chart below. Power is shown as the black line on the top.



The graph below shows the total energy consumption of the system (top line), and that both the red and blue pumps consume roughly the same amount of energy (red and blue lines):



Business Benefits

The ability of the Toshiba P9 drive to quickly reach the desired set-point provides numerous benefits for deployment in mission critical environments. Several of the most important benefits are discussed below:

- Energy efficiency
- Longer pump life
- More up-time
- Less training for operators
- Faster configuration of complex systems
- Reduced damage potential

The first benefit is increased energy efficiency. As shown in the test "VLP with 'Across the line' Booster", the VLP is more energy efficient than the traditional VIP software. This allows the drives to maximize energy savings on variable torque loads.

The VLP algorithm linearizes the traditional non-linear pump curve, which results in a more stable and precise variable pumping control. The VLP software reduces heat loss, vibration, and mechanical stress. This leads to longer equipment life, another cost savings. The benefit is more up-time, allowing pumping and drilling operations to become more cost-efficient.

Using VLP drives, pump operator personnel require less training. Operators configure the drives in five simple steps. The VLP algorithm solves the problem of load-balancing over multiple pumps, thereby eliminating PID tuning. The result is faster and easier configuration of multiple machines in series or in parallel.

Using VLP, it is more difficult for operators to inadvertently damage pumps, especially in multi-machine and complicated configurations. The VLP software has built-in protection against dead head, loss of suction pressure, cavitation, thrust bearing and other unwanted effects. As shown in the test "VLP Direct Mode Load Balance with Empty Pipeline", VLP will limit pump overload that normally occurs when starting a pump on an empty pipeline. The Toshiba P9 drive also self-calibrates and eliminates common pump anomalies.

The above benefits offer an unprecedented savings to operations that depend upon serious pump applications.

Summary

The new VLP algorithm for the Toshiba P9 drive provides enhanced control, expanded configuration options, and improved energy efficiency over the conventional PID method. Process control via traditional ASDs with centrifugal devices has an inherent problem of attempting to use a linear equation to solve a non-linear problem. By contrast, VLP software corrects the power needed before any change comes from the feedback loop. This has a two-fold advantage: more accurate process control, and consequently, less power is used by the pump. Extensive testing was conducted at the Hydro, Inc. pump testing facilities to accurately measure and then analyze the differences between the VIP and VLP algorithms. The results were then discussed in detail. The benefits of the VLP software offer an unprecedented savings to operations that depend upon serious pump applications.

Abbreviations

ASD: Adjustable Speed Drive
CAD: Computer Aided Design
DCS: Distributed Control System
P: Power as represented by the Pump Affinity Laws
PID: Proportional Integral Derivative
PLC: Programmable Logic Controller
VFD: Variable Frequency Drive
VLP: Virtual Linear Pump
VSD: Variable Speed Drive

About Kurt Bihler:

Kurt has over 30 years of experience in industrial controls. Past work includes programming in the USA and Japan for SORD Computer. Since 1993, Kurt was president of Bihlertech, Inc., a company that specialized in building pump station controls. Mr. Bihler is now a consultant to Toshiba and is a co-inventor of the VLP algorithm.

<http://www.bihlertech.org>

About Dana Dominiak:

Dana Dominiak holds a Ph.D. in Computer Science from the Illinois Institute of Technology. With vast programming experience in many languages including C and C++, Dana specializes in advanced automation programming. In addition, she has extensive experience programming graphical interfaces of energy analysis systems for institutions such as Argonne National Laboratory and the International Atomic Energy Agency. As a hobby, Dr. Dominiak is an Adjunct Professor at Lewis University and teaches courses such as Computer Graphics and C/C++ Programming.

<http://www.AutomateTheWorld.com>