THE PUMP GUY

BEWARE THE AFFINITY POLICE

If you're caught breaking a traffic law, you'll go to traffic court. If you violate a criminal statute, you could find yourself before the criminal court judge. You certainly don't want to be hauled in to the affinity court for breaking one of the affinity laws.

The affinity laws are a group of laws and rules that govern your pumps. Sometimes they're called the laws of similarity. Until a few years ago, the affinity laws were on the back burner and mostly ignored. They were only recalled upon exporting a pump to a country with different electricity.

Electricity in the United States is at 60 cycles per second, or hertz. Pump performance curves are mostly based on standard electric motor speeds in rpm. Speed is critical to the pump's performance because the speed and diameter of the pump impeller govern the pressure (head) that the pump will generate. And the speed and height of the impeller blades will govern the pump's flow in gpm. A pump and motor spinning at 1800 rpm at 60 hertz, would spin at only 1500 rpm when exported to a country with 50 hertz electricity.

The change in speed would bring about a corresponding change in the head, flow, and horsepower requirements of the pump. Likewise, the data on the performance curve would have to be adjusted. How? By the Affinity Laws. Let's look at them, incorporate them into your CHEAT SHEETS, and remember them.

Stated simply, the affinity laws are:
* $Q \alpha N$ or, the change in flow is proportional to the change in speed
* $H \alpha N^2$ or, the change in head is proportional to the square of the change in speed
* $BHP \alpha N^3$ or, the change in horsepower is proportional to the cube of the change in speed

Mathematically, we would write the equations as:
* New Flow = Old Flow x (new speed/old speed)
* New Head = Old Head x $(\text{new speed/old speed})^2$
* New BHP = Old BHP x $(\text{new speed/old speed})^3$

Another set of the affinity laws deal with changes to the diameter of the impeller. We'll deal with them later. Why are these laws important to your work with pumps?

These are the days of the variable speed motor. By varying the frequency of the motors, the speed is also variable. The earlier models were somewhat problematic, costly, tended to overheat, and difficult to repair. The newer models are almost perfected, quite efficient, and low maintenance. As the cost of energy goes up, the variable frequency drive, VFD, is taking its place in industry. Our cars are a form of variable speed drive. Our foot on the gas pedal governs the speed of the auto. No one would drive his car by setting the cruise control on 100 mph, and then govern the speed of the car with the other foot on the brake pedal. This would be stupid, and yet it's the way we've operated pumps in the past. We'd turn on an electric motor at say 1800 rpm, and then govern the flow through the pipes by opening and closing valves. Now That's Stupid!!!

Every day there are more and more VFDs, and you can bet they're in your near future. As I travel around lecturing on pumps, I always try to ask my students about the variable speed AC motors in their plants. Someone said, "Our electric motor salesman said to put VFDs on fans, but not on centrifugal pumps." Sometimes they say VFDs work on some applications but not on others. Still others say they're just now getting started with VFDs, and have a few models running on test. And some people respond that about 50% of their motors are VFDs. This broad range of responses makes sense upon re-examining the affinity laws.

The first affinity law is easy to follow. Flow is proportional to speed. 10% more speed would be 10% more flow or gpm. Twice the speed would be twice the gpm. 3/4 the speed would be 3/4 the gpm. X-speed would be X-gpm, and 0-speed would be 0-gpm. Process Engineers lock onto this law as a means to control the flow of process chemicals. If production is reduced to half and you need 50% less gpm from a centrifugal pump, the best way to achieve this would be to reduce the speed of the motor by 50%. This is preferred over throttling a control valve to reduce flow by 50% on a flow meter. If demand goes up 20%, then the process engineer could increase the speed of the motor by 20% and increase production by 20%.

You can see now why operators prefer to manipulate the speed of the motor to govern flow as opposed to cranking on valve wheels. Why stand next to a hot, noisy, foul smelling pump sweating and jacking on a rusty valve wheel, when you can sit in an air-conditioned room, look at a video screen, and turn a knob.

The second affinity law is more interesting. Head changes by the square of the speed change. In this case, head means all pump heads, including the shut-off head, best efficiency head, net positive suction head, friction head, discharge pressure, seal chamber pressure and all elevation changes. A pump previously generating 100 psi would now generate 156 psi (56% more) with a 25% increase in speed, although the flow would increase by 25%. A pump capable of elevating a liquid into a 100-ft. high tank at 1800 rpm, would now be capable of filling a 400-ft. high tank at 3600 rpm. A 200-psi filter press would become an 800-psi filter press at twice the motor speed.

So now the production team likes VFDs to control the flow. They run up the speed to increase production, and burst the filter screens on the basket strainers, and take out a couple of mechanical seals. The mechanic gets blamed for installing the filter screen wrong, and for not properly installing the mechanical seal. To correct the problem, the mechanic will be sent to a mechanical seal installation course. The operator brings down the speed to reduce the gpm, and now complains that the pump will no longer fill the tank. (Remember that one half the speed would be one-fourth the elevation). The mechanic and his supervisor will be sent to a pump rebuild course. Their progress will be tracked by the recently hired maintenance management team leader.

Isn't it interesting that the operations department has budget money left over at the end of the year, and the maintenance department ran out of money in mid-November? Put this information into your CHEAT SHEETS, with the other Pump Guy articles. Be prepared to defend yourself, because the VFDs and the affinity police are looking for you.

Now you can understand why some people put VFDs on fans and blowers, but not on centrifugal pumps. A fan or blower is only a flow application. If you needed air pressure, you'd be using a compressor.

A pump has a flow (gpm) element, and it has a pressure (psi) element. And this is why some people say that VFDs work well with certain pumps, but not so well with others. A VFD would complement a pump on a chill water loop, but might be problematic on a cooling tower pump. A hydronic boiler re-circulating pump would be an easy application for a VFD, but not a steam boiler feed water pump. If this information is leaving you in the dirt, please go to the CHEAT SHEET from the Pump Guy's Carpal Tunnel Headache article (www.energy-tech.com/features).

Now let's consider the third affinity law that deals with horsepower. A standard four door sedan automobile has an engine with about 100-horsepower. If you were to press the gas pedal to the floor on an open highway, you could probably accelerate the car to about 100-miles per hour. Now let's consider NASCAR racing at the Talladega and Daytona long tracks. These cars travel at approximately 200-miles per hour, and sport engines approaching 800-horsepower under the hoods. Their speed is two times a normal car's maximum speed, and their engines have about 8-times the horsepower of a standard sedan. This third affinity law states that the horsepower (and all energy factors including labor and downtime) changes by the cube of the speed change. In a pump, twice the motor speed would be 2^3, or 8-times the horsepower requirement to power the pump.

Here's a practical application with a pump. You probably already know that AC induction motors have a rated speed, and a synchronous speed based on the slip factor. An 1800-rpm motor with a 4% slip factor would have a synchronous speed of 1730 rpm. An 1800-rpm motor with a 1% slip factor would have a synchronous speed of 1780-rpm. Let's say you were running a pump with a 1730-rpm motor and actually consuming 10-BHP of a 10-hp rating. If you replaced the 1730-rpm motor, with a 1780-rpm motor (this is done daily in a maintenance function), the 50-rpm speed increase would cause the pump to burn 10.9-BHP and might trip the breaker. By changing the speed, it might be necessary to install a 15-hp motor on the application.

Let's consider how a speed change would affect the pump. Let's say we have a theoretical centrifugal pump with efficiency coordinates at 100-gpm, developing 100-psi, and consuming 100-BHP at 1800 rpm on a variable speed drive motor. If the speed were reduced to 900 rpm, the pump would now pump 50-gpm ($\frac{1}{2}x$), and develop 25-psi ($\frac{1}{2}^{2}x$), and consume 12.5-BHP ($\frac{1}{2}^{3}x$). If the speed were increased to 3600-rpm, the pump would pump 200-gpm (2), develop 400-psi (2^2), and consume 800-BHP (2^3).

Let's look at the maintenance implications of arbitrary speed changes:
* 2 times the speed = 2 times the flow
* 2 times the speed = 2 times the capacity
* 2 times the speed = 2 times the gpm
* 2 times the speed = 2 times the production
* 2 times the speed = 4 (2^2) times the head and elevation
* 2 times the speed = 4 times the psi
* 2 times the speed = 4 times the NPSHr
* 2 times the speed = 4 times the bearing misalignment, maintenance and failure
* 2 times the speed = 8 (2^3) times the BHP requirements
* 2 times the speed = 8 times the maintenance costs

* 2 times the speed = 8 times the downtime and labor
* 2 times the speed = 8 times the erosion in the pipes, valves seats, and elbows
* 2 times the speed = 8 times the impeller wear
* 2 times the speed = 8 times the wear ring wear
* 2 times the speed = 8 times the wear on all strict tolerances
* 2 times the speed = 8 times the vibration and all other energy factors

Now you can see how the operations department has free reins to purchase VFDs with the surplus from last years budget, and the maintenance department will deplete its budget in mid-November.

Variable speed motors are definitely good for pumps and industry. You must understand the affinity laws and work with them, or they'll work against you. Variable speed motors can be mostly operated over their entire range when mated to pumps in flow applications. Variable speed motors can be used with pumps in pressure applications, but they may be valid only between 85 to 100% speed. The operator doesn't have complete freedom with his VFD in these applications because 50% speed would only be 25% pressure, head, or elevation generated.