Variable Frequency Drives for a Vacuum Pump System

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Editor's Note: Responding to requests from readers many of whom work with vacuum pumping systems Pumps and Systems is introducing this new column with the January issue. Look for it periodically.

In many process plant applications, using a Variable Frequency Drive (VFD) to control the capacity of a liquid ring vacuum pump (LRVP) is an innovation. Previous system designs consisted of sizing the LRVP to operate efficiently for a certain portion of the process cycle and then using a recycle control valve system to maintain the desired LRVP suction pressure. This usually meant a loss of system efficiency for most of the operation cycle.

A liquid ring pump can be used in vessel evacuation or batch processes where the load volume is high at startup and diminishes as the vessel is emptied and the subsequent vacuum level increases. At the end of the cycle the usual intent is to hold as high a vacuum level as possible for a given period of time. This high vacuum level is a function of the properties of the service liquid, which boils or vaporizes as specific conditions exist. The liquid ring pump handles the least amount of net capacity at this high vacuum. The majority of the capacity at this point is the vaporized service liquid. The LRVP operating at full load rpm is oversized for the vacuum end point. By slowing down the pump, the operator can maintain the desired vacuum, but pumping capacity is decreased, lowering the brake horsepower.

An additional feature is that the drive could be set up to operate at a speed that stays within the horsepower rating of the motor and automatically adjusts as the LRVP power demand decreases.

An energy audit of a particular facility may be required to determine the feasibility of installing VFD's on the current LRVP system.

A given frame size pump has a predetermined impeller tip speed range that would be programmed into operational parameters in the control room. The impeller tip speed is a function of the impeller diameter. (The tip speed or tangential velocity is the rate of the outer tip of the impeller.) The pump would then run in this tip speed range while staying below the maximum horsepower rating of the motor. At the holding point, the pump is slowed to the minimum speed low enough to hold the desired vacuum. This saves power and wear on the pump. Current system design usually includes a provision for over-capacity at the holding point. The device may be a vacuum relief valve or recycle valve system. This design approach can waste energy. An energy audit of a particular facility may be required to determine the feasibility of installing VFD's on the current LRVP system. The system design engineers should take a serious look at incorporating this approach in future design specifications.

Useful LRVP Calculations (approx. relationships):

$rpm_1/rpm_2 = (hp_1/hp_2)^2$

$Capacity_1 / Capacity_2 = rpm_1/rpm_2$

As an example, the capacity of a 25 horsepower LRVP can be adjusted while operating from about 1000 rpm up to 1750 rpm. This represents an impeller tip speed range of 40 to 70 ft/sec. At 1750 rpm and at atmospheric suction pressure, the capacity of this pump is approximately 300 Actual Cubic Feet per Minute (ACFM). Depending on user specific conditions, the brake horsepower (BHP) may exceed 25 briefly during an evacuation cycle.

The motor rpm can be reduced to keep the brake horsepower below 25 during this period. When the system is totally evacuated and the vacuum level is at its maximum, the pump is then slowed to a speed at which it operates adequately and does not cavitate. A word of caution - there is a minimum impeller tip speed which is a function of the pump's compression ratio or vacuum level. If the pump speed is reduced below this minimum impeller speed, the liquid ring will collapse, causing system instability or "upset."

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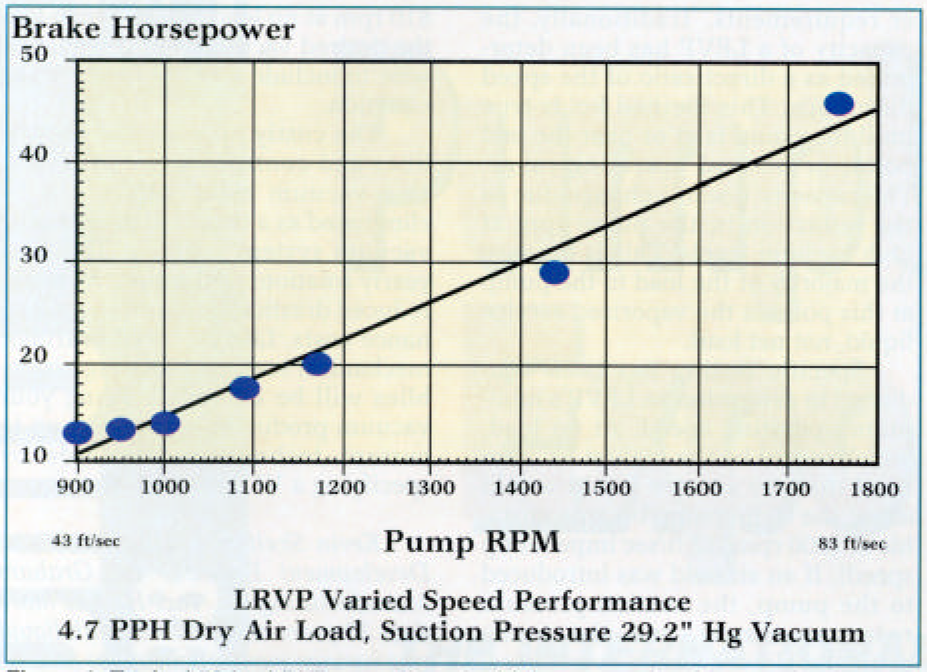

Figure 1. Typical 50 hp LRVP operating at a high vacuum level – note that horsepower requirement drops dramatically as the rpm is reduced while the suction pressure remains constant.

The minimum impeller speed can be determined to be the noncondensable load quantity (which sets the pump suction pressure) as a function of the compression ratio desired. More energy is required in the liquid ring to achieve a high vacuum than a low vacuum, so as the compression ratio increases, the pump must rotate faster than it does at lower compression ratios. On the other hand, at low vacuum levels it is beneficial to maintain as high an impeller speed as possible in order to maximize the pump's ACFM capacity.

Figure 1 illustrates a typical 50 horsepower LRVP operating at a high vacuum level. As you can see, the horsepower requirement drops dramatically as the rpm of the pump is reduced while the suction pressure remains constant.

To illustrate the energy savings over a year, the assumption was made that the pump was operating continuously but at the holding vacuum level only for 60% of the time.

From Figure 1:

Operating hp @ 1750 rpm	=46 hp
Operating hp @ 900 rpm	=13 hp
hp saved	33 hp

33HP(.746 kW / lHP)(8760 hours / year)($0.06 / kW hour)(0.6) $7884

This is the savings for one 50 hp liquid ring vacuum pump for one year.

Power generating facilities use much larger LRVP systems to maintain vacuum level on steam turbine condensers. These pumps operate over 90 percent of the time at the holding vacuum level, utilizing a vacuum relief valve to introduce air load to the LRVP in order to maintain a vacuum which is above the cavitation point.

This larger sized LRVP operating @ 720 rpm with an impeller tip speed of about 65 ft./sec has a bhp of 82. Slowing the pump down to 475 rpm will result in a bhp of 36 a difference of 46hp. 46HP (.746 kW / lhp) (8760hr / yr) ($0.06 / kW hr)(.9) = $16,233 per year for each condenser vacuum pump.

Electrical savings can quickly be calculated because the hp requirement is the square of the ratio of the speed difference. This calculation is fairly accurate and a good 'rule of thumb' method of determining power requirements. Traditionally, the capacity of a LRVP has been determined as a direct ratio of the speed difference. This method holds true until the pump is at or near the end point, or noload operating range. The capacity doesn't change due to the reduction in the pump rpm at high vacuum levels. This is because the majority of the load to the pump at this point is the vaporized service liquid, not net load.

Specific testing has been conducted to determine an LRVP's minimum operating speed. At no load, which would be the highest vacuum level that the service liquid would allow, the 50 hp pump became unstable at 1000 rpm (32 ft / sec impeller tip speed). If an air load was introduced to the pump, the suction pressure rose accordingly, and the pump could be slowed down even more, perhaps even to 800 rpm at a 27"Hg vacuum. In this application, the set point would want to approach the 1000 rpm point as this is the minimum required for stable operation. A 25 hp pump could be slowed down to 810 rpm at no load and still maintain the desired vacuum, but it would be wise to include a safety factor in the equation.

The costly approach of recycle lines and control valves, or unreliable vacuum relief valves can be eliminated as a means of maintaining vacuum system stability. The total yearly rotations of the equipment are reduced drastically, lowering maintenance costs. Life cycles of bearings, mechanical seals and rotating assemblies will be extended. Bring your vacuum producing equipment up to current technology standards by specifying a VFD control.

■ *Kevin Skelton is a Research and Development Engineer for Graham Corporation. He has more than 20 years of experience with liquid ring vacuum pump applications and liquid service. He currently holds a patent for operational improvement of the design.*