SPEED CONTROL

Steve Rush, Nikkiso Cryo, Inc., USA,
argues that cryogenic submerged motor pumps offer high speed designs and variable speed control advantages.

As owners/operators strive for greater flexibility in process plant designs, and as energy costs and energy efficiency become more important, equipment suppliers, system designers and operators will maximise the efficiency of system components and make adjustments to reduce power.

In designing a pumping system, controllability using variable speed to adjust pump operation to match system requirements can help greatly in achieving energy savings (Opex savings).

Increasing rotational speed above normal line frequencies as well as using higher speed motors (2-pole vs. 4-pole designs) also leads to more compact and lighter pumps. These smaller units result in smaller components, fewer impeller stages, lower initial installation costs and ultimately lower maintenance costs (Capex savings).

While using variable speed with centrifugal pumps is nothing new, the use of higher speed and variable speed for submerged motor cryogenic pumps is only now becoming more widespread due to the need to reduce costs.

Centrifugal pump and system performance

Fluid flow through a process system can be characterised by a typical system curve (see Figure 1). This curve represents the required head at various flow rates to overcome system losses, a combination of the elevation (static head) and the friction of pipe bends, valves and other components within the system (note that the static head for the curve example has been set at zero for simplicity). The pump curve can be placed on the system curve to show the desired pump rated conditions for the process with a given system. The duty point of the pump in a system will typically be selected at the intersection between the pump curve and the system curve.

Centrifugal pumps used in cryogenic service are typically driven using motors operating at line frequencies of 50 or 60 Hz, with 2 and 4 pole motors running at 3600 and 1800 rpm (at 60 Hz) or 3000 and 1500 rpm (at 50 Hz). At those fixed speeds, the pump will produce a single flow vs. head curve (see Figure 1). Pumps are selected to have a rated flow point at which the pump is designed to run near the best efficiency point (BEP).

If process changes are necessary, the system curve is typically changed by making adjustments to the control valve downstream of the pump. These changes move the flow away from the BEP and increase or decrease the head from what may be required for the process. In many cases, a by-pass return flow piping system is installed to be able to keep the pump closer to its rated operating point or BEP, particularly when operating at low flow rates. Control valves with by-pass return piping systems have been used for many years in pump systems but are inherently inefficient as the pump power remains the same due to the combined total flow of the main discharge and by-pass system.

The traditional methods of adjusting a pumping system using a control valve and by-pass piping system can be particularly detrimental in a cryogenic liquefied gas system where production of excess flow and/or excess head yields a double Opex penalty; first due to pump power consumption, and second due to boil-off gas loss or handling.

An alternative to matching the system curve is to adjust the diameter of the impeller(s) in the pump. However, it is not practical to change the impeller diameter when conditions are expected to vary.

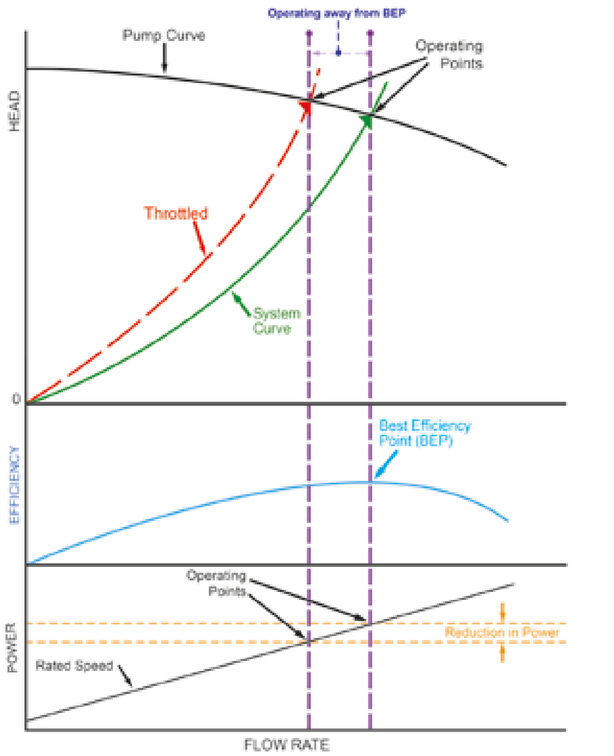

Figure 1. Fixed speed performance.

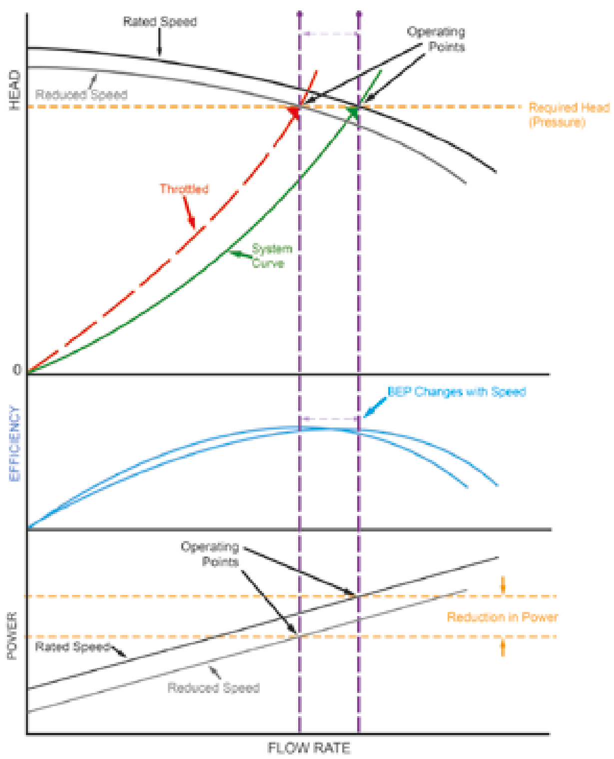

Figure 2. Variable speed performance.

Variable speed operating theory

The characteristics of centrifugal pumps follow what are called 'affinity laws'. These laws describe the change in performance when the speed or the impeller diameter is changed, which both have essentially the same effect. This discussion, for simplicity, will cover changes in speed only and not impeller diameter. The affinity laws can be used to predict a pump's performance when speed is changed and energy savings can then be calculated accordingly. If a pump is being operated well above process requirements, energy savings can be achieved by using a variable speed drive to better match the system resistance. Throttling the pump using a valve adds additional resistance to the system to control the pump and is not as efficient as changing the speed.

The affinity laws are:

$Q_2 = (N_2 / N_1) \times Q_1$

$H_2 = (N_2 / N_1)^2 \times H_1$

$P_2 = (N_2 / N_1)^3 \times P_1$

Note: subscript 1 indicates exsting conditions, subscript 2 indicates changed conditions.

Put simply, if the speed is doubled, the capacity will double, the head will increase by a factor of 4, and the power will increase by a factor of 8. Thus it is clear that small changes in speed can result in more significant changes in head and power. Note that the NPSHR will also increase by a factor of 4, which is compensated for by the use of specially designed Zero Enabled NPSHR (ZEN) spiral inducers (a Nikkiso Cryo, Inc. exclusive design).

The power required at the shaft (motor output) can be calculated from the formula: (Q x H x Specific Gravity) / (367 x pump efficiency), where Q = flow [m^3/h] and H = head [m]) (note: With fluids other than water, the fluid's specific gravity affects the power). This formula can also be used to predict the operating cost. The electric motor driving the pump also has an efficiency that needs to be considered, so to determine the operating cost, factor in the motor by: (pump power) / (efficiency of the motor) = absorbed input kW.

Variable speed

It is common for pump applications to be over-sized. This is because process design tolerances are added to allow for variations in liquid properties, uncertainties in pressure drops through systems and other conditions in which the system may operate. In many cases, once plant commissioning has been completed, the pumps are found to be operating below their design point due to the tolerances added during the design stage. If the pumps are installed initially with a variable frequency drive (VFD), the speed can be turned down to meet actual process conditions, thus providing considerable cost savings over a period of time. These savings can easily offset the initial cost of the VFD. Using a VFD to adjust the power demand to the operational conditions is the most effective method of optimising the process.

Efficiency of pump operation at flow points that are off-design can be improved by varying the pump speed to a point on the pump hydraulic curve that is closer to the BEP for the desired flow. A standard VFD can be used to control the speed of the submerged induction motors used in cryogenic pump service.

In Figure 2, the rated operating condition is shown as well as the change in performance using a VFD. By reducing speed at the reduced flow, the same pressure can be maintained, resulting in lower power and higher efficiency.

Another feature that is enhanced by applying a VFD to centrifugal pump operation is starting. Starting a pump/motor with a direct online system produces a high transient torque, resulting in high loading on bushings and bearings, as well as high in-rush current. Pump startup using a VFD results in a much 'softer' start, reducing in-rush current and mechanical loads on the pump shaft, bearings and other components.

In actual case studies, the power savings in a cryogenic loading pump system were reduced by as much as 43% at lower flow rates using a VFD when compared to throttling using a control valve and as much as 20% in a high pressure sendout pump system.

Benefits of applying VFD's in cryogenic pump systems include the following:

- Reduction or elimination of hydraulic water hammer and electrical starting current, thus reducing capital costs.
- Better ability to operate multiple pumps in parallel to meet process requirements.
- In some cases, a VFD driven pump may cover more than one duty, potentially eliminating the need for two pumps at different duties.
- Ability to adjust the pump system automatically when piping, valves or other physical changes are made during debottlenecking or other system changes.
- Improved process control resulting in lower operating costs.

Higher speeds

One of the simplest ways to increase speed is to use a 2-pole motor at normal line frequencies of 50 or 60 Hz (3000 to 3600 rpm) instead of a 4-pole motor at lower speed (1500 to 1800 rpm). This method does not require a VFD. However, while this may help reduce the pump size and weight, the performance is still restricted to a single fixed speed and does not allow the same flexibility and potential cost savings as using a VFD.

One distinct advantage that the pump designer has in selecting hydraulic combinations for variable speed drives is to use speeds higher than that of the synchronous line speed. Higher operating speed can reduce the number of stages, which results in improved efficiency of

Figure 3. Cargo pump (*left*) and line packing pump (*right*).

approximately 0.5% per stage that is removed. The improvement in efficiency due to de-staging the pump is limited to approximately 3 - 4%. This limit is due to the additional losses incurred by higher recirculation losses due to the increase in head produced by each stage. Variation in speed allows the pump design to be optimised by operating closer to the BEP at each speed and flow point.

For more conventional external motor designs in cryogenic service, one of the weaknesses is the shaft seal that is required where the shaft exits the liquid containment vessel. This seal becomes even more of a concern if higher speeds are applied, resulting in increased wear and, ultimately, seal failure. The application of submerged motor pumps with no shaft seals is therefore ideally suited for higher speed operation.

Taking advantage of the submerged motor cryogenic pump design, engineers at Nikkiso Cryo Inc. (NCI) are designing pumps that are smaller, more compact and able to operate at higher speed. Pumps have been developed using a synchronous motor speed of 7200 rpm with a 2-pole motor driven at 120 Hz with a VFD. High costs have kept VFDs from extensive use in the past. However, recent advances in solid state devices have reduced the size and costs significantly, making VFD's a much more attractive option with a positive return on investment.

NCI has been supplying its range of high speed, super-synchronous, submerged motor designs for many years, servicing various duties in LNG, LPG, ethylene, propylene and other liquefied gases for onshore and offshore applications. The company's original technologies have been adapted well to the harsh operating conditions associated with offshore floating production facilities.

These technologies have been developed and successfully validated over several years of proven operation. The pumps cover LNG/LPG applications such as primary feed; HP send out; line packing (hi speed) and main cargo unloading. These products are presently in service or due to be installed in facilities for ExxonMobil, Excelerate, Exmar, Höegh LNG, Golar LNG, Shell and Petronas, among others.

Benefits of applying higher speed to submerged motor cryogenic pumps include:

- Smaller footprint and lighter weight, resulting in lower capital costs.
- Higher efficiency with proven higher reliability under field operation conditions, thus lower operating costs.
- Reduced maintenance costs due to compact size, ease of handling and fewer parts.
- Small size and fewer impeller stages, resulting in lower material and parts costs.

LNG line packing pumps for FSRU applications

Line packing pumps are operated during start-up of the regasification unit on board floating storage and regasification units (FSRUs) to reduce thermal shock and water hammer while pressurising the vaporisers and downstream pipelines. These 200 kW pumps deliver the same differential head as the main high pressure send-out pumps (2370 m), but at a lower flow rate (20 m^3/h). The line packing pumps are a suction pot type mounted on the bow of the ship along with the HP send-out pumps. The line packing pump specification presents a challenge for a centrifugal pump in that the duty requires the combination of low flow and high head. Traditional centrifugal pump selection based on a 60 Hz two-pole motor would have led to a slim, 20-stage, 3.4 m long pump. NCI has specifically developed a small high pressure (SHP Model) pump for this application, which takes advantage of higher speed to reconcile the low flow and high head. The company's line packing pump uses a VFD driven motor at 120 Hz. This SHP pump has only eight stages and measures 1.9 m in length.

Cargo pumps

With the construction of the world's first floating LNG (FLNG) plants currently under way, the requirements for this challenging pump application are slightly different from those for traditional LNG carriers. Since the vessels will be moored in place almost indefinitely, it was determined that a retractable (removable) pump design was better suited. This design can be easily removed for maintenance when required compared to traditional fixed-mounted cargo pumps in LNG carriers, which can only be removed when the tanks are gas-free. While this application does not use a VFD, the selection of a higher speed pump using a 2-pole vs. 4-pole motor resulted in some of the same benefits. If a traditional 4-pole (1800 rpm) pump was used, a larger, heavier pump would be required. Due to the critical necessity to reduce space requirements and weight, NCI's application of a 2-pole (3600 rpm) machine was accepted and is due to be installed. The company selected a 2-pole design using hydraulics, which reduce the diameter and length of the pumps, providing considerable weight savings as well as increasing topside deck space for access and handling during maintenance. These pumps are fitted with the latest generation ZEN spiral inducer for super low tank pumping operations and compact radial diffuser (CRD) designs. This new hydraulic combination resulted in a low 0.15 m NPSHR with a pump efficiency of 77%, thus resulting in significant installation and operating cost savings. LNG

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