Using Speed Variation for Pumps

Roman Dorfman P.Eng.
November 2018

BBA.CA

Disclaimer

Executive Summary

Industrial, commercial and municipal engineering facilities use many types of rotating equipment. Pumping systems account for nearly 20% of the world's energy used by electric motors and 25% to 50% of the total electrical energy used in certain industrial facilities.

This paper describes opportunities to reduce energy consumption and possibly improve performance and reliability along with reducing lifecycle costs when pump flow is controlled with variable speed drives. It focuses on the advantages this method can have for mineral processing facilities, where variable speed drives can optimize plant production and save energy.

It also includes a discussion on the impact pumping systems have on the efficiency of a speed control method. This paper also describes several types of speed variation devices currently used for pumps.

Finally, it refers readers to a publication by the Hydraulic Institute for more in-depth information about variable speed pumping.

Table of contents

Introduction

Industrial, commercial and municipal engineering facilities use many types of rotating equipment. Variable speed drives (VSDs) can be used on a variety of machines, from conveyors to boiler feed pumps, and from crushers and mills to large fans.

While many applications can benefit from variable speed control, the most common applications are quadratic torque loads, such as fans and centrifugal pumps. In these cases, not only does this provide a variable output from the machine, but it also reduces required power. For example, on a centrifugal pump, the power requirement is proportionate to the cube of its rotational speed (kW ~ N3). If the pump is only required to run at 80% speed, the power drawn is theoretically 51% of that required at full speed. Variable speed control may provide for significant power savings compared to other methods, such as dampers, throttle valves or bypass lines.

Pumping systems account for nearly 20% of the world's energy used by electric motors and 25% to 50% of the total electrical energy used in certain industrial facilities. Significant opportunities exist to reduce pumping system energy consumption through smart design, retrofitting and operating practices. In particular, many pumping applications with variable-duty requirements hold great potential for savings, which often go well beyond energy and may include improved performance and reliability as well as reduced lifecycle costs.

Most existing systems requiring flow control use bypass lines, throttling valves or pump speed adjustments. As mentioned above, the most efficient of these is pump speed control. When a pump's speed is reduced, less power is sent to the fluid, which in turn means that less energy needs to be throttled or bypassed. Speed can be controlled in a number of ways, with the most popular type of VSD being the variable frequency drive.

VSDs have become an integral part of mineral processing plants to optimize plant production and save energy. A typical wet mineral processing plant with an automated process uses 20 to 40 VSDs to control slurry flows. Slurry pump boxes are generally operated on a level control loop. A relatively constant slurry level in the pump box is maintained by balancing the material flowrate out of the pump box with the material flow rate into the pump box. For this reason, discharge pumps are often equipped with VSDs. The pump box level controller adjusts the pump speed to maintain the desired slurry level. The feed to a slurry pump box often consists of several process streams, including slurries from upstream and downstream operations, water and reagents. The speed of the slurry discharge pump could be the key parameter for maintaining a balanced operation.

Pumping Systems

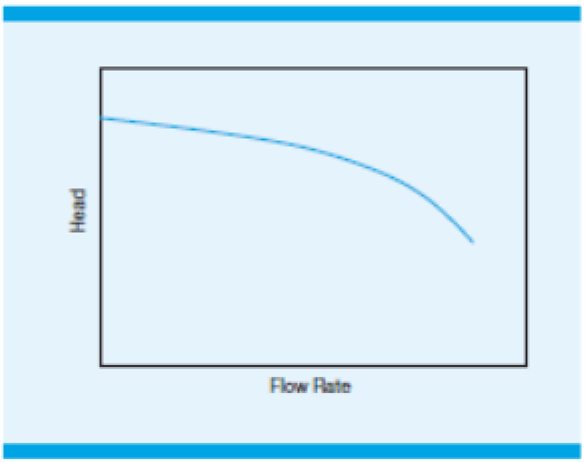
A proper discussion of pumping includes not just the pump, but the entire pumping "system" and how the system components interact. The recommended systems approach to evaluation and analysis includes both the supply and demand aspects of the system.

Pumping System Hydraulic Characteristics

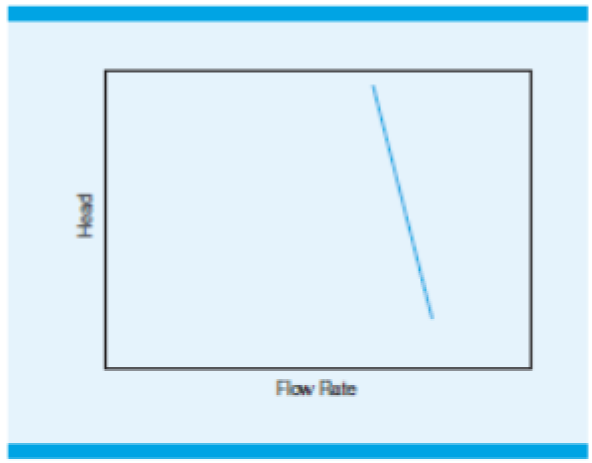
In a pumping system, the objective, in most cases, is either to transfer a liquid from a source to a required destination, e.g., filling a high-level reservoir, or to circulate liquid around a system, e.g., as a means of heat transfer. Pressure is needed to make the liquid flow at the required rate and this must overcome losses in the system. Losses are of two types: static and friction head. Static head, in its most simple form, is the difference in height of the supply and destination of the liquid being moved, and/or the pressure in a vessel into which the pump is discharging, if it is independent of flow rate. Friction head (sometimes called dynamic head loss), is the friction loss on the liquid being moved, in pipes, valves and other equipment in the system. This loss is proportional to the square of the flow rate. A closed-loop circulating system, for example, without a surface open to atmospheric pressure, would exhibit only friction losses. Most systems have a combination of static and friction head. The ratio of static to friction head over the operating range influences the benefits achievable from VSDs.

Proper selection of pumps, motors and controls to meet process requirements is essential to ensure that a pumping system operates effectively, reliably and efficiently. All pumps are divided into two major categories: positive displacement (PD) and rotodynamic. The performance of a pump can be expressed graphically as head against flow rate. The rotodynamic pump has a curve where the head falls gradually with increasing flow. However, for a PD pump, the flow is almost constant whatever the head. When a pump is installed in a system, the effect can be illustrated graphically by superimposing pump and system curves. The operating point will always be where the two curves intersect. For a PD pump, if the system resistance increases, i.e., the system curve is moved upwards, the pump will increase its discharge pressure and maintain a fairly constant flow rate, dependent on viscosity and pump type. For a rotodynamic pump, an increasing system resistance will reduce the flow eventually to zero, but the maximum head is limited. In this paper, we will limit our discussion to the rotodynamic pumps.

As a last comment on PD pumps, I want to draw the reader's attention to the fact that when PD pumps are installed in parallel to provide for a large total flow (tailings discharge, long distance concentrate pipelines), all operating pumps need to have synchronous speed variation in order to minimize adverse pulsation effects.



Performance curve for a rotodynamic pump



Performance curve for a positive displacement pump

Many pumping systems require a variation of flow or pressure. Either the system curve or the pump curve must be changed to get a different operating point. Where a single pump has been installed for a range of duties, it will have been sized to meet the greatest output demand. It will therefore usually be oversized and will be operating inefficiently for other duties. Consequently, there is an opportunity to achieve an energy cost savings by using control methods, such as variable speed, which reduce the power to drive the pump during reduced demand.

In mineral processing, speed variation might also be the optimum way of adjusting the pump performance to the changing operating conditions, such as flow, slurry concentration/density. It may constitute a viable alternative to slurry dilution with water to keep velocities in the piping system within required limits (above deposition in case of settling slurries), which increases power demand for pumping excessive water and might have a negative effect on the downstream process. It may also follow the change in discharge conditions as in a conventional tailings deposition where length of piping and elevation of discharge change over time. Additionally, it may benefit from minimizing water dilution at the feed to compensate for change in tailings throughput within the set line velocities operating range.

For systems where friction loss predominates, reducing pump speed moves the intersection point on the system curve along a line of constant efficiency (refer to figure 1). The operating point of the pump, relative to its best efficiency point, remains constant, and the pump continues to operate in its ideal region. The Affinity Laws are obeyed, which means that there is a substantial reduction in power absorbed accompanying the reduction in flow and head, making variable speed the ideal control method.

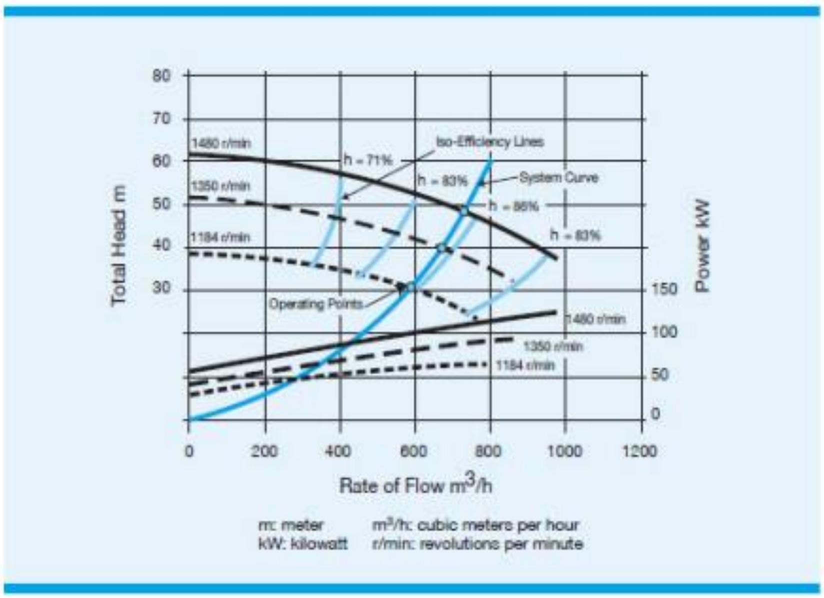


Figure 1: Effect of pump speed change in a system with only friction loss.

However, in systems with high static head, the system curve does not start from the origin, but at some non-zero value on the y-axis corresponding to the static head. Hence, the system curve does not follow the curves of constant efficiency. Instead, it intersects them (refer to figure 2). The reduction in flow is no longer proportional to speed; a small turn down in speed greatly reduces flow rate and pump efficiency. A common mistake is to also use the Affinity Laws to calculate energy savings in systems with static head. Although this may be performed as an approximation, it can also lead to major errors and special attention should be paid while applying a speed control concept to the systems of this category.

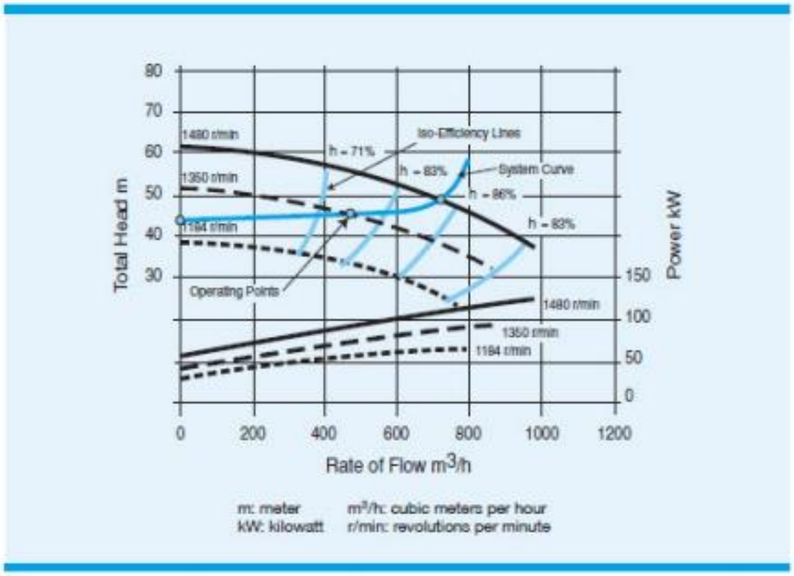


Figure 2: Effect of pump speed change in a system with high static head.

It is relevant to note that flow control by speed regulation is always more efficient than by a control valve. In addition to energy savings, there could be other benefits to lower speed. The hydraulic forces on the impeller, created by the pressure profile inside the pump casing, reduce approximately with the square of speed. These forces are carried by the pump bearings, thus, reducing speed increases bearing life. It can be shown that for a rotodynamic pump, bearing life is proportional to the seventh power of speed. In addition, vibration and noise are reduced and seal life is increased, provided that the duty point remains within the allowable operating range. Also, in case with slurry pumps, wear could be reduced with the speed reduction, provided that efficiency is not greatly compromised as lower efficiency means higher recirculation within the pump casing and associated wear increase.

Proper suction conditions are paramount to the satisfactory performance of the pumping systems. Increasing pump speed will negatively affect pump suction performance and should be thoroughly investigated. Conversely, reducing speed will have a positive effect.

Potential Drawbacks of VSDs

VSDs also have some potential drawbacks, which can be avoided with appropriate design and application.

Structural Resonance

Resonance conditions can cause excessive vibration levels, which in turn are potentially harmful to equipment and environment. Pumps, their support structure and piping are subject to a variety of potential structural vibration problems (resonance conditions). Fixed-speed applications often miss these potential resonance situations because the common excitation harmonics due to running speed, vane passing frequency, plunger frequency in PD pumps, etc., do not coincide with structural natural frequencies. For VSD applications, the excitation frequencies become variable and the likelihood of encountering a resonance condition within the wide operating speed range is greatly increased. Pump vibration problems typically occur with bearing housings and the support structure (baseplate for horizontal applications, motor and stool for vertical applications).

Rotor Dynamics

The risk of the rotating element encountering a lateral critical speed increases with the application of a VSD. Lateral critical speeds occur when running speed excitation coincides with one of the rotor's lateral natural frequencies. The resulting rotor vibration may be acceptable or excessive. Variable speed vertical pumps are more likely than horizontal machines to exhibit operational zones of excessive vibration. This is because such pumps' lower natural frequencies are more likely to coincide with running speed.

Types of speed variation devices

- The most popular industry option for rotational speed control today is an electronic VSD, commonly referred to as a variable frequency drive (VFD). The most common form of VFD is the voltage-source, pulse-width modulated (PWM) frequency converter (often incorrectly referred to as an inverter). In its simplest form, the converter develops a voltage directly proportional to the frequency, which produces a constant magnetic flux in the motor.

Before VFD were developed and commercialized, which began in the 1970s, several technologies were in widespread use for variable speed pumping.

- Wound rotor induction motors, with secondary (rotor) resistance control. With this system, the motor speed is controlled using a liquid rheostat system or a series of switched values of large resistors connected to the motor rotor circuit.
- Hydroviscous or oil shear type clutches (turbo-couplings). These are hydrokinetic drives where power is transmitted by kinetic energy. The input of the turbo-coupling is connected to an electric motor and the output to the driven machine (either directly or through a gearbox). The circuit comprises of an impeller (input side) and runner (output side), where the impeller acts like a centrifugal pump and the runner as a turbine. The oil forms a vortex inside the coupling and the more oil that flows into the vortex, the stronger the drive; the less oil that flows, the weaker the drive, so output speed is dependent upon the amount of oil flowing in the vortex.

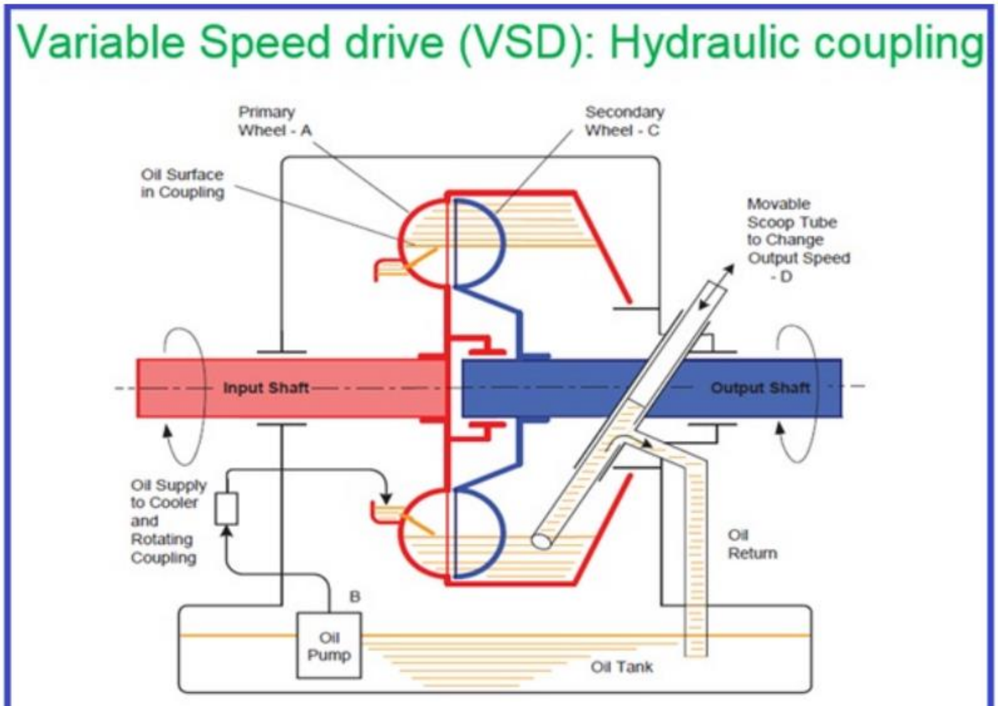


Figure 6. Hydraulic Variable Speed Turbo Coupling

Turbo-coupling has a very high efficiency rate of 96–97% at full speed. Because it is a slipregulating device, its predominant loss is due to slip. As the slip increases to reduce speed, slip loss increases.

The reliability of these machines has improved over the last 20 years or so, while maintenance complexity and cost has gone down. BBA has introduced turbo-couplings in some of its recent large capital projects for speed control of big pumps as a cost-effective alternative to mediumvoltage VFDs.

- Adjustable-pitch belt drives. These simple units include a constant speed motor and a pair of V-belt sheaves that can change effective diameter. They are usually applied in small horsepower applications requiring infrequent changes in speeds. They are usually manually adjustable, while automated remote adjustment systems are also available.

- Eddy current drives, also known as eddy current clutches or magnetic drives. These machines are driven at full speed by a standard induction motor and employ a variable strength magnetic field to control torque and speed to the driven load. Among non-VFD solutions, the Eddy current drive is the most common and has been recently gaining in popularity in municipal water and wastewater pumping. These devices were used in mineral processing prior to VFD invention. Certain conservative views and reservations with regard to applying Eddy current drives for slurry pumps has been observed in the pump and drive manufacturing community. The Eddy current drive solution can avoid several complications that can be associated with VFD applications, such as harmonic distortion on the feeder system, VFD reliability problems due to poor plant power quality, such as unstable voltage, large space and air-conditioning requirements, the need for expensive harmonic filters for VFDs, severe high-frequency audible motor noise and some others. One important factor is the early obsolescence of VFDs caused by advancing technology or competitive pressure leading to high repair costs or even unavailable repair parts, sometimes resulting in complete VFD replacement.

More in-depth analysis of electrically modulated VSDs is certainly worth writing about in another blog by Electrical Department to complement this one, which focuses solely on mechanical aspects.

Rare earth strong permanent magnet drives (e.g., by MagnaDrive). MagnaDrive's patented technology uses high power permanent magnets to create an induced magnetic force used for torque transfer. The system physically separates the motor system's two elements, placing magnet discs on the load shaft and a conductor assembly on the motor shaft. Motor torque is transferred to the load across an air gap. Varying the air gap between the magnets and the conductor changes the strength of the magnetic field and hence controls output speed. Some of the features and benefits of this technology include no-contact power transfer that eliminates vibration, reduces noise, tolerates misalignment, provides overload protection, extends motor and equipment life and reduces overall maintenance costs. Rare earth permanent magnets are made of a combination of neodymium, iron and boron (NdFeB). Rare earth technology is the most recent addition to the high-performance permanent magnet family and became commercially available in the 1980's. NdFeB magnets have the highest energy product of all permanent magnets, allowing for the small size and high torque transmission capability of MagnaDrive products. NdFeB magnets retain their performance in environments up to 350o F and have a half-life of over 2,000 years.

References

It is strongly recommended that engineers involved in VSD design and selection for pumps become familiar with the "Application Guideline for Variable Speed Pumping" issued in 2017 by the Hydraulic Institute in cooperation with Europump.

About the Author

Roman Dorfman, P. Eng.
Mechanical/Piping Engineer
roman.dorfman@bba.ca

Roman Dorfman has more than 30 years of experience in mechanical design of piping, pumps, and mechanical equipment, and possesses project engineering expertise. He has strong knowledge in hydraulics of pressure and gravity flow pipeline systems, including those for mineral slurry transport, along with a comprehensive proficiency in mineral processing and smelting of iron, steel, aluminum, gold, and nickel.

BBA.CA