Best Practice
Variable Speed
Pump Systems
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Pump speed adjustments provide the most efficient means of controlling pump flow. By reducing pump speed, less energy is imparted to the fluid and less energy needs to be throttled or bypassed. There are two primary methods of reducing pump speed: multiple-speed pump motors and variable speed drives (VSDs). Although both directly control pump output, multiple-speed motors and VSDs serve entirely separate applications. Multiple-speed motors contain a different set of windings for each motor speed; consequently, they are more expensive and less efficient than single speed motors. VSDs allow pump speed adjustments over a continuous range, avoiding the need to jump from speed to speed as with multiple-speed pumps.
General Recommendations

- Eliminate unnecessary uses
  - Schedule pumps to turn off whenever possible
  - Avoid unnecessary recirculation through bypass lines
- Minimize throttling
- Assess pumping system suitability for current application.
  Many installed systems are oversized, providing an opportunity to:
  - Install a full size impeller with variable frequency drive
  - Remove stages
  - Downsize pump
  - Install a smaller and/or a more efficient pump motor
  - Replace worn impellers
- Reduce pump speed or install appropriate speed control devices
  - Install a lower speed motor
  - Consider variable frequency drives
- Improve piping configuration
  - Eliminate unnecessary turns, valves, accessories
  - Optimize pump inlet and outlet piping
Restrictions
Pump speed adjustment is not appropriate for all systems. In applications with high static head, slowing a pump risks inducing vibrations and creating performance problems that are similar to those found when a pump operates against its shutoff head (zero flow through the system). For systems in which the static head represents a large portion of the total head, caution should be used in deciding whether to use VFDs. Operators should review the performance of VFDs in similar applications and consult VFD manufacturers to avoid the damage that can result when a pump operates too slowly against high static head.

Motor driven systems
Pumps are part of a motor driven system, comprising the pump, the motor, the coupling between them and the capacity control system.

When looking for an optimum in performance and energy efficiency one should always look at the total system for the best cost effective solution.

Savings in the order of 20-30% on the energy efficiency are possible.

The Best Practices for individual parts (high efficiency motors, capacity control and variable speed drives) are given in separate documents.

Source: Spice3 workshop SBE September 2014 presentation efficient motor drives
Pumping Systems

In a pumping system, the objective, in most cases, is to transfer a liquid from a source to a required destination. 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 is the difference in height of the supply and destination of the liquid being moved, or the pressure in a vessel into which the pump is discharging, if it is independent of flow rate. Friction head is the friction loss on the liquid being moved, in pipes, valves, and other auxiliaries in the system. This loss is proportional to the square of the flow rate. A closed-loop circulating system would exhibit only friction losses.

Static head is a characteristic of the specific installation. Reducing the head whenever possible generally reduces both the cost of the installation and the cost of pumping the liquid. Friction head losses must be minimized to reduce pumping cost, but after eliminating unnecessary pipe fittings and length, further reduction in friction head will require larger diameter pipes, which adds to installation cost and for other reasons may not be desirable due to lower velocity.

Pump Types

All pumps are divided into the two major categories: positive displacement (PD) and centrifugal.

- A positive displacement pump causes a fluid to move by trapping a fixed amount of it then forcing (displacing) that trapped volume into the discharge pipe. PD pumps can be classified into two main groups: rotary and reciprocating.
  - Rotary pumps typically work at pressures up to 25 Bar (360 psi). These pumps transfer liquid from suction to discharge through the action of rotating screws, lobes, gears, rollers, etc.
  - Reciprocating pumps typically work at pressures up to 500 Bar. These pumps discharge liquid by changing the internal volume. Reciprocating pumps can generally be classified as having a piston, plunger, or diaphragm, displacing a discrete volume of liquid between an inlet valve and a discharge valve.

- A centrifugal pump uses a rotating impeller to increase the pressure of a fluid. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radially outward into a diffuser or volute chamber (casing), from where it exits into the downstream piping system. More than one impeller may be fitted on same shaft operating in similarly designed casing. Such Pumps are called Two-Stage, Three–Stage, or Multi-Stage Centrifugal Pumps. The performance of a pump can be expressed graphically as head against flow rate (see fig 1).
The centrifugal 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.

Interaction of Pumps and Systems
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. When a valve is used on the system, as the valve closes, flow will decrease and the pressure upstream of the valve will increase. Changes in pump head will occur as the control valve throttles towards a closed position.

The effects are illustrated in Fig 2.

A fall in flow rate not only increases the pump pressure but may also increase the power consumed by the pump. 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 the periods of reduced demand.

**Figure 1: Performance curve for a pump**

**Figure 2: The effects**
Effects of Speed Variation on Centrifugal Pumps

A centrifugal pump is a dynamic device with the head generated by a rotating impeller. Varying the rotational speed has a direct effect on the pump’s performance. For systems where friction loss predominates, reducing pump speed moves the intersection point on the system curve along a line of constant efficiency (see Fig 3). The operating point of the pump, relative to its best efficiency point, remains constant and the pump continues to operate in its ideal region. There is a substantial reduction in power absorbed accompanying the reduction in flow and head, making variable speed the ideal control method.

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, and so reducing speed increases bearing life.

Effect of Speed on Pump Suction Performance

If the incoming liquid is at a pressure with insufficient margin above the vapour pressure, then vapour cavities, or bubbles, appear along the impeller vanes just behind the inlet edges. These collapse further along the impeller vane where the pressure has increased. This phenomenon is known as cavitation, and has undesirable effects on pump life.

**Figure 3: Performance curve for a pump**
Variable Speed Drives

Variable Frequency Drive (VFD) is being used to control the speed of the pump to attain the desired flow/head and temperature in the system but it is more expensive compared to other methods. By using the VFD, it is possible to obtain large energy savings when the demand for flow decreases.

For example when flow demand decreases by 50%, the head is reduced by 75% and, at the same time, the power need is reduced to 20% (see fig 4). Where the head must be kept constant but flow may vary, installing a variable frequency drive is not an option. Instead, use a multiple pump system which will start if discharge pressure starts to drop.

Example: Centrifugal pump
Consider an 11kW 2-pole EFF1 motor driving a product transfer fan for a milk powder processing plant. The fan motor operates 6,000 hours per year. Air flow is controlled via a manual damper set to 50% open. The motor efficiency is 90.5%. From the curve representing the system in Figure 4 below, we see how the damper setting reduces the input power requirement by a factor of about 0.75. A cost of electricity of € 0.08 per kWh is assumed.
The annual cost of running the motor without VSD is as follows:

**ANNUAL RUNNING COST WITHOUT VSD =**
Input power * Input power reduction factor * Run hours * Electrical cost = (11kW/0.905) * (0.75) * (8000) * (€ 0.08 / kWh) = € 5,834

**With VSD**
If the valve is replaced with a VSD, the curve in Figure 4 shows that the input power is now reduced to 20% of maximum when running at 50% of full load. If we assume that the combined efficiency of the motor and the VSD is now 86% (efficiency motor * efficiency VSD), then the annual running cost of the motor combined with VSD can be calculated as follows:

**ANNUAL RUNNING COST WITH VSD =**
Input power * Input power reduction factor * Run hours * Electrical cost = (11kW/0.86) * (0.2) * (8000) * (€ 0.08 / kWh) = € 1,637

Thus the annual cost savings achieved by replacing the damper with the VSD are as follows:
Cost savings with VSD = € 5,834 - € 1,637 = € 4,196 p.a.
If we assume a cost of € 6,000 to supply and install the VSD, this gives us the following payback period:
Payback period = € 6,000 / € 4,196 = 1.4 years

In this simplified example, a payback of around two years has been calculated. The load profile has been simplified to a constant 50% of full load. In practice, a more detailed examination of a varying load profile would be needed to calculate the true annual running costs.

**Benefits of VSDs:**

- **Energy Savings**
  With centrifugal pump installations, savings of between 30% and 50% have been achieved in many installations by installing VSDs. Where PD pumps are used, energy consumption tends to be directly proportional to the volume pumped and savings are readily quantified.

- **Improved Process Control**
  By matching pump output flow or pressure directly to the process requirements, small variations can be corrected more rapidly by a VSD than by other control forms, which improves process performance.

- **Improved System Reliability**
  Any reduction in speed achieved by using a VSD has major benefits in reducing pump wear, particularly in bearings and seals.
**Financial Savings**

Using control methods that reduce the power to drive the pump during the periods of reduced demand can save energy costs. Varying pump performance by changing speed is most often the best energy-efficient control method. Figure 5 shows the energy consumption of other popular control methods when compared to variable speed control.

**Elimination of Control Valves**

Control valves are used to adjust centrifugal pump output to suit varying system requirements. Usually a constant-speed pump is pumping against a control valve, which is partially closed for most of the time. Even at maximum flow conditions, a control valve is normally designed to be 10% shut, for control purposes. Hence, a considerable frictional resistance is applied. Energy is therefore wasted overcoming the added frictional loss through the valve. Using a VSD to control flow can eliminate the control valve.

**Elimination of Bypass Lines**

All fixed-speed centrifugal pumps have a minimum flow requirement. If the pump is operated at flow rates below the minimum for extended periods, various mechanical problems can occur. If the flow requirements in a system can drop below this minimum flow capacity, it is necessary to install a constant or switched bypass to protect the pump. The use of a VSD greatly reduces the volume to be bypassed.