Pumping System Performance Improvements

An Online Continuing Education Course for Engineers

Course Number: M-7001

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Pumping System Performance Improvements

Section 1: Pumping System Basics

Overview

Pumps are used widely in industry to provide cooling and lubrication services, to transfer fluids for processing, and to provide the motive force in hydraulic systems. In fact, most manufacturing plants, commercial buildings, and municipalities rely on pumping systems for their daily operation. In the manufacturing sector, pumps represent 27% of the electricity used by industrial systems. In the commercial sector, pumps are used primarily in heating, ventilation, and air-conditioning (HVAC) systems to provide water for heat transfer. Municipalities use pumps for water and wastewater transfer and treatment and for land drainage. Since they serve such diverse needs, pumps range in size from fractions of a horsepower to several thousand horsepower.

In addition to an extensive range of sizes, pumps also come in several different types. They are classified by the way they add energy to a fluid: **positive displacement pumps**[1] squeeze the fluid directly; **centrifugal pumps** (also called "roto-dynamic pumps") speed up the fluid and convert this kinetic energy to pressure. Within these classifications are many different subcategories. Positive displacement pumps include piston, screw, sliding vane, and rotary lobe types; centrifugal pumps include **axial** (propeller), mixed-flow, and **radial** types. Many factors go into determining which type of pump is suitable for an application. Often, several different types meet the same service requirements.

Pump reliability is important—often critically so. In cooling systems, pump failure can result in equipment overheating and catastrophic damage. In lubrication systems, inadequate pump performance can destroy equipment. In many petrochemical and power plants, pump downtime can cause a substantial loss in productivity.

[1] Terms in bold type are defined in the glossary in Appendix A.

Pumps are essential to the daily operation of many facilities. This tends to promote the practice of sizing pumps conservatively to ensure that the needs of the system will be met under all conditions. Intent on ensuring that the pumps are large enough to meet system needs, engineers often overlook the cost of oversizing pumps and err on the side of safety by adding more pump capacity. Unfortunately, this practice results in higher-than-necessary system operating and maintenance costs. In addition, oversized pumps typically require more frequent maintenance than properly sized pumps. Excess flow energy increases the wear and tear on system components, resulting in valve damage, piping stress, and excess system operation noise.

Pumping System Components

Typical pumping systems contain five basic components: pumps, prime movers, piping, valves, and end-use equipment (e.g., heat exchangers, tanks, and hydraulic equipment). A typical pumping system and its components are illustrated in Figure 1.

◆ Pumps

Although pumps are available in a wide range of types, sizes, and materials, they can be broadly classified into the two categories described earlier—positive displacement and centrifugal. These categories relate to the manner in which the pumps add energy to the working fluid. Positive displacement pumps pressurize fluid with a collapsing volume action, essentially squeezing an amount of fluid equal to the displacement volume of the system with each piston stroke or shaft rotation. Centrifugal pumps work by adding kinetic energy to a fluid using a spinning **impeller**. As the fluid slows in the diffuser section of the pump, the **kinetic energy** of the fluid is converted into pressure.

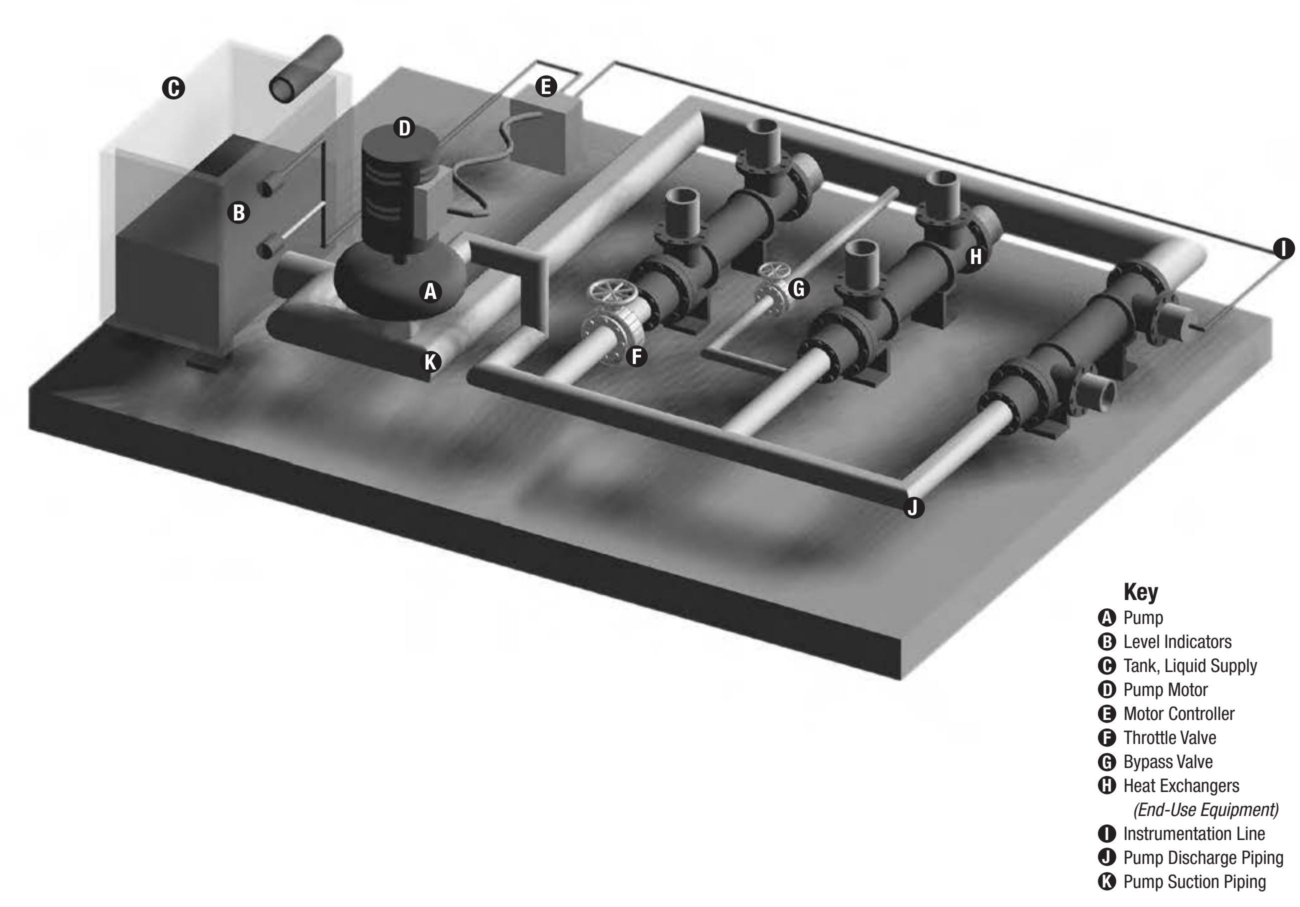

Figure 1. Typical Pumping System Components

Although many applications can be served by both positive displacement and centrifugal pumps, centrifugal pumps are more common because they are simple and safe to operate, require minimal maintenance, and have characteristically long operating lives. Centrifugal pumps typically suffer less wear and require fewer part replacements than positive displacement pumps. Although the **packing** or **mechanical seals** must be replaced periodically, these tasks usually require only a minor amount of downtime. Centrifugal pumps can also operate under a broad range of conditions. The risk of catastrophic damage due to improper valve positioning is low, if precautions are taken.

Centrifugal pumps have a variable flow/pressure relationship. A centrifugal pump acting against a high system pressure generates less flow than it does when acting against a low system pressure.

A centrifugal pump's flow/pressure relationship is described by a **performance curve** that plots the flow rate as a function of head (pressure). Understanding this relationship is essential to properly sizing a pump and designing a system that performs efficiently. For more information, see the subsection in Section 2 titled *Centrifugal Pumps.*

In contrast, positive displacement pumps have a fixed displacement volume. Consequently, the flow rates they generate are directly proportional to their speed. The pressures they generate are determined by the system's resistance to this flow. Positive displacement pumps have operating advantages that make them more practical for certain applications. These pumps are typically more appropriate for situations in which the following apply:

- The working fluid is highly viscous
- The system requires high-pressure, low-flow pump performance
- The pump must be self-priming
- The working fluid must not experience high shear forces
- The flow must be metered or precisely controlled
- Pump efficiency is highly valued.

A disadvantage is that positive displacement pumps typically require more system safeguards, such as relief valves. A positive displacement pump can potentially overpressurize system piping and components. For example, if all the valves downstream of a pump are closed—a condition known as **deadheading**—system pressure will build until a relief valve lifts, a pipe or fitting ruptures, or the pump **motor** stalls. Although relief valves are installed to protect against such damage, relying on these devices adds an element of risk. In addition, relief valves often relieve pressure by venting system fluid, which may be a problem for systems with harmful or dangerous system fluids. For more information on this type of pump, see the subsection in Section 2 titled *Positive Displacement Pump Applications.*

◆ Prime Movers

Most pumps are driven by electric motors. Although some pumps are driven by direct current (dc) motors, the low cost and high reliability of alternating current (ac) motors make them the most common type of pump prime mover.

A subcomponent of a pump motor is the motor controller. The motor controller is the switchgear that receives signals from low-power circuits, such as an on-off switch, and connects or disconnects the high-power circuits to the primary power supply from the motor. In dc motors, the motor controller also contains a sequence of switches that gradually builds up the motor current during start-ups.

In special applications, such as emergency lubricating oil pumps for large machinery, some pumps are driven by an air system or directly from the shaft of the machine. In the event of a power failure, these pumps can still supply oil to the bearings long enough for the machine to coast to a stop. For this same reason, many fire service pumps are driven by diesel engines to allow them to operate during a power outage.

◆ Piping

Piping is used to contain the fluid and carry it from the pump to the point of use. The critical aspects of piping are its dimensions, material type, and cost. Since all three aspects are interrelated, pipe sizing is an iterative process. The flow resistance at a specified flow rate of a pipe decreases as the pipe diameter gets larger; however, larger pipes are heavier, take up more floor space, and cost more than smaller pipe. Similarly, in systems that operate at high pressures (for example, hydraulic systems), small-diameter pipes can have thinner walls than large-diameter pipes and are easier to route and install.

Small-diameter pipes restrict flow, however, and this can be especially problematic in systems with surging flow characteristics. Smaller pipes also operate at higher liquid velocity, increasing erosion effects, wear, and friction head. Increased friction head affects the energy required for pumping.

◆ Valves

The flow in a pumping system may be controlled by **valves**. Some valves have distinct positions, either shut or open, while others can be used to throttle flow. There are many different types of valves; selecting the correct valve for an application depends on a number of factors, such as ease of maintenance, reliability, leakage tendencies, cost, and the frequency with which the valve will be open and shut.

Valves can be used to isolate equipment or regulate flow. Isolation valves are designed to seal off a part of a system for operating purposes or maintenance. Flow-regulating valves either restrict flow through a system branch (throttle valve) or allow flow around it (bypass valve). A throttle valve controls flow by increasing or decreasing the flow resistance across it. In contrast, a bypass valve allows flow to go around a system component by increasing or decreasing the flow resistance in a bypass line. A check valve allows fluid to move in only one direction, thus protecting equipment from being pressurized from the wrong direction and helping to keep fluids flowing in the right direction. Check valves are used at the discharge of many pumps to prevent flow reversal when the pump is stopped.

◆ End-Use Equipment (Heat Exchangers, Tanks, and Hydraulic Equipment)

The essential purpose of a pumping system may be to provide cooling, to supply or drain a tank or reservoir, or to provide hydraulic power to a machine. Therefore, the nature of the end-use equipment is a key design consideration in determining how the piping and valves should be configured. There are many different types of end-use equipment; the fluid pressurization needs and pressure drops across this equipment vary widely. For heat exchangers, flow is the critical performance characteristic; for hydraulic machinery, pressure is the key system need. Pumps and pumping system components must be sized and configured according to the needs of the end-use processes.

Pumping System Principles

◆ Design Practices

Fluid system designs are usually developed to support the needs of other systems. For example, in cooling system applications, the heat transfer requirements determine how many heat exchangers are needed, how large each heat exchanger should be, and how much flow is required. Pump capabilities are then calculated based on the system layout and equipment characteristics. In other applications, such as municipal wastewater removal, pump capabilities are determined by the amount of water that must be moved and the height and pressure to which it must be pumped. The pumps are sized and configured according to the flow rate and pressure requirements of the system or service.

After the service needs of a pumping system are identified, the pump/motor combination, layout, and valve requirements must be engineered. Selecting the appropriate type of pump and its speed and power characteristics requires an understanding of its operating principles.

The most challenging aspect of the design process is cost-effectively matching the pump and motor characteristics to the needs of the system. This process is often complicated by wide variations in flow and pressure requirements. Ensuring that system needs are met during worst-case conditions can cause designers to specify equipment that is oversized for normal operation. In addition, specifying larger than necessary pumps increases material, installation, and operating costs. Designing a system with larger piping diameters might reduce pumping energy costs, however. See the subsection titled *Piping Configurations To Improve Pumping System Efficiency* in Section 2.

◆ Fluid Energy

For practical pump applications, the energy of a fluid is commonly measured in terms of **head**. Head is usually expressed in feet or meters, which refers to the height of a column of system fluid that has an equivalent amount of potential energy. This term is convenient because it incorporates density and pressure, which allows centrifugal pumps to be evaluated over a range of system fluids. For example, st
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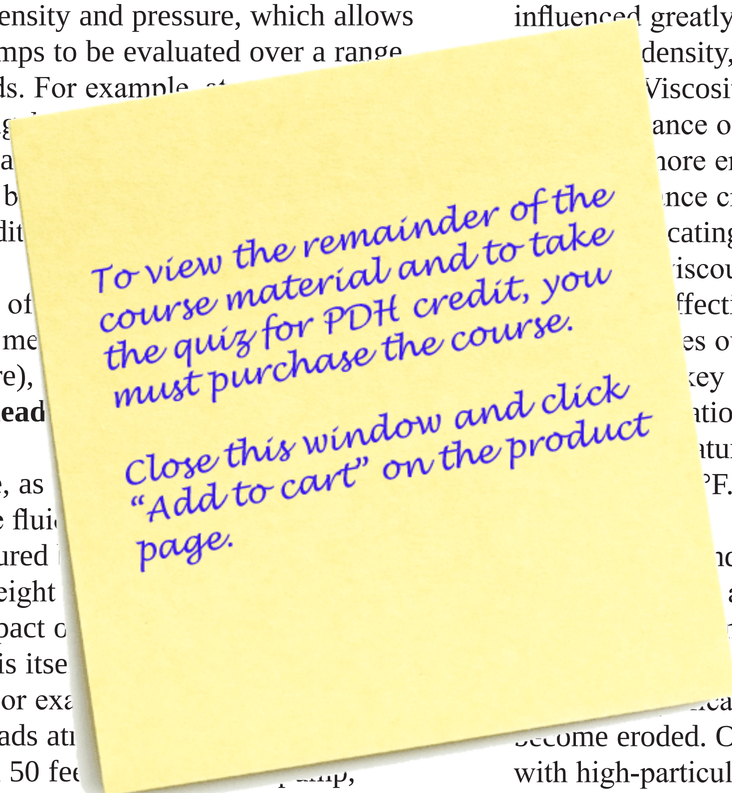

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(gauge pressure),
and **velocity head**

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however, the pump would have to generate at least 50 ft of static pressure (for tap water, the gauge would have to read 21.7 pounds per square inch [psi]) to push water into the tank.

Velocity head (also known as "dynamic head") is a measure of a fluid's kinetic energy. In most systems, the velocity head is small in comparison to the static head. For example, the flow velocity in cooling systems does not typically exceed 15 ft per second, which is roughly equivalent to 3.5 ft of head (if the system fluid is water, this velocity head translates to about 1.5 psi gauge [psig]). The velocity head of a fluid must be considered when siting pressure gauges, when designing a system, and when evaluating a reading from a pressure gauge, especially when the system has varying pipe sizes. A pressure gauge downstream of a pipe reduction will read lower than one upstream of the reduction, although the distance may only be a few inches.

◆ Fluid Properties

In addition to being determined by the type of system being serviced, pump requirements are influenced greatly by fluid characteristics such as
density, particulate content, and **vapor**
Viscosity is a property that measures the
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become eroded. Other pumps are designed for use with high-particulate-content fluids. Because of the way they operate, centrifugal pumps are often used to move fluids with high particulate content, such as coal slurries.

The difference between the vapor pressure of a fluid and the system pressure is another fundamental factor in pump design and selection. Accelerating a fluid to high velocities—a characteristic of centrifugal pumps—creates a drop in static pressure. This drop can lower the fluid pressure to the fluid's vapor pressure or below. At this point, the fluid "boils," changing from a liquid to a vapor. Known as **cavitation,** this effect can severely impact a pump's performance. As the fluid changes phase during cavitation, tiny bubbles form. Since vapor takes up considerably more volume than fluid, these bubbles decrease flow through the pump.