VERTICAL DIFFUSER TYPE TURBINE, MIXED-FLOW, AND AXIAL-FLOW (PROPELLER) PUMPS—A BRIEF OVERVIEW

by

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ABSTRACT

Vertical diffuser type pumps, their applications, advantages, disadvantages, multistaging, manufacturing, material selection, construction possibilities, operation, and repair are reviewed. Also discussed are semi-open and closed impellers and pullout construction. Illustrations of basic vertical pump types (per Hydraulic Institute Standards) and curve shapes for various impellers are introduced.

INTRODUCTION

Vertical diffuser type pumps are used wherever a liquid needs to be pumped upward from ground water tables, man made underground storage caverns, tanks, and open bodies of liquid such as oceans, rivers, lakes, cooling ponds, and sumps. Vertical pumps are also commonly used for inline systems, pipelines, booster applications, and low net posivitive suction head (NPSH) systems.

BASIC VERTICAL PUMP TYPES

The vertical turbine pump is extremely well suited for high head applications. These pumps are available in a variety of metals, including exotic alloys for pumping volatile, acidic, caustic, or polluting fluids.

Deepwell Applications

Deepwell vertical turbine pumps (Figures 1 and 2 [1]) are commonly used for applications such as:

- Agricultural irrigation.
- Water supply for municipalities and industries.
- Butane, propane, oil, and anhydrous ammonia caverns.
- Geothermal "downhole" pumping.
- Mine dewatering.

Short-setting Applications

Short-setting vertical turbine pumps (Figures 3, 4, 5, and 6 [1]) are also used for applications such as:

- Industrial processes, especially low-NPSH applications.
- Pumping from sumps of any kind.
- Supplying water, including cooling water, from lakes, ponds, rivers, canals and oceans.
- Power plant applications: circulating water, cooling towers, condensate, and heater drain.
- Flood control.

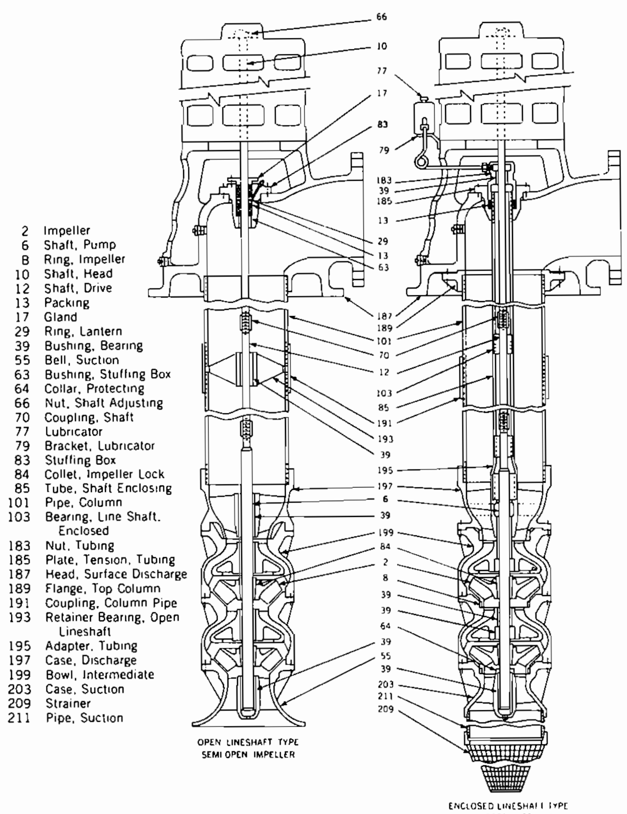
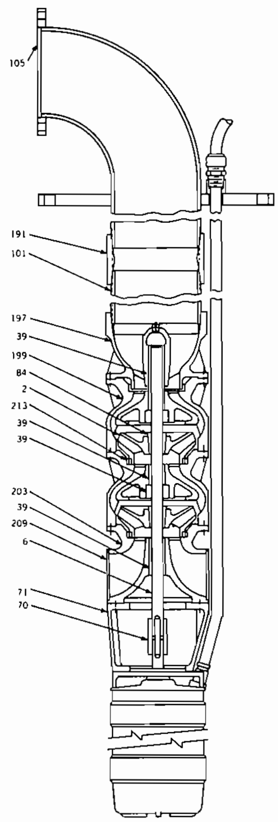
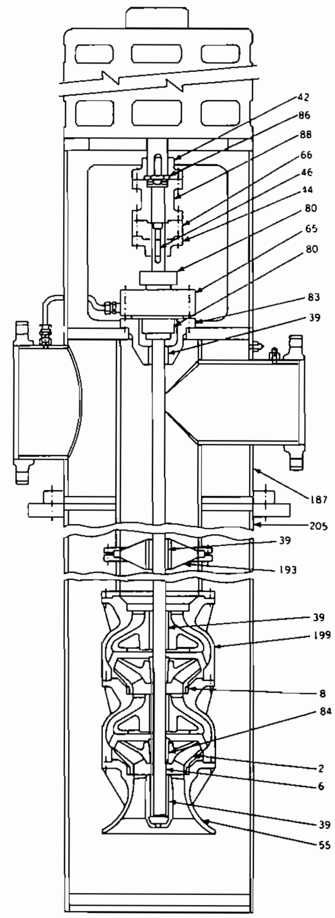


Figure 1. Open Lineshaft and Enclosed Lineshaft Type Pumps.



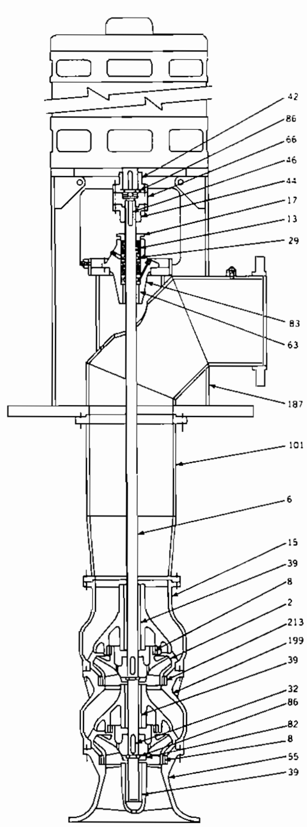
2 Impeller
6 Shaft, Pump
39 Bushing, Bearing
70 Coupling, Shaft
71 Adapter
84 Collet, Impeller Lock
101 Pipe, Column
105 Elbow, Discharge
191 Coupling, Column Pipe
197 Case, Discharge
199 Bowl, Intermediate
203 Case, Suction
209 Strainer
213 Ring, Bowl

Figure 2. Submersible Turbine Type Pump.



2 Impeller
6 Shaft, Pump
8 Ring, Impeller
39 Bushing, Bearing
42 Coupling Half, Driver
44 Coupling Half, Pump
46 Key, Coupling
55 Bell, Suction
65 Seal, Mechanical, Stationary Element
66 Nut, Shaft Adjusting
80 Seal, Mechanical, Rotating Element
83 Stuffing Box
84 Collet, Impeller Lock
86 Ring, Thrust, Split
88 Spacer, Coupling
187 Head, Surface Discharge
193 Retainer, Bearing, Open Lineshaft
199 Bowl, Intermediate
205 Barrel or Can Suction

Figure 4. Barrel or Can Turbine Type Pump.



2 Impeller
6 Shaft, Pump
8 Ring, Impeller
13 Packing
15 Bowl, Discharge
17 Gland
29 Ring, Lantern
32 Key, Impeller
39 Bushing, Bearing
42 Coupling Half, Driver
44 Coupling Half, Pump
46 Key, Coupling
55 Bell, Suction
63 Bushing, Stuffing Box
66 Nut, Shaft Adjusting
82 Ring, Thrust, Retainer
83 Stuffing Box
86 Ring, Thrust, Split
101 Pipe, Column
187 Head, Surface Discharge
199 Bowl, Intermediate
213 Ring, Bowl

Figure 3. Short Setting Turbine Type Pump.

For short-setting applications requiring medium heads, mixed-flow pumps (Figure 5) are commonly used, while axial-flow (propeller) pumps (Figure 6) are often used for low-head requirements.

ADVANTAGES OF VERTICAL DIFFUSER TYPE PUMPS

- No priming is necessary, since the bowl assembly is submerged in the fluid to be pumped.
- In systems where NPSH must be considered, the first stage can be positioned at the level where NPSH required is less than the NPSH available. This feature is especially effective where absolute system pressure is close to the vapor pressure of liquid to be pumped.
- Pumps are built to fit the customer's performance, mechanical, metallurgical, and dimensional requirements.
- Floor space requirements are minimal.
- A wide range of specific speeds is available for proper selection.

DISADVANTAGES

- The bearing system is submerged.
- The pumping element is out of sight.

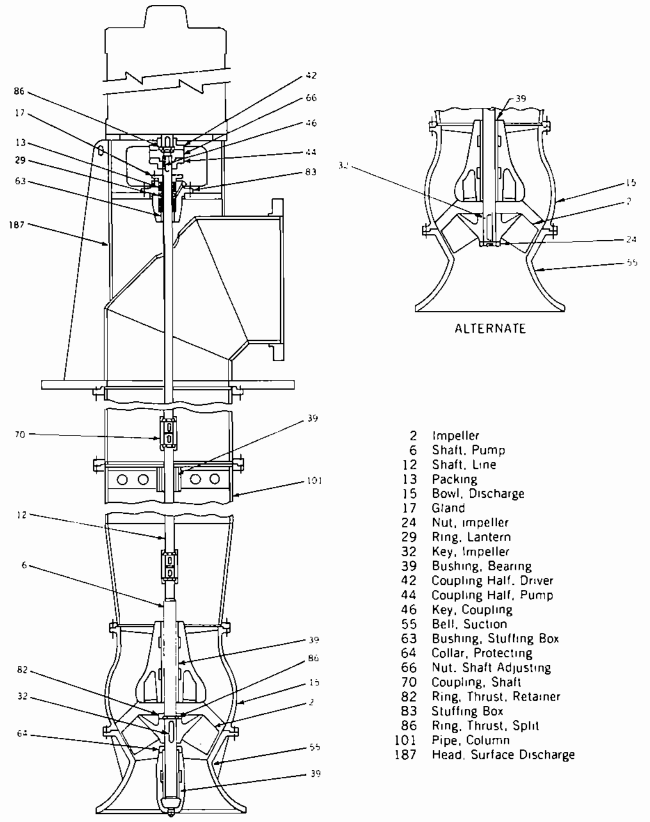


Figure 5. Mixed-Flow Type Pump.

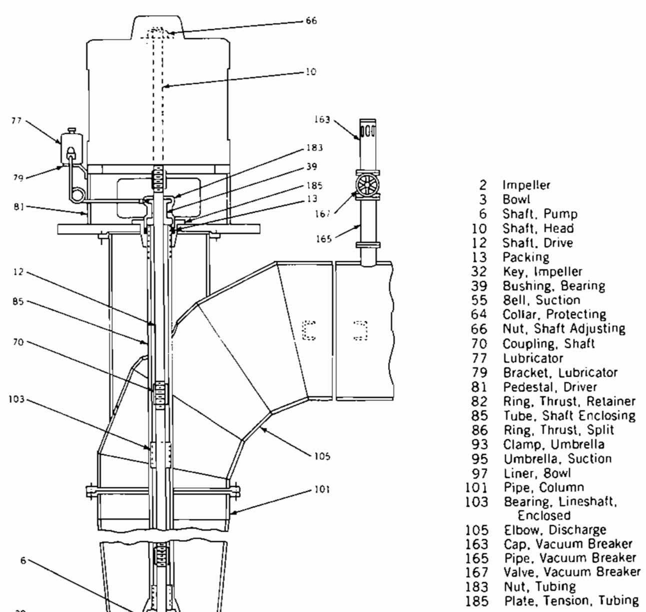


Figure 6. Axial-flow (Propeller) Type Pump.

- Installation and removal require special equipment.
- In buildings, larger-than-normal headroom may be required.

INSTALLATION

Vertical pump discharge heads are capable of taking a certain amount of pipe strain; however, excessive stress will cause bending of the equipment and premature wear. API, for example, specifies moments and forces that the pump must be able to handle without damage. Reaction forces must be anticipated and properly countered with tiebars or anchors, if necessary, and expansion joints must be properly retained. Underground (below base) discharges, especially, require proper countering of pipe strain; any undue strain at such an installation could cause a large moment on the base.

Pumps must be installed vertically. Most pumps will do fine if up to two degrees off vertical, but if the margin is greater, special provisions and designs may be necessary.

The impellers must be properly adjusted and lifted off their seats to the recommended clearance before starting. Rotation and runouts must be checked and corrected, if necessary, in which caseseal and packing adjustments must be made. It should be easy to turn the pump after all checks and adjustments have been completed.

MANUFACTURING

For practical purposes, manufacturing vertical pumps is a question of building to order with as many standard pieces and designs as possible. Three basic types of vertical turbine pumps are produced (Figures 1 and 2):

- Enclosed lineshaft type
- Open lineshaft type
- Submersible

Any of these may have an above-ground (base) discharge or a below-ground (base) discharge.

The enclosed lineshaft type is usually oil lubricated; oil is drip fed into the lineshaft enclosure to lubricate the lineshaft bearings. In the open lineshaft type, the lineshaft bearings are lubricated by the fluid pumped.

The submersible turbine pump normally has the motor mounted below the bowl assembly, and the pump/motor combination is submerged in the fluid pumped. In most cases, the submersible pump is not as efficient as the motor-driven lineshaft pump, since the efficiency of the submersible motor is generally lower than that of the above-ground driver.

Multistaging is standard practice to satisfy head requirements. The wide range of selection possibilities allows for whatever variations the process may require. For example, if a steep curve is desired, multistaging will provide it. This can be accentuated with higher specific speed pumps, which have lower head per stage and a steeper curve to begin with than pumps with low specific speed and higher head per stage. Curve shapes of impellers of various specific speed designs are reflected in Figures 7 and 8.

Material selection and construction selection are practically unlimited. The standard bowl is cast iron and the standard impeller is bronze. However, many kinds of alloys can be used to meet special requirements. Corrosion resistant coatings, including coal-tar types, coal-tar epoxies, and other epoxies, are used both for new pumps and repairs, as one abrasion corrosion-resistant coatings—mainly epoxies and abrasion-resistant filled epoxies. Bearing systems are normally bronze, synthetic rubber, or a combination of both, and are lubricated by the fluid pumped. Abrasives, corrosives and petrochemical fluids may call for other types of bearing materials and systems; hard bear-

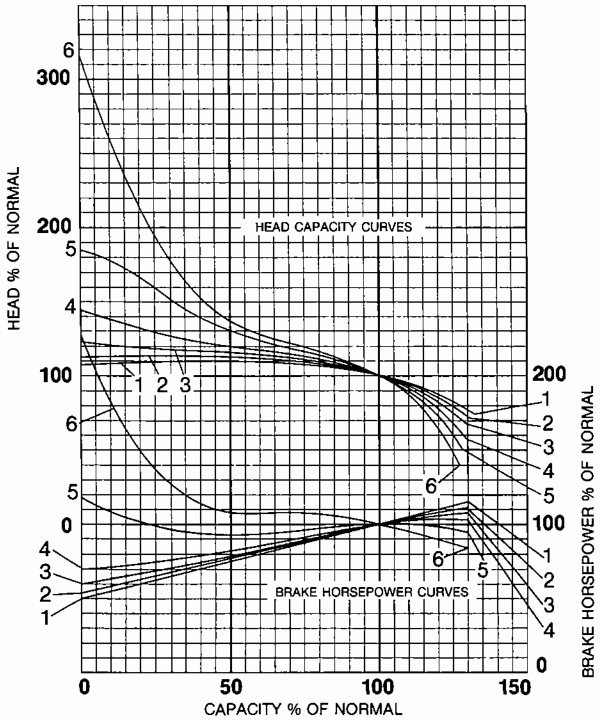


Figure 7. Typical Performance Curve Shapes for Impellers of Various Specific Speed Design (also see figure 8).

ings and hard-faced journals, carbides, ceramics, plastics, carbon, and filled carbon may all be used in various services.

Some bearing systems are lubricated by a fluid different from the pumped fluid. An oil lubricated, enclosed lineshaft type is a primary example, but various clean liquids or grease may be introduced into all bearings in a vertical pump. Shafting will also vary from standard steel to highgrade alloys and may have hard faced journals such as industrial hard chrome, carbides and ceramics for resistance to corrosion and wear.

The pressure containing parts of a pump can be built to retain the system pressure—up to 5000 psi is not unusual, and can be provided to meet various codes and specifications such as ASME section VIII, API 610, and individual customer specifications.

Discharge Head Construction for Lineshaft Pumps

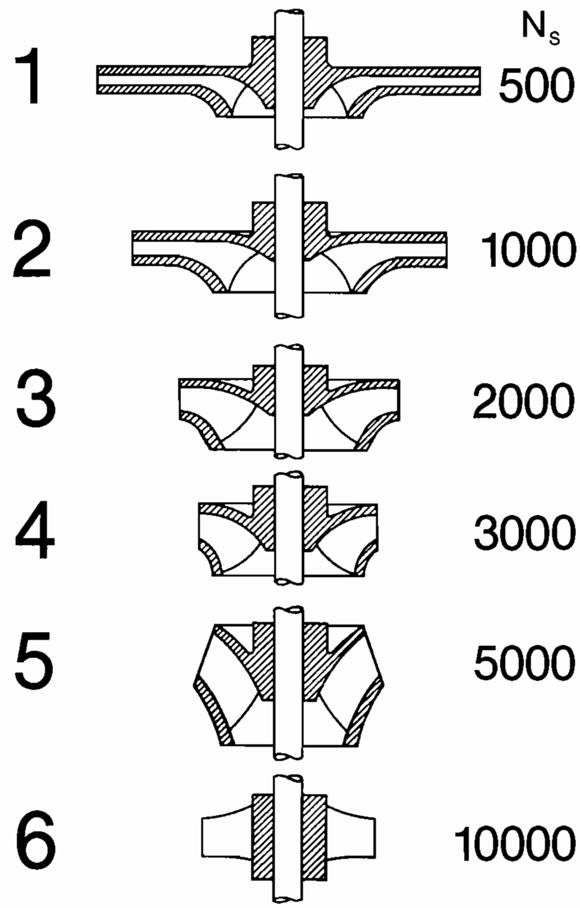
The discharge head has many functions, including:

- Supporting the pump
- Guiding the fluid into the process piping
- Accommodating a sealing arrangement
- Supporting the driver

The sealing arrangement and driver support must be concentric and parallel for proper operation. The head and driver must be designed to avoid natural frequency problems.

Column, Tube, and Shaft Assembly

The same requirements for concentricity and parallelism apply to the column, tube (if used), and shaft assembly, along with another important consideration: *bearing spacing*. The bearings must be spaced to avoid critical speeds. And above all, the shaft must be *straight*. For hard bearings, the spacing must be well below critical speed length. For rubber bearings, the spacing should be between the first and second critical speed lengths on deepwell pumps; on short setting pumps, the rubber



$$N_S = \frac{N\sqrt{Q}}{H^{3/4}}$$

Figure 8. Impellers of Various Specific Speed Design.

bearing spacing is the same as that for hard bearings. (Bearing manufacturers publish spacing charts; also see API 610.)

Bowl Assembly

The bowl assembly's proper operation also depends on the three "musts:" concentricity, parallelism, and straightness. The vertical pump bowl assembly differs from horizontal multistage pumps in one important respect: *endplay*. This is the amount of vertical play the impeller requires for proper adjustment. When the pump is installed, the impellers rest on the seats in the bowls. Before running the pump, the impellers should be lifted off the seats to allow for column and shaft stretch and to keep the impellers from dragging. Normally, the driver coupling allows for this adjustment.

Most deepwell pumps are constructed with threaded column, tube, and shaft, whereas most process pumps have flanged column and product-lubricated lineshaft bearings. Again, bearing selection and spacing are important.

Variable speed vertical pump units may sometimes run at a speed equal to the natural frequency of the head and driver assembly, causing resonance problems. While it may not be economically feasible to "design around" this tendency, it may be possible to "block out" a region of speed and avoid problems.

DRIVERS

The drivers commonly used with vertical pumps include vertical motors and right angle gears with horizontal engines, motors, or turbines; sometimes vertical steam turbines are employed.

Motors and gears are either hollow shaft or solid shaft. Hollow shaft drivers are standard on deepwell pumps since this construction simplifies the impeller-setting procedure. Solid shaft drivers are standard on short setting process pumps (usually up to about 50 feet).

Thrust bearings are required to carry the thrust produced by the impellers and the weight of the rotating assembly. The thrust bearing assembly is normally mounted in the driver, sometimes in a separate "thrust pot." Thrust bearings range in load carrying capacity from deep groove ball bearings for light loads to plate type bearings for the highest loading. Angular contact ball bearings are used for medium loads, and spherical roller type bearings for medium to heavy loading.

During startup, most vertical pumps experience a temporary upthrust, and the driver must be able to handle this; therefore, it is a standard practice to order vertical pump drivers with momentary upthrust protection rated at 30 percent of the downthrust capacity of the driver.

In some cases, a pump will run in continuous upthrust, usually because of high suction pressure or running at much lower head than that for which the pump is designed. In such cases, the driver must be capable of carrying continuous upthrust as well as downthrust.

Short setting pumps using hollow shaft drivers should be supplied with a shaft centering bushing in the bottom end of the driver, and upthrust must be limited to that which occurs momentarily during startup.

OPERATION

Most vertical pumps are "out of sight" when operating, and, unfortunately, they are sometimes "out of mind" as well. That is to say, their operation may not be monitored carefully enough. It is just as important to check periodically on the performance of a vertical pump as on any other piece of rotating equipment. Head and capacity degradation and vibration are the usual telltale signs of problems. These pumps have been known to self destruct without much vibration increase, but in such a case the head capacity degradation is usually quite obvious.

Head capacity problems can only be detected by knowing the required performance versus the system curve on which the pump is working. It has been pointed out in many papers and articles that off-peak performance can cause damage and waste money, so here are some important factors to keep in mind:

- Select the pump properly. Avoid selecting a higher head than necessary for the capacity wanted.
- Select a pump with a reasonable speed (Figure 9). For example, if a pump has to run in excess of 20 percent off peak efficiency conditions for a considerable time, consider selecting a pump with lower speed than normal to avoid damage from off-peak performance.
- Understand your system curve.
- Run the pump near BEP as much as possible and check vibration regularly.
- Check discharge pressure and calculate total head. Compare with BHP measured to original curve (flow is normally very hard to check) and compare to system curve.
- Check runout of visible shafting.
- Check leakage of packing box or seal.
- Keep records of the above.

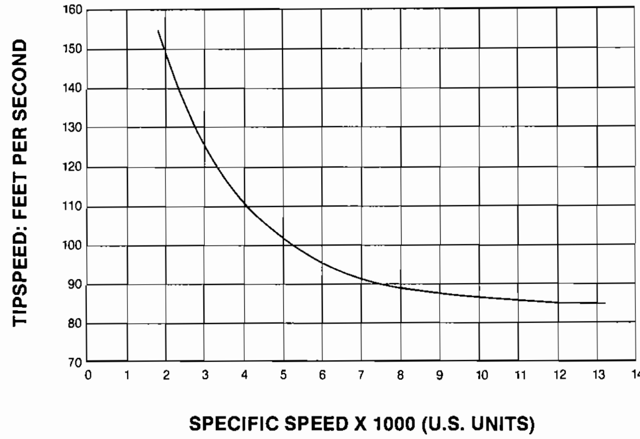


Figure 9. Recommended Maximum Tipspeeds (in feet per second versus specific peed) for Clean Fluids, Standard Materials (cast iron and bronze), and Continuous Operation.

VERTICAL PUMP REPAIR

When repair is needed, resist the temptation to apply "sledgehammer" techniques. The working end of a vertical pump often looks like a bunch of dirty piping covered with rust, oil, dirt, algae or barnicles—and it frequently gets treated as such. *Wrong*! Handle that dirty-looking bowl assembly and column assembly with *care* or further damage and increased repair costs will occur. As mentioned earlier (and it bears repeating), proper vertical pump operation depends very much on *concentricity, parallelism* and *straightness*. These should all be as close to perfect as possible when the repair is completed, so it is extremely important to check *all* the pieces for these characteristics and repair the pump accordingly. Many users have found that an original pump lasted a certain number of years and the repaired pump lasted a much shorter period. The reason for the difference is simple: the pump wasn't repaired properly.

If the pump needing repair did not last an acceptable time, then consideration must be given to upgrading the pump. The type of wear (e.g., abrasion, corrosion, erosion, cavitation, bearing wear, shaft wear) may indicate the need to upgrade materials; but it could also point to such drastic measures as reducing the pump output or pump size—i.e., pumping less at the same speed, or reducing the speed. Double the speed, and the wear and tear increases five to six times; the reverse beneficial effect is obvious.

A good example is circulating water pumps used in the power industry. During the 1960s, many of them were installed to run at speeds much higher than those common in the industry. The power industry had a standard requirement of 40-year pump life. The increased speeds made that nearly impossible. The choices now are:

- Repair pumps far more often than before.
- Use a smaller bowl assembly, reducing initial output but achieving more flow at better efficiencies over the average life cycle.
- Reduce the speed. The effect will be the same as above: less initial flow, but on average, much more output at better efficiencies overall.
- Upgrade materials.
- Improve operation, if possible.
- Improve intake (if it is a problem).

Vibration

If the pump vibrates too much to begin with, have the pump manufacturer solve that problem for you. However, if the pump runs properly for awhile, then starts vibrating, look for these causes:

- Worn bearings. Will the shaft move sideways easily? If so, check the bearings.
- Could something have lodged in the impellers or bowls, thus throwing the unit out of balance?
- Has the piping stress load changed? If so, it could have put the head out of alignment or caused a natural frequency problem.
- A system change may have shifted head and capacity off the best efficiency point (BEP), causing vibration.
- Bad alignment may have caused rapid bearing wear, resulting in vibration.
- Driver problems.

To check for these problems, disconnect the pump from the driver and run the driver by itself. If the driver is an electric motor and the vibration is still present, push the stop button and coast the driver to a stop while checking the vibration. If vibration disappears immediately after pushing the stop button, there are these two possibilities: (1) a natural frequency problem (quite common), or (2) an electrical unbalance (more rare). The natural frequency problem may be proved by changing pipe loading—i.e., disconnecting and checking for movement. The problem can be solved sometimes by loosening anchorbolts. If vibration reduces with the speed, the driver is out of balance. If the driver does not vibrate at all, the problem is in the pump. Try backflushing first, and if that does not solve the problem, the pump must be pulled and repaired or the foreign object must be removed.

Flow Problems

Flow to the pump must be evenly distributed. The best flow is in a deep well where the liquid comes straight up into the suction of the pump. This is not normally the case in intakes and barrels or cans; thus allowances must be made for proper design of intakes and barrels. Recommended intakes are described in the Hydraulic Institute Standards as well as published by the British Hydromechanics Research Association (BHRA). In barrels or cans, it helps to install guides to avoid swirling and swaying of the bowl assembly, thus creating proper flow into the pump. (Dicmas' publication contains valuable information about fluid velocities into the pump versus submergence requirements. [2]) To achieve proper flow and to avoid vortices, it is recommended that intakes for pumps of 50,000 gpm capacity or more be model tested.

If a pump weaves, wobbles or sways, chances are that the flow into the suction bell is not evenly distributed; bearing wear will result as the uneven loading of the impeller is transmitted to the bearing. The shaft will come into direct contact with the bearing, causing abnormally high wear. The bronze bearing could be protected by grease lubrication. Of course, check to see if the flow into the pump can be improved.

Strainers should be used only to keep rocks and large aquatic animals from entering a pump. Where plastics, trash, aquatic growth, and plants are present, trashracks are a must, since the strainer alone will simply plug up and collapse.

Sometimes a vertical pump is excessively noisy or vibrates more than necessary, but the operator is not concerned because "it's always been that way." If he's right, then there's always been something wrong with the pump. A properly installed and applied vertical pump should be far less noisy than the driver, and the flow into the pump should be smooth and free of surface or submerged vortices.

Surface vortices are easy to see. Submerged vortices are not usually visible, but you can be heard: they sound like cavitational "crackling," but the noise is intermittent. (Cavitation caused by lack of NPSH produces a continuous noise.) Submerged vortices usually can be eliminated by constructing cones or splitters under the pump.

Pullout Construction—A Thing of the Past

In the power plant industry one finds the so-called pullout construction, where shafting, impeller and diffuser can be removed while the column, bowl enclosure and bell stay in place. This was a very useful construction years ago when the column had to be made of cast metal; in those days there were no hydraulic or air wrenches—only slugging wrenches—and the pumps were extremely heavy, with large bolting. Pumps are not that heavy today. Fabrication (versus casting) is much lighter; smaller bolting is used; and one can always get to the discharge even if it is below-base. This all means that pull-out construction is not necessary anymore. In fact, when repairing old pull-out pumps these days, even those parts designed to stay in place have to be pulled–because they also need to be repaired.

Semi-open Versus Closed Impellers (Figures 10 and 11)

In large pumps it is not unusual for high horsepower loading per blade to cause blade breakage on semi-open impellers. This does not happen with closed impellers, which are much stronger. When properly adjusted, semi-open impellers are generally more efficient than closed impellers. However, adjusting large semi-open impellers is quite difficult when the engineer is trying to produce maximum efficiency such as that achieved in the manufacturer's test lab–and it is harder still when dealing with multistage pumps with semi-open impellers. It is much easier to adjust closed impellers with standard seal rings (also called wear rings). Repairing or replacing seal rings is relatively easy.

Figure 10. Semi-open Impeller.

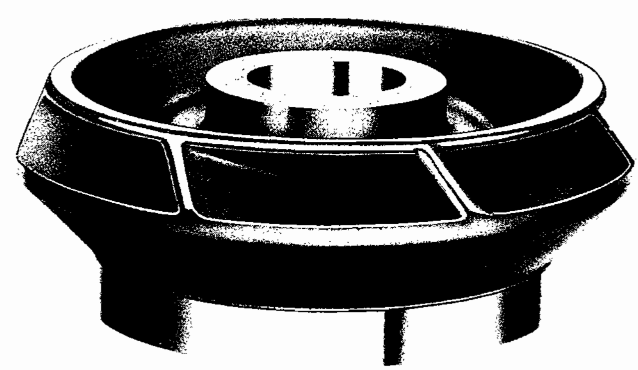


Figure 11. Closed Impeller.

However, after semi-open impeller vanes wear off, they have to be built up again—a very difficult and imprecise procedure.

A semi-open impeller can be adjusted to leave a larger gap for internal bypass, if desired. This can also be accomplished with a closed impeller by using tapered seal rings. However, using a bypass piping system is much better than bypassing internally in the pump, since the latter creates additional wear and tear and additional efficiency loss.

Semi-open impellers are used mainly in higher specific speed pumps, e.g., mixed-flow pumps used originally for flood control, an application in which seal rings would not be practical, because of all the debris that must be passed. Generally, mixed-flow impellers are not as high in horsepower per blade as the semi-open turbine type.

Repair to "As New"

Here are some other important points to keep in mind when repairing vertical pumps:

• Metal-to-metal joints for pressure seal must be machined to a minimum of 125 rms finish, and all nicks, chips, and hammer marks must be avoided. These joints normally have registers which may have to be repaired, too.

• Shaft ends for threaded shafts should be machined to 64 or 32 rms without filing or polishing so that the shafts butt absolutely square and straightness is maintained. Shaft straightness must be within 0.0005-in per foot of total indicator run-out (TIR) and must stay within 0.005-in for any length over 10 ft.

• During assembly, all joints must be kept clean and true.

• Since pumps are built up of many parts with slip fits, off-center assembly from one part to the next is possible. The problem shows up in the field when the motor is hooked up to the pump. Especially in the case of solid shaft motors, to get good alignment the coupling again might have to be loosened again, and a part of the coupling might be switched 90 degrees or 180 degrees. *A word of caution:* Do not rely totally on the reguster fit between solid-shaft motors and heads, because on standard motors there is a considerable tolerance on shaft concentricity as it relates to the register. (Half-NEMA tolerances on shaft-centering *vs* registers would be a great help.)

• *Balancing impellers:* Most vertical turbine pumps will run well with impellers that have been repaired and only statically balanced. Individual impellers may be dynamically balanced if this service is available. Do not balance complete rotors, since they have to be disassembled again for installation.

Of course, if all else fails, there's always the cliche but true solution: Read the manufacturer's installation and operation instructions!

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