EPRI

Pump Troubleshooting, Volume 2

TR-114612, Volume 2

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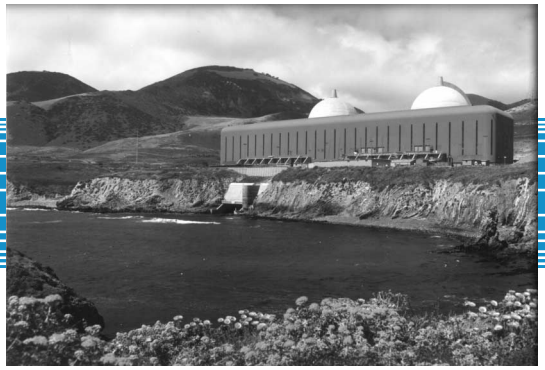
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NMAC

Pump Troubleshooting, Volume 2

TR-114612, Volume 2

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Final Report, October 2000

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REPORT SUMMARY

Background

Pumps are an integral part of many systems in nuclear power plants. Reliable operation and maintenance of these components are vital to sustained plant operation and availability. The ability to accurately diagnose and troubleshoot pump problems is essential to maintenance, engineering, and operating staffs of these power plants. The late Dr. Elemer Makay, a world-renowned expert in the field of pump design, operation, and troubleshooting, conducted significant research on pumps and acquired many years of experience with them. This work was collected with the assistance of Will Gates, an understudy of Dr. Makay, and was presented in Volume 1 of this guide (TR-114612-V1). Volume 2 has been developed with the assistance and input of utility and industry experts in the field of power plant pumps with the intent of providing additional assistance to power plant personnel in dealing with pump problems.

Objectives

- To provide a practical application of many of the principles defined in Volume 1
- To describe the use of basic pump diagnostic information and provide guidelines for its use by many levels of the plant organization, from the new system engineer to the experienced pump mechanic

Results

This report provides a practical troubleshooting process that can be used by power plant personnel to diagnose and troubleshoot pump performance and system-related problems. The guide is valuable for both the component and system engineer and provides instructions and recommendations for determining the nature of pump reliability problems through the use of diagnostic information and analytical methods. A generic troubleshooting approach is provided to enable personnel to evaluate plant conditions and determine proper actions to take. Application (that is, pump type) specific symptoms and solutions are provided to help establish corrective measures to be taken.

EPRI Perspective

When used in conjunction with Volume 1, the information contained here represents a significant collection of technical information, including case studies and implemented solutions, related to the troubleshooting of pump and pump-related problems in power plants. This report provides a single point of reference for power plant personnel, both in the present and in the future. The intended audience of Volume 2 includes component, maintenance, and system engineers involved in maintaining, operating, and troubleshooting pumps. This report will be helpful in evaluating pump application problems in existing systems, selecting new and replacement pumps/pump components, and understanding pump performance and reliability.

Keywords

Design engineers
Plant Support Engineering
Plant maintenance
Plant operations

ABSTRACT

This report provides a practical troubleshooting process that can be used by power plant personnel to diagnose and troubleshoot pump performance and system-related problems. The information here is valuable for both component and system engineers and provides instructions and recommendations for determining the nature of pump reliability problems through the use of diagnostic information and analytical methods.

The report is a companion document to EPRI *Pump Troubleshooting, Volume 1*, TR-114612-V1, authored by Dr. Elemer Makay and Will Gates. The guidance contained in this second volume provides a clear logic that utility system/component engineering personnel can use to assist them in determining the root causes of pump performance problems and the means for evaluating the benefits of possible solutions. This second volume also provides a way to communicate more current technical guidance regarding pump troubleshooting techniques that were not discussed in the original report.

An overview of pump design fundamentals is summarized in Section 2. Section 3 provides a generic process and detailed guidance for troubleshooting operating pumps/fluid systems in a nuclear power plant. The technical scope of this report encompasses the following major categories of pumps commonly installed in nuclear power plants:

- Vertical pumps (Section 4)
- Multi-stage, horizontal pumps (Section 5)
- Single-stage, horizontal pumps (Section 6)
- Positive displacement pumps (Section 7)

The first part of Sections 4–7 provides a grouping of the major types of pumps in each respective category, a brief technical overview of the pump design, and sectional views of similar pumps. The second part of these sections provides a listing of typical nuclear plant applications for each type of pump and a listing of typical manufacturers and models of each category of pump. Finally, these sections also include a troubleshooting matrix that provides a consistent format for communicating pump performance indicators (that is, problems/symptoms), an associated list of potential root causes, and associated corrective actions that a nuclear component/system maintenance engineer might consider.

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1
INTRODUCTION

1.1 Issue

In the past, EPRI has published a number of guides providing technical guidance for engineers and other plant personnel on equipment and component operation, selection, installation, failure mode analysis, and maintenance recommendations to optimize equipment operating life. To date, much of the pump troubleshooting and diagnostic guidance made up only a relatively small portion of EPRI guidelines that focused more on pump maintenance practices. As such, there was no consolidated guidance for troubleshooting pump problems that presented a consistent process for assessing pump performance.

Earlier in 2000, EPRI completed the updating and publication of *Pump Troubleshooting, Volume 1*, TR-114612-V1. This report provides a detailed compilation of technical issues that relate to diagnosing pump performance problems, as well as a number of actual case studies. The subject of Volume 1 is the "significant developments and corrective actions for high-energy-input pumps in U.S. power plant applications from 1965 to 1995." The intent with Volume 2 is to build upon Volume 1 and provide a consistent, systematic methodology that nuclear power plant maintenance and engineering personnel can use to diagnose common pump/system performance problems.

1.2 Purpose

This report provides a practical troubleshooting process that can be used by power plant personnel to diagnose and troubleshoot pump performance and system-related problems. The guideline is valuable for both the component and system engineer and provides instructions and recommendations for determining the nature of pump reliability problems through the use of diagnostic information and analytical methods.

The report is a companion document to EPRI *Pump Troubleshooting, Volume 1,* authored by Dr. Elemer Makay and Will Gates. The guidance contained in this second volume provides a logical approach that utility system/component engineering personnel can use to assist them in determining the root causes of pump performance problems and the means for evaluating the benefits of possible solutions. This second volume also provides a way to communicate more current technical guidance regarding pump troubleshooting techniques that were not discussed in the original report.

1.3 Scope

1.3.1 General Scope of the Report and Types of Pumps

An overview of pump design fundamentals is summarized in Section 2. Section 3 provides a generic process and detailed guidance for troubleshooting operating pumps/fluid systems in a nuclear power plant.

The technical scope of this report encompasses the following four major categories of pumps commonly installed in nuclear power plants:

- Vertical pumps (Section 4)
- Multi-stage, horizontal pumps (Section 5)
- Single-stage, horizontal pumps (Section 6)
- Positive displacement pumps (Section 7)

The first part of Sections 4–7 provides a grouping of the major types of pumps in each respective category, a brief technical overview of the pump design, and sectional views of similar pumps. The second part of these sections provides a listing of typical nuclear plant applications for each type of pump and a listing of typical manufacturers and models for each category of pump. Finally, these sections also include a troubleshooting matrix that provides a consistent format for communicating pump performance indicators (that is, problems/symptoms), an associated list of potential root causes, and associated corrective actions that a nuclear component/system/ maintenance engineer might consider.

1.3.2 Pump Troubleshooting Matrices

The pump troubleshooting matrices should be used as shown in the generic process in Section 3. Section 3.2 describes how the matrices are structured and what information is provided to assist the system/component engineer.

1.3.3 Basic Premises

While the troubleshooting matrices were being developed, a number of causes of pump performance problems arose that were generic in nature. These causes typically dealt with the adequacy of the maintenance and installation and the quality of the replacement items used during the maintenance. Although these are viable concerns, the prevention of these situations or their resolution is typically outside the scope of the detailed troubleshooting matrices contained in this report. As such, the following basic premises should be considered as fundamental elements when you implement the generic troubleshooting process discussed in Section 3:

- The design of each pump and its subcomponents is suitable for the installed application.
- All subcomponents of the pump (including all replacement parts, assemblies, etc.) are present and have been installed in accordance with each manufacturer's recommendations. Experience has shown that there is a greater risk of inadvertently installing the wrong item or installing a replacement item in an application that is unsuitable when replacing commodity-type items such as packing, lubricants, and/or bearings. As such, the detailed troubleshooting matrices may, in some cases, list these issues as probable causes of pump performance problems.

- All replacement parts are either physically identical to the original or have been determined to be equivalent to the original items. Each utility has a process for the procurement and receipt of alternate replacement items. Proper implementation of this process should avoid the installation of items that do not perform as intended due to manufacturer's design/manufacturing changes.
- Maintenance personnel are properly trained and qualified to perform the scope of work necessary to maintain the pump that is experiencing performance problems.
- Procedures and manufacturer's maintenance instructions are current and have been properly applied to the pump that is experiencing performance problems.

Engineering personnel implementing these guidelines are qualified in accordance with each utility's requirements and have sufficient experience with the equipment described in this report.

2
PUMP FUNDAMENTALS AND PUMP DESIGN OVERVIEW

The following overview is based on excerpts from the following reports:

- *American National Standard for Centrifugal Pumps for Nomenclature, Definitions, Application and Operation.* Hydraulic Institute, Parsippany, NJ, May 1994. ANSI/HI 1.1-1.
- *American National Standard for Vertical Pumps for Nomenclature, Definitions, Application and Operation.* Hydraulic Institute, Parsippany, NJ, May 1994. ANSI/HI 2.1-2.
- *Centrifugal Pump Fundamentals.* Ingersoll-Dresser Pump Co, Phillipsburg, NJ, 1998.

2.1 Pump Fundamentals

2.1.1 Classes of Pumps

Pumps can be broadly divided into two major classes—kinetic and positive displacement. The most common of the kinetic class pumps are the centrifugal pumps, which are discussed in detail in this section as well as in Sections 4, 5, and 6. Positive displacement pumps are discussed in Section 7 of this report.

2.1.2 Casing Configuration of Centrifugal Pumps

Typically, centrifugal pumps are classified by one of two casing configurations—volute or diffuser. A volute is a spiral-like form such that as the liquid is discharged from the impeller into the volute casing, the volute areas increase at a rate proportional to the discharge of liquid from the impeller, and a constant velocity exists around the periphery of the impeller. This velocity is then diffused in the casing nozzle.

The other common casing classification is diffuser construction. A diffuser is actually a series of vanes surrounding the impeller that accept the discharge of liquid from the impeller. The vanes efficiently reduce the velocity to increase pump head and, in the case of a multi-stage pump, direct this lower-velocity fluid into vaned return channels that guide the liquid to the inlet or eye of the next stage impeller. In the case of single-stage pumps, the discharge from the diffuser is collected in a surrounding casing that guides the liquid out of the pump through the discharge nozzle.

2.1.3 Impeller Types

There are three basic impeller types that can classify a pump. These types include the following:

- A completely open impeller (which has the vanes extending from the hub)
- A semi-open impeller (which has the vanes cantilevered from a back shroud plate and no front shroud plate)
- A completely enclosed impeller (which has full front and back shrouds to completely enclose the vanes)

Figure 2-1 illustrates the three types of impellers.

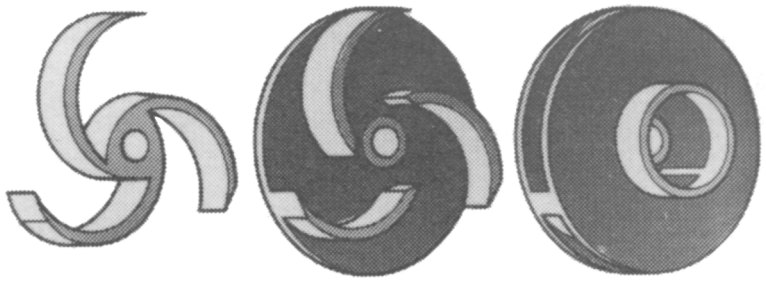


Figure 2-1
Pump Impeller Types

The open and semi-open impeller types are usually installed in smaller pumps to handle solid-liquid mixtures, improve productivity, or reduce costs. In many applications, especially in larger pumps, an open or semi-open impeller may be more efficient than a closed impeller. The fully enclosed impeller, however, is normally required for higher energy/head applications and multi-stage pumps.

2.2 Pump Specific Speed

Pump specific speed is a dimensionless number that is usually denoted as NS, Ns, or N_S. The specific speed of an impeller is defined as the revolutions per minute (speed – N) at which a geometrically similar impeller would run if it were of such a size as to discharge one gallon per minute against one foot head. Specific speed can be calculated as follows:

$$N_S = (RPM)(GPM)^{1/2} / (H)^{3/4}$$

Specific speed is indicative of the shape and characteristics of an impeller. It has been found that the ratios of major dimensions vary uniformly with specific speed. Specific speed is useful to the designer in predicting proportions required and to the application engineer in checking suction limitations of pumps, as shown in Figures 2-2 and 2-3. It can be seen that there is a gradual change in the vane profiles from the radial to the axial flow configuration.

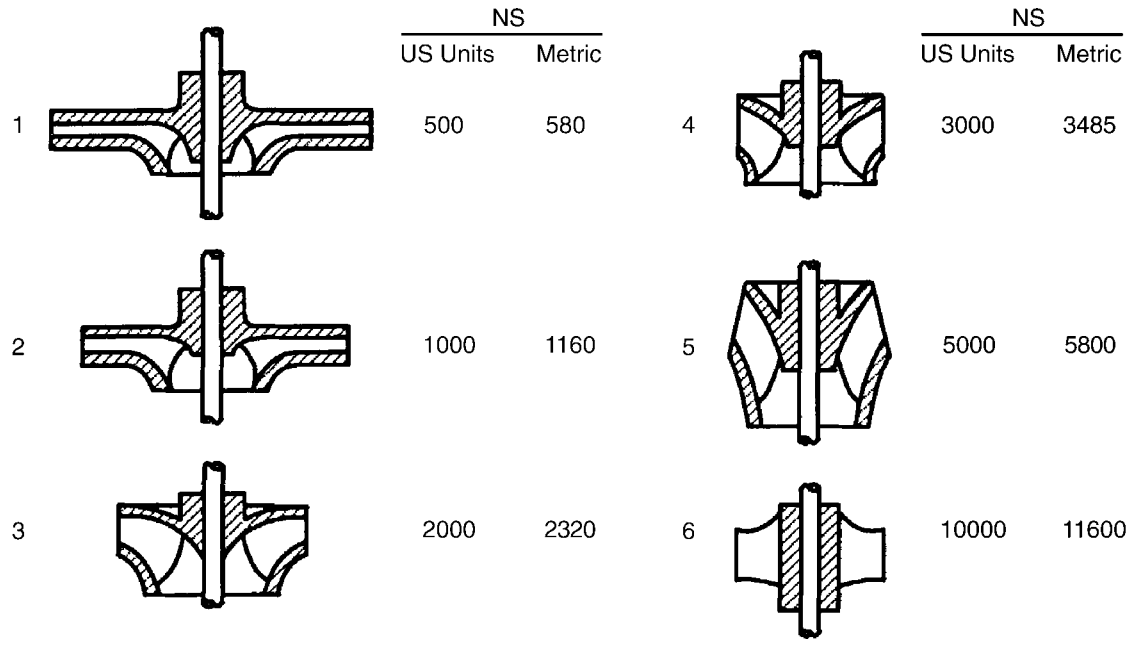
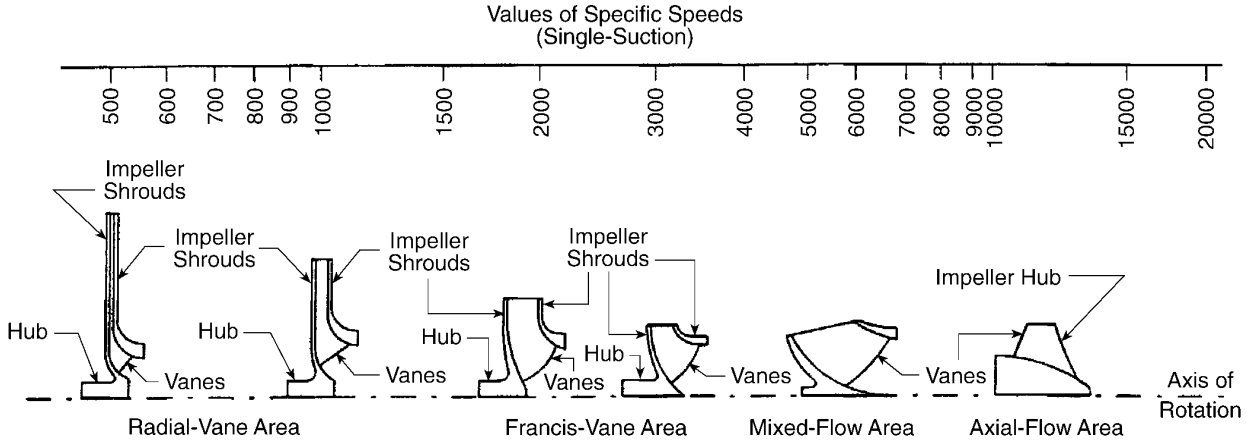
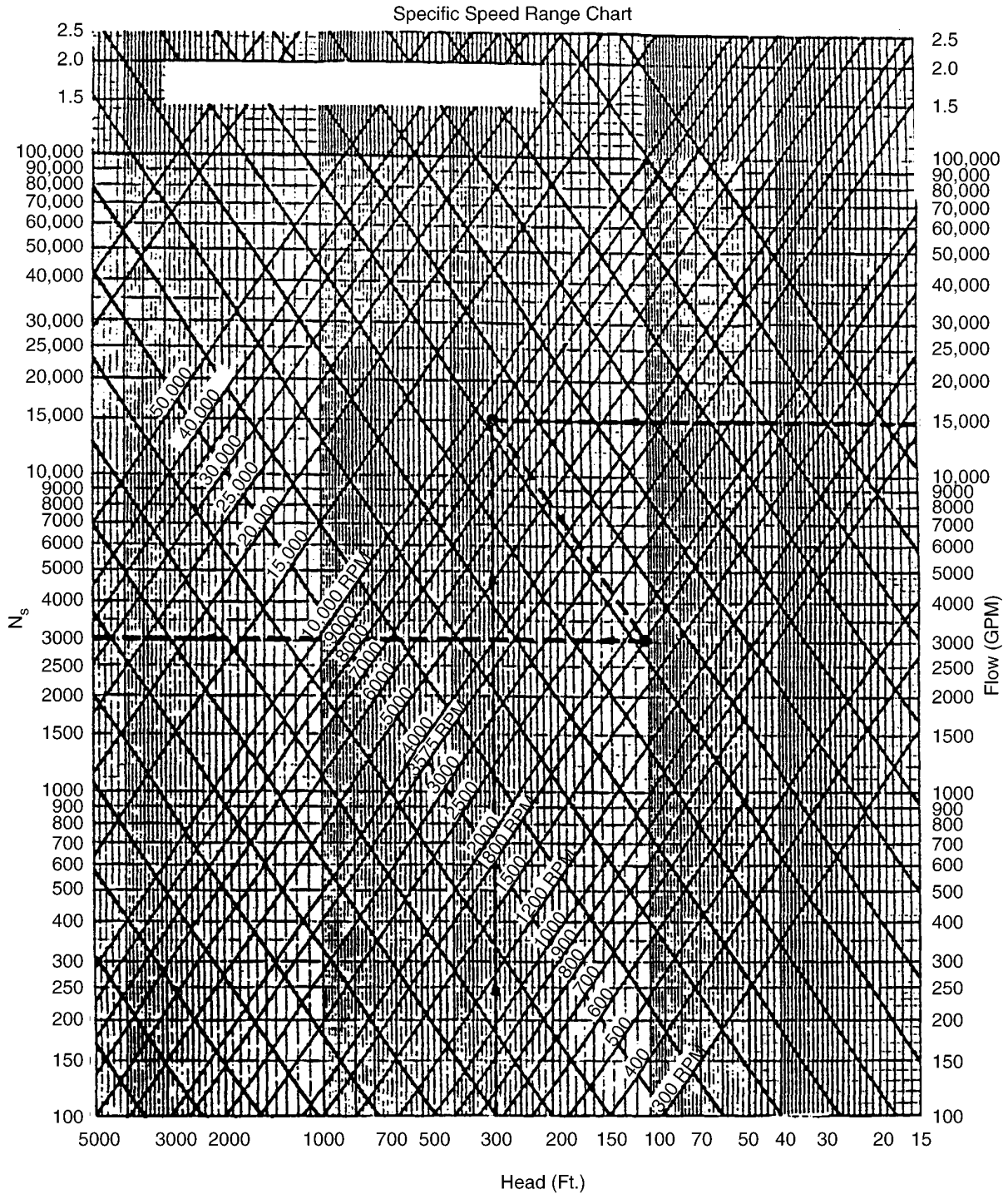


Figure 2-2
Comparison of Impeller Profiles for Various Specific Speed Designs



Note: Profiles of several pump impeller designs ranging from a low specific speed radial flow on the left to a high specific speed axial flow on the right are placed according to where each design fits on the specified speed scale.

Figure 2-3
Comparison of Pump Profiles



Using Chart: Plot head-capacity point. Move from this point, parallel to heavy lines, to correct speed. From there, move horizontally to the left and read specific speed.

Example: (Dashed lines) H = 300 feet, Q = 15,000 GPM, N = 1800 RPM ⟶ N_s = 3058

Figure 2-4
Expected Centrifugal Pump Efficiency as a Function of Specific Speed, Flow, and Impeller Geometry

The pump specific speed defines the shape of the impeller and the expected efficiency versus flow requirements as shown in Figure 2-4. Most power plant pumps have a specific speed in the range of:

$$1000 \leq N_s \leq 3000$$

except for the large circulating pumps and most reactor coolant pumps, which are in the vicinity of 4500.

2.3 Impeller Designs

Figure 2-3 illustrates that there is a continuous change from the radial flow impeller, which develops pressure principally by the action of centrifugal force, to the axial flow impeller, which develops most of its head by the propelling or lifting action of the vanes on the liquid.

2.3.1 Radial Flow Impellers

Pumps with a radial flow impeller have very low specific speeds (up to approximately 1,000). The liquid enters the eye of the impeller and is turned by the impeller vanes and shroud to exit perpendicular to the axis of the pump shaft. Profile 1 in Figure 2-2 illustrates a typical radial flow impeller used in a vertical centrifugal pump. Pumps with radial flow impellers are installed in high-head, low-flow applications. In pumps of this type, the liquid enters the impeller at the hub and flows radially to the periphery as shown in Figure 2-5.

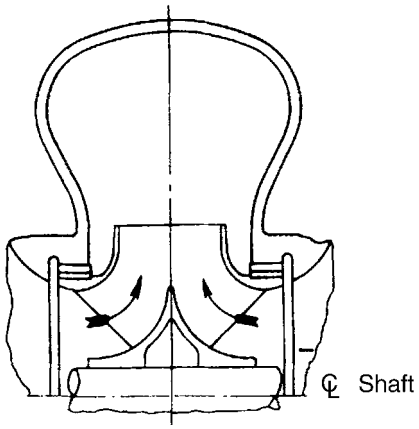


Figure 2-5
Radial Flow Pump Impeller (Double-Suction)

A pump with a modified radial flow impeller usually has specific speeds ranging from around 1,000 to 4,000. In pumps of this type, the liquid enters the impeller at the eye and exits semi-radially, at about a 60° or 70° angle with the shaft axis. Profiles 2, 3, and 4 in Figure 2-2 illustrate typical modified radial flow impellers used in vertical centrifugal pumps.

2.3.2 Mixed Flow Impellers

A pump with a mixed flow impeller has a single inlet impeller with the flow entering axially and discharging at about a 45° angle with the shaft axis to the periphery. Pumps of this type usually have a specific speed from 4,000 to 9,000. Profile 5 in Figure 2-2 illustrates a typical mixed flow impeller used in a vertical-type centrifugal pump. Pumps with mixed flow impellers are installed in moderate head and flow applications.

Pumps of this type with single inlet impellers usually have a specific speed below 4200, and with double-suction impellers, they have a specific speed below 6000. Figure 2-6 provides a sectional view of a mixed flow pump impeller used in a horizontal centrifugal pump.

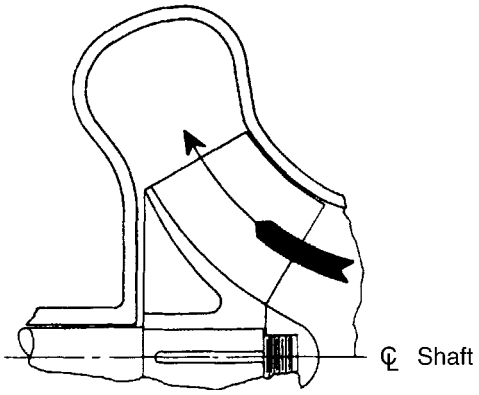


Figure 2-6
Mixed Flow Pump Impeller

2.3.3 Axial Flow Impellers

A pump with an axial flow impeller, also called a *propeller pump*, has a single inlet impeller with the flow entering axially and discharging nearly axially. Pumps of this type usually have a specific speed above 9,000. Axial flow impellers do not have a shroud attached to the impeller because the shroud is typically part of the stationary assembly. Profile 6 in Figure 2-2 illustrates a typical axial flow impeller used in a vertical centrifugal pump. Pumps with impellers of this type are installed in low-head, high-flow applications.

Figure 2-7 provides a sectional view of an axial flow pump impeller used in a horizontal centrifugal pump.

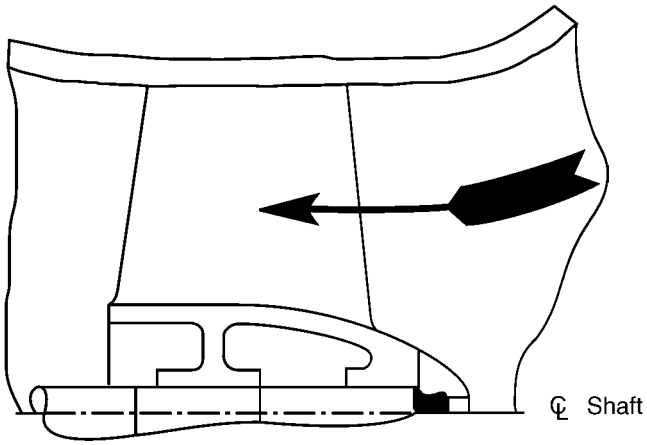


Figure 2-7
Axial Flow Pump Impeller

2.4 NPSH Terms and Derivations

Basically, most pumps operate with either suction lift or suction head. In suction lift, the liquid level on the suction side of the pump is below the centerline of the pump suction. In suction head, the liquid level is above the centerline of the pump impeller. All pumps have an associated required net positive suction head, commonly abbreviated as $NPSH_R$. It is a function of pump and impeller designs and varies with pump flow.

The net positive suction head available ($NPSH_A$) to a pump is defined as the absolute barometric pressure plus the suction head or minus the suction lift, minus the friction loss in the piping system leading to the pump suction, and minus the vapor pressure of the liquid being pumped.

$$NPSH_A = H_{absolute} +/- H_S - H_f - H_{vp}$$

Where,

$H_{absolute}$ is the absolute barometric pressure.

H_S is the suction head or suction lift.

H_f is the friction loss.

H_{vp} is the vapor pressure of the liquid being pumped.

To avoid significant cavitation, this NPSH available at the pump suction must always be greater than the NPSH required by the pump at a given flow. When the NPSH available is less than that required by the pump, cavitation occurs in the inlet of the impeller, as well as associated head loss.

To avoid damage from or issues associated with cavitation, the available NPSH should be greater than that shown on a typical 3% degraded $NPSH_R$ curve. Cavitation can be characterized by vapor bubbles forming at the impeller inlet vanes and then collapsing as they move into the higher pressure areas of the impeller. When these bubbles collapse, the energy that is released can create noise and damage. Depending on the magnitude of the cavitation, pump performance may degrade over time.

The NPSH required by a pump at various flows and speeds is measured by testing. A common method of NPSH testing is to establish a constant NPSH available to the pump at a speed and vary the pump flow by means of a discharge valve until a break-off in pump head-capacity performance is determined. Another method is to hold pump speed and capacity constant while the NPSH available is reduced either by throttling or changing the vacuum on the pump suction. With valve throttling (suppression testing), a valve is located in the suction line leading to the pump, and throttling this valve reduces the suction pressure on the pump to create varying NPSH conditions.

An alternative to valve suppression testing is to create a vacuum on the suction side of the pump. A tank or "hotwell" is used in which a liquid level is established, and the pressure above that liquid level is reduced by an ejector or a vacuum pump. Regardless of the method used, the technique is to establish specific NPSH requirements at various pump flows. From these established values, an NPSH required curve can be constructed. Typically, the NPSH values are established at discharge head break amounts with the most common being 3% of the nominal first-stage developed head at a given flow.

2.5 Speed-Torque Relationship

For pumps driven by electric motors, the motor has a specific amount of torque available at any given speed, and the pump requires another specific amount of torque. The difference between the two is the torque that will bring the pump up to speed. Eventually, the pump and motor will operate at the speed where the speed-torque curves of the pump and motors intersect. If, anywhere in the speed-torque relationship, the motor torque is less than the pump torque, the pump-motor unit will run at the reduced speed intersection of the torque curves and will never come up to full speed; the pump performance will be affected. The motor may quickly overheat in this condition and will trip if it has overload protection devices.

The pump torque requirement, as a function of revolutions per minute (rpm), can be calculated from a known pump performance curve. When the pump speed-torque curve has been established and superimposed on the motor speed-torque curve, it can be determined whether the motor will indeed start the pump. It can also be determined whether the unit can be started under reduced voltage conditions. The pump speed-torque curve must be established relative to pump flow.

For most pumps, it is desirable to start against a closed discharge valve to minimize starting torque requirements. If the pump is started against a partially-opened discharge valve or in conjunction with an opened bypass system, torque requirements will increase.

On high specific speed pumps, especially large vertical pumps where maximum pump horsepower requirements are at low flow or shutoff, starting the pump with an open discharge valve will reduce the starting horsepower. However, it is standard practice to start these large pumps with a closed discharge valve to avoid water hammer within the system. The valve is then gradually opened as the pump comes up to speed.

2.6 Pump Affinity Laws

There are three relationships of pump parameters that are known as the Affinity Laws. These three laws state:

1. Capacity (Q) varies directly as the speed ratio (N) and impeller diameter ratio (D):

   $Q_2/Q_1 = (N_2/N_1) = (D_2/D_1)$

2. Head (H) varies as the square of the speed ratio (N) and impeller diameter ratio (D):

   $H_2/H_1 = (N_2/N_1)^2 = (D_2/D_1)^2$

3. Brake horsepower (BHP) varies as the cube of the speed ratio (N) and impeller diameter ratio (D):

   $BHP_2/BHP_1 = (N_2/N_1)^3 = (D_2/D_1)^3$

2.7 Typical Pump Performance Curves

If it were not for losses, a vertical or horizontal centrifugal pump would generate a straight-line head-capacity curve. The slope of this head-capacity curve would be a function of impeller vane angles and other basic hydraulic parameters. Because of losses, however, the curve is not a straight line. Because friction losses increase as a function of capacity, the actual head-capacity curve is steeper than the theoretical curve, with the degree of steepness increasing as a function of capacity. When hydraulic shock losses (which occur at flows both to the left and to the right of the design or best efficiency point (BEP) flow) are added, the actual pump curve deviates further from the theoretical straight-line approach.

Two major factors affecting pump curve shape are specific speed and impeller/casing interactions. Figure 2-8 illustrates the relationship between total head, flow, brake horsepower, and NPSH on a typical pump performance curve.

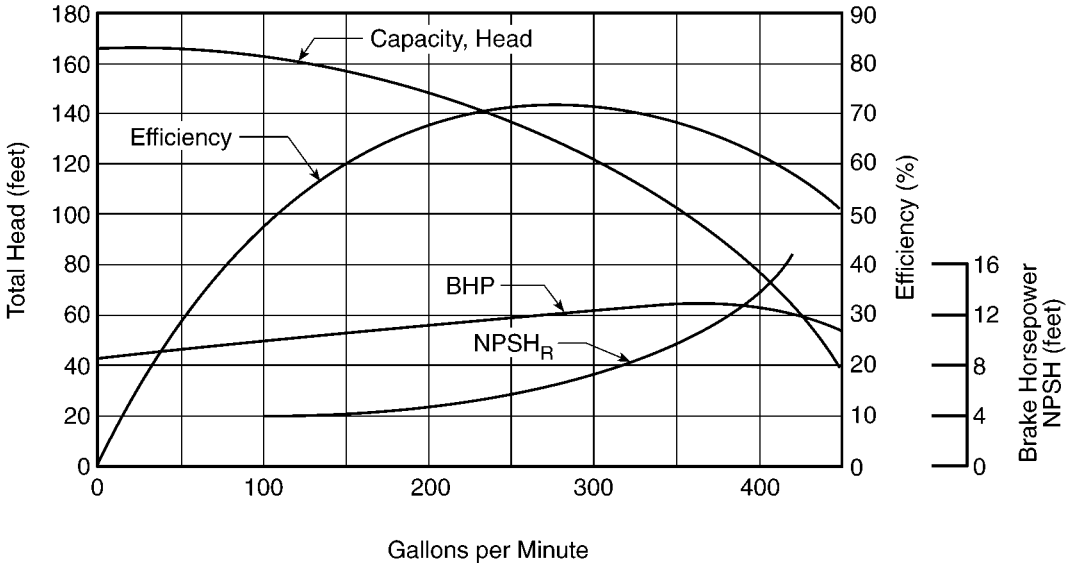


Figure 2-8
Typical Pump Performance Curve

2.8 Types of Pump Bearings

The bearing types used in centrifugal pumps can be generally categorized as either radial bearings or thrust bearings. Radial bearings are usually ball bearings (sometime referred to as anti-friction bearings), sleeve bearings, or tilt pad bearings. Radial bearings are typically arranged to carry only radial loads. Thrust bearings can be either ball-type anti-friction bearings or hydrodynamic-type tilting shoe bearings.

Overhung coupled impeller pumps usually employ ball (antifriction) bearings only. In vertical overhung uncoupled impeller pumps, both radial and thrust bearings may be in the motor only. In a typical two-bearing housing arrangement, the radial ball bearing is located adjacent to the impeller or in the inboard position, and is arranged to take only radial loads. The thrust bearing is located closest to the coupling and usually consists of a duplex pair of angular contact antifriction bearings. The thrust bearings can be mounted in several types of arrangements. Refer to the vendor drawings for the correct mounting configuration.

For between-bearing pumps as shown in Figure 6-2, the ball radial bearing and the ball thrust bearing combination have individual bearing housings. The radial bearing is normally located at the coupling end of the pump. The ball thrust bearing is located at the outboard pump end. The thrust bearing must be secured axially on the shaft to transmit the axial thrust load to the bearing housing through the bearing. The bearing is usually located against a shoulder on the shaft and is locked in place by a bearing nut. This means that the shaft diameter under the thrust bearing is less than the shaft diameter under the radial bearing. Thus, by mounting the radial bearing on the inboard or coupling end of the pump shaft, a larger shaft diameter is available to transmit pump torque from the coupling to the impeller. Whereas the thrust bearing is locked axially in the thrust bearing housing, the radial bearing is axially loose in its housing to allow for axial thermal growth.

Another bearing combination for two-bearing pumps consists of sleeve radial bearings and a ball thrust bearing. In such an arrangement, all radial pump loads are handled by the sleeve radial bearings. The ball thrust bearing is mounted in the thrust bearing housing such that the thrust bearing carries only axial loads. The housing around the ball thrust bearing is radially loose. A clamp is used on the outer races of the thrust bearing that locks into the bearing housing to prevent rotation of the outer race. This bearing arrangement is useful in higher horsepower and higher speed applications where ball radial bearings would be impractical due to speed, load, and lubrication limitations. Because the ball thrust bearing is located on the outboard end of the shaft, the shaft diameter under the ball thrust bearing can be relatively small since torque requirements are low at this end of the shaft.

For applications where ball bearings would be impractical due to shaft size, loads, and speeds, sleeve or tilt pad radial bearings are used in conjunction with tilt pad thrust bearings. Again, the radial bearing housing is generally located at the coupling or inboard end of the pump, and the housing containing the radial bearing and thrust bearing combination is located at the outboard end of the pump. The tilting pad thrust bearing is capable of operating at high speeds and high axial loads. Lubrication of this type of bearing is force fed to the bearing, and a common arrangement is to couple a shaft-driven oil pump to the thrust bearing end of the pump shaft.

In vertical pumps in water service, it is common to use water-lubricated radial sleeve bearings and a thrust bearing in the motor to support the weight of the pump rotor and downward thrust loads during operation. In smaller pumps, especially small multi-stage vertical pumps, the radial bearings are normally of simple sleeve design and are arranged to ensure a flow of water lubrication to the bearing clearances. On larger vertical pumps, rubber bearings, with large flutes for passage of the water lubrication, are commonly used. There are also designs that have enclosing tubes around the shaft and radial bearings to allow for an alternative clean water supply to lubricate the radial bearings.

2.9 Pump Lubrication

The common types of lubricants used for pump bearings are grease and oil. Grease lubrication is normally limited to small, simple pumps that operate with relatively light loads at relatively low speeds. The grease supply can be located in the bearing housing surrounding the bearing, or the bearings themselves can be packed with grease and sealed (shielded bearings).

A more common lubrication system for centrifugal pumps is referred to as an *oil flood*. In such an arrangement, the bearing housing provides a sump or an oil reservoir. This sump maintains a level of oil at or near the centerline of the lowermost ball of the bearings. This oil level is usually maintained constant by a constant level oiler.

In engineered pumps where, because of speeds or loads, a simple oil flood system is not adequate, an oil atmosphere is created in the bearing housing by the use of oil rings. These oil rings are located axially on the shaft adjacent to both the radial and/or the thrust bearings. The rotation of the pump shaft drives the oil rings that carry oil to the shaft. The oil is thrown from the shaft by oil flingers, located adjacent to each oil ring. This creates an oil atmosphere, the oil is fed to each bearing, and the oil rings are typically submerged in about one-half inch (1.3 cm) of oil.

Another popular system for oil lubrication is called *pure mist lubrication*. In such an arrangement, an oil/air mist, under pressure, is fed directly into the bearing housing. There is no reservoir of oil in the housing, and oil rings are not used. The pressurized mist permeates the bearings. Vents are located on the backside of each bearing to ensure that the mist travels through the bearings. A drain is typically located in the bottom of the bearing housing to prevent the buildup of condensed oil.

Another version of the oil mist system is called a *purge mist*. This system is used in conjunction with a conventional oil flood or oil ring lubrication system. It combines the advantages of the positive oil circulation created by the oil ring or oil flood system with the pressurized uncontaminated oil mist system.

Sleeve bearings can be lubricated either by oil rings or forced feed. When sleeve bearings are used in conjunction with a tilting pad thrust bearing, both the sleeve bearings and the thrust bearing are lubricated with a forced-feed system. Radial tilt pad bearings also require a forced-feed lubrication system.

2.10 Pump Vibration Analysis

EPRI *Pump Troubleshooting, Volume 1*, TR-114612-V1, provides detailed guidance for interpreting pump vibration. The main objectives of several of the sections in Volume 1 are to determine:

- Which vibration frequency is responsible for the rotor, piping, or system damage
- What the root cause of the vibration is
- How to find the most appropriate solution

Most high-energy-input and high-speed pumps with flexible rotor geometry exhibit one or more of the following common vibration frequencies:

- Rotational (synchronous: 1 x N)
- Two times rotational (first harmonic: 2 x N)
- Subsynchronous (a fraction of running speed, such as 0.5 x N or 0.65 x N or less than 10 Hz)
- Vane passing (number of impeller vanes [Z] times rotation [Z x N])
- Multiples of vane passing (n x [Z x N])

Vibration in general can be grouped into two major categories:

- Forced vibration, which is speed dependent:
  - Unbalance (dynamic or hydraulic: 1 x N)
  - Vane passing (hydraulic: Z x N)
- Self-exciting vibration, which is independent of speed, always at some fraction of speed, and usually less than N (that is, subsynchronous):
  - Oil-whip (journal-bearing-related, also called bearing instability)
  - Friction or rubbing induced
  - Hydraulic instability (percent of design flow dependent)

In many cases, a combination of two or more of the above vibration frequencies is detected in a centrifugal pump. Volume 1 provides detailed troubleshooting guidance for determining the root causes of pump degraded performance or failure, based upon the combination and/or types of vibration frequencies exhibited. Refer to the following sections in Volume 1 for further guidance:

- Section 4, Synchronous Vibration Frequency
- Section 5, Subsynchronous Vibration Frequency
- Section 6, Examples of Vibration Combinations
- Section 7, Vane Passing Frequency and Its Multiples
- Section 8, Very Low Frequency Vibration

2.11 Acronyms Used in This Report

ANSI American Nuclear Standards Institute

BEP best efficiency point

BHP brake horsepower

CCW component cooling water

CRD control rod drive

EHC electro-hydraulic control

EPRI Electric Power Research Institute

GPM gallons per minute

HI Hydraulics Institute

HPCI high-pressure coolant injection

INPO Institute of Nuclear Power Operators

IDP Ingersoll-Dresser Pump Company

MFW main feedwater

NMAC Nuclear Maintenance Applications Center

NP nuclear power

NPSH net positive suction head

NRC Nuclear Regulatory Commission

NSR non-safety related

OEM original equipment manufacturer

PD positive displacement

RCIC reactor core injection cooling

RHR residual heat removal

RPM revolutions per minute

RWCU reactor water clean-up

TR Technical Report

3
EVALUATING PUMP PERFORMANCE PROBLEMS

3.1 Generic Process for Pump Troubleshooting

Figure 3-1 depicts the generic process for troubleshooting pump performance problems. The process is primarily divided into a preliminary evaluation and a more detailed troubleshooting process.

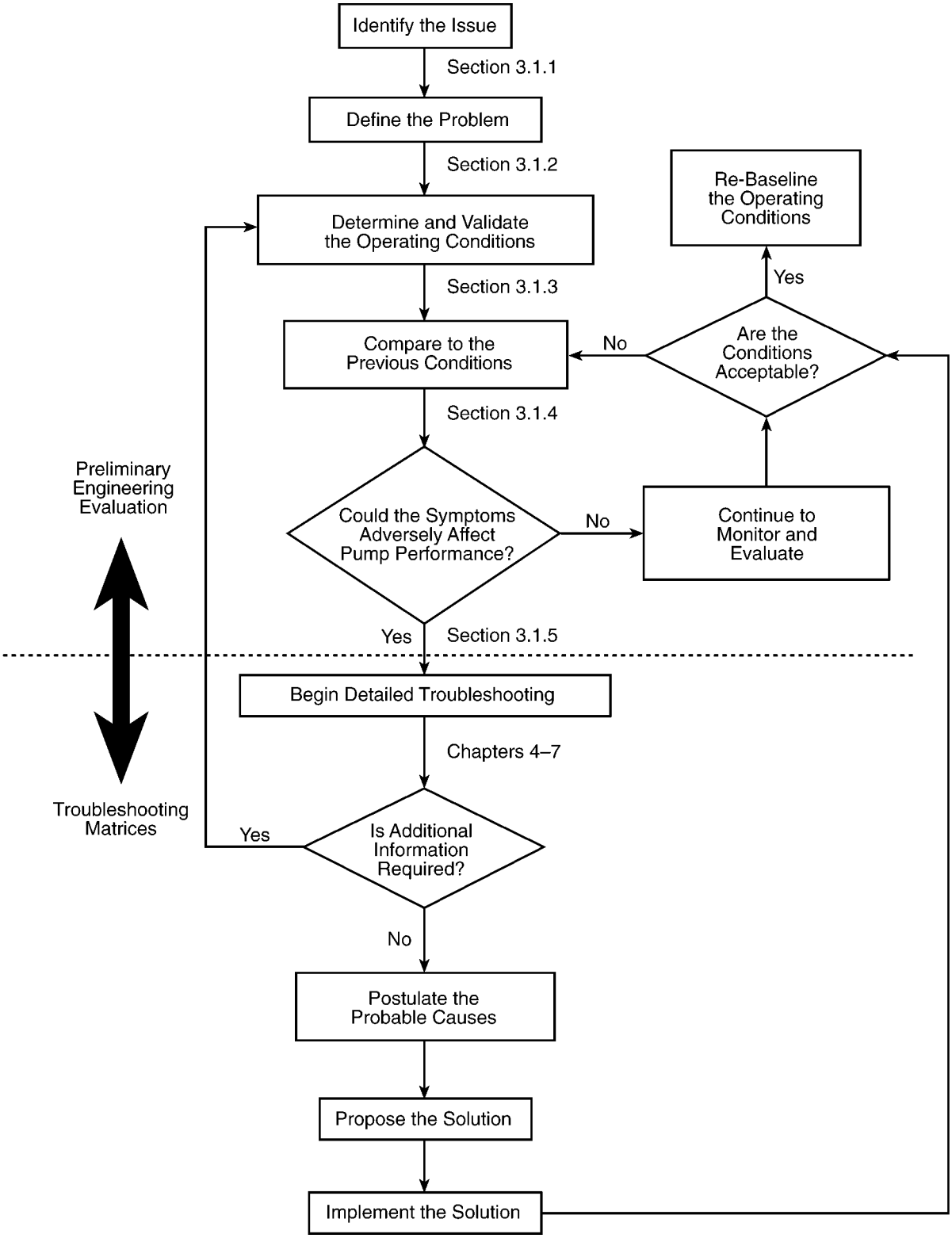


Figure 3-1
Generic Process for Troubleshooting Pump Performance Problems

3.1.1 Identifying the Issue

A performance issue can be communicated to a system/component engineer in a number of ways. Figure 3-2 illustrates that the issue could be something observed by maintenance personnel, a symptom of a more serious problem, or a management directive to take corrective action. In any case, the system/component engineer must gain a clear understanding of the issue before a root cause solution can be reached. This requires eliminating or understanding the unknowns and acting on the known facts in a systematic manner. Thus, a solid grasp of the facts is essential for the troubleshooting process to be successful in as few iterations as possible.

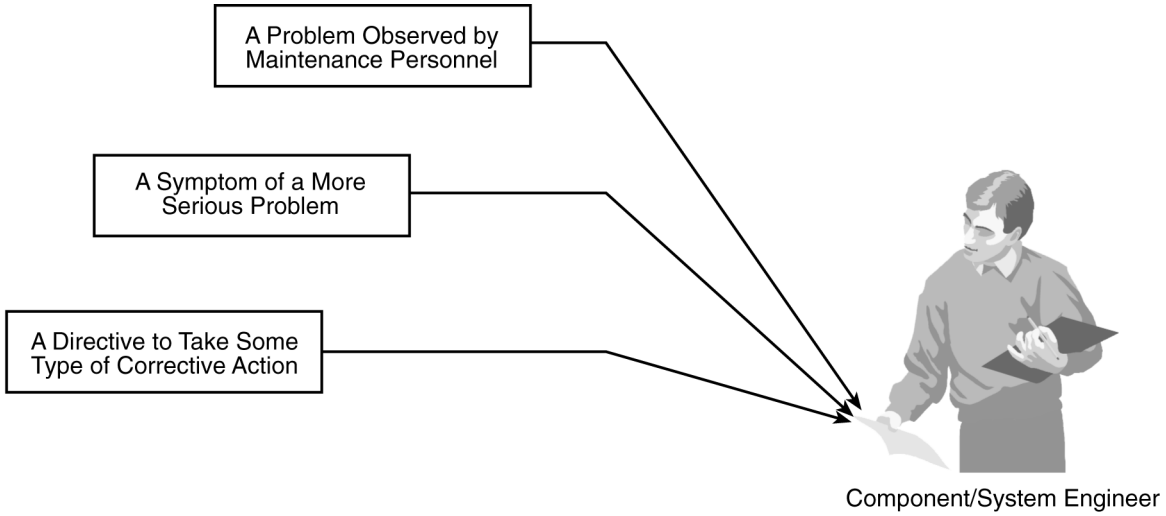


Figure 3-2
Communicating Issues to Component/System Engineers

Pump performance issues and component failures can be communicated to a system/component engineer in any of the following ways:

- Maintenance work order
- Failed inservice test
- Corrective action report
- Performance monitoring (condition monitoring reports)
- Phone call
- Operations rounds or turnover sheets
- Vendor technical bulletins
- INPO/NRC reported industry events
- Engineer walkdowns

3.1.2 Defining the Problem

As noted above, the component/system/maintenance engineer should clearly define the problem before proceeding with pump troubleshooting. The engineer should try to understand the scope and nature of the issue, identify the severity of the problem, and learn to what extent the problem has been observed in the plant or operating system. To accomplish this, the engineer should:

- Understand how the problem could apply to other pumps of similar design and applications.
- Validate the information (symptom) to ensure that it is reasonable, technically accurate, and representative of observed conditions. A face-to-face interview with the personnel communicating the pump performance issue should be considered.
- Contact outside sources such as the NMAC Pump Users Group Web Site or the OEM or review NRC Information Notices to obtain clarification and insight into whether the problem has occurred with other pumps of the same design installed in similar applications.
- Perform an eyewitness/hands-on inspection of the equipment to validate the issue and subsequently define the actual problem.

After these actions are taken, the engineer should be able to understand the issue that was initially communicated, identify the actual symptoms of the pump performance, and begin to focus the scope of further troubleshooting efforts (including measurements of operating conditions).

3.1.3 Determining and Validating Operating Conditions

After the issue is clearly defined, the next step in the troubleshooting process is to determine which operating conditions should be measured or what additional information should be collected and how that information will be validated. Typically, the engineer should consider measuring any of the plant, system, or component parameters noted in Figure 3-3.

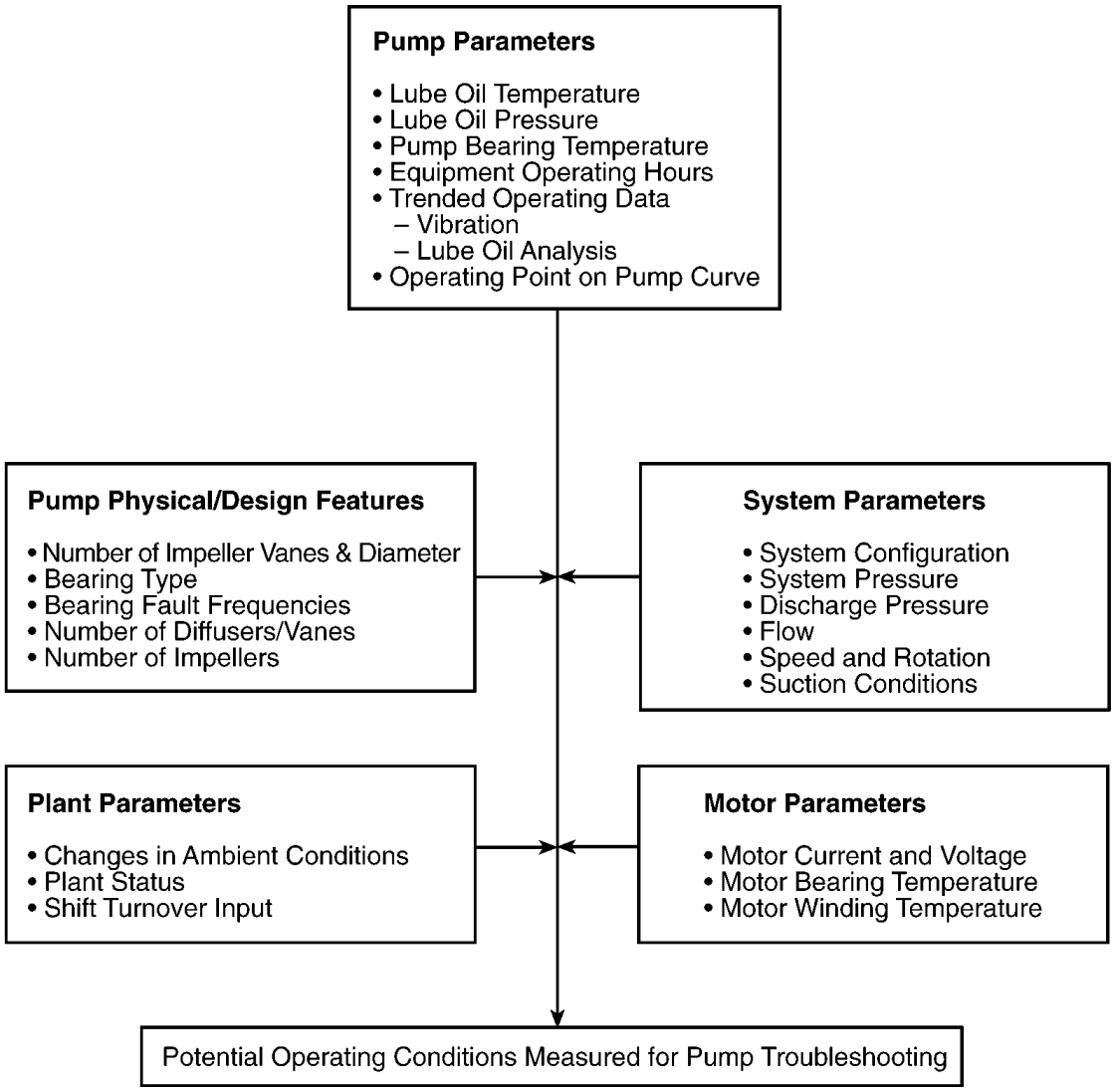


Figure 3-3
Operating Conditions Measured for Pump Troubleshooting

Measurements should be taken using calibrated instruments and reviewed for consistency against system design basis documents/outputs.

3.1.4 Comparing to Previous Conditions

3.1.4.1 Comparison to Design Requirements/Historical Performance

The next step in the troubleshooting process is to compare the measured parameters against the most recent or historical operating conditions. The engineer should try to detect trends in performance. If only one parameter changed since the previous conditions were monitored, the first action might be to validate the calibration of the instrumentation used to take the most recent measurement. However, if the comparison reveals that a number of parameters have changed or that the changes are following a trend and are degrading over time, then further investigation is warranted. The measured data should be compared against maintenance history and design requirements that can be found in documents such as:

- Pump curve
- Nameplate data
- Pump configuration drawings
- IST baseline data
- Pump and motor data sheets
- System head curve
- Vendor technical manuals
- Parts and materials list
- Recommended replacement parts list

Consideration of industry-wide historical operating conditions of the pump either at other nuclear sites or at other utilities should be an option at this point in the troubleshooting process.

3.1.4.2 Sources of Design Information

The design documents noted above might not provide all of the design information related to the system in which the pump is installed. As such, the following sources of design information should be also be considered:

- System design calculations
- System descriptions
- Design basis documents
- Materials management information system
- Component/system technical specifications
- Component procurement specifications
- Final Safety Analysis Report
- Component assembly drawings

3.1.5 Determining If Symptoms Could Adversely Affect Pump Performance

The engineer should make this determination considering the factors shown in Figure 3-4.

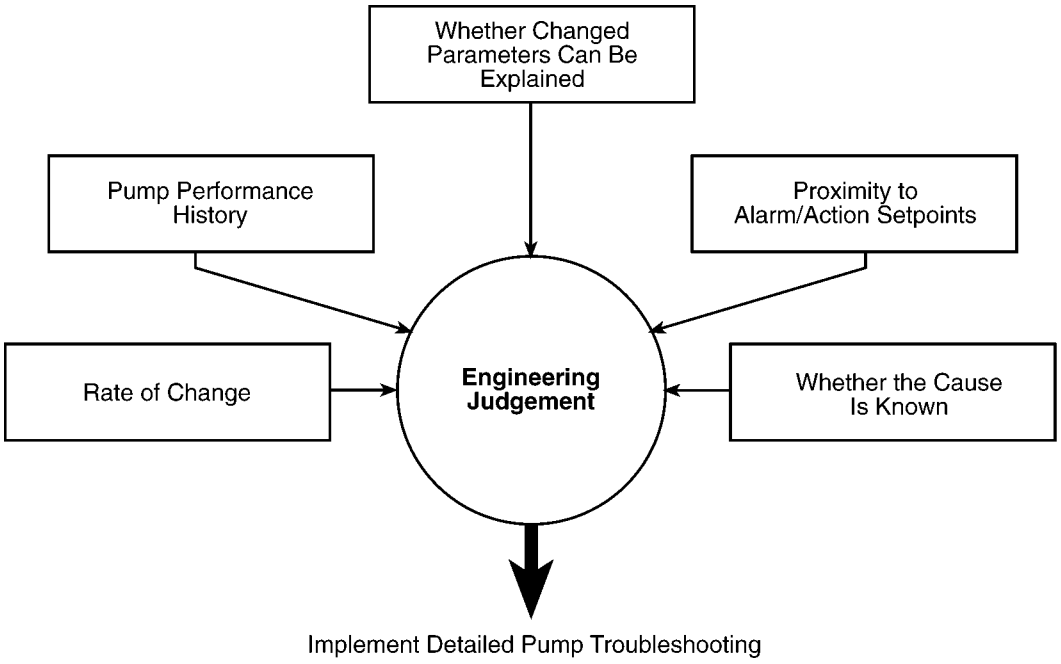


Figure 3-4
Factors Affecting the Need for Detailed Pump Troubleshooting

Figure 3-4 illustrates that the determination is very subjective and will vary depending on the level of conservatism of each engineer and possibly on the work processes/scheduling controls in place. If the conditions warrant further investigation and more detailed troubleshooting, the engineer should refer to the pump-specific troubleshooting guidance provided in Sections 4–7 of this report. If the conditions do not warrant detailed troubleshooting, the engineer should consider continued or increased monitoring of the pump performance parameters, including the test parameters. Experience and conservatism may result in doing both increased monitoring and detailed troubleshooting to some reasonable extent.

3.2 Performing Detailed Pump Troubleshooting

One of the key components of troubleshooting is determining if the problem is related to flow or speed. The troubleshooting recommendations described in this report include actions to make system or condition changes that will assist in arriving at this determination. The pump troubleshooting matrices are designed to assist the system/component/maintenance engineer after the decision has been made to conduct detailed troubleshooting.

The detailed troubleshooting matrices in Sections 4–7 contain the following three fields of information:

- The first column lists commonly found symptoms associated with pump performance. These symptoms are not prioritized in any manner.
- The second column lists probable causes for each symptom that are prioritized and correlate directly to a list of recommended actions. These causes are listed in order, beginning with the ones that would result in the least intrusive actions and ending with those that would result in physical modification/internal repair of the pump.
- The third column lists the recommended actions to be taken by engineering/maintenance that correspond to the probable causes listed in the second column.

To avoid redundancy in the matrices, performing vibration spectrum analysis is recommended for troubleshooting any probable cause that is associated with either excessive pump vibration or noise.

4
VERTICAL PUMPS

4.1 Pump Design Overview

A centrifugal pump is a kinetic machine that converts mechanical energy into hydraulic energy through centrifugal force. A vertical (centrifugal) pump is physically oriented so that the pump shaft and impeller are perpendicular to the water surface in which the pump is submerged.

The following overview is an excerpt from *American National Standard for Vertical Pumps*, Hydraulic Institute, Parsippany, NJ, May 1994. ANSI/HI 2.1-2.

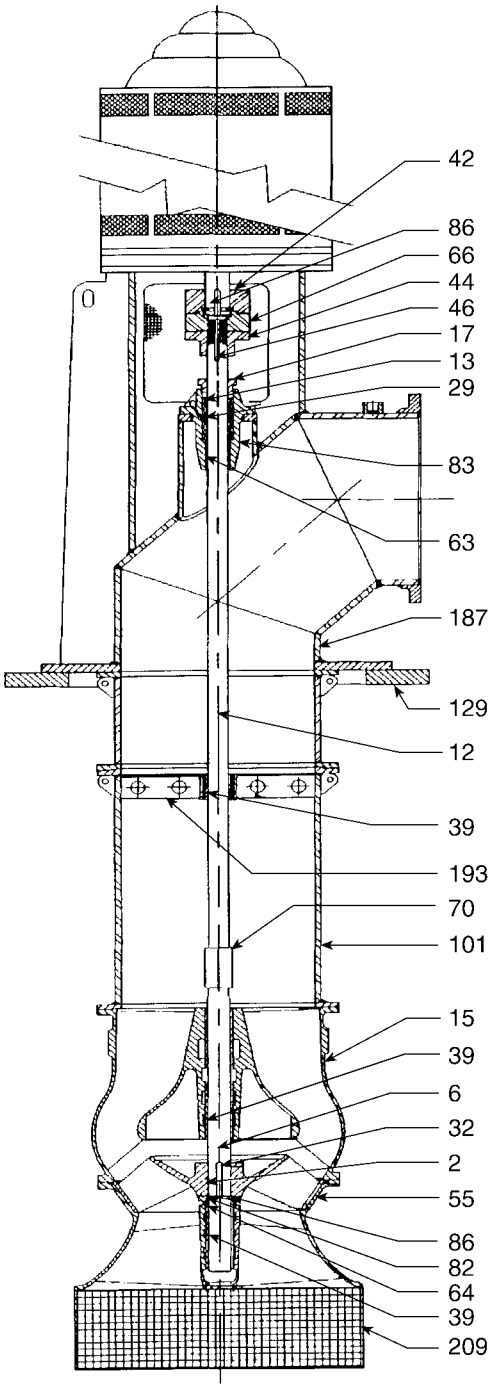
4.1.1 General Pump Design Attributes

All vertical pumps contain one or more stages (bowls/diffusers/guide vanes). Typically, a vertical pump is equipped with one of the following three types of impellers:

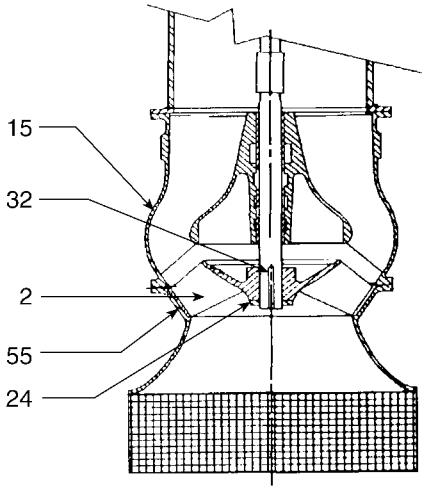
- Radial flow (includes modified radial flow such as turbine pumps)
- Mixed flow
- Axial flow (propeller pumps)

The pumps, particularly the radial flow and modified radial flow types, are usually designed for multi-staging, by bolting or threading individual bowls together. The pumping element (bowl assembly) is usually suspended by a column pipe, which also carries the liquid from the bowl assembly to the discharge opening. The driver is mounted either:

- On the discharge head (lineshaft pumps)
- Directly to the bowl assembly, either above or below (pumps with submersible motors)
- In a horizontal configuration, such as an electrical motor or engine, driving through a right angle gear



2	Impeller
6	Shaft, Pump
12	Shaft, Line
13	Packing
15	Bowl, Discharge
17	Gland
24	Nut, Impeller
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
64	Collar, Protecting
66	Nut, Shaft, Adjusting
70	Coupling, Shaft
82	Ring, Thrust, Retainer
83	Stuffing Box
86	Ring, Thrust, Split
101	Pipe, Column
129	Sole Plate
187	Head, Surface Discharge
193	Retainer Bearing Open Lineshaft
209	Strainer (optional)



Bearing Below Impeller

Without Bearing Below Impeller

Figure 4-1
Section View of Mixed Flow Vertical Pump (Open Line Shaft)

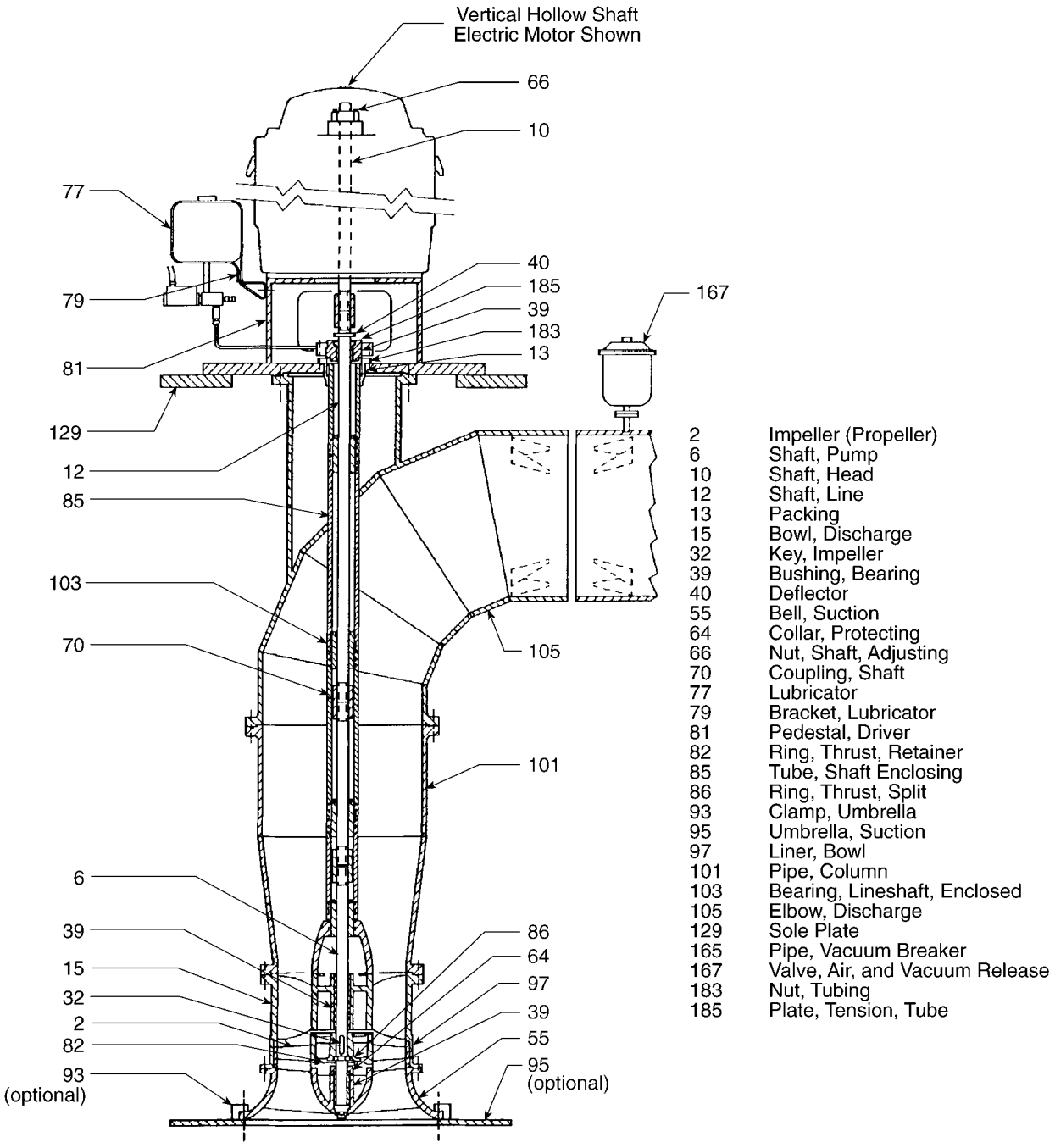
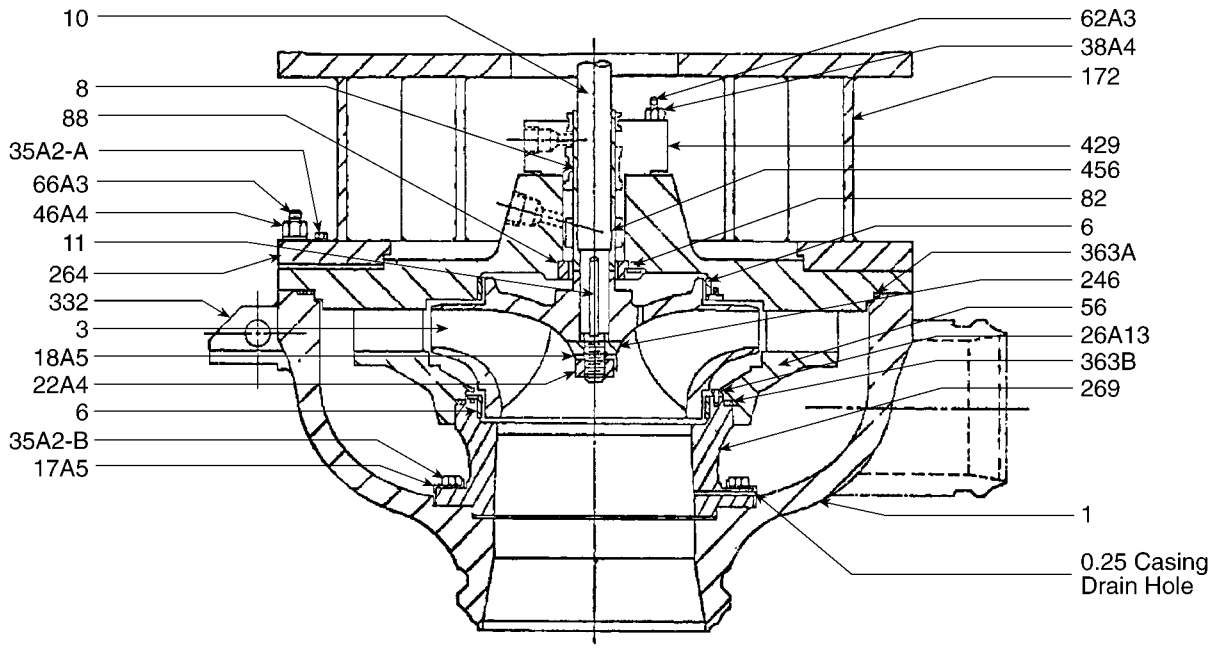


Figure 4-2
Section View of Axial Flow Vertical Pump (Enclosed Line Shaft)



1	Casing	56	Diffuser
3	Impeller (248-302 BHN)	88	Stuffing Box Bushing
6	Casing Rings	172	Supporting Head
8	Shaft Sleeve	22A4	Impeller Nut (1.250)
10	Shaft Furnished by Motor Manufacturer	18A5	One-Tab Washer
11	Key (Impeller & Shaft Sleeve)	246	Washer
17A5	Two-Tab Washer	264	Stuffing Box Extension
26A13	Anti-Rotation Pin (Driv-Loc)	269	Suction Ring
35A2-A	Cap Screw (.750)	363A	Gasket, Spiral Wound Flexitallic
35A2-B	Cap Screw (.500)	363B	Gasket, Spiral Wound Flexitallic
38A4	Gland Nuts (.750)	332	Pump Feet
46A4	Nuts (2.000)	429	Mechanical Seal - Complete (Gland)
62A3	Gland Studs (.750)	456	O-Ring
66A3	Studs (2.000)		
82	Lock Screw		

Figure 4-3
Section View of Ingersoll-Dresser Type WDF Vertical Pump

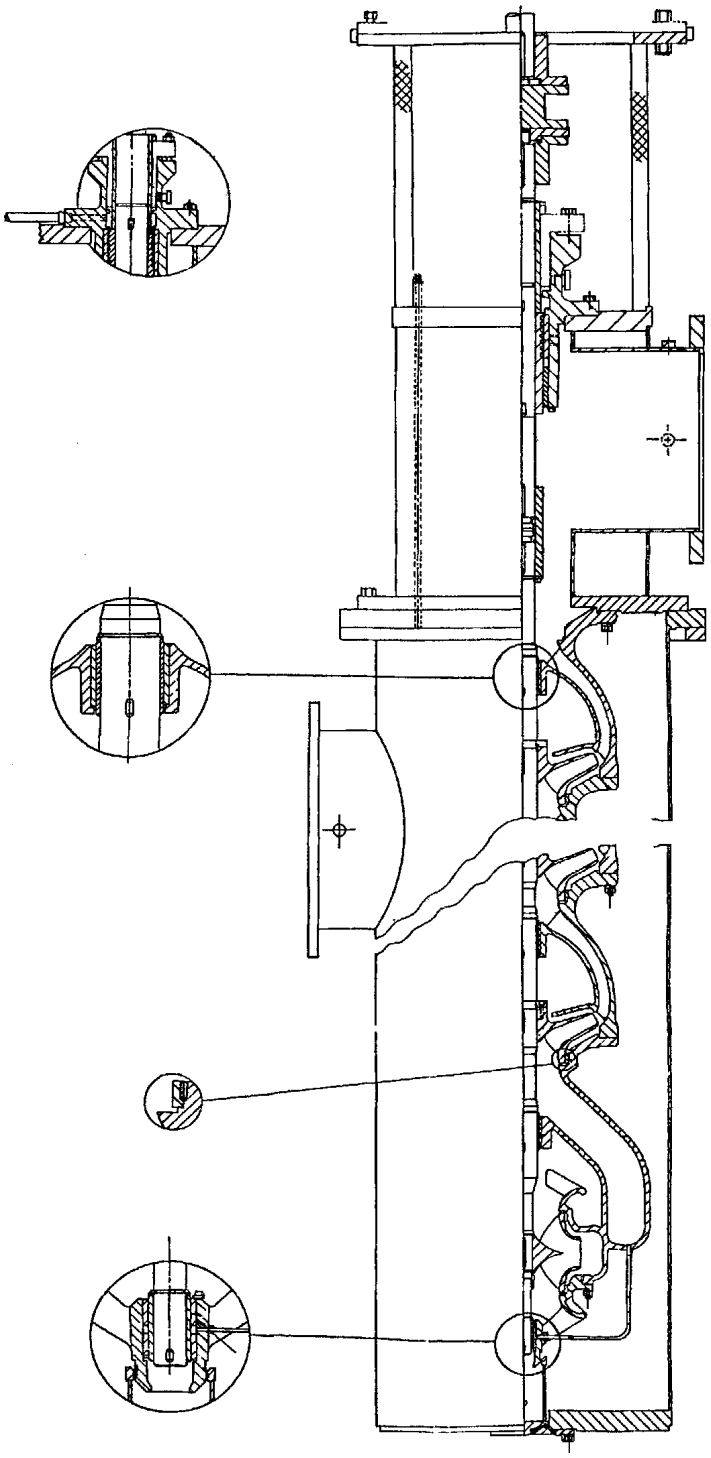


Figure 4-4
Section View of Ingersoll-Dresser Type APKD Vertical Pump

4.2 Nuclear Plant Applications and Detailed Troubleshooting Matrix

Typical nuclear plant applications for each of the three types of vertical pumps are provided in Table 4-1 below. The list of nuclear plant applications is provided for as a reference only. The applications do not represent a complete list because applications can vary from plant to plant. Likewise, the list of representative manufacturers and model numbers is not all-inclusive. This list does not represent an endorsement of the respective manufacturers or their products in any way.

Table 4-1
Nuclear Plant Applications and Typical Manufacturers/Models of Vertical Pumps

Nuclear Plant Applications for Vertical Pumps (Axial Flow, Mixed Flow, and Radial Flow)	Typical Manufacturers and Models of Vertical Pumps
Auxiliary salt water supply	Allis-Chalmers
Biology laboratory supply	Aurora – 20KM
Circulating water	Byron Jackson - KXH, VMT, CKXLH, CXL, CKXH, KXL, WX, DFSS
Condensate hotwell	Foster Wheeler
Containment spray	Hayward Tyler - VSN
Cooling tower supply and make-up	Ingersoll-Dresser - APKD, WDF, KD, APH, APM
Fire pumps	Johnston - CC, DC, CMC
Heater drain	Layne & Bowler - SKK
Reactor (main/primary) coolant	Peerless - 16M
Reactor recirculation	Sulzer Bingham - VCR, VCM, RQV, CVIC, VTM, VTR, CVDS, RV, SAFV, FFM, CVA
Residual heat removal (RHR)	Westinghouse/Hagan – 93 Series, 90MT
RHR (essential/emergency) service water	Worthington - QL
Service/river water	
Sump drain/dewatering	
Tank dewatering	
Traveling water screen spray wash	
Turbine lubricating oil	

Table 4-2
Troubleshooting Matrix for Vertical Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Insufficient capacity and/or pressure	Insufficient water supply or low suction pressure	Determine the proper supply of water for the pump and/or the proper level of pump submergence or suction pressure. Check for partially open suction valves or clogged strainers. Check for pin-holes in the suction piping.
	Speed too low	Check the power supply for the correct voltage and amperage. Confirm the speed with a tachometer or vibration frequency analysis.
	Worn casing or impeller wear rings	Examine the pump parameter trends and test data, the maintenance history, and the conditions of similar model/type pumps.
	Foreign material in inlet bell, impeller, casing vanes, and/or discharge head nozzle	Attempt a nonintrusive visual inspection (diver or boroscope). Dismantle the pump, inspect it for damage, and remove any foreign material.
	Mechanical defects (impeller damaged, failed/sheared impeller or coupling keys, broken shaft,[1] or failed coupling)	Dismantle the pump, inspect it, and correct the condition.
	Impeller lift set too high or worn[2] vanes or case	Verify that the lift meets the supplier recommendation. Reset the lift if required.
Pump does not rotate freely (by hand)	Pump binding at running fits	Verify the alignment and the lift. Dismantle the pump and correct the condition.
	Motor binds	Uncouple the pump and the motor, and verify free rotation.
	Packing is too tight	Remove the foreign material
	Foreign material in pump	Loosen the packing gland. Repack the pump stuffing box.

Table 4-2 (cont.)
Troubleshooting Matrix for Vertical Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Excessive packing or seal leakage	Packing not seated	The gland is not tightened evenly. Loosen the nut and tighten it evenly.
	System or pump transient	Review the system operating history for pressure spikes. Minimize transients.
	Worn pump	Replace the worn pump parts.
	Worn packing, shaft sleeve, or seal components	Replace the worn packing, shaft sleeve, or seal components.
	Incorrect packing or packing/lantern ring stack-up	Evaluate the packing material or the stack-up of the packing/lantern ring.
Excessive pump vibration[3]	Cavitation	Determine the proper supply of fluid for the sump and/or the proper level of pump submergence. Listen for noise as evidence of cavitation.
	Off-design flow operation	Compare the operating point to the pump best efficiency point (BEP) and historical operating points.
	Structural resonance	Inspect for structural integrity.[4] Review any recent modifications. Perform resonance testing.
	Motor-induced vibration	Perform an uncoupled run.[5]
	Imbalance	Consider an *in situ* balancing. Dismantle the pump and inspect it for foreign material, shaft run-out, mechanical imbalance, impeller erosion, or misalignment.
	Worn or damaged coupling	Inspect the coupling bolts and tighten them if needed. Inspect the coupling and replace it, if needed.
	Shaft misalignment	Check the alignment and correct it.

Table 4-2 (cont.)
Troubleshooting Matrix for Vertical Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Excessive pump vibration[3] (cont.)	Mechanical defects (shaft bent, bearings worn)	Dismantle the pump and replace the part or parts causing the vibration.
	Mounting and support flange joints allow rocking	Check the tightness and stability of each accessible joint between the head, motor, and support mounting. Use a feeler gauge while monitoring the vibration.
	Rubbing of mating parts[6]	Monitor the vibration during coast-down. Hand rotate the pump and/or motor. Uncouple the motor and the pump to verify free rotation of the motor and proper lift of the pump.
	Pump is not plumb	Level the baseplate.
Pump overloads driver	Pump running off-design due to system configuration changes[7]	Verify the system alignment. Plot the discharge pressure on the pump curve. Check the motor amperage.
	Fluid temperature changes	Review the design vs. operating conditions (density/specific gravity changes).
	Insufficient impeller lift	Confirm that the impeller lift is correct for the temperature of the pump fluid.
	Pump bearings seize or rotating element binds	Verify the proper bearing fits (designated by prefix and suffix). Hand rotate the pump and check for binding. Dismantle the pump and replace the part or parts causing seizures or binding.
Stuffing box overheats (packing)	Packing is too tight Insufficient leak-off flow	Loosen the packing follower nuts and retighten them finger tight in an attempt to achieve the proper leakage. Inspect the finish (roughness) of the stuffing box and pump sleeve. Repack the stuffing box with new packing and tighten the packing follower nuts finger tight.

Table 4-2 (cont.)
Troubleshooting Matrix for Vertical Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Stuffing box overheats (packing) (cont.)	Loss of cooling water supply	Verify the location of the lantern ring. Verify that the supply lines are clear. Reestablish the cooling water flow.
Seal chamber overheats (mechanical seal)	Loss of cooling water supply Inadequate venting	Reestablish the cooling water flow. Vent the system as necessary.
Pump is noisy	Cavitation	Verify the proper suction pressure or pump submergence. Determine the proper supply of water in the sump and/or the proper level of pump submergence during operation. Check for pin-holes in the suction piping.
	Vortex flow	Review the intake sump/suction design and configuration, the water level, the distance from the sides of the sump, and the flow patterns. Inspect for damaged vortex breakers.
	Noise in driver	Troubleshoot the driver.
	Off-design flow operation	Compare the operating point to the pump best efficiency point (BEP) and historical operating points.
	Mechanical looseness or worn parts	Tighten or replace the defective or worn part.

Notes:

1. A broken shaft (between the driver and impeller) or a failed coupling could result in no pressure or flow.

2. This applies primarily to open-vane impellers.

3. Performing vibration spectrum analysis is a common action to address any of the probable causes when there is excessive pump vibration.

4. Verifying structural integrity typically includes inspection of grout, mounting bolts, casing integrity, piping loads, and/or hangers.

5. An uncoupled run might not eliminate the motor as a probable cause of vibration because there will be minimal thrust load under this condition.

6. Thermally induced rubs may abate after temperature gradients stabilize.

7. This could result from either high or low flow, depending on pump brake horsepower curve characteristics (for example, large circulating water pumps exhibiting higher horsepower at lower flows).

Sources:

- *Instructions for Installing, Operating and Maintaining Pacific Pumps, Type JTC.* Dresser Industries, Inc., Huntington Park, CA. Manual No. 1100.4
- *Ingersoll Dresser Pump Instruction Manual for APMA-Type Pumps*. Ingersoll-Dresser Pump Co., Phillipsburg, NJ.

5
MULTI-STAGE HORIZONTAL PUMPS

5.1 Pump Design Overview

As noted in Section 4, a centrifugal pump is a kinetic machine that converts mechanical energy into hydraulic energy through centrifugal force. A horizontal (centrifugal) pump is physically oriented so that the pump shaft and impeller are parallel to the floor on which the pump is mounted.

The following overview is an excerpt from *American National Standard for Centrifugal Pumps*, Hydraulic Institute, Parsippany, NJ, May 1994. ANSI/HI 1.1-1.

5.1.1 General Pump Design Attributes

Multi-stage horizontal pumps are employed to generate high discharge pressures by discharging the fluid through a series of impellers or stages. Centrifugal pumps can be categorized by such methods as impeller configuration, impeller design, casing configuration, application of the pump, specific speed, or mechanical configuration. However, for the purposes of this report, the major distinction for categorizing nuclear plant applications is the casing configuration. Section 2 discusses pump categories based on impeller configuration, impeller design, and specific speed.

5.1.2 Casing Configurations

For the purposes of pump troubleshooting and distinguishing nuclear power plant applications, multi-stage horizontal pumps are categorized in Section 5.2 based on casing configurations: split casing and barrel casing.

5.1.2.1 Split Casings

A split casing has the casing split in half along its longitudinal axis and separated, in order to lift the pump internals. The split casings are typically held together with bolted flanges or casing rings.

5.1.2.2 Barrel Casings

A barrel casing has the casing configured in one hollowed piece instead of two halves. The pump internals are removed from the hollowed end of the barrel.

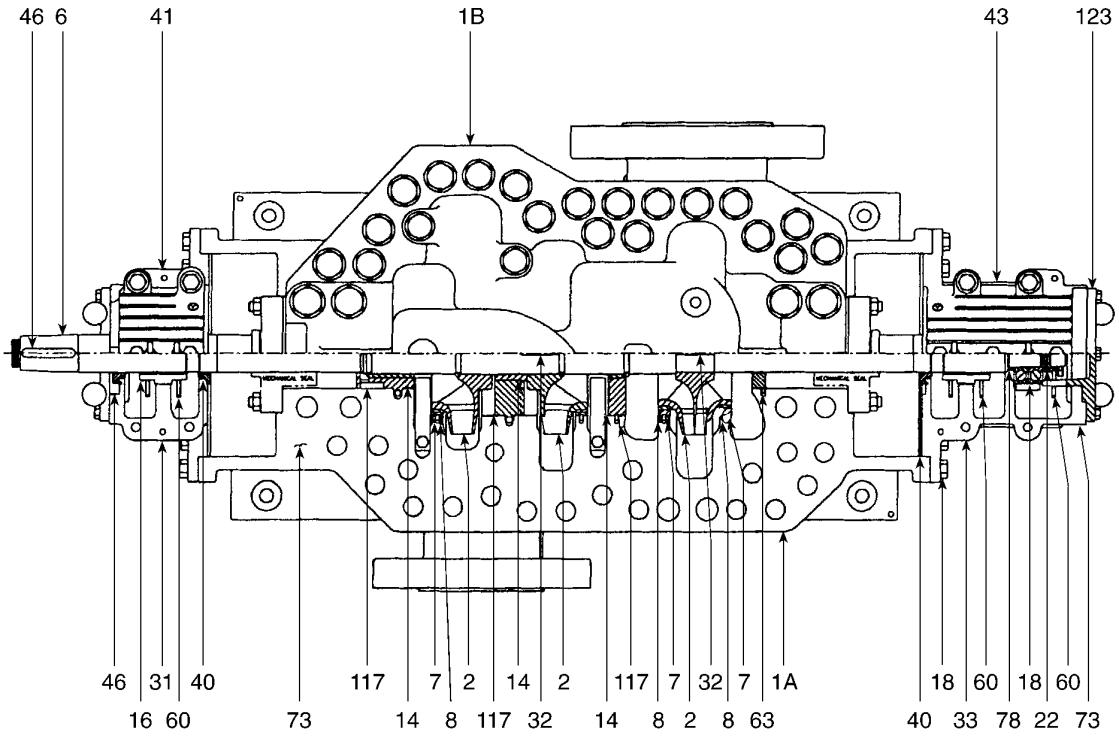
5.1.3 Impeller Configurations for Multi-Stage Horizontal Pumps

5.1.3.1 Overhung Impeller Types

In this group, the impellers are mounted on the end of a shaft that is cantilevered or "overhung" from its bearing supports. These pumps are either close coupled, where the impellers are mounted directly on the driver shaft, or separately coupled, where the impellers are mounted on a separate pump shaft supported by its own bearing.

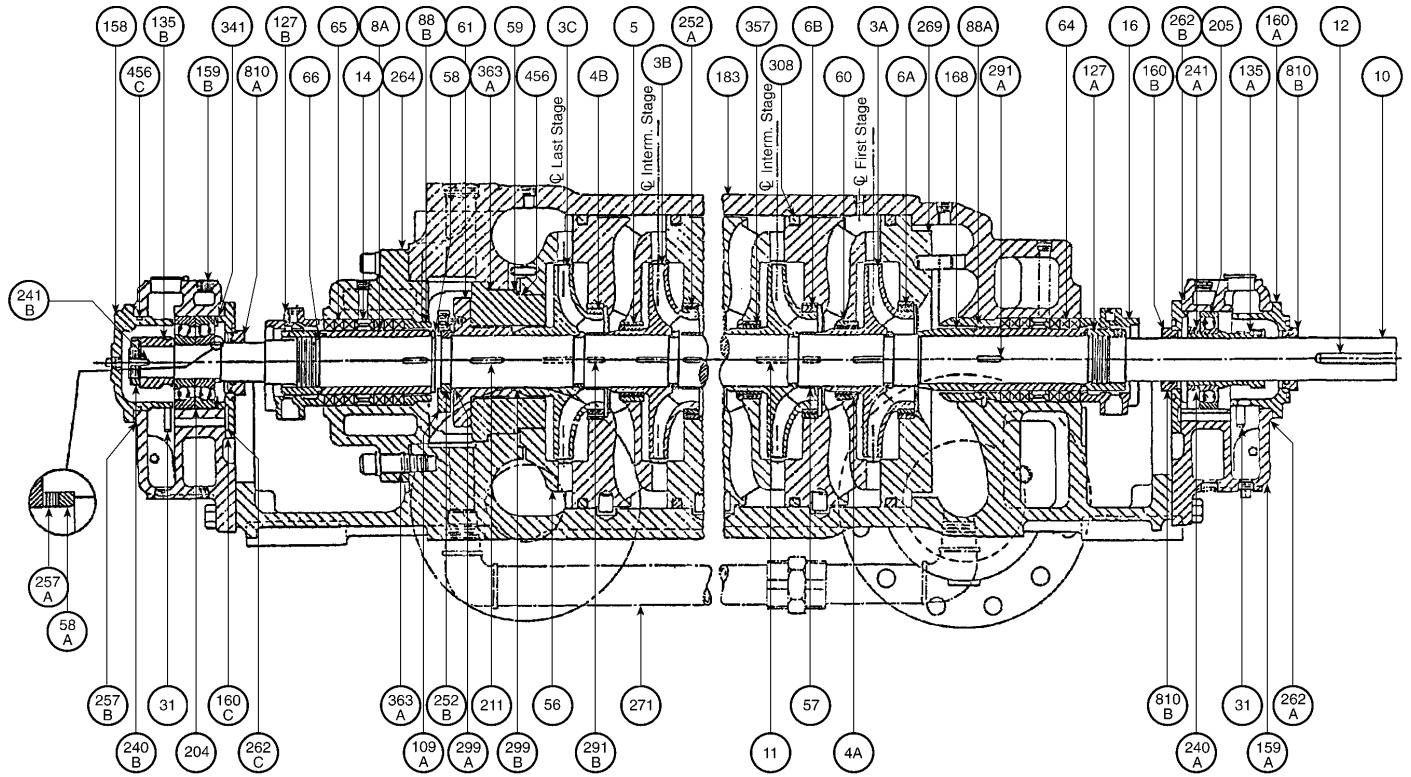
5.1.3.2 Impeller Between Bearings Type

In this group, the impellers are mounted on a shaft with bearings at both ends. The impellers are mounted "between bearings."



1A	Casing, Lower Half	33	Housing, Bearing, Outboard
1B	Casing, Upper Half	40	Deflector
2	Impeller	41	Cap, Bearing, Inboard
6	Shaft, Pump	43	Cap, Bearing, Outboard
7	Ring, Casing	46	Key Coupling
8	Ring, Impeller	60	Ring, Oil
14	Sleeve, Shaft	63	Bushing, Stuffing Box
16	Bearing, Inboard	73	Gasket
18	Bearing, Outboard	78	Spacer, Bearing
22	Locknut, Bearing	117	Bushing, Pressure Reducing
31	Housing, Bearing Inboard	123	Cover, Bearing End
32	Key, Impeller		

Figure 5-1
Multi-Stage Horizontal Pump (Axial Impeller Between Bearings, Split Casing)



3A	Impeller–First Stage	58	Distance Sleeve	159B	Bearing Housing–Thrust Bearing	262C	Gasket–Thrust Bearing–Pump Side
3B	Impeller–Intermediate Stage	58A	Distance Sleeve (Thrust Bearing)	160A	End Cover–Outboard (Radial Bearing)	262D	Gasket–Thrust Bearing–Outboard Side
3C	Impeller–Last Stage	59	Balancing Sleeve	160B	End Cover–Inboard (Radial Bearing)	264	Stuffing Box Extension
4A	Impeller Ring–Front–First Stage	60	Channel Ring	160C	End Cover–Inboard (Thrust Bearing)	269	Suction Ring
4B	Impeller Ring–Front–Specify Stage	61	Balancing Drum	168	Shoulder Collar	271	Balance Pipe (When Specified)
5	Impeller Bushing Ring	64	Packing–Stuffing Box (Suction End)	183	Casing–Complete	291A	Shaft Sleeve Key
6A	Casing Ring–First Stage	65	Packing–Stuffing Box (Discharge End)	204	Thrust Ball Bearing	291B	Intermediate Sleeve Key
6B	Casing Ring–Specify Stage	66	Packing–Shaft Sleeve	205	Radial Ball Bearing	299A	Retaining Washer–Balancing Drum and Split Ring at Impellers
8A	Shaft Sleeve (Packed Box)	88A	Stuffing Box Bushing (Suction End)	211	Balancing Drum Key	299B	Retaining Washer–Balancing Drum to Last Stage Impeller
10	Shaft	88B	Stuffing Box Bushing (Discharge End)	240A	Locknut–Radial Bearing	308	Sealing Ring–Channel Ring and Suction Ring
11	Impeller Key	109A	Retaining Ring (Balancing Drum)	240B	Locknut–Thrust Bearing	341	Spring–Schnoor
12	Coupling Key–Radial Bearing End	127A	Shaft Sleeve Nut (Suction End)	241A	Lockwasher–Radial Bearing	357	Channel Ring Bushing
14	Water Seal Cage (When Specified)	127B	Shaft Sleeve Nut (Discharge End)	252A	Split Ring–Impellers	363A	Gasket–Stuffing Box Extension to Casing
16	Gland–Two Halves	135A	Journal Sleeve–Radial Bearing	252B	Split Ring–Balancing Drum	363B	Gasket–Balncing Sleeve to Casing
31	Oil Ring	135B	Journal Sleeve–Thrust Bearing	257A	Shim–Thrust Bearing	456	O-Ring–Balancing Sleeve to Diffuser
56	Diffuser	158	End Cover–Thrust Bearing	257B	Shim–Thrust Bearing End Cover	456C	O-Ring–Outboard End Cover
57	Intermediate Sleeve	159A	Bearing Housing–Radial Bearing	262A	Gasket–Radial Bearing–Coupling Side	810A	Bearing Guard–Thrust Housing
						810B	Bearing Guard–Radial Housing

Figure 5-2
Section View of Ingersoll-Dresser Type HMTA Horizontal Pump

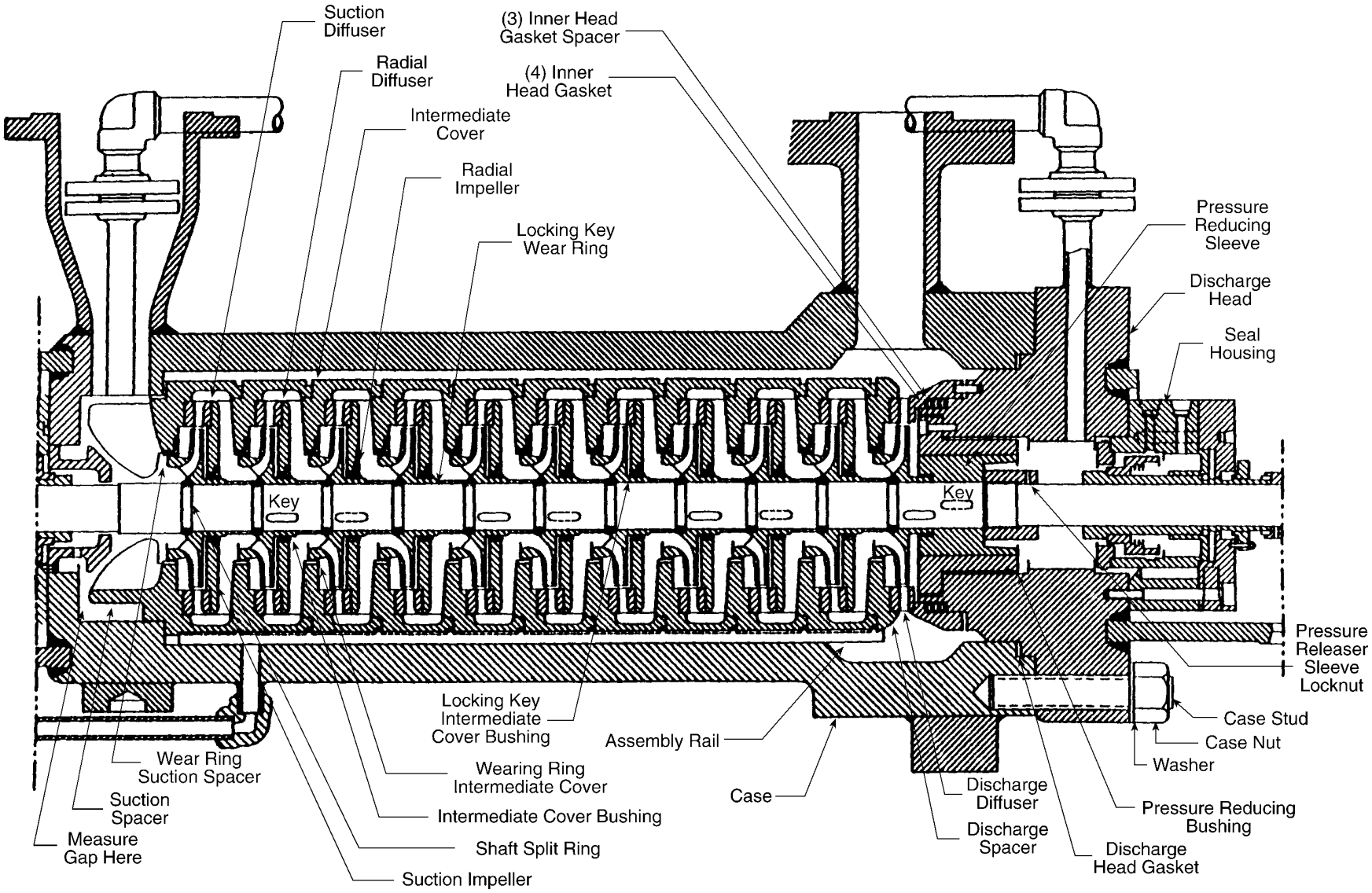


Figure 5-3
Section View of Pacific Model RLIJ 11-Stage Horizontal Pump

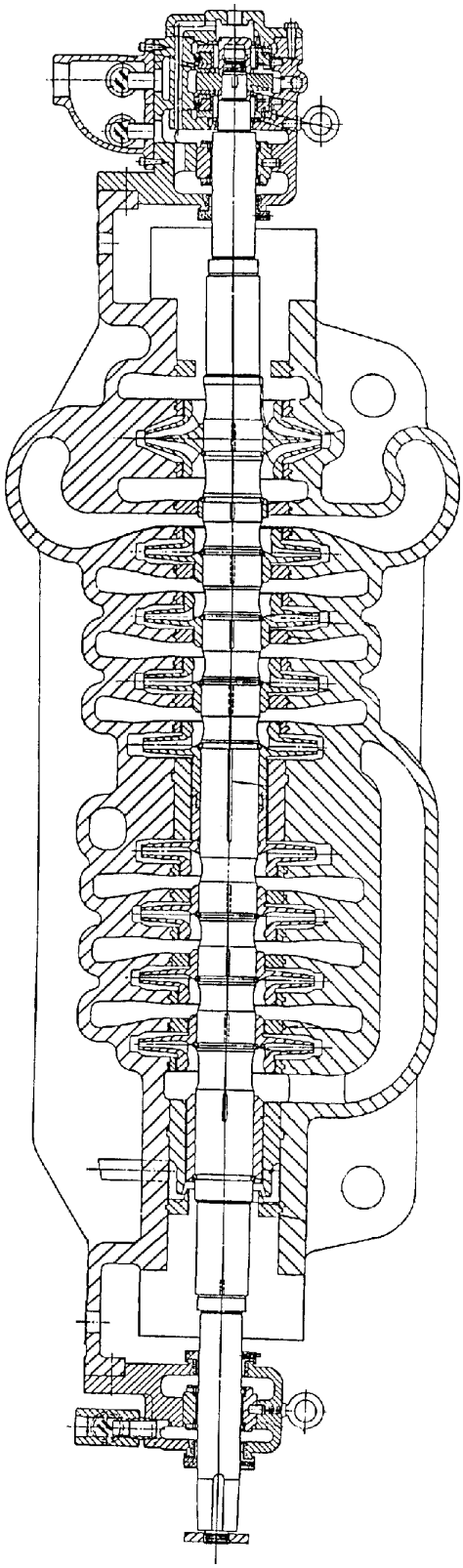


Figure 5-4
Section View of Byron Jackson Type-DVMX Horizontal Pump with Axially Split Case

5.2 Nuclear Plant Applications and Detailed Troubleshooting Matrix

Typical nuclear plant applications for each of the three types of vertical pumps are provided in Table 5-1 below. The list of nuclear plant applications is provided for as a reference only. The applications do not represent a complete list because applications can vary from plant to plant. Likewise, the list of representative manufacturers and model numbers is not all-inclusive. This list does not represent an endorsement of the respective manufacturers or their products in any way.

Table 5-1
Nuclear Plant Applications and Typical Manufacturers/Models of Multi-Stage Horizontal Pumps

Nuclear Plant Applications for Multi-Stage Horizontal Pumps (Split Casing and Barrel Casing)	Typical Manufacturers and Models of Multi-Stage Horizontal Pumps
Auxiliary feedwater	Byron Jackson - DVMX, DVS
Centrifugal charging	Ingersoll-Dresser - HMTA, C, CA, NH
Control rod drive (CRD)	Pacific - DSK, RHCH, RLIJ, JHF, JTCH
High-pressure coolant injection (HPCI)	Sulzer Bingham - MSD, CP, MSE, CP-D, MSD-D
High-pressure core spray	Union - MNB, MNC, MM
High-head safety injection	Worthington - WTF, WT, WTS
HPCI booster	
Main feed	
Reactor core injection cooling (RCIC)	
Safety injection (SI)	

Table 5-2
Troubleshooting Matrix for Multi-Stage Horizontal Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Failure to deliver required head and/or flow at start-up or during operation	Driver speed too low	Check the power supply for the correct frequency of the motor. Check the actual speed of the driver against the rated speed listed on the pump data sheet.
	Air leaks in suction line when operating under vacuum	Secure all vent connections. Check the flanges and expansion joints for leakage.
	Air/vapor pocket in suction line	Bleed the line through the vent connections. Operate the pump at the highest flow possible to sweep air from the system.
	Off-design pump operation	Check the pump data sheet or performance curve and adjust the system conditions to the rated head-flow levels. Check that normally closed discharge flow paths are not open, such as normally closed bypass lines.
	Actual NPSH available is lower than the specified NPSH requirement	Check the suction piping configuration and the open/closed position of the suction valve.
		Investigate for entrained air or air leaks when the suction pressure is low or a vacuum. The NPSH available may not be sufficient for acceptable performance.
		Check the suction strainer pressure drop. Clean the strainer if appropriate.
	Excessive recirculation from discharge to inlet	Check the flow through the bypass or recirculation lines. Adjust the valve if necessary. Check the clearances of internal wear surfaces.
	Incorrect direction of rotation	Correct the rotation.
	Installed impeller backward or in wrong location	Verify the proper configuration of the assembly.
	Foreign material in suction or discharge line	Clear the line of all foreign material, including the suction strainer and isolation valve.

Table 5-2 (cont.)
Troubleshooting Matrix for Multi-Stage Horizontal Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Failure to deliver required head and/or flow at start-up or during operation (cont.)	Material buildup and/or clogged passageways	Clear areas of foreign material.
	Pump not completely filled with liquid	Fill and vent the pump.
	Broken shaft	Inspect and repair the shaft.
	Impeller key sheared or missing from assembly	Disassemble and check the impeller key. Remove and replace it if damaged.
	Impeller damaged	Remove and replace the impeller.
Excessive vibration[1]	Cavitation	Determine the proper supply of process fluid. Verify that there is no leakage of air at the suction. Listen for noise as evidence of cavitation.
	Off-design flow operation	Compare the operating point to the pump best efficiency point (BEP) and historical operating points.
	Structural resonance	Inspect for structural integrity.[2] Review any recent modifications. Validate them with temporary supports. Perform resonance testing.
	Air or gas in liquid	Vent the air and check the suction for leaks. Check the alignment and tighten the flange bolts.
	Motor-induced vibration	Perform an uncoupled run.[3]
	Imbalance	Consider an *in situ* balancing. Dismantle and inspect the pump for foreign material, shaft run-out, mechanical imbalance, impeller erosion, and misalignment.
	Worn, locked, mismatched, or damaged coupling	Inspect the coupling bolts and tighten them if needed. Inspect the coupling. Verify the axial float.

Table 5-2 (cont.)
Troubleshooting Matrix for Multi-Stage Horizontal Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Excessive vibration[1] (cont.)	Shaft misalignment	Check the alignment and correct it.
	Mechanical defects (shaft bent, bearings worn)	Check the bearing fits (the housing ID to bearing OD and/or the bearing ID to shaft OD). Check the bearing to shaft clearance.[4] Dismantle the pump and replace the part or parts causing the vibration.
	Loose joints	Check the interface of each accessible joint between the casing, head, bearing bracket, bearing housing, and base/bed-plate. Use a feeler gauge while monitoring the vibration.
	Loose or improperly torqued bolting	Loosen and retorque the bolts.
	Rubbing of mating parts[5]	Monitor the vibration during coastdown. Uncouple the pump and the motor to verify free rotation of both.
	Inadequate bed-plate grouting or support	Regrout or add support if damage is found. Inspect the grout/bed plates for voids.
	Inadequate or misaligned pipe supports	Inspect the supports for looseness or anchoring problems and alignment.
	Foreign material in impeller(s) causing imbalance	Inspect with a boroscope. Dismantle the pump, if needed, and remove any foreign material.
Discharge pressure oscillations	Air leaks in suction line	Secure all vent connections. Check the flanges for leakage.
	Off-design flow operation	Compare the operating point to the pump best efficiency point (BEP) and historical operating points.
	Air/vapor pocket in suction line	Bleed the line through the vent connections.

Table 5-2 (cont.)
Troubleshooting Matrix for Multi-Stage Horizontal Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Discharge pressure oscillations (cont.)	Actual NPSH available is lower than the specified NPSH requirement	Check the suction piping configuration.
		Investigate for entrained air or air leaks when the suction pressure is a vacuum. The NPSH available may not be sufficient for acceptable performance.
		Check the suction strainer pressure drop. Clean the strainer if appropriate.
	Impeller is no longer axially centered	Inspect the float of the thrust bearing. Center the rotating element.
High pump bearing temperature	Off-design flow operation	Compare the operating point to the pump best efficiency point (BEP) and historical operating points.
	Improper coupling gap	Verify the coupling installation gap. Verify the correct axial float.
	Lack of lubrication	Perform an oil analysis on the used oil and replace it, if necessary. Check the condition of the grease-lubricated bearing. Perform an oil flush and verify the correct orifice sizes.
	Improper lubrication	Verify that the reservoir is not overfilled. Perform an oil analysis. Replenish the oil/grease with the proper grade lubricant.
	Performance/configuration of constant-level oiler	Verify the proper setting and physical location on the bearing housing.[6] Verify that the reservoir is not overfilled.
	Inadequate cooling to bearing housing or oil cooler	Check the cooling source and flow.
	Balance drum is set improperly	Perform an ultrasonic flow measurement of the balance lines, and check the setting against the recommended value. Dismantle and reset the balance drum as required.

Table 5-2 (cont.)
Troubleshooting Matrix for Multi-Stage Horizontal Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
High pump bearing temperature (cont.)	Blocked balance/equalizing lines	Inspect the lines and clean them as necessary.
Reduced balance line flow (warm to the touch)[7]	Restriction in balance line	Check the operating configuration of the recirculation system. Check for foreign material.
Seal chamber overheats (mechanical seal)	Loss of cooling water supply	Reestablish the cooling water flow.
Discharge pressure trending downward	Normal wear of pump subcomponents	Review the performance history for trends, number of operating hours, and number of starts and stops. Check the balance drum/disc line pressure/flow, lift, and thrust.
	System anomaly	Walkdown the system and analyze its performance.
Stuffing box overheats (packing)	Packing is too tight Insufficient leak-off flow	Loosen the packing follower nuts and retighten them finger-tight or until the proper leakage is obtained. Repack the stuffing box with new packing.
	Loss of cooling water supply	Verify the location of the lantern ring. Verify that the supply lines are clear. Reestablish the cooling water flow.
Pump does not rotate freely (by hand)	Pump/driver binds	Uncouple and verify free rotation of the pump/driver.
	Pump binding at running fits	Verify the rotor radial and axial positions, axial float, and bearing bracket settings. Dismantle the pump and correct the problem.
	Packing is too tight	Loosen the packing follower. Inspect and repack the pump stuffing box.
	Bearing failure	Inspect and replace the bearing if needed.

Table 5-2 (cont.)
Troubleshooting Matrix for Multi-Stage Horizontal Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Pump overloads driver	Pump run-out due to system configuration changes	Verify the system alignment. Plot the discharge pressure and motor horsepower on the pump curve.
	Off-design flow operation	Reduce the flow. Increase the flow after installation of the miniflow line.
	Fluid temperature changes	Review the design vs. the operating conditions (density/specific gravity changes).
	Improperly sized replacement impellers	Verify the correct impeller size and install a replacement.
	Driver speed too high	Verify the speed and adjust as necessary.
	Pump bearings seize or rotating element binds	Check the run-out and thrust. Check the bearing metal temperature or bearing drain temperature. Dismantle the pump and replace the part or parts causing seizures or binding.
	Material buildup and/or corrosion on surfaces adjacent to the impeller	Check the areas adjacent to the impeller for foreign material and remove it. Replace any part that cannot be restored either due to severe corrosion or mechanical damage.
	Foreign material	Inspect and remove the foreign material if necessary.
Pump loses prime after starting	Insufficient liquid supply	Ensure that the suction valve is wide open. Check for the proper supply of liquid to be pumped.
	Excessive amount of air or vapor in the liquid	Check the suction system for air leakage and correct it. Inspect for pin-holes in the suction piping.
	Clogged impeller(s)	Dismantle the pump and correct the problem.
	Suction pipe clogged	Remove the foreign material. Verify the valve alignment.

Table 5-2 (cont.)
Troubleshooting Matrix for Multi-Stage Horizontal Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Pump is noisy	Cavitation	Verify the proper suction pressure. Check the suction strainer pressure drop. Clean the strainer if appropriate.
	Noise in driver	Troubleshoot the driver.
	Off-design flow operation	Compare the operating point to the pump best efficiency point (BEP) and historical operating points.
	Air leaks in suction line	Secure all vent connections. Check the flanges for leakage.
	Air/vapor pocket in suction line	Bleed the line through the vent connections.
	Mechanical looseness or worn parts	Tighten or replace the defective or worn part.
	Driver speed too high	Verify the driver speed.
	Incorrect suction piping configuration creating undesirable flow patterns	Check the suction piping configuration.
	Foreign material in suction line	Clear the foreign material from the suction/discharge pipes, strainer, isolation valves and pump.
	Imbalance	Consider an *in situ* balancing. Dismantle the pump and inspect for foreign material, shaft run-out, mechanical imbalance, impeller erosion, or misalignment.
	Bearing failure	Inspect and replace the bearing if needed.

Notes:

1. Performing vibration spectrum analysis is a common action to address any of the probable causes when there is excessive pump vibration or noise.

2. Verifying structural integrity typically includes inspections of grout, mounting bolts, casing integrity, piping loads, and/or hangers.

3. An acceptable uncoupled run might not eliminate the motor as a probable cause of vibration because there will be minimal thrust load under this condition.

4. This is applicable only for sleeve-type bearings.

5. Thermally induced rubs may abate after temperature gradients stabilize.

6. The constant level oiler should be installed in proper relationship to shaft rotation (that is, on the side of the bearing housing where the oil level is higher).

7. Typically, a temperature more than 10°F (5.6°C) warmer than the process fluid would warrant concern.

Sources:

- *Instructions for Installing, Operating and Maintaining Pacific Pumps, Double Stage Split Casing with Balance Drum.* Dresser Industries, Inc., Huntington Park, CA. Manual No. 2286.
- *Ingersoll Dresser Pump Instruction Manual for DA-Type Pumps*. Ingersoll-Dresser Pump Co., Phillipsburg, NJ.

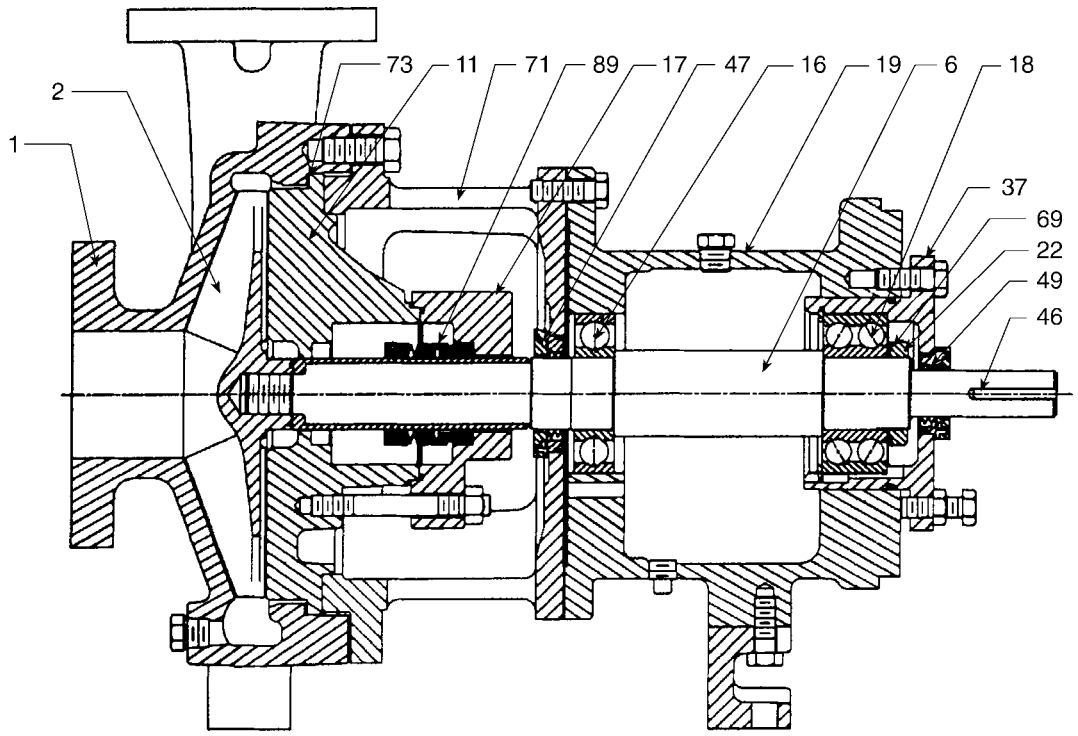
6
SINGLE-STAGE HORIZONTAL PUMPS

6.1 Pump Design Overview

A design feature of single-stage pumps is the configuration of the inlet of the impeller. The two major types of suction configurations are single suction and double suction.

6.1.1 Single (End Suction) Configuration

A single-suction configuration is often used with a radially split casing to achieve higher design pressures and temperatures. The disadvantage of this suction configuration is that it typically requires higher NPSH than a double-suction configuration.

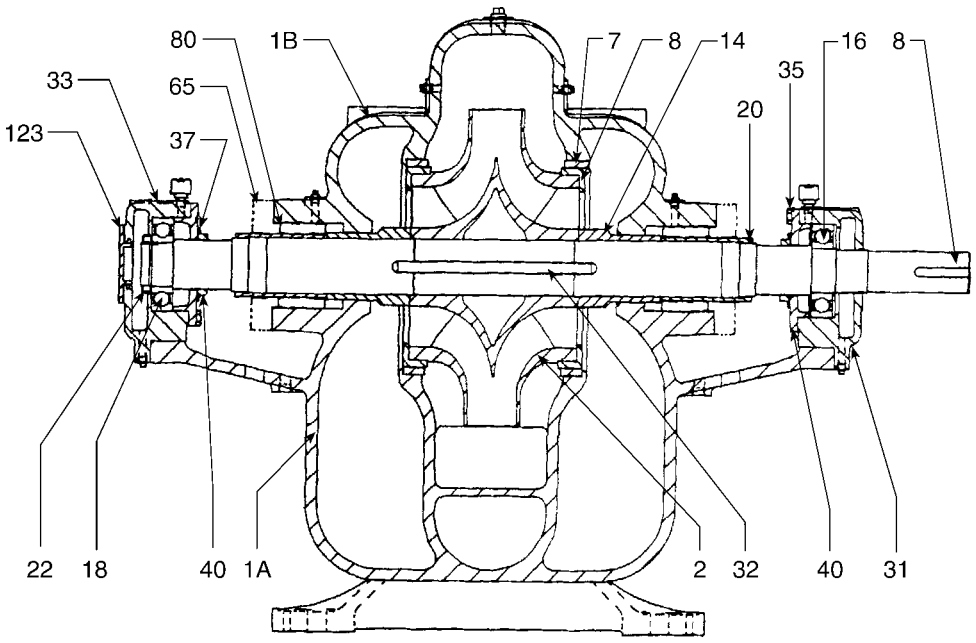


1	Casing	37	Cover, Bearing, Outboard
2	Impeller	46	Key, Coupling
6	Shaft, Pump	47	Seal, Bearing Cover, Inboard
11	Cover, Seal Chamber	49	Seal, Bearing Cover, Outboard
16	Bearing, Inboard	69	Lockwasher
17	Gland	71	Adapter
18	Bearing, Outboard	73	Gasket
19	Frame	89	Seal
22	Locknut, Bearing		

Figure 6-1
Single-Stage Horizontal Pump (End Suction)

6.1.2 Double-Suction Configuration

The primary advantage of a double-suction configuration is that a lower NPSH is required than for a single-suction configuration. In a double-suction pump, the flow comes from a single source and splits, thereby doubling the inlet area. The doubling of the inlet area subsequently lowers the inlet velocity and the NPSH required.



1A	Casing, Lower Half	22	Locknut
1B	Casing, Upper Half	31	Housing, Bearing Inboard
2	Impeller	32	Key, Impeller
6	Shaft	33	Housing, Bearing Outboard
7	Ring, Casing	35	Cover, Bearing Inboard
8	Ring, Impeller	37	Cover, Bearing, Outboard
14	Sleeve, Shaft	40	Deflector
16	Bearing, Inboard	65	Seal, Mechanical Stationary Element
18	Beaing, Outboard	80	Seal, Mechanical Rotating Element
20	Nut, Shaft Sleeve		

Figure 6-2
Single-Stage Horizontal Pump (Double Suction)

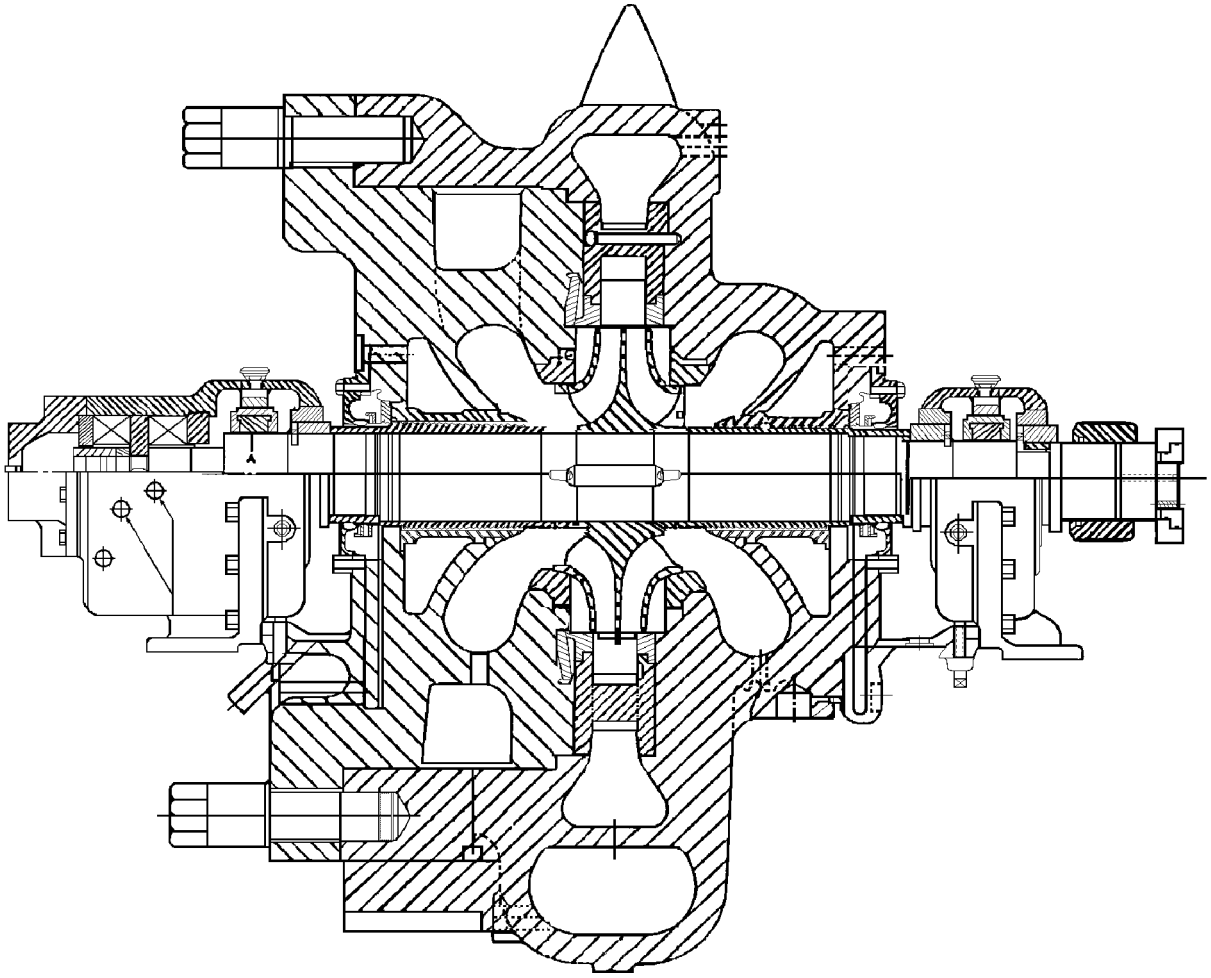


Figure 6-3
Section View of Delaval Type 1BSX Horizontal Pump

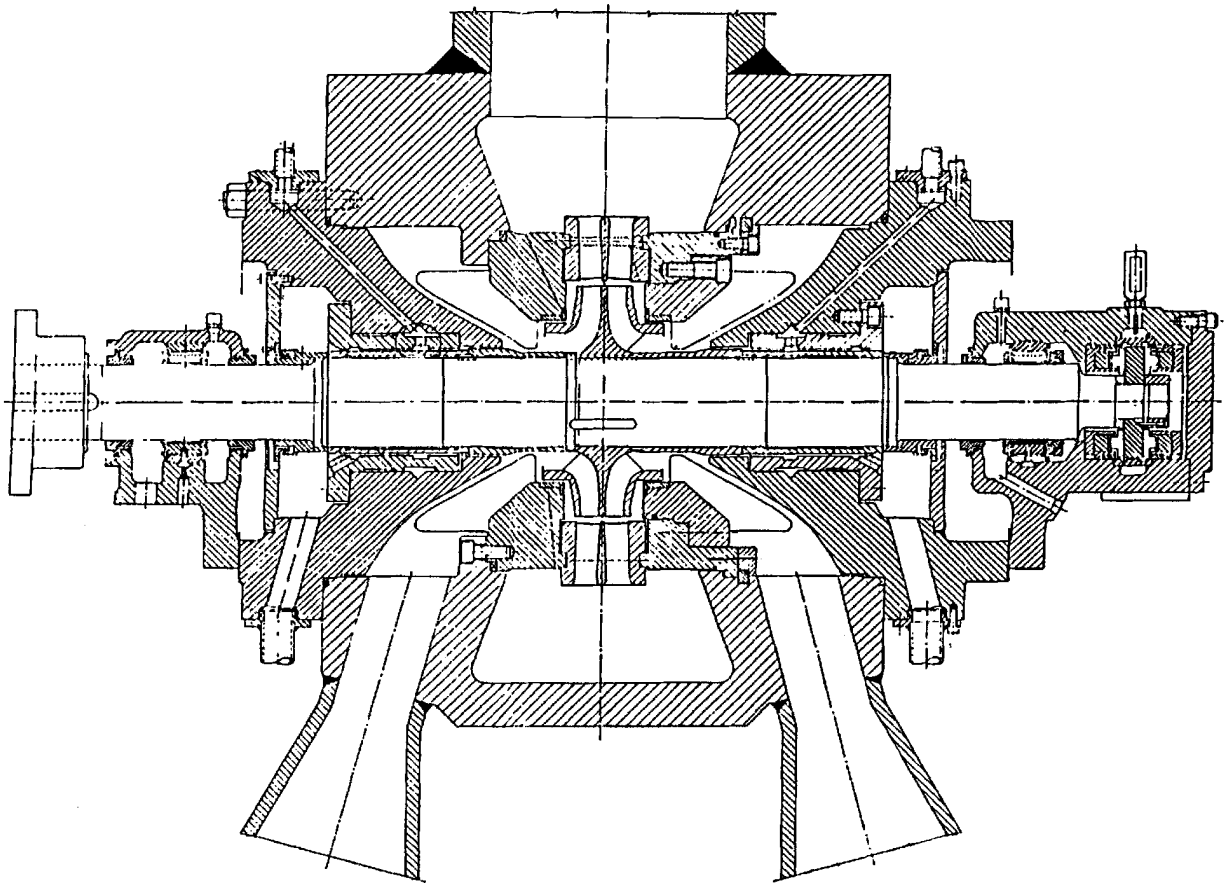


Figure 6-4
Section View of Pacific Type HVF Horizontal Pump with Double Cover

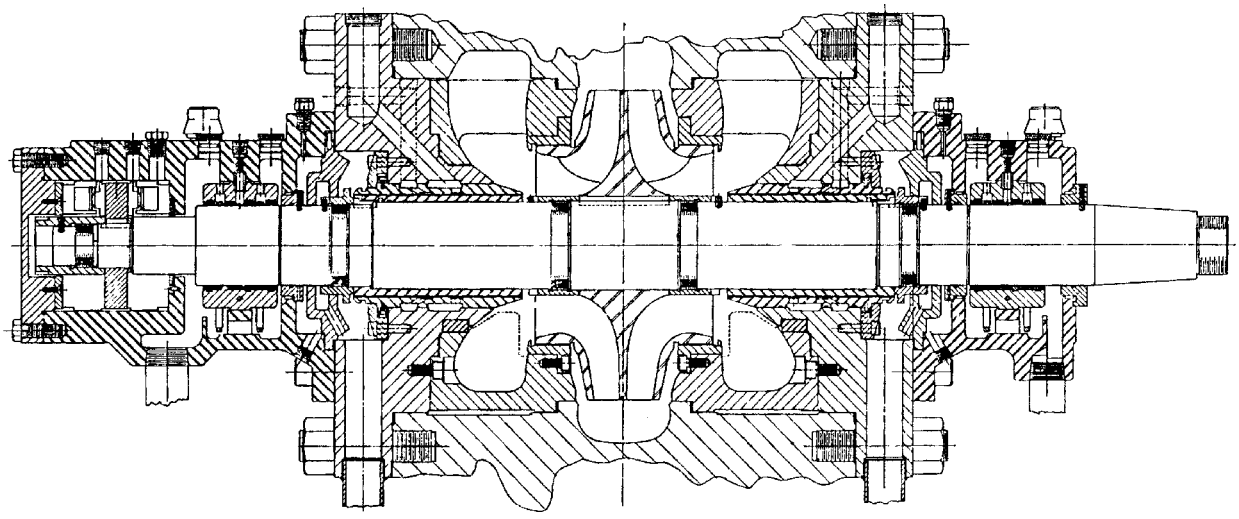


Figure 6-5
Section View of Bingham Type CD Horizontal Pump

6.2 Nuclear Plant Applications and Detailed Troubleshooting Matrix

Typical nuclear plant applications for each of the three types of vertical pumps are provided in Table 6-1 below. The list of nuclear plant applications is provided for as a reference only. The applications do not represent a complete list because applications can vary from plant to plant. Likewise, the list of representative manufacturers and model numbers is not all-inclusive. This list does not represent an endorsement of the respective manufacturers or their products in any way.

Table 6-1
Nuclear Plant Applications and Typical Manufacturers/Models of Single-Stage Horizontal Pumps

Nuclear Plant Applications for Single-Stage Horizontal Pumps (Single Suction and Double Suction)	Typical Manufacturers and Models of Single-Stage Horizontal Pumps
Boric acid transfer	Allis Chalmers - NR-C16
Component cooling water (CCW)	Byron Jackson - DVSR, DVS
Condensate	Crane Deming - 4211, 4221
Condensate booster	Decatur - G5
Condensate transfer	Delaval - BSX
Containment spray	Goulds - 3196, 3415, 3405
Demineralized water transfer	Ingersoll-Dresser - A, S, CN, SE, SH, LN, LP
Diesel jacket water cooling	Peerless - B5588JR
Fire protection jockey	Pacific - SVC
Fire service	Sulzer Bingham - CD, HSB, HSA, HSL, HS, CAP
General chemical/water services	Weinman - MGV, GVS
Generator stator cooling water	Worthington - WNC, HQ
Heater drain (drip) tank	
Main feedwater (MFW)	
Reactor feed	
Reactor make-up water	
Reactor water clean-up (RWCU)	
Residual heat removal (RHR)	
Screen wash	
Service water	
Spent fuel pool cooling	
Steam generator blow-down	
Waste disposal	
Waste liquid drain	

Table 6-2
Troubleshooting Matrix for Single-Stage Horizontal Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Failure to deliver required head and/or flow at start-up or during operation	Driver speed too low	Check the power supply for the correct frequency of the motor. Check the actual speed of the driver against the rated speed listed on the pump data sheet.
	Air leaks in suction line when operating under vacuum	Secure all vent connections. Check the flanges and expansion joints for leakage.
	Air/vapor pocket in suction line	Bleed the line through the vent connections. Operate the pump at the highest flow possible to sweep the air from the system.
	Off-design pump operation	Check the pump data sheet or performance curve and adjust the system conditions to the rated head-flow levels. Check that normally closed discharge flow paths are not open, such as normally closed bypass lines.
	Actual NPSH available is lower than the specified NPSH requirement	Check the suction piping configuration and the open/closed position of the suction valve.
		Investigate for entrained air or air leaks when the suction pressure is low or a vacuum. The NPSH available may not be sufficient for acceptable performance.
		Check the suction strainer pressure drop. Clean the strainer if appropriate.
	Excessive re-circulation from discharge to inlet	Check the flow through the minimum flow re-circulation line. Adjust the valve if necessary. Check the clearances of internal wear surfaces.
	Incorrect direction of rotation	Correct the rotation.
	Installed impeller backward or in wrong location	Verify the proper configuration of the assembly.
	Foreign material in suction or discharge line	Clear the line of all foreign material, including the suction strainer and isolation valve.

Table 6-2 (cont.)
Troubleshooting Matrix for Single-Stage Horizontal Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Failure to deliver required head and/or flow at start-up or during operation (cont.)	Material buildup and/or clogged passageways	Clear the areas of foreign material.
	Pump not completely filled with liquid	Fill and vent the pump.
	Broken shaft	Inspect and repair the shaft.
	Impeller key sheared or missing from assembly	Disassemble and check the impeller key. Remove and replace it if damaged.
	Impeller damaged	Remove and replace the impeller.
Excessive vibration[1]	Cavitation	Determine the proper supply of process fluid. Verify that the there is no leakage of air at the suction. Listen for noise as evidence of cavitation.
	Off-design flow operation	Compare the operating point to the pump best efficiency point (BEP) and historical operating points.
	Structural resonance	Inspect for structural integrity.[2] Review recent modifications. Perform resonance testing.
	Air or gas in liquid	Vent the air and check the suction for leaks. Check the alignment and tighten the flange bolts.
	Motor-induced vibration	Perform an uncoupled run.[3]
	Imbalance	Consider an *in situ* balancing. Dismantle and inspect the pump for foreign material, shaft run-out, mechanical imbalance, impeller erosion, or misalignment.
	Worn, locked, mismatched, or damaged coupling	Inspect the coupling bolts and tighten them if needed. Inspect the coupling and replace it if needed. Verify the axial float.

Table 6-2 (cont.)
Troubleshooting Matrix for Single-Stage Horizontal Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Excessive vibration[1] (cont.)	Shaft misalignment	Check the alignment and correct it.
	Mechanical defects (shaft bent, bearings worn)	Check the bearing fits (housing ID to bearing OD and/or bearing ID to shaft OD). Check the bearing-to-shaft clearance.[4] Dismantle the pump and replace the part or parts causing the vibration.
	Loose joints	Check the interface of each accessible joint between the casing, head, bearing bracket, bearing housing, and base/bed-plate. Use a feeler gauge while monitoring the vibration.
	Loose or improperly torqued bolting	Loosen and retorque the bolts.
	Rubbing of mating parts[5]	Monitor the vibration during coastdown. Uncouple the pump and the motor to verify free rotation of both.
	Inadequate bed-plate grouting or support	Regrout or add support if damage is found. Inspect the grout/bed plates for voids.
	Inadequate or misaligned pipe supports	Inspect the supports for looseness or anchoring problems and alignment.
	Foreign material in impeller(s) causing imbalance	Inspect with a boroscope. Dismantle the pump and remove any foreign material.
Discharge pressure oscillations	Air leaks in suction line	Secure all vent connections. Check the flanges for leakage.
	Off-design flow operation	Compare the operating point to the pump best efficiency point (BEP) and historical operating points.
	Air/vapor pocket in suction line	Bleed the line through the vent connections.

Table 6-2 (cont.)
Troubleshooting Matrix for Single-Stage Horizontal Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Discharge pressure oscillations (cont.)	Actual NPSH available is lower than the specified NPSH requirement	Check the suction piping configuration.
		Investigate for entrained air or air leaks when the suction pressure is a vacuum. The NPSH available may not be sufficient for acceptable performance.
		Check the suction strainer pressure drop. Clean the strainer if appropriate.
	Impeller is no longer axially centered	Inspect the float of the thrust bearing. Center the rotating element.
High pump bearing temperature	Off-design flow operation	Compare the operating point to the pump best efficiency point (BEP) and historical operating points.
	Improper coupling gap or lock-up	Verify the coupling installation gap. Verify the correct axial float.
	Lack of lubrication	Perform an oil analysis on the used oil and replace it, if needed. Check the condition of the grease-lubricated bearing. Perform an oil flush and verify the correct orifice sizes.
	Improper lubrication	Perform an oil analysis. Replenish the oil/grease with the proper grade lubricant.
	Performance/configuration of constant-level oiler	Verify the proper setting and physical location on the bearing housing.[6] Verify that the reservoir is not overfilled.
	Inadequate cooling to bearing housing or oil cooler	Check the cooling source and flow.
	Blocked balance/equalizing lines	Inspect the lines and clean them as necessary.

Table 6-2 (cont.)
Troubleshooting Matrix for Single-Stage Horizontal Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Seal chamber overheats (mechanical seal)	Loss of cooling water supply	Reestablish the cooling water flow.
Discharge pressure trending downward	Normal wear of pump subcomponents	Review the performance history for trends, number of operating hours, and the number of starts and stops. Check the balance drum/disc line pressure/flow, lift, and thrust.
	System anomaly	Walkdown the system and analyze its performance.
Stuffing box overheats (packing)	Packing is too tight. Insufficient leak-off flow	Loosen the packing follower nuts and retighten them finger-tight or until the proper leakage is obtained. Repack the stuffing box with new packing.
	Loss of cooling water supply	Verify the location of the lantern ring. Verify that the supply lines are clear. Reestablish the cooling water flow.
Pump does not rotate freely (by hand)	Pump binding at running fits	Verify the rotor radial and axial positions, axial float, and bearing bracket settings. Dismantle the pump and correct the problem.
	Pump/driver binds	Uncouple and verify free rotation of the pump/driver.
	Packing is too tight	Loosen the packing follower. Inspect and repack the pump stuffing box.
	Bearing failure	Inspect and replace the bearing if needed.
Pump overloads driver	Pump run-out due to system configuration changes	Verify the system alignment. Plot the discharge pressure and motor horsepower on the pump curve.
	Off-design flow operation	Reduce the flow. Increase the flow after installation of the miniflow line.
	Fluid temperature changes	Review the design vs. operating conditions (density/specific gravity changes).
	Improperly sized replacement impellers	Verify the correct impeller size and install a replacement.

Table 6-2 (cont.)
Troubleshooting Matrix for Single-Stage Horizontal Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Pump overloads driver (cont.)	Driver speed too high	Verify the speed and adjust as necessary.
	Pump bearings seize or rotating element binds	Check the run-out and thrust. Check the bearing metal temperature or bearing drain temperature. Dismantle the pump and replace the part or parts causing seizures or binding.
	Material buildup and/or corrosion on surfaces adjacent to the impeller	Check the areas adjacent to the impeller for foreign material and remove it. Replace any part that cannot be restored either due to severe corrosion or mechanical damage.
	Foreign material	Inspect and remove the foreign material if necessary.
Pump loses prime after starting	Insufficient liquid supply	Ensure that the suction valve is wide open. Check for the proper supply of the liquid to be pumped.
	Excessive amount of air or vapor in the liquid	Check the suction system for air leakage and correct the problem. Inspect for pin-holes in the suction piping.
	Clogged impeller(s)	Dismantle the pump and correct the problem.
	Suction pipe clogged	Remove the foreign material. Verify the valve alignment.
Pump is noisy	Cavitation	Verify the proper suction pressure. Check the suction strainer pressure drop. Clean the strainer if appropriate.
	Noise in driver	Troubleshoot the driver.
	Off-design flow operation	Compare the operating point to the pump best efficiency point (BEP) and historical operating points.
	Air leaks in suction line	Secure all vent connections. Check the flanges for leakage.
	Air/vapor pocket in suction line	Bleed the line through the vent connections.

Table 6-2 (cont.)
Troubleshooting Matrix for Single-Stage Horizontal Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Pump is noisy (cont.)	Mechanical looseness or worn parts	Tighten or replace the defective or worn part.
	Driver speed too high	Verify the driver speed.
	Incorrect suction piping configuration creating undesirable flow patterns	Check the suction piping configuration.
	Foreign material in suction line	Clear the foreign material from the suction/discharge pipes, strainer, isolation valves, and pump.
	Imbalance	Consider an *in situ* balancing. Dismantle and inspect for foreign material, shaft run-out, mechanical imbalance, impeller erosion, or misalignment.
	Bearing failure	Inspect and replace the bearing if needed.

Notes:

1. Performing vibration spectrum analysis is a common action to address any of the probable causes when there is excessive pump vibration or noise.

2. Verifying structural integrity typically includes inspections of grout, mounting bolts, casing integrity, and piping loads and/or hangers.

3. An acceptable uncoupled run may not eliminate the motor as a probable cause of vibration because there will be minimal thrust load under this condition.

4. This is applicable only for sleeve-type bearings.

5. Thermally induced rubs may abate after temperature gradients stabilize.

6. A constant level oiler should be installed in proper relationship to shaft rotation (that is, on the side of the bearing housing where the oil level is higher).

Source:

Instructions for Installing, Operating and Maintaining Pacific Pumps, Type DS. Dresser Industries, Inc., Huntington Park, CA. Manual No. 1100.5.

7
POSITIVE DISPLACEMENT PUMPS

7.1 Pump Design Overview

7.1.1 General Pump Design Attributes

Positive displacement (PD) pumps are divided into two broad classifications, reciprocating and rotary, as shown in Figure 7-1.

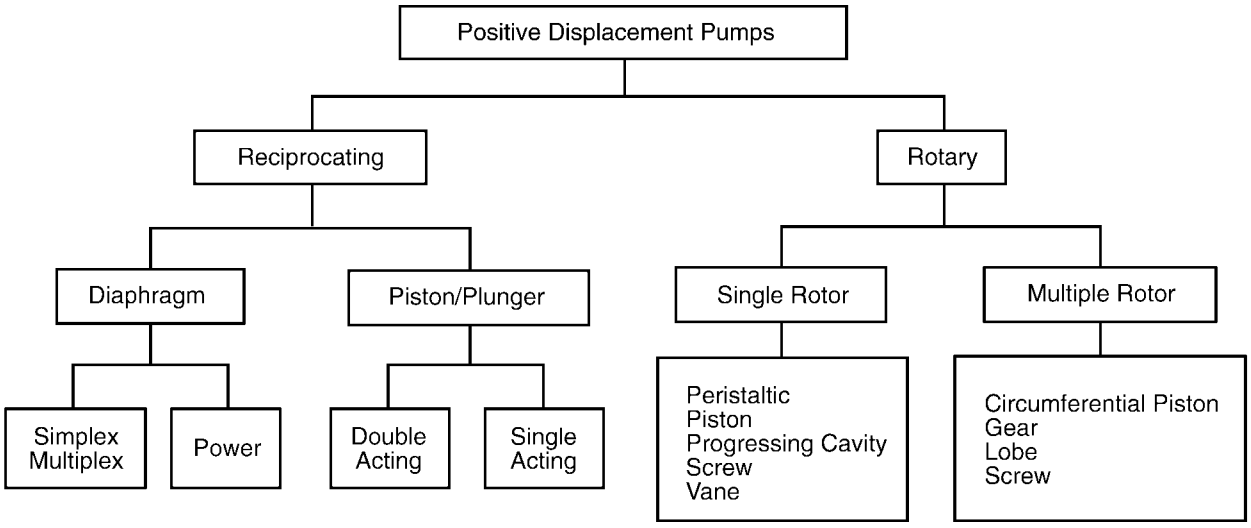


Figure 7-1
Types of Positive Displacement Pumps

By definition, PD pumps displace a known quantity of liquid with each revolution of the pumping elements (that is, the gears, rotors, screws, or vanes) or with each stroke of the diaphragm, piston, or plunger. PD pumps displace liquid by creating a space between the pumping elements and trapping liquid in the space. The rotation or stroking of the pumping elements then reduces the size of the space and moves the liquid out of the pump. PD pumps can handle fluids of viscosities up to 1,320,000 cSt/6,000,000 SSU, capacities up to 1,150 m^3 per hr/5,000 gpm, and pressures up to 700 BAR/10,000 psi.

7.1.2 Rotary Pump Design

Rotary pumps operate in a circular motion and displace a constant amount of liquid with each revolution of the pump shaft. In general, this is accomplished by pumping elements (that is, the gears, lobes, vanes, or screws) moving in such a way as to expand volumes to allow liquid to enter the pump. These volumes are then contained by the pump geometry until the pumping elements move in such a way as to reduce the volumes and force liquid out of the pump. Flow from rotary PD pumps is relatively unaffected by differential pressure and is smooth and continuous. Rotary PD pumps have very tight internal clearances that minimize the amount of liquid that "slips back" from the discharge to the suction side of the pump (internal recirculation). Because of this, rotary PD pumps are very efficient. These pumps work well with a wide range of viscosities, particularly high viscosities.

Centrifugal pumps differ from rotary pumps in that they rely on kinetic energy rather than mechanical means to move liquid. Liquid enters the pump at the center of a rotating impeller and gains energy as it moves to the outer diameter of the impeller. Liquid is forced out of the pump by the energy it obtains from the rotating impeller. Centrifugal pumps can transfer large volumes of liquid, but efficiency and flow decrease rapidly as pressure and/or viscosity increases.

7.1.3 Types of Rotary Pump Designs

Rotary pumps are self-priming and deliver a constant, smooth flow, regardless of pressure variations. However, "slippage" or internal recirculation tends to increase as discharge pressures increase. (The following information is taken from the Hydraulic Institute's, *Pump Types and Nomenclature*, 1994.)

7.1.3.1 Internal Gear

Internal gear pumps (Figure 7-2) carry fluid between the gear teeth from the inlet to outlet ports. The outer gear (rotor) drives the inner or idler gear on a stationary pin. The gears create voids as they come out of mesh and liquid flows into the cavities. As the gears come back into mesh, the volume is reduced, and the liquid is forced out of the discharge port. The crescent prevents liquid from flowing backward from the outlet to the inlet port.

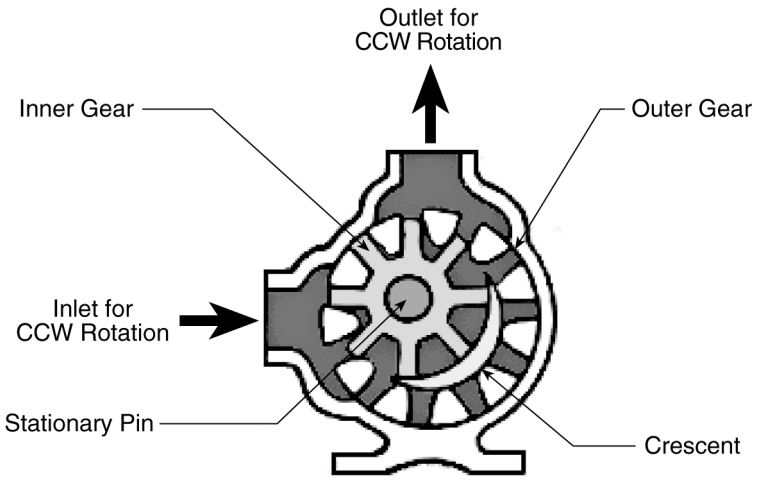


Figure 7-2
Internal Gear PD Pump

7.1.3.2 External Gear

External gear pumps (Figure 7-3) also use gears that come in and out of mesh. As the teeth come out of mesh, liquid flows into the pump and is carried between the teeth and the casing to the discharge side of the pump. The teeth come back into mesh, and the liquid is forced out the discharge port. External gear pumps rotate two identical gears against each other. Both gears are on a shaft with bearings on either side of the gears.

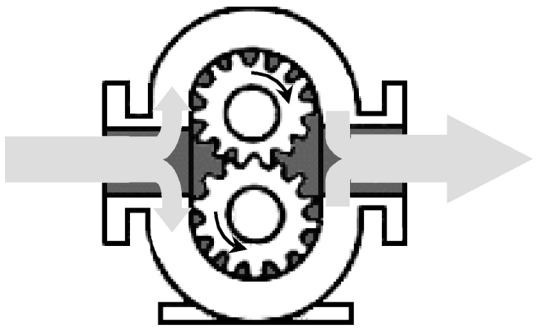


Figure 7-3
External Gear PD Pump

7.1.3.3 Vanes

The vanes—blades, buckets, rollers, or slippers—work with a cam action to draw fluid into and force it out of the pump chamber. The vanes may be in either the rotor or stator. The vane-in rotor pumps may be made with constant or variable displacement pumping elements. Figure 7-4 shows a sliding vane pump.

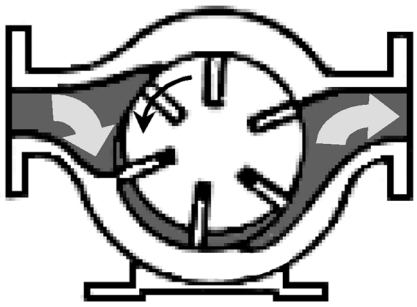


Figure 7-4
Sliding Vane PD Pump

7.1.3.4 Flexible Members

This principle is similar to the vane principle except the vanes flex rather than slide. The fluid pumping and sealing action depends on the elasticity of the flexible members. The flexible members may be a tube, a vane, or a liner. Figure 7-5 shows a flexible vane pump.

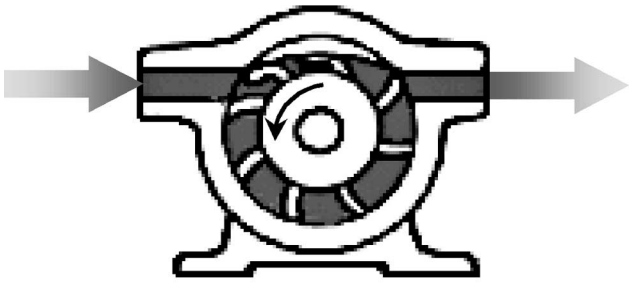


Figure 7-5
Flexible Vane PD Pump

7.1.3.5 Lobes

Fluid is carried between the rotor teeth and the pumping chamber. The rotor surfaces create continuous sealing. Both gears are driven and are synchronized by timing gears. Rotors include bi-wing, tri-lobe, and multi-lobe configurations. Figure 7-6 is a tri-lobe pump.

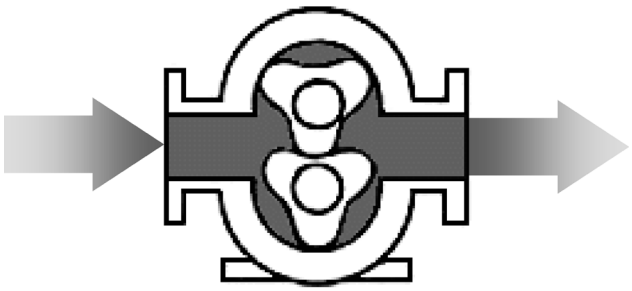


Figure 7-6
Tri-Lobe PD Pump

7.1.3.6 Screw Pumps

Screw pumps carry fluid in the spaces between the screw threads. The fluid is displaced axially as the screws mesh. Single screw pumps (Figure 7-7) are commonly called *progressive cavity pumps*. They have a rotor with external threads and a stator with internal threads. The rotor threads are eccentric to the axis of rotation. A hand-cranked meat grinder is one example of this type of pump.

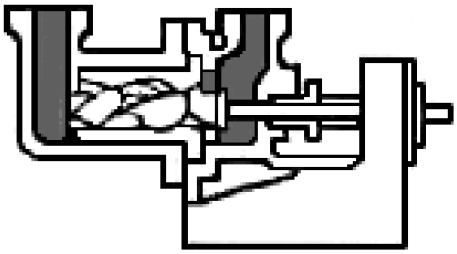


Figure 7-7
Single Screw PD Pump

7.1.4 Types of Reciprocating Pump Designs

Reciprocating positive displacement pumps can be categorized into two major types (as shown in Figure 7-1). These are piston type designs, which include single-acting and double-acting, and diaphragm, which include power and simplex/multiplex designs. Reciprocating pumps displace the fluid with a back-and-forth motion, as contrasted with the rotary family of PD pumps that displace the fluid with a circular motion of the piston or diaphragm initiated by a crankshaft or camshaft.

7.2 Nuclear Plant Applications and Detailed Troubleshooting Matrix

Typical nuclear plant applications for each of the three types of vertical pumps are provided in Table 7-1 below. The list of nuclear plant applications is provided for as a reference only. The applications do not represent a complete list because applications can vary from plant to plant. Likewise, the list of representative manufacturers and model numbers is not all-inclusive. This list does not represent an endorsement of the respective manufacturers or their products in any way.

Table 7-1
Nuclear Plant Applications and Typical Manufacturers/Models of Positive Displacement Pumps

Nuclear Plant Applications for Positive Displacement Pumps (Reciprocating and Rotary)	Typical Manufacturers and Models of Positive Displacement Pumps
Auxiliary lubricating oil supply	Ajax
Charging	Demag Delaval
Diesel fuel booster	Dennison
Diesel fuel oil transfer	Gaulin
Diesel generator auxiliary diesel lubricating oil	Goulds
Diesel generator main lubricating oil	IMO
Diesel injection	Milton-Roy
Electro-hydraulic control (EHC)	Nash
Fuel oil transfer	Roper - 17AM08, 20047
Air/hydrogen seal oil	Union
Main turbine bearing oil lift	Vickers
RCIC gland seal condensate	Viking - GG475M, GG195, FH, HL195, GV, H75M, HL75M, HE65
RCP motor oil lift	Worthington - 5GAUM, GAFTM, GAM, HYDREX II
Stand-by liquid control	

Table 7-2 provides detailed troubleshooting for piston/plunger reciprocating PD pumps. The table is limited to reciprocating PD pumps primarily because the troubleshooting for most rotary PD pumps is generic in nature and consists of removing the pump from service and either replacing any damaged or worn parts or replacing the entire pump with a new one. Further details regarding the troubleshooting of other reciprocating PD pumps or rotary PD pumps should be obtained from the manufacturer.

Table 7-2
Troubleshooting Matrix for Piston/Plunger Reciprocating Positive Displacement Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Liquid end noise[1]	Insufficient suction pressure	Verify the suction flow path.
	Over-speed	Adjust the speed.
	System shocks/pulsations	Check the condition of the pulsation damper.
	Damaged/loose pipe supports	Verify the pipe supports and secure them.
	Grout failure or voiding	Reapply grout; fill any voids as needed.
	Air in fluid	Evaluate for entrained air. Check the suction piping for leakage. Bleed the air from the fluid; inspect the foot valve.
	Partial loss of prime	Check for air leaks in the pipes, suction valve packing, suction tank return line, and foot valve.
	Broken or badly worn valves or seats	Grind or replace the valves or seats.
	Packing badly worn or running loose, especially on high lifts	Repair or replace the packing.
	Obstruction under valve	Remove the obstruction.
Power end noises	Loose/worn main or rod bearings/bearing caps/bolts	Inspect and replace the bearings.
	Low oil level	Verify the proper oil level. Fill to the proper oil level.
	Low or no oil pressure	Evaluate the lubricating oil pump, relief valve, and worn bearings. Check for broken lube oil piping or fittings.
	Loose plunger	Evaluate the cause of looseness. Tighten according to the manufacturer's recommendations.

Table 7-2 (cont.)
Troubleshooting Matrix for Piston/Plunger Reciprocating Positive Displacement Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Rapid packing or plunger wear	Fluid is dirty	Check the filter of the supply fluid. Increase the lubrication.
	Environment is dirty	Install dust covers.
	Boron accumulation on the plungers	Replace the packing.
	Packing is too tight	Adjust or replace the packing as needed.
	Inadequate lubrication system	Verify that the lubrication water paths are clear.
Overheated power end	Over-pressure	Correct the system requirements.
	Low oil level	Verify the proper oil level. Fill to the proper oil level.
	Low oil pressure	Evaluate the lubricating oil pump/piping.
	Inadequate ventilation	Verify the ambient conditions. Ventilate the component as needed.
	Water intrusion into the crankcase	Eliminate the source of water intrusion.
Water in crankcase	Packing and/or lip seals worn	Replace the seals, and verify the adequacy of the routine maintenance.
	Plugged leak-off drain	Clean the drain, and verify the adequacy of the preventive maintenance.
	Worn liquid end packing, abnormal leakage	Replace and repack as needed.
	Broken or missing deflectors	Replace the defective parts.
	Scored plunger shaft	Replace the shaft as needed.
Oil leak from crankcase	Oil level is too high	Verify the proper oil level. Fill to the proper oil level.
	Obstructed vent plug/crankcase breather	Clean or replace the breather as needed.

Table 7-2 (cont.)
Troubleshooting Matrix for Piston/Plunger Reciprocating Positive Displacement Pumps

Symptom (Performance Indicator)	Probable Causes	Recommended Actions
Oil leak from crankcase (cont.)	Worn seals and/or packing	Replace the seals and/or packing, and verify the adequacy of the preventive maintenance.
	Scored plunger shaft or cross heads	Replace the shaft or cross heads as needed.
Loss of prime	Insufficient suction pressure	Verify the suction flow path.
	Leaking suction or foot valve	Repair and reprime the pump.
Leaking at strong-backs or between frame and stuffing box	Over pressure	Evaluate the discharge flow path. Inspect the relief valve.
	Loose fasteners	Tighten the nuts as required.
	Leaking connection (gasket or lapped joints)	Replace the worn or broken items.
	System shocks	Verify the condition of the pulsation damper (cushion chamber).
Pitted valves or seats	Fluid is dirty	Check the filter of the supply fluid. Increase the lubrication flow.
	Cavitation of fluid	Adjust the speed.
		Check for air leaks in the suction pipes.
		Grind or replace any broken or badly worn valves/seats.
		Adjust or replace any badly worn or loose packing.

Notes:

1. Performing vibration spectrum analysis is a common action to address any of the probable causes when there is excessive pump vibration.

Source:

Ingersoll-Dresser Pump Instruction Manual for Vertical and Horizontal Plunger Pumps. Ingersoll-Dresser Pump Co., Phillipsburg, NJ.

8
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Targets:
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