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IDENTIFIERS *Millwrights; *Pumps

ABSTRACT

This packet, part of the instructional materials for the Oregon apprenticeship program for millwright training, contains seven modules covering pumps. The modules provide information on the following topics: types and classification of pumps, applications, construction, calculating heat and flow, operation, monitoring and troubleshooting, and maintenance of pumps. Each module consists of a goal, performance indicators, student study guide, vocabulary, introduction, information sheets illustrated with line drawings and photographs, an assignment sheet, a job sheet, a self-assessment test with answers, a post-assessment test with answers for the instructor, and a list of supplementary references. (Copies of supplementary references, which are sections of lectures from a correspondence course published by the Southern Alberta Institute of Technology, are included in the packets.) (KC)

ED254723

APPRENTICESHIP

MILLWRIGHT

RELATED
TRAINING MODULES

9.1-9.7 PUMPS

CE040999

STATEMENT OF ASSURANCE

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APPRENTICESHIP

MILLWRIGHT
RELATED TRAINING MODULES

SAFETY

1.1 General Safety
1.2 Hand Tool Safety
1.3 Power Tool Safety
1.4 Fire Safety
1.5 Hygiene Safety
1.6 Safety and Electricity
1.7 Fire Types and Prevention
1.8 Machine Safeguarding (includes OSHA Handbook)

ELECTRICITY/ELECTRONICS

2.1 Basics of Energy
2.2 Atomic Theory
2.3 Electrical Conduction
2.4 Basics of Direct Current
2.5 Introduction to Circuits
2.6 Reading Scales
2.7 Using a V.O.M.
2.8 OHM'S Law
2.9 Power and Watt's Law
2.10 Kirchoff's Current Law
2.11 Kirchoff's Voltage Law
2.12 Series Resistive Circuits
2.13 Parallel Resistive Circuits
2.14 Series - Parallel Resistive Circuits
2.15 Switches and Relays
2.16 Basics of Alternating Currents
2.17 Magnetism

COMPUTERS

3.1 Digital Language
3.2 Digital Logic
3.3 Computer Overview
3.4 Computer Software

TOOLS

4.1 Boring and Drilling Tools
4.2 Cutting Tools, Files and Abrasives
4.3 Holding and Fastening Tools
4.4 Fastening Devices
4.5 Basic Science - Simple Mechanics
4.6 Fasteners

DRAFTING

HUMAN RELATIONS

BOILERS

TURBINES

MILLWRIGHT
SUPPLEMENTARY REFERENCE DIRECTORY

Note: All reference packets are numbered on the upper right-hand corner of the respective cover page.

Supplementary Packet #	Description	Related Training Module	
1.8	Concepts & Techniques of Machine Safeguarding, U.S.D.L., O.S.H.A.	1.8	Machine Safeguarding
12.1	Correspondence Course, Lecture 1, Sec. 2, Steam Generators, Types of Boilers I, S.A.I.T., Calgary, Alberta, Canada	7.1	Boilers, Fire Tube Type
12.2	Correspondence Course, Lecture 2, Sec. 2, Steam Generators, Types of Boilers II, S.A.I.T., Calgary, Alberta, Canada	7.2	Boilers, Water Tube Type
12.3	Correspondence Course, Lecture 2, Sec. 2, Steam Generators, Boiler Construction & Erection, S.A.I.T., Calgary, Alberta, Canada	7.3	Boilers, Construction
12.4	Correspondence Course, Lecture 4, Sec. 2, Steam Generators, Boiler Fittings II, S.A.I.T., Calgary, Alberta, Canada	7.4	Boilers, Fittings
12.4	Correspondence Course, Lecture 4, Sec. 2, Steam Generators, Boiler Fitting I, S.A.I.T., Calgary, Alberta, Canada	7.4	Boilers, Fittings
12.5	Correspondence Course, Lecture 10, Sec. 2, Steam Generation, Boiler Operation, Maintenance, Inspection, S.A.I.T., Calgary, Alberta, Canada	7.5	Boilers, Operation
12.7	Correspondence Course, Lecture 3, Sec. 2, Steam Generation, Boiler Details, S.A.I.T., Calgary, Alberta, Canada	7.7	Boilers Heat Recovery Systems
		PUMPS	
13.1 13.2 13.4 13.6 13.7	Correspondence Course, Lecture 9, Sec. 2, Steam Generator, Power Plant Pumps, S.A.I.T., Calgary, Alberta, Canada	9.1 9.2 9.4 9.6 9.7	Types & Classifications Applications Calculating Heat & Flow Monitoring & Troubleshooting Maintenance
13.3 13.5	Correspondence Course, Lecture 6, Sec. 3, Steam Generators, Pumps, S.A.I.T., Calgary, Alberta, Canada	9.3 9.5	Construction Operation

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Supplementary Packet #	Description	Related Training Module
14.3 12.8	Correspondence Course, Lecture 6, Sec. 3, Steam Generators, Steam Generator Controls, S.A.I.T., Calgary, Alberta, Canada	14.3 Steam Transport 7.8 Boilers, Instruments & Controls
14.4	Correspondence Course, Lecture 11, Sec. 2, Steam Generators, Piping II, S.A.I.T., Calgary, Alberta, Canada	14.4 Steam Purification
15.1	Correspondence Course, Lecture 1, Sec. 4, Prime Movers, & Auxiliaries, Steam Turbines, S.A.I.T., Calgary, Alberta, Canada	8.1 Steam Turbines, Types
15.2	Correspondence Course, Lecture 4, Sec. 3, Prime Movers, Steam Turbines I, S.A.I.T., Calgary, Alberta, Canada	8.2 Steam Turbines, Components
15.3	Correspondence Course, Lecture 2, Sec. 4, Prime Movers & Auxiliaries, Steam Turbine Auxiliaries, S.A.I.T., Calgary, Alberta, Canada	8.3 Steam Turbines, Auxiliaries
15.4	Correspondence Course, Lecture 6, Sec. 3, Prime Movers, Steam Turbine Operation & Maintenance, S.A.I.T., Calgary, Alberta, Canada	8.4 Steam Turbines, Operation & Maintenance
15.5	Correspondence Course, Lecture 8, Sec. 3, Prime Movers, Gas Turbines, S.A.I.T., Calgary, Alberta, Canada	8.5 Gas Turbines
16.2	Boilers [illegible]ired with Wood & Bark Residues, D.D. Junge, F.R.L., O.S.U[illegible]75	10.2 Combustion Types of Fuel
16.2	Correspondence Course, Lecture 5, Sec. 2, Steam Generators, Fuel Combustion, S.A.I.T., Calgary, Alberta, Canada	10.2 Combustion Types of Fuel
16.3	Correspondence Course, Lecture 5, Sec. 2, Plant Services, Fuel & Combustion, S.A.I.T., Calgary, Alberta, Canada	10.3 Combustion Air & Fuel Gases
17.1	Correspondence Course, Lecture 12, Sec. 3, Steam Generation, Water Treatment, S.A.I.T., Calgary, Alberta, Canada	12.1 Feedwater, Types & Operation
17.2	Correspondence Course, Lecture 12, Sec. 2, Steam Generation, Water Treatment, S.A.I.T., Calgary, Alberta, Canada	12.2 Feedwater, Water Treatments

Supplementary Packet #	Description	Related Training Module
17.3	Correspondence Course, Lecture 7, Sec. 2, Steam Generators, Boiler Feedwater Treatment, S.A.I.T., Calgary, Alberta, Canada	12.3 Feedwater, Testing
18.1	Correspondence Course, Lecture 2, Sec. 5, Electricity, Direct Current Machines, S.A.I.T., Calgary, Alberta, Canada	11.1 Generators, Types & Construction
18.1 18.2	Correspondence Course, Lecture 4, Sec. 5, Electricity, Alternating Current Generators, S.A.I.T., Calgary, Alberta, Canada	11.1 Generators, Types & Construction 18.2 Generators, Operation
19.1	Correspondence Course, Lecture 5, Sec. 4, Prime Movers & Auxiliaries, Air Compressor I, S.A.I.T., Calgary, Alberta, Canada	13.1 Air Compressors, Types
19.1	Correspondence Course, Lecture 6, Sec. 4, Prime Movers & Auxiliaries, Air Compressors II, S.A.I.T., Calgary, Alberta, Canada	13.1 Air Compressors, Types 13.2 Air Compressors, Operation & Maintenance
20.1	Basic Electronics, Power Transformers, EL-BE-51	15.4 Transformers
21.1	Correspondence Course, Lecture 6, Sec. 5, Electricity, Switchgear & Circuit, Protective Equipment, S.A.I.T., Calgary, Alberta, Canada	15.3 Circuit Protection
22.1	Correspondence Course, Lecture 10, Sec. 3, Prime Movers, Power Plant Erection & Installation, S.A.I.T., Calgary, Alberta, Canada	15.1 Installation Foundations

RECOMMENDATIONS FOR USING TRAINING MODULES

The following pages list modules and their corresponding numbers for this particular apprenticeship trade. As related training classroom hours vary for different reasons throughout the state, we recommend that the individual apprenticeship committees divide the total packets to fit their individual class schedules.

There are over 130 modules available. Apprentices can complete the whole set by the end of their indentured apprenticeships. Some apprentices may already have knowledge and skills that are covered in particular modules. In those cases, perhaps credit could be granted for those subjects, allowing apprentcies to advance to the remaining modules.

We suggest the the apprenticeship instructors assign the modules in numerical order to make this learning tool most effective.

SUPPLEMENTARY INFORMATION

ON CASSETTE TAPES

Tape 1:	Fire Tube Boilers - Water Tube Boilers and Boiler Manholes and Safety Precautions
Tape 2:	Boiler Fittings, Valves, Injectors, Pumps and Steam Traps
Tape 3:	Combustion, Boiler Care and Heat Transfer and Feed Water Types
Tape 4:	Boiler Safety and Steam Turbines

NOTE: The above cassette tapes are intended as additional reference material for the respective modules, as indicated, and not designated as a required assignment.

Modules 18.1, 19.1, and 20.1 have been omitted because they contain dated materials.

9.1

PUMPS -- TYPES AND CLASSIFICATIONS

Goal:

The apprentice will be able to describe types and classifications of centrifugal pumps.

Performance Indicators:

1. Classify pumps according to their method of operation.
   - Centrifugal
   - Rotary
   - Reciprocating

2. Describe types of pumps in each major class.

Study Guide

* Read the goal and performance indicators for this package.

* Read the vocabulary sheet to become acquainted with the trade terms that will be introduced in this package.

* Study the introduction and information sheets for technical information.

* Complete the job sheet.

* Complete the self-assessment sheet and check your answers with the answer sheet.

* Complete the post-assessment and ask the instructor to check your answers.

Vocabulary

* Axial flow pump
* Axially split casing
* Casing
* Centrifugal flow
* Centrifugal force
* Centrifugal pump
* Diaphragm pump
* Direct driven simplex pump
* Diffuse
* Double acting pump
* Double suction inlet pump
* Horizontal shaft pump
* Horizontally split casing
* Impeller
* Lobe pump
* Mixed flow pump
* Multi-stage pump
* Power driven pump
* Pump discharge
* Radially split casing
* Reciprocating pump
* Regenerative pump
* Screw pump
* Single acting pump
* Single suction inlet pump
* Single stage pump
* Sliding vane pump
* Spur gear pump
* Vertical shaft pump
* Vertically split casing
* Volute pump

Introduction

Pumps are used to move fluids from one place to another. There are many uses of pumps in industrial settings. Those uses include the movement of feedwater, fuel, cooling water, chemicals and condensate within the power plant.

Pumps are classified into major classes according to their method of operation. Each of the major classes is subdivided into types according to their design or application.

The pump is an important part of a power plant. The apprentice must understand the classes, types, functions and applications of pumps in order to operate power plant equipment.

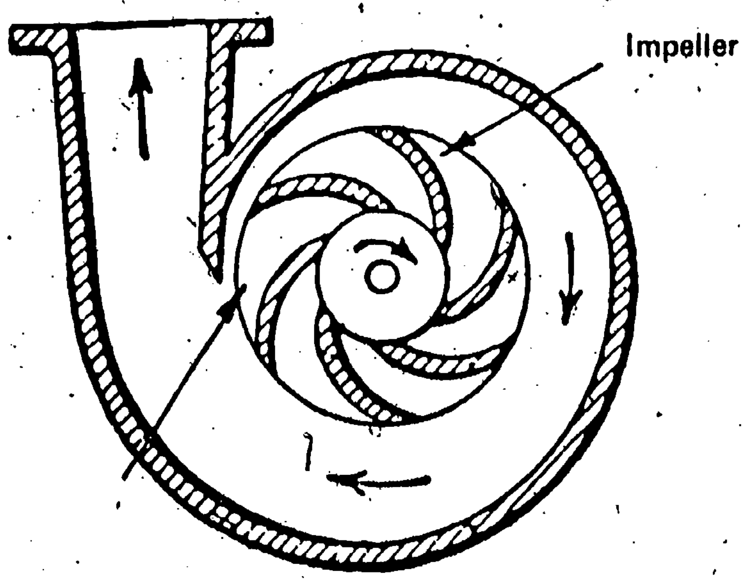
Information

In order to describe pumps, we must first classify them into groups with similar characteristics. All pumps can be classified into three groups according to their method of operation:

1. Centrifugal
2. Rotary
3. Reciprocating

Centrifugal Pumps

A centrifugal pump has an impeller that rotates inside a casing. The rotation of the impeller causes the liquid to move to the outside because of centrifugal force. As the liquid moves to the outside, it is forced through the pump discharge.



Types of Centrifugal Pumps

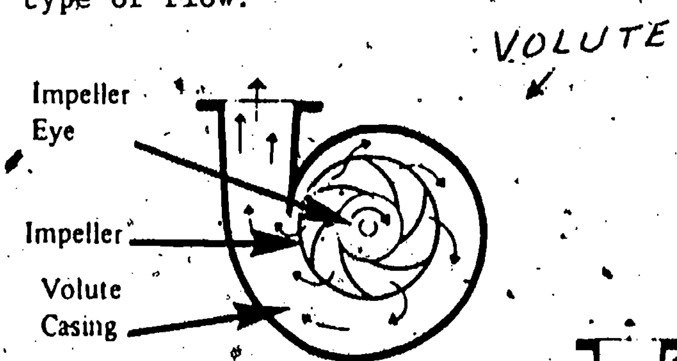
Centrifugal pumps may be further classified according to:

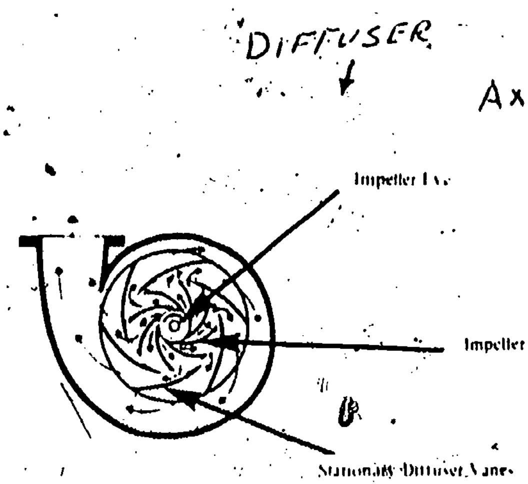
1. Type of flow -- centrifugal, axial, mixed flow or regenerative.
2. Number of stages -- single or multistage.
3. Type of casing -- horizontal or vertical split.
4. Position of shaft -- horizontal, vertical, submerged.
5. Suction -- single or double
6. Application -- general purpose, boiler feed pump, condensate pump, circulating pump.

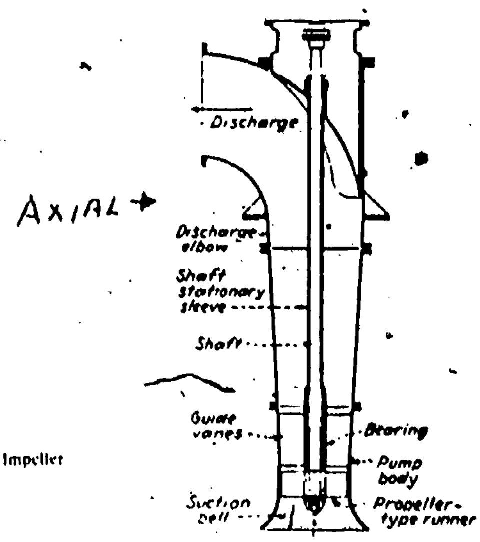
Information

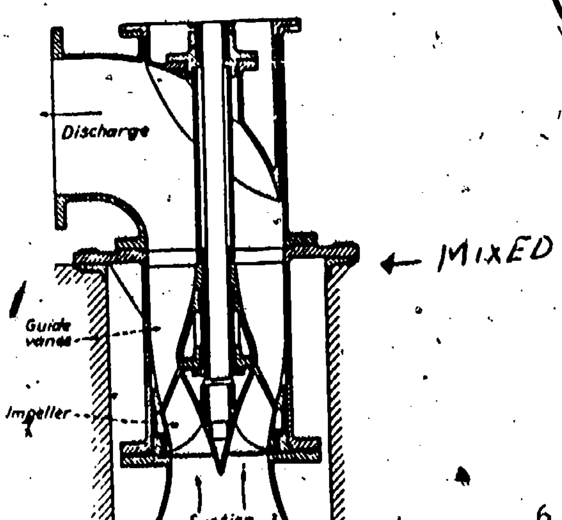
Types of Flow

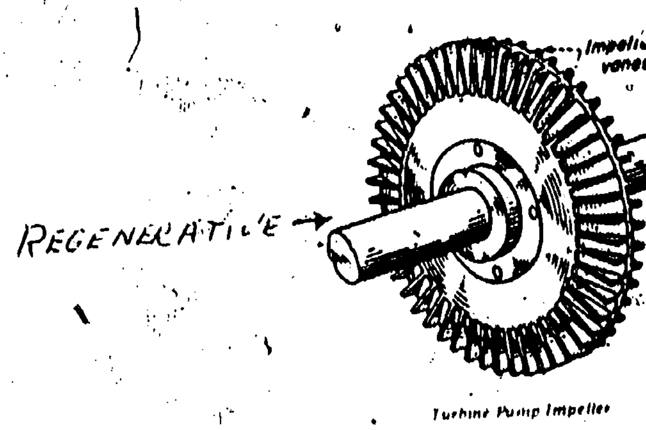
A centrifugal flow is one that pulls the liquid into the eye of the impeller and discharges it from the outer rim of the impeller blades. The increased pressure forces the fluid into a discharge tube. A volute centrifugal pump consists of an impeller made up of vanes that rotates inside a volute casing. Volute means that the casing increases in cross-section as it nears the discharge area. A diffuser centrifugal pump is designed with vanes or diffusers between the impeller rim and the casing. The diffusers convert the high velocity liquid into pressure energy as it passes through the diffuser vanes. An axial flow uses impellers to provide lifting action on the liquid. The pump is arranged vertically and the impellers lift the liquid upward to the discharge tube. A mixed flow combines features of volute and diffuser centrifugal flow with axial flow. The pressure is developed by centrifugal force and axial lift of impeller vanes. A regenerative pump uses an impeller with a double row of vanes in its rim. Liquid enters the outer rim and is rotated almost a complete circle before being discharged from the outer rim. The regenerative pump is commonly called a turbine regenerative pump. The following diagrams show the features of each type of flow.











Turbine Pump Impeller

6

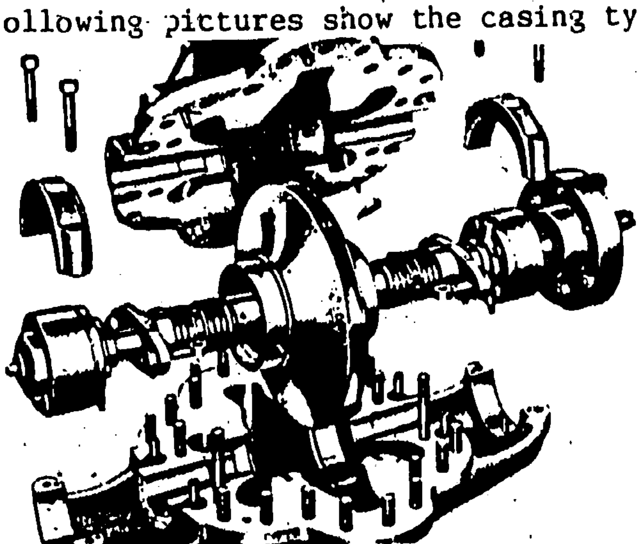
Information

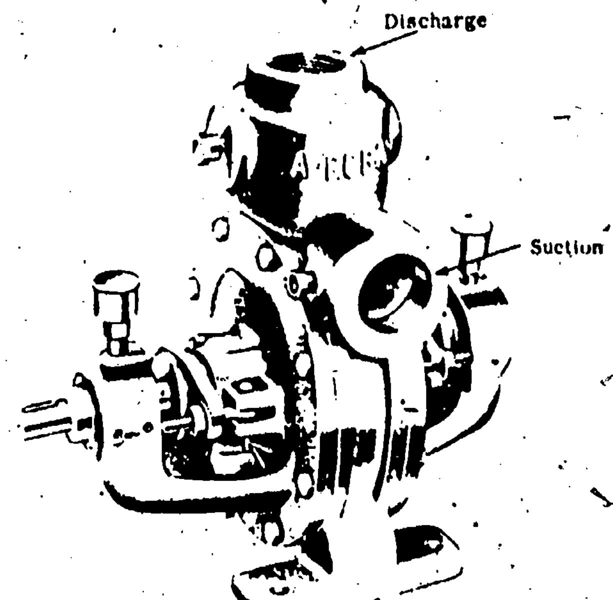
Number of Stages

A pump with a single impeller is called a single stage pump. When two or more impellers are operated in a series to give higher discharge pressures, it becomes a multi-stage pump.

Type of Casing

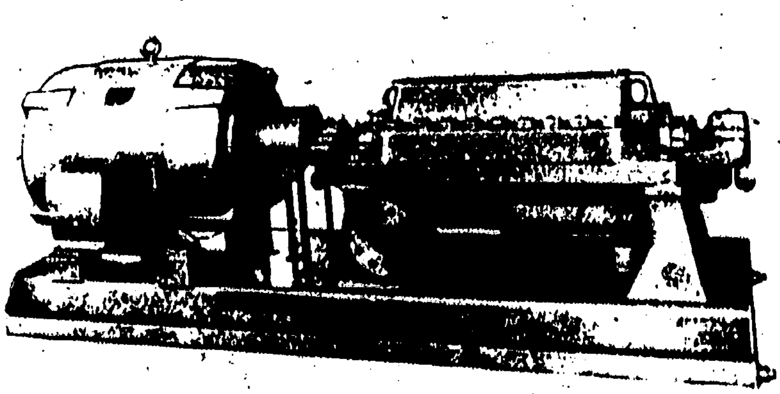
Pump casings are assembled in two sections so that the pump may be taken apart for inspection and repair. If the casing is divided along a horizontal plane it is a horizontally or axially split casing. When the casing divides along vertical lines it is called a vertically or radially split casing. The following pictures show the casing types.

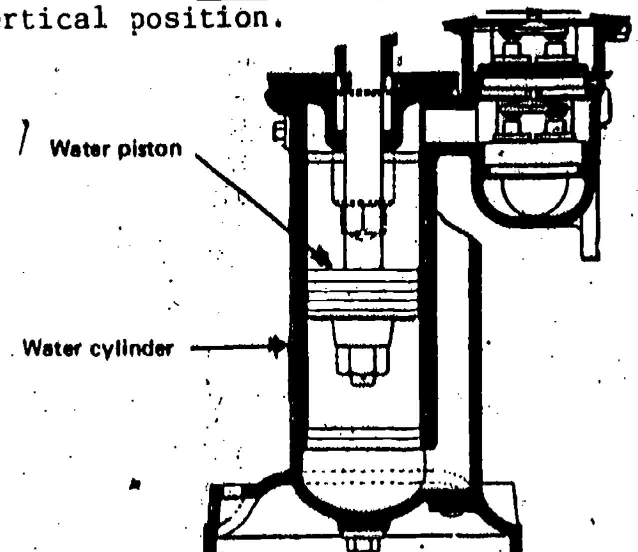




Position of Shaft

Pumps are sometimes classified according to the position of the pump shaft. If the shaft operates on a horizontal plane, it is called a horizontal shaft pump. On a vertical shaft pump the shaft lies in a vertical position.

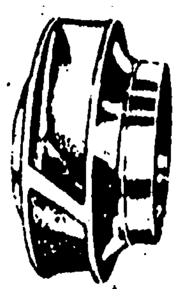


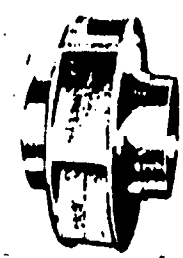


Information

Suction

Water enters the impeller through the eye of the impeller. If water enters from only one side, it is a single suction inlet pump. One designed to allow water to enter the eye of the impeller from both sides is a double inlet pump.





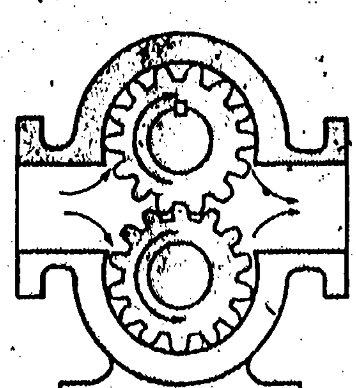
Rotary Pumps

Rotary pumps are positive displacement pumps. Positive displacement means that the pump will displace a given amount of fluid at any given time. Rotary pumps trap the liquid and push it toward the discharge. The major types of rotary pumps are:

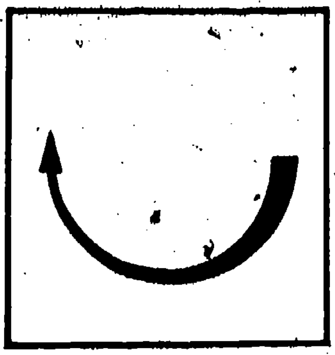
1. Spur gear pumps
2. Lobe pumps
3. Sliding vane pumps
4. Screw pumps

Spur Gear Pumps

The spur gear pump consists of two gears that mesh together inside a housing. One gear is a driver and the other is an idler. The gears rotate and trap the liquid between the gear teeth. Liquids are carried in the spaces between the teeth toward the discharge. The liquids cannot return to the suction because the teeth mesh at the points of return. The following diagram shows how a gear pump operates to move liquid.

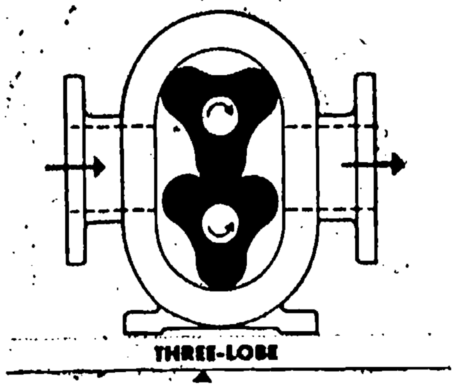


Information



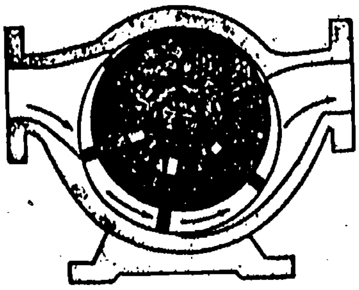
Lobe Pump

The lobe pump operates much like the spur gear pump except that it uses rotors instead of gears for moving the liquid. The rotors have three lobes that trap the liquid and move it toward the discharge. A lobe pump is shown in the following diagram.



Sliding Vane Pump

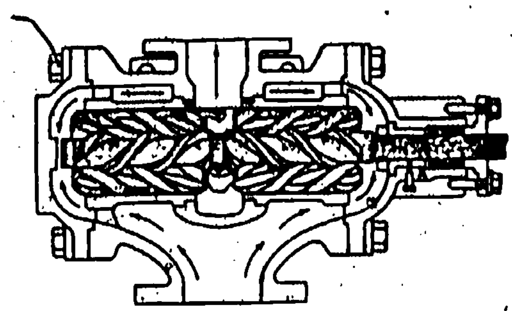
The sliding vane pump uses an off-center rotor with sliding vanes to move liquid. The sliding vanes move out toward the housing by centrifugal force. Liquid is trapped between the vanes and moved toward the discharge. A sliding vane pump is shown in the diagram below.



Information

Screw Pump

A screw pump is made with one driver rotor sandwiched between two idler rotors. The rotors are made of threaded screw augers. The liquid is carried along the screw threads to the discharge. A screw pump is shown in the following diagram.



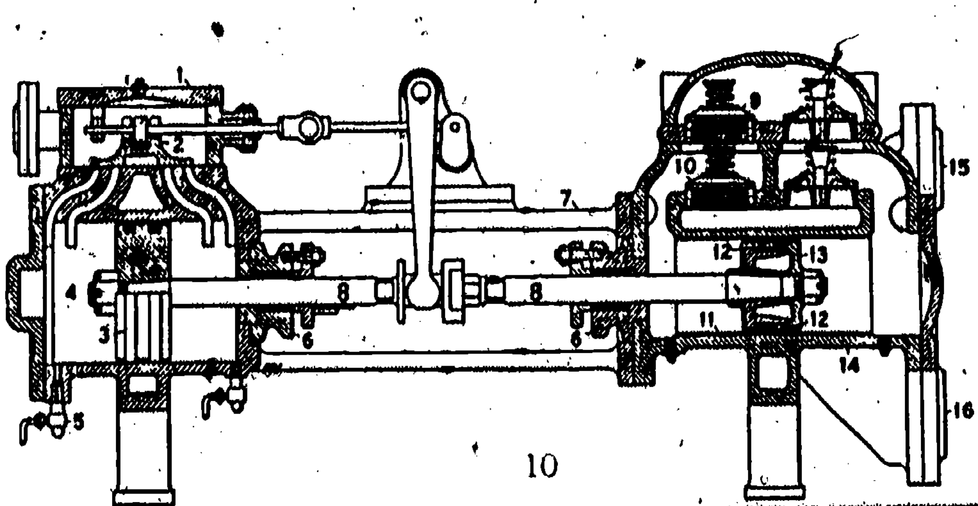
Reciprocating Pumps

A reciprocating pump uses the action of a piston, diaphragm or plunger to move fluid through the pump. Reciprocating pumps are positive displacement pumps. Several types of reciprocating pumps are used in steam generation.

Direct Driven Duplex Pump

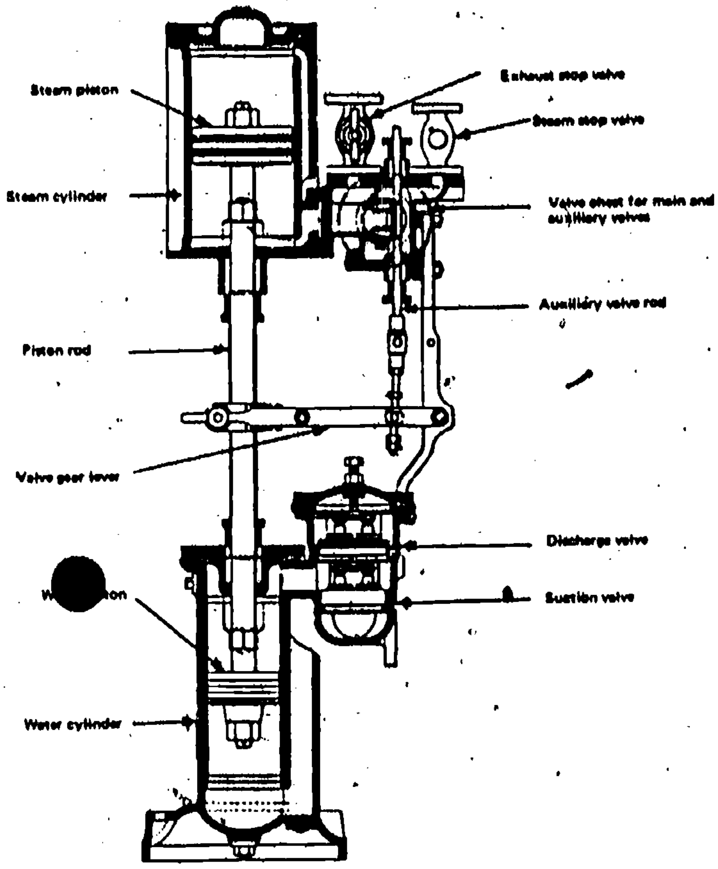
This pump uses drive pistons to drive the pumping pistons. The pumping pistons have overlapping action so that one is at maximum pressure while the other is at minimum pressure. This tends to smooth out the discharge of fluid. The diagram shows features of a horizontal duplex pump.

1. steam chest
2. slide valve
3. piston rings
4. steam cylinder
5. drain cock
6. stuffing box
7. cradle
8. piston rod



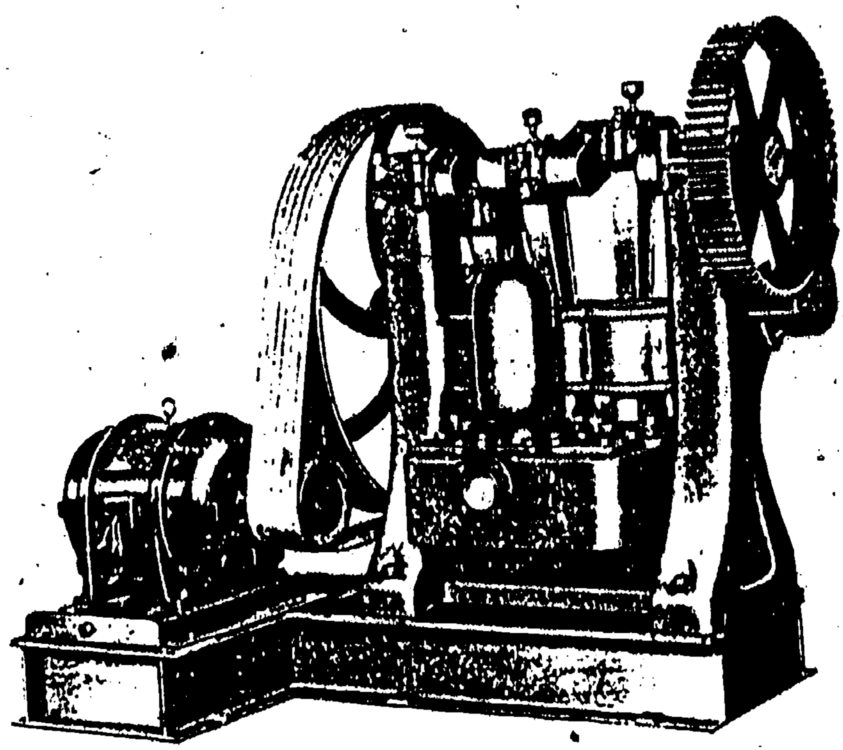
9. discharge valve
10. suction valve
11. liner
12. packing ring
13. liquid piston
14. liquid cylinder
15. discharge port
16. suction port

Information



Direct Driven Simplex Pump

This pump has one driving piston and one double-acting pumping piston. The simplex pump may be of vertical or horizontal types.



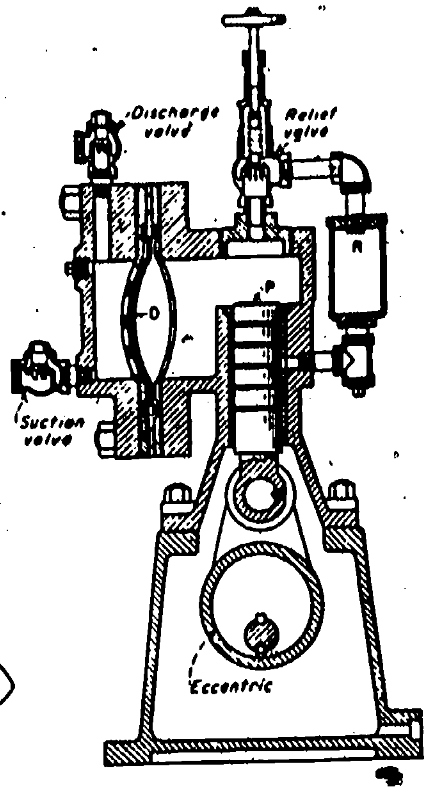
...wer Driven Pumps

Power pumps are driven by some external power source through a crankshaft. A single acting pump discharges water from the cylinder only on the downstroke of the pumping piston. Double acting pumps discharge during each stroke. A power pump is shown in the photograph.

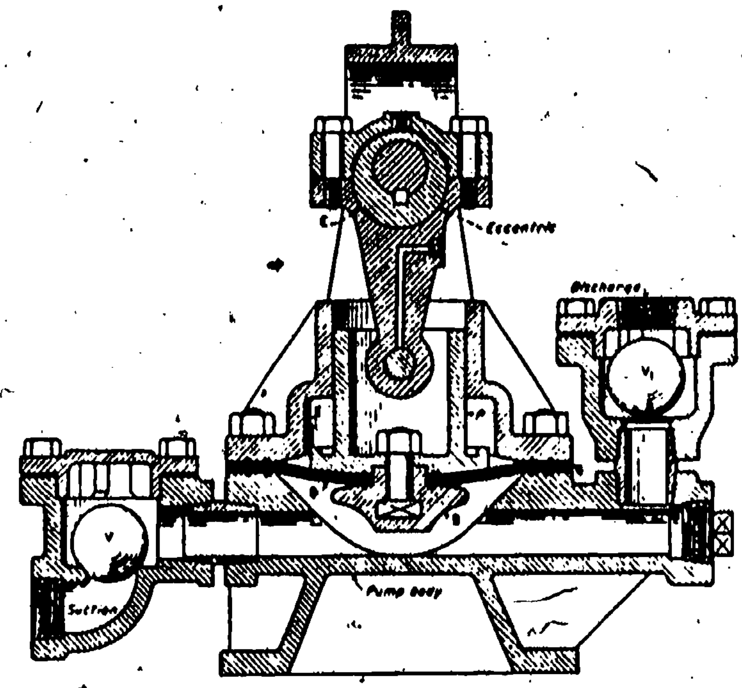
Diaphragm Pumps

Diaphragm pumps use a metal, plastic or rubber material for moving the liquid. The diaphragm is a flexible membrane that is operated mechanically or hydraulically. In this type of pump, the fluid does not come in contact with the reciprocating parts of the pump. In a mechanically actuated diaphragm pump an eccentric is used to flex the diaphragm and cause a pumping action. In a hydraulic actuated diaphragm, the piston pushes a fluid toward the diaphragm causing it to flex and give a pumping action. Diagrams of the two types of diaphragm pumps are shown on the next page.

Information



Hydraulically Actuated
Diaphragm Pump



Mechanically Actuated Diaphragm Pump

Assignment

* Complete the job sheet.
* Complete the self-assessment and check your answers with the answer sheet.
* Complete the post-assessment and have the instructor check your answers.

Job Sheet

INVENTORY PUMPS AT WORK SITE

* Conduct an inventory of the pumps used at your work site. Classify them according to the major class and type shown in package.

PUMP #	LOCATION	CLASS Rotary, reciprocating, centrifugal	TYPE
1			
2			
3			
4			
5			
6			

* Keep the completed inventory sheet for use in other packages on pumps.

Self Assessment

Match the following pump types according to their class. (Reciprocating, rotary, centrifugal.)

____ 1. Direct driven simplex

____ 2. Spur gear

____ 3. Regenerative

____ 4. Axial flow

____ 5. Sliding vane

____ 6. Diaphragm

____ 7. Volute

____ 8. Diffuser

____ 9. Screw

____ 10. Lobe

A. Reciprocating

B. Rotary

C. Centrifugal

Self Assessment Answers

1. A
2. B
3. C
4. C
5. B
6. A
7. C
8. C
9. B
10. B

Post Assessment

Name 3 types of rotary pumps.

1.

2.

3.

Name 4 types of centrifugal pumps.

4.

5.

6.

7.

Name 3 types of reciprocating pumps.

8.

9.

10.

Instructor Post Assessment Answers

1.

2. Spur gear, lobe, sliding vane, screw

3.

4.

5.

6. Volute, diffuser, axial flow, mixed flow, regenerative

7.

8.

9. Direct driven duplex, direct driven simplex, power driven, diaphragm

10.

Supplementary References

* Correspondence Courses. Southern Institute of Technology. Calgary, Alberta, Canada.

INSTRUCTIONAL LEARNING SYSTEMS

9.2

PUMPS -- APPLICATIONS

Goal:

The apprentice will be able to describe applications and limitations of various types of pumps.

Performance Indicators:

1. Describe examples of pump applications in power plants.
2. Describe limitations of pumps.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Ash handling pumps
* Boiler circulating pumps
* Boiler feedwater pumps
* Circulating pumps
* Chemical pumps
* Condensate pumps
* Fuel oil pumps
* Vacuum pumps

Introduction

Pumps are often described in relation to their intended applications. The apprentice must be able to relate the various pump types to the needs of a power plant.

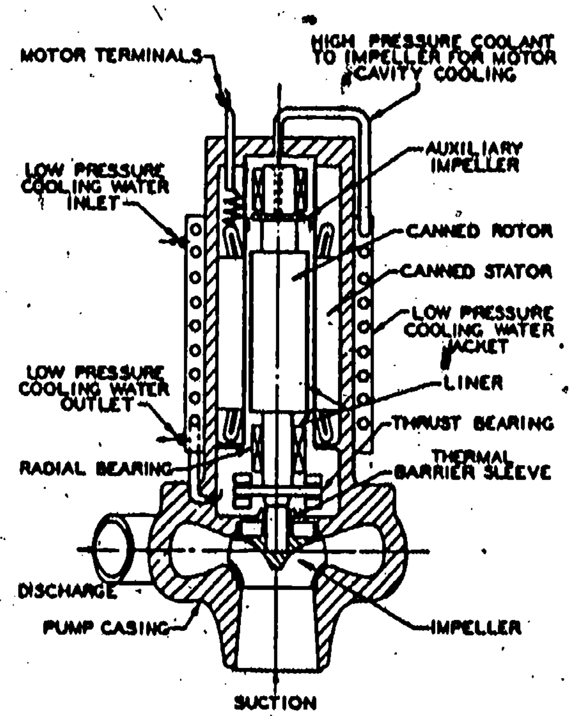
This package shows the major applications and the types of pumps used for each application. The special features or requirements for those applications are shown in a chart in the information sheet.

The apprentice should learn the applications of pumps described in the previous learning package -- "Pumps -- Types and Classifications". The job sheet will provide further understanding of pump types and applications.

Information

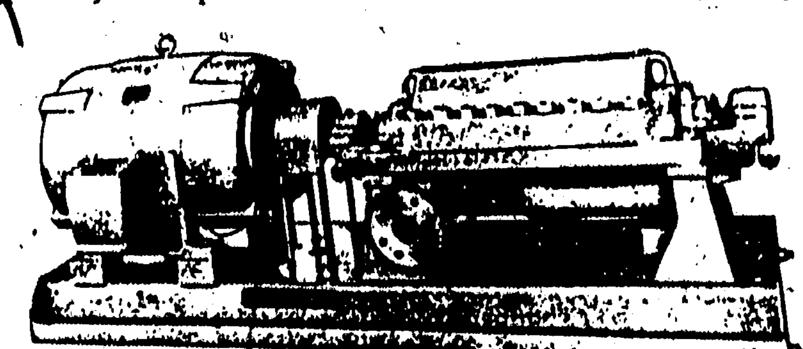
Boiler Circulating Pumps

Most boilers operate at high pressures and require forced circulation through the boiler tubes. Pumps are necessary to keep a flow through the boiler tubes.



Boiler Feedwater Pumps

Pumps are needed to provide the boiler with feedwater. The type of pump needed will depend on the capacity and pressure of the boiler that is being provided with feedwater.



Condensate Pumps

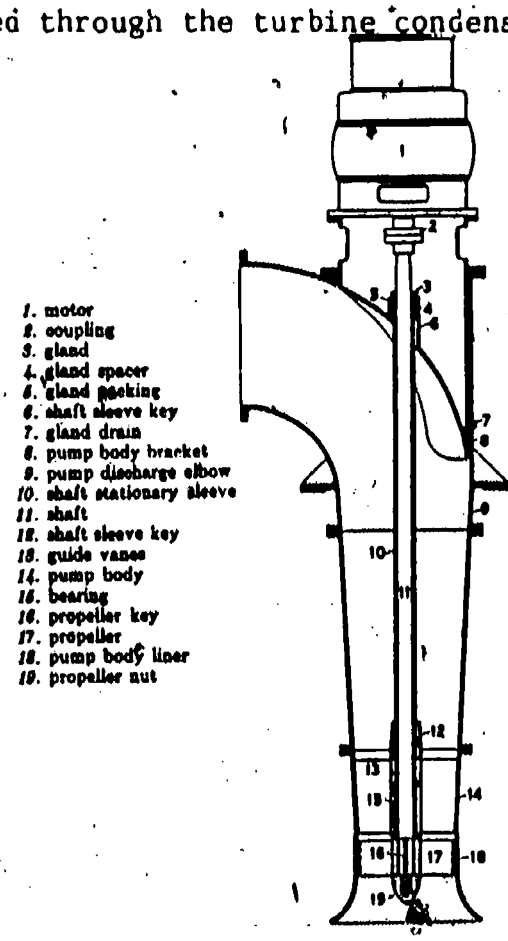
Condensate must be removed from the condensor hotwell and pumped to the boiler as feedwater. In some plants, the condensate pump also serves as a feedwater

Information

pump. High pressure steam plants use pumps to extract condensate from the steam condensors. These pumps are sometimes called extraction pumps.

Circulating Water Pumps

Large volumes of water must be moved through the turbine condensor to cool the steam into water form.



Propeller Type Circulating Water Pump

Information

Fuel Oil Pumps

A pump is necessary for bringing the fuel oil from the storage tank to the boiler burners.

Chemical Feed Pumps

Boiler feedwater is treated with chemicals to neutralize some of the harmful effects caused by impurities in the feedwater. Pumps are required for handling these chemicals.

Vacuum Pumps

Vacuum pumps remove air and gases from the turbine condensor.

Ash Handling Pumps

These pumps are used to pump out ash that has been mixed with water to form a slurry.

Information

TYPES AND APPLICATIONS OF PUMPS

APPLICATION	TYPES OF PUMP	CHARACTERISTICS/LIMITATIONS
Boiler Circulating Pump	Conventional Drive	* Special shaft seals required when presures are high.
	Submerged motor - Wet type - Canned type	* Waterproof insulation for windings required. * Thermal barrier required to retard flow of heat from pumped water into motor of pump.
Boiler Feedwater Pumps	Reciprocating - Direct steam driven - Power driven	* Steam driven pumps limited to pressures less than 2750 kPa. * Power pumps cost more than steam pumps. * Power pumps are subject to increased wear when operating under high pressures and temperatures.
	Centrifugal - Volute - Diffuser - Regenerative	* Bartel type casing required when pressures exceed 10,000 kPa. * Regenerative pump used in small, low-pressure plants.

Information

APPLICATIONS	TYPES	CHARACTERISTICS/LIMITATIONS
Condensate Pumps	Centrifugal - Single stage	* Use large inlet to avoid flashing or cavitation. * Shaft glands must be water-sealed to avoid air leakage when on standby.
Circulating Water Pumps (Cooling water)	Centrifugal - Volute - Axial flow - Mixed flow	* Usually low head, large volume, low speed and single stage design. * 50% capacity pumps are often used.
Miscellaneous Pumps - Fuel oil pump	Rotary (positive displacement)	* Requires a relief or bypass valve to protect pump and discharge lines against excessive pressure.
- Chemical pumps	Reciprocating plunger type-motor driven	* Requires relief valve to avoid damage from over pressure.
- Vacuum pomps	Reciprocating piston type pump	* Positive displacement or jet type. Jet pump uses high pressure steam to operate.
- Ash handling pumps	Centrifugal (Single stage)	* Requires flat bladed impellers of wear resistant alloy.

Assignment

* Read pages 15 - 25 in supplementary reference.
* Complete job sheet.
* Complete self-assessment and check answers with answer sheet.
* Complete post-assessment and have the instructor check your answer.

Job Sheet

ANALYZE APPLICATIONS OF PUMPS AT JOB SITE.

* Use the completed inventory from package (Pumps--Types and Classifications).

* Identify the application and characteristics/limitations for each pump on the inventory sheet. What is the pump used for? Add two more columns to the inventory sheet for applications and characteristics/limitations.

PUMP #	LOCATION	CLASS	TYPE	APPLICATION	CHARACTERISTICS/LIMITATIONS
Example:					
1.	Boiler Rm	Centrif.	Single Stage	Condensate Pump	Use large inlet to avoid cavitation.
2.					
3.					

* Ask your instructor to review the completed job sheet and suggest additions.

Self Assessment

List one type of pump that would be suitable for the following purposes.

1. Condensate pump

2. Fuel oil pump

3. Vacuum pump

4. Circulating water pump (cooling water)

5. Boiler circulating pump

6. Boiler feedwater pump

What is the purpose of the following?

7. Boiler feedwater pumps

8. Circulating water pumps

9. Fuel oil pump

10. Vacuum pump

Self Assessment Answers

1. Centrifugal

2. Rotary

3. Reciprocating

4. Centrifugal

5. Reciprocating -- convential drive or submerged water

6. Reciprocating or centrifugal

7. Provide boiler with feedwater

8. Move cooling water through turbine condensor

9. Brings fuel oil from storage tank to boiler furnace

10. Removes air and gases from the turbine condensor

Post Assessment

Match the following applications with the appropriate type of pump.

____ 1. Boiler circulating pump

____ 2. Condensate pump

____ 3. Vacuum pump

____ 4. Boiler feedwater pump

____ 5. Circulating water pump

____ 6. Fuel oil pump

____ 7. Chemical pump

____ 8. Regenerative pump

____ 9. Conventional drive pump

____ 10. Ash handling pump

A. Requires special shaft seals

B. Used in low pressure plants

C. Reciprocating--steam driven

D. Rotary (positive displacement)

E. Centrifugal--single stage

F. Reciprocating piston type

G. Submerged motor

H. Reciprocating plunger type

I. Centrifugal--volute, mixed flow

J. Centrifugal single stage with flat bladed impellers

Instructor Post Assessment Answers

1. G
2. E
3. F
4. C
5. I
6. D
7. H
8. B
9. A
10. J

Supplementary References

* Correspondence Course. Lecture 9. Section 2. First Class. Southern Institute of Technology. Calgary, Alberta, Canada.

INSTRUCTIONAL LEARNING SYSTEMS

9.3

PUMPS -- CONSTRUCTION

Goal:

The apprentice will be able to describe the construction of the major components of pumps.

Performance Indicators:

1. Describe construction of reciprocating pumps.
2. Describe construction of rotary pumps.
3. Describe construction of centrifugal pumps.
4. Describe pump drives.

1

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Axial thrust
* Balancing disc
* Balancing drum
* Balancing holes
* Ball (roller) bearing
* Double inlet impellers
* External gear pump
* Gland
* Impellers
* Induction motor
* Internal gear pump
* Lantern ring (seal cage)
* Lobe pump
* Mechanical seals
* "O" rings
* Packing
* Pump casing
* Pump shaft sealing
* Relief valve
* Rotating seal
* Screw pump
* Sealing ring
* Single inlet impellers
* Sleeve bearing
* Sliding vane pump
* Stationary seal
* Steam piston
* Stem guided valves
* Stuffing boxes
* Synchronous motor
* Thrust bearing
* Valve disc seats
* Valve stems
* Water piston
* Wear rings
* Wing-guided valves

Introductio

The efficiency of pumps is largely determi
function to prevent leakage of fluid back t
problem of axial thrust that tends to move
end of the pump.

Special packing and seals help to contro
controlled by specialized components that
impeller.

This package introduces the apprentice t
pumps.

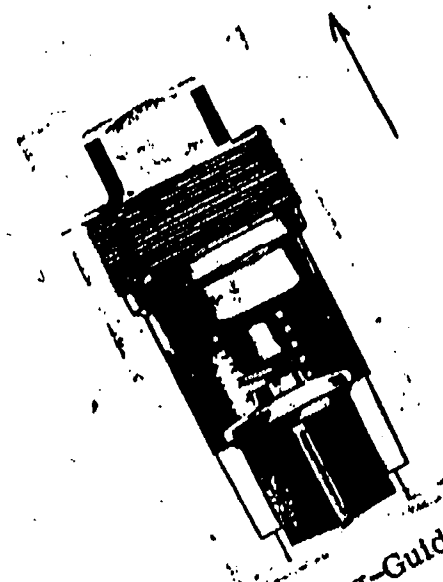
BEST COPY AVAILABLE

..ormation

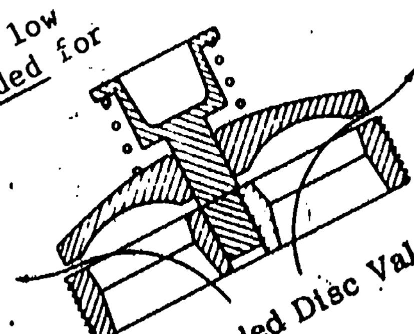
Components of Reciprocating Pumps

Pump Valves

Valve disc seats and stems are made of bronze or other alloy that will be wear resistant. Reciprocating pumps have many different designs for valves. The valves are stem-guided for low pressure systems and wing-guided for moderate and high pressures.



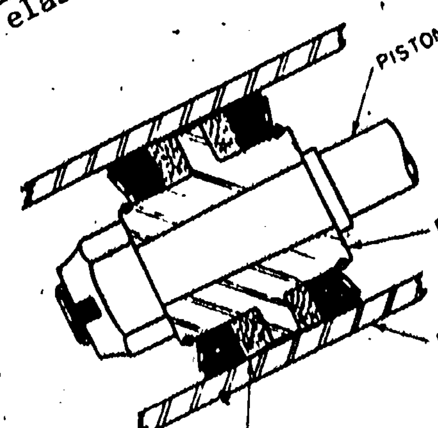
Wing-Guided Valve

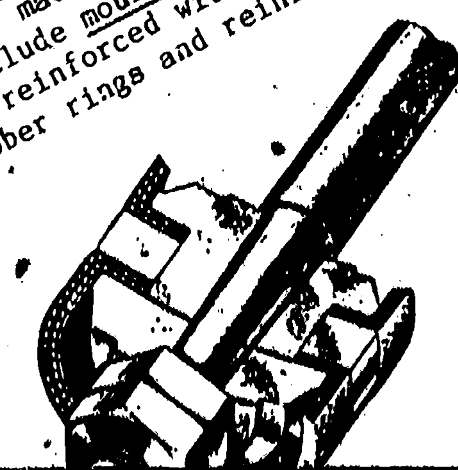


Stem-Guided Disc Valve

Piston and Rod Packing

Reciprocating pumps have a steam piston with cast iron piston rings fitted into grooves. The rings prevent leakage between the piston and cylinder wall. Water pistons are sealed in the cylinder by square fibrous rings or packing. Packing is made with an asbestos core covered with canvas. Other means of packing include moulded cup and reinforced elastomer. The moulded cup is made of rubber reinforced with fabric. The reinforced elastomer packing consists of solid rubber rings and reinforced elastomer.





Information

Relief Valves

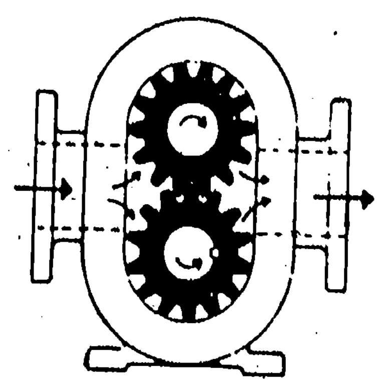
Power driven reciprocating pumps require a relief valve to prevent damage from overpressure. The relief valve is mounted on the pump discharge ahead of the first stop valve. Relief valves are not needed on steam driven reciprocating pumps.

Rotary Pumps

Rotary pumps are used for handling fuel, liquefied gases and hydraulic oils. These pumps use gears, lobes, vanes and screws to move liquids inside a casing. Rotary pumps are made in many designs. Some of the common designs are explained below.

External Gear Pump

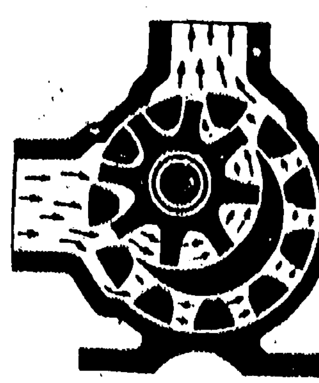
This pump has two gears that turn in opposite directions. The gears trap the liquid and move it toward the discharge. Gear teeth mesh to prevent the liquid from flowing back toward the inlet.



EXTERNAL GEAR

Internal Gear Pump

The internal gear pump has one external cut gear that meshes with an internal cut gear on one side. A moon shaped partition prevents the liquid from passing back toward the inlet.

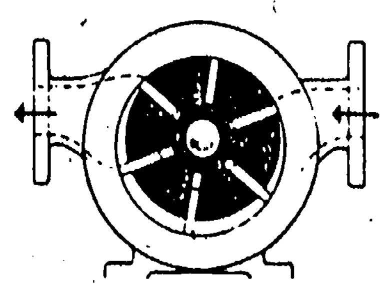


INTERNAL GEAR

Information

Sliding Vane Pump

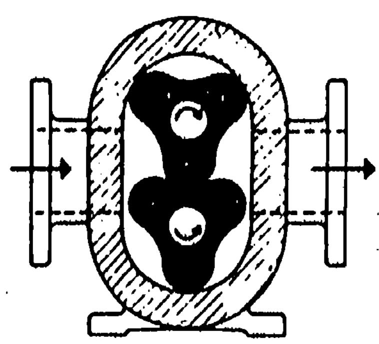
The sliding vane pump has a rotor that is mounted off-center in the casing. The rotor has vanes set in slots on the rotor. The vanes rotate close to the casing on one on one side and have clearance on the other. This forces liquids to move through the clearance toward the discharge.



SLIDING-VANE

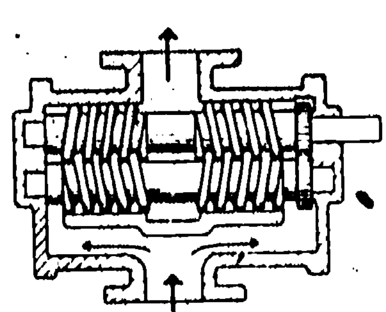
Lobe Pump

This pump has two rotors that are operated by external gears. The liquid is trapped in the pockets of the lobes and carried toward the discharge.



Screw Pump

Screw pumps are designed with two or three screw threads. Liquid is carried between the threads of the rotors and forced toward the discharge.



Information

Centrifugal Pumps

Impeller Types

Impellers are designed in many ways. The design depends on the speed, pump application and how the liquid is to be drawn into the impeller eye. Single inlet impellers pull liquid in from one side. The double inlet impeller pulls liquid in from both sides. The impeller may be constructed like a propeller or have vanes. Some impeller types are shown below.

Pump Casings

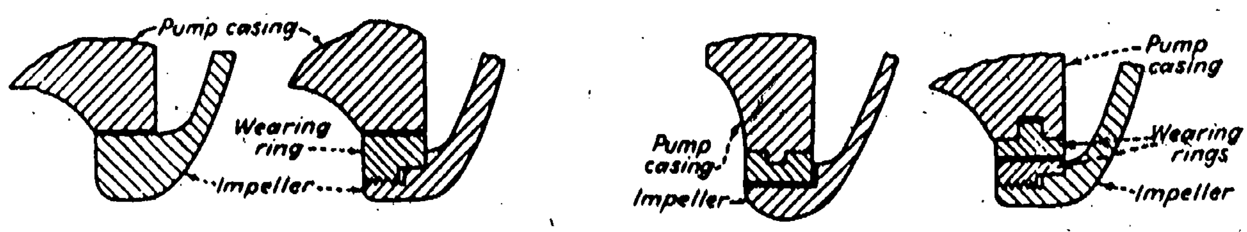
Centrifugal pump casings are split so that the pump can be opened for inspection. These pumps may be split horizontally, vertically or diagonally. Horizontally split casings are called axially split. Vertically split casings are termed radially split. Some centrifugal pumps are encased in a barrel casing to prevent leakage along the split. The barrel casing is an inner casing fitted into the outer casing.

Wearing Rings

The impeller must be sealed in the casing to prevent leakage. The seal is usually provided by a close tolerance joint between the casing and the rim of the impeller eye. As the pump operates, the joint wears and more leakage occurs. At that point, the clearance must be restored by building up the worn surfaces. The cost of restoring the clearance can be reduced by using wear rings. Wear rings are made of softer material than the casing or impeller. Wearing rings are made of bronze or cast iron so that the wear will be smooth.

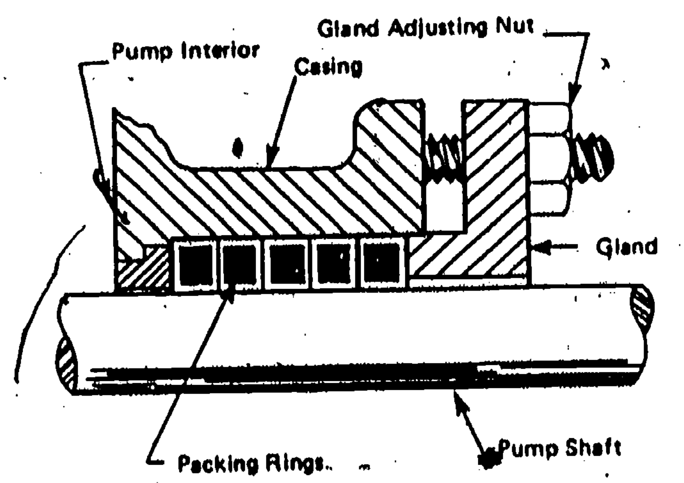
Information

The rings are available in continuous ring or half-ring types. They are fitted into ridges or grooves of the casing and secured with set screws.



Pump Shaft Sealing

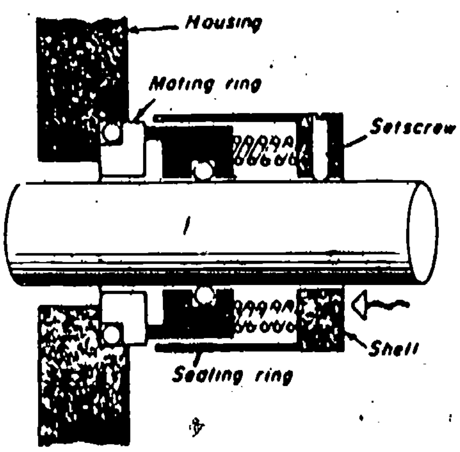
Leakage can occur where the pump shaft passes through the casing. To prevent such leakage, stuffing boxes or mechanical seals are used. A stuffing box is a recess around the shaft that holds a number of packing rings. Packing is held in place by a gland that compresses the rings.



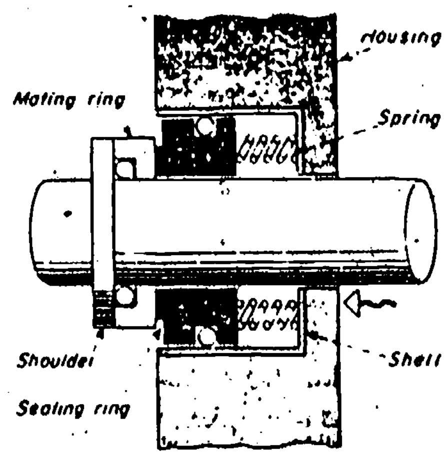
Packing rings are ~~made of~~ materials such as woven asbestos, nylon, flax or teflon. Metals such as lead, copper and aluminum are sometimes used as packing rings. The lantern ring (seal cage) is a metal ring with machined channels that distribute sealing liquid to the packing. The lantern ring is used in pumps that handle sand or other gritty materials.

Information

Mechanical seals are used in pumps that handle fuels, acids and other liquids where leakage is objectionable. Leakage is less than can be provided with stuffing boxes. The mechanical seal involves two flat rings with polished sealing surfaces. One ring (the sealing ring) is held in position by a spring. The other ring (mating ring) faces the sealing ring. There are two types of mechanical seals. The rotating seal has the sealing ring attached to the shaft so that it rotates with the shaft. The stationary seal rotates the mating ring while the sealing ring is attached to the pump housing. "O" rings are used to prevent leakage between the rings and the casing and shaft.



Rotating Seal



Stationary Seal

Pump Bearings

Centrifugal pumps use bearings to support the shaft and allow it to turn freely. Bearings are either sleeve or shell or ball or roller types. Small pumps have bronze bushings or sleeves that closely fit about the shaft. Large pumps use half-shell sleeve bearings that are made of cast-iron or steel and lined with babbitt. Many modern pumps use ball or roller bearings instead of sleeve bearings. Small shaft pumps use ball bearings while large shaft pumps use roller bearings.

Control of Axial Thrust

During the operation of a pump, forces tend to move the impeller out of position. This causes an axial thrust back toward the suction. Several ways have been developed for control of axial thrust. Thrust bearings on the shaft of low capacity pumps will control the problem. Balancing holes are used to control axial thrust on single-inlet pumps. Sometimes axial thrust is controlled by facing impellers in a manner that the inlets are opposed to each

Information

other. A balancing drum can be installed on the shaft between the impeller and the balancing chamber. The drum tends to balance the thrust toward the discharge instead of the suction. Balancing discs can be used to control axial thrust when mounted on the shaft. The balancing disc is not widely used because it can have more problems than the balancing drum.

Pump Drives

Pumps are driven by many power sources. The most common power source is the electric motor. The squirrel cage induction motor is the most common. The synchronous motor is used for large capacity pumps. Steam turbines are often used to drive centrifugal and rotary pumps. Internal combustion engines can also be used to drive pumps.

Assignment

* Read pages 16-42 in supplementary reference and study diagrams.
* Complete the job sheet.
* Complete the self-assessment and check answers with answer sheet.
* Complete the post-assessment and have the instructor check your answers.

Job Sheet

DISASSEMBLE A CENTRIFUGAL PUMP

* Obtain a centrifugal pump (functional or non-functional).

* Remove half of the casing.

* Identify:

  - Type of impeller (single or double-inlet).
  - Type of flow (volute, diffuser, axial or mixed).
  - Type of casing (horizontal split, vertical split).
  - How wear rings are attached.
  - How pump shaft is sealed (stuffing bix, mechanical seal).
  - Location of gland.
  - Use of lantern ring.
  - Use of "O" rings.
  - Type of bearings.
  - How axial thrust is controlled (thrust bearing, balancing drum, balancing holes, balancing disc).
  - How pump is driven (type of motor, coupling).

* Ask instructor to explain those things that you do not understand.

Self Assessment

Match the following terms with the proper applications.

1. Stem guided valves	A. Used to drive large capacity pumps.
2. Wing guided valves	B. Prevents damage from overpressure.
3. Steam pistons	C. Type of impeller.
4. Water pistons	D. Used on high pressure systems.
5. Relief valve	E. Sealed in piston with cast iron piston rings.
6. Single-inlet	F. Type of packing.
7. Thrust bearings	G. Used on low pressure systems.
8. Stuffing boxes	H. Sealed in cylinders with packing.
9. Synchronous motors	I. Used to seal between shaft and housing.
10. Reinforced elastomer	J. Controls axial thrust.

Self Assessment Answers

1. G
2. D
3. E
4. H
5. B
6. C
7. J
8. I
9. A
10. F

Post Assessment

Match the following pump parts with their construction features.

1. Valve disc seats
2. Induction motors
3. Balancing drum
4. Packing
5. Synchronous motors
6. Reinforced elastomer
7. Moulded cup
8. Radially split casings
9. Gland
10. Single-inlet impeller

A. Used to hold packing in place.

B. Casing opens along vertical line.

C. Made with asbestos core covered with canvas.

D. Most common motor for pumps.

E. Used to drive large capacity pumps.

F. Made of bronze or alloy.

G. Pulls liquid into one side only.

H. Made with rubber reinforced with fabric.

I. Made of solid rubber rings and reinforcement.

J. [illegible] to control axial thrust.

Instructor Post Assessment Answers

1. F
2. D
3. J
4. C
5. E
6. I
7. H
8. B
9. A
10. G

Supplementary References

* Correspondence Course. Lesson 6. Section 3. Third Class. Southern Institute of Technology. Calgary, Alberta, Canada.

INSTRUCTIONAL LEARNING SYSTEMS

9.4

PUMPS -- CALCULATING HEAD AND FLOW

Goal:

The apprentice will be able to calculate head and flow rates.

1

Performance Indicators:

1. Calculate net positive suction head.
2. Calculate change in pump power due to changes in size and speed of impeller.
3. Calculate change in head due to changes in size and speed of impeller.
4. Calculate change in quantity pumped due to changes in size and speed of impeller.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.

* Read the vocabulary list to find new words that will be used in package.

* Read the introduction and information sheets.

* Complete the job sheet.

* Complete self-assessment.

* Complete post-assessment.

Vocabulary

* Capacity
* Friction head
* kPa (Pascal)
* Net positive suction head
* Pressure head
* Pump efficiency
* Pump power
* Static discharge head
* Static head
* Static suction head
* Static suction lift
* Total head
* Velocity head.

Introduction

Pumps must be selected according to the requirements of the job to be performed. In order to make wise selections of centrifugal pumps, someone must be able to calculate such things as head, power requirements of pumps, quantities of fluids that can be pumped and efficiency of pumps.

An apprentice should understand the basic principles of pumps and be able to make calculations needed for selection of pumps. The ability to make such calculations will insure a better job of matching pumps with the jobs they are to perform.

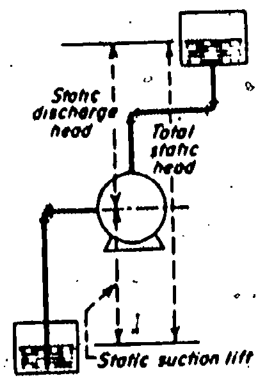
Information

Capacity

Capacity is the quantity of liquid handled by a pump in a given period of time. It is usually expressed as GPM (gallons per minute).

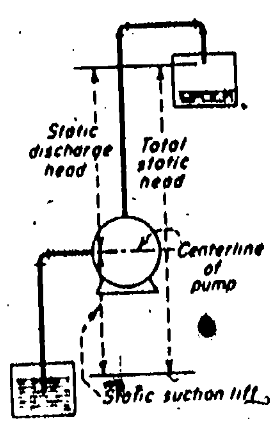
Static Head

Total static head is the total distance that a liquid moves in passing through a pump.



Static Discharge Head

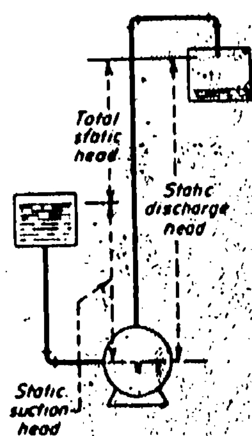
Static discharge head is the vertical distance from the center line of the pump to the surface of liquid in the discharge well.



Information

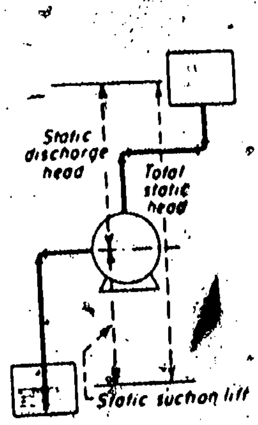
Static Suction Head

This is the vertical distance from the pump center line to the surface of the liquid in the source of supply. Static suction head exists when the supply is located above the center line of the pump.



Static Suction Lift

This condition exists when the source of supply is below the center line of the pump. It is the vertical distance from the surface of the liquid in the suction well to the center line of the pump.



Friction Head

This is the head needed to overcome friction of the liquid flow through the pipes and fittings.

Information

Velocity Head

The head through which a liquid would need to fall to acquire pumping velocity.

Pressure Head

The head caused by pressure of the liquid in the suction well or discharge well.

Total Head

Total head is the sum of static head plus velocity head plus friction head plus pressure head.

Net Positive Suction Head

This is the total head of liquid in feet at the suction nozzle, minus the vapor pressure of the liquid.

Calculating Head

In order to calculate head, one must first calculate pressure. Pressure is expressed in a unit called Pascal or in kPa (thousands of Pascals).

p = pressure (Pascals)
w = force of gravity (mass x density x 9.8)
h = height of free surface above point of measurement

For example, we wish to measure the pressure of water 5 meters below the surface. Water has a density of 1,000 kilograms per cubic meter. The formula would be:

$p = wh$
$p = 1{,}000 \times 1 \times 9.8 \times 5 = 49{,}000$ Pa or 49 kPa

Other liquids will have other densities which will change the value of w in the formula. For example, gasoline has a relative density of .75. The same problem as above would be calculated as:

$p = wh$
$p = 1{,}000 \times .75 \times 9.8 \times 5 = 36{,}750$ Pa or 36.75 kPa

Net positive suction head is used by pump manufacturers to express pump

Information

capacity. When selecting a pump, one must make certain that the net positive suction head requirements are met. The formula for net positive suction head is:

$$\text{Net positive suction head} = \frac{.1048\,(Pa-Pv)}{RD} + He - Hf$$

Pa = pressure of atmosphere or in the suction vessel
RD = relative density of liquid at pumping temperature
He = suction head in meters, either positive or negative depending on whether the pump is above or below the suction well
Pv = vapor pressure of liquid at pumping temperature in kPa from steam table
Hf = friction head in meters of suction piping

For example, a pump is lcoated 4.5 meters above the supply and is pumping 30oC water of RD of 1.0. The atmospheric pressure is 101.325 kPa and the friction head is .3 meters. Calculate the net positive suction head in this example:

Pa = 101.325 kPa
Pv = 4.246 kPa (from steam table)
RD = 1.0
He = -4.5 meters
Hf = .3 meters

$$NPSH = \frac{.10148\,(101.325 - 4.246)}{1.0} - 4.5 - 0.3$$

$$NPSH = 9.8516 - 4.8$$

$$NPSH = 5.85 \text{ meters}$$

Calculating Pump Performance[1] (Centrifugal Pumps)

The quantity of water pumped will be affected by the size of the impeller and will vary according to the diameter of the impeller. Head will vary with the square of the impeller speed. The power to drive the pump will vary as the cube

Information

of the impeller speed or diameter. Head will also vary as the diameter of the impeller squared. Pump performance at different speeds and impeller sizes can be compared.

$$\text{Pump power (KW)} = \frac{\text{Kilograms of fluid delivered per minute} \times \text{Distance fluid is lifted in meters}}{6115.94}$$

For example, a pump is required to lift 400 kg of water for 8 meters:

$$KW = \frac{400 \times 8}{6115.94}$$

$$KW = .52$$

If KW = pump power
H = head (m)
D = impeller diameter (mm)
E = pump efficiency
n = pump speed (revolutions per minute)
Q = quantity pumped (liters per minute)

We can compare two pumps through equations. The effects of speed and impeller size on quantity pumped, head, power requirements and efficiency are considered in the following equations:

$$Q_2 = Q_1 \times \frac{n_2}{n_1} \times \frac{D_2}{D_1}$$

$$H_2 = H_1 \times \left(\frac{n_2}{n_1}\right)^2 \times \left(\frac{D_2}{D_1}\right)^2$$

$$KW_2 = KW_1 \left(\frac{n_2}{n_1}\right)^3 \times \left(\frac{D_2}{D_1}\right)^3$$

$$E_1 = E_2$$

Information

Example:

A centrifugal pump delivers 20,000 liters per minute of water against a head of 40 meters when running at 2,000 revolutions per minute. The pump efficiency is 80 percent and requires 120 KW to drive the pump. The diameter of the impeller is 320 mm. If we reduce the impeller diameter to 300 mm and speed the pump to 2,100 revolutions per minute, what will be the performacne of the pump?

$$\text{Quantity pumped } Q_2 = Q_1 \times \frac{n_2}{n_1} \times \frac{D_2}{D_1}$$

$$Q_2 = 20{,}000 \times \frac{2100}{2000} \times \frac{300}{320}$$

$$Q_2 = 20{,}000 \times 1.05 \times .93$$

$$Q_2 = 19{,}520 \text{ liters per minute}$$

The change in impeller size and speed caused the pump to pump 480 liters less water per minute.

Let's take a look at the effect of those changes on head developed by the pump.

$$\text{Head } (H_2) = H_1 \times \left(\frac{n_2}{n_1}\right)^2 \times \left(\frac{D_2}{D_1}\right)^2$$

$$H_2 = 40 \times \left(\frac{2100}{2000}\right)^2 \times \left(\frac{300}{320}\right)^2$$

$$H_2 = 40 \times 1.10 \times .86$$

$$H_2 = 37.84 \text{ meters}$$

The change in impeller size and speed would reduce the head 2.16 meters.

If we wish to compare the pump power requirements, the cube formula is used:

$$KW_2 = KW_1 \left(\frac{n_2}{n_1}\right)^3 \times \left(\frac{D_2}{D_1}\right)^3$$

$$KW_2 = 120 \times \left(\frac{2100}{2000}\right)^3 \times \left(\frac{300}{320}\right)^3$$

$$KW_2 = 120 \times 1.33 \times .80$$

$$KW_2 = 127.20$$

The required pump power would be increased by 7.2 KW as a result of changing the size and speed of the impeller.

Assignment

* Read pages 33-38 in supplementary reference.
* Complete the job sheet.
* Complete the self-assessment and check your answers with the answer sheet.
* Complete the post-assessment and ask the instructor to check your answers.

Job Sheet

IDENTIFY THE RATINGS OF A CENTRIFUGAL PUMP AT YOUR WORKSHOP.

* Find the rated speed of a centrifugal pump impeller. (n_1)
* Find the diameter of the impeller. (D_1)
* Find the rated flow of the pump. (Q_1)

Calculate the change in quantity that can be pumped by increasing the speed of the impeller by 100 revolutions per minute.

Self Assessment

Using the equations:

$$Q_2 = Q_1 \times \frac{n_2}{n_1} \times \frac{D_2}{D_1}$$

Calculate the change in quantity pumped by the following centrifugal pump when the impeller size is changed.

The pump now delivers 12,000 liters/minute against a 40m head when running at 1600 revolutions. The impeller diameter is 300 mm. If we change the impeller size to 320 mm and increase the speed to 1700 revolutions, how will the quantity of fluid pumped change?

Remember that Q_2 = Quantity pumped after change

Q_1 = Quantity pumped before change

n_2 = Pump speed after change

n_1 = Pump speed before change

D_2 = Impeller diameter after change

D_1 = Impeller diameter before change

Self Assessment Answers

$$Q_2 = Q_1 \times \frac{n_2}{n_1} \times \frac{D_2}{D_1}$$

$$Q_2 = 12000 \times \frac{1700}{1600} \times \frac{320}{300}$$

$$Q_2 = 12000 \times 1.06 \times 1.06$$

Q_2 = 13,440 liters/per minute

This is an increase of 1440 liters/per minute

Post Assessment

Using the equation:

$$H_2 = H_1 \times \left(\frac{n_2}{n_1}\right)^2 \times \left(\frac{D_2}{D_1}\right)^2$$

Calculate the change in head developed by a pump as a result of changing speed and size of the impeller.

Problem:

A pump delivers 12,000 liters per minute against a 40 meter head when running at 1600 revolutions. The impeller diameter is 300 mm. If we change the impeller size to 320 mm and increase the speed to 1700 revolutions, what will be, the change in head developed by the pump?

Remember: H_2 = Head after change

H_1 = Head before change

n_2 = Pump speed after change

n_1 = Pump speed before change

D_2 = Impeller diameter after change

D_1 = Impeller diameter before change

Instructor Post Assessment Answers

$$H_2 = H_1 \times \left(\frac{n_2}{n_1}\right)^2 \times \left(\frac{D_2}{D_1}\right)^2$$

$$H_2 = 40 \times \left(\frac{1700}{1600}\right)^2 \times \left(\frac{320}{300}\right)^2$$

$$H_2 = 40 \times (1.06)^2 \times (1.06)^2$$

$$H_2 = 40 \times 1.12 \times 1.12$$

$$H_2 = 50.17 \text{ meters}$$

The larger impeller size and increased speed results in an increase of 10.17 meters of head.

Supplementary References

* Correspondence Course. Lecture 9. First Class. Southern Alberta Institute of Technology. Calgary, Alberta, Canada.

INSTRUCTIONAL LEARNING SYSTEMS

9.5

PUMPS -- OPERATION

Goal:

The apprentice will be able to describe steps in operation of pumps.

Performance Indicators:

1. Describe steps in priming of pumps.
2. Describe steps in starting a pump.
3. Describe steps in stopping a pump.
4. Describe cavitation.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Air vent petcock
* Casing
* Cavitation
* Discharge valve
* Priming
* Suction line

Introduction

Pumps can be problems if the proper procedural steps are not followed in their priming, starting and stopping. The apprentice should learn the sequence of steps that avoid problems with pumps.

This package is designed to help the apprentice learn the proper operational steps so that priming, starting and stopping pumps will become a part of work habit.

Information

Priming a Pump

Reciprocating and rotary pumps are self-priming when in good condition and under normal lifts. Centrifugal pumps are not self-priming. These pumps must be primed with water before start-up. When the pump is located above the source, follow the following priming procedures:

1. Fill suction line and casing with liquid through discharge valve bypass, auxillary line or be using a priming valve to draw air from the casing.
2. A foot valve on the suction line will allow liquids to enter the line but will prevent it from draining out.

If the pump is located below the supply, follow the following procedures:

1. Close discharge valve.
2. Open air vent petcocks.
3. Slowly open the suction valve.
4. Close air vent petcocks when liquid appears through them.
5. Open discharge valve before starting pump.

Starting Pumps

The following procedure should be followed when starting centrifugal pumps.

1. Check oil level in bearing housings.
2. Turn on cooling water for pump bearings, stuffing boxes and mechanical seals, if parts are water cooled.
3. Open suction valve and close discharge valve.
4. Close all drains in casing, suction and discharge piping.
5. Prime pump and open discharge valve.
6. Start pump and bring to speed.
7. Check leakage of stuffing boxes.
8. Adjust sealing liquid in stuffing boxes.
9. Check oil rings on sleeve bearings to see that they turn freely.
10. Check suction and discharge pressures.
11. Feel pump bearings for overheating.
12. If pump is being started for the first time:
    - Check that rotor turns freely.
    - Check alignment of pump and driver.
    - Check direction of rotation of driving motor.

Information

Stopping Pumps

When stopping centrifugal pumps, follow these procedures:

1. Close discharge valve slowly (large radial flow pumps).
2. Stop pump driver.
3. Shut off cooling water.
4. Close suction valve.

Cavitation

Cavitation is a condition caused by vaporization of liquids moving through a pump. It occurs when the pressure in the pump falls below the liquid vapor pressure. A vapor is formed as a result of the unequal pressure. Cavitation causes erosion of metal parts, vibration and pulsations as vapor pockets break down. Cavitation is caused by the following:

1. Suction velocity is too high.
2. Suction lift is too high.
3. Temperature of liquid is too high.
4. Suction line has too many sharp changes in its direction of flow.

Assignment

* Read pages 42-45 in supplementary reference.
* Complete job sheet.
* Complete self-assessment and check answers with answer sheet.
* Complete post-assessment and ask instructor to check your answers.

Job Sheet

PRIME A CENTRIFUGAL PUMP

* Locate a centrifugal pump at your work site and get permission to prime, start and stop it.

* Follow the procedures outlined in the information sheet.

* Prime, start and stop the pump in the proper sequence of operational steps.

Self Assessment

1. ____________________ pumps must be primed before starting.

2. A ____________________ valve on the suction line prevents liquid from draining out during priming.

3. The ____________________ valve must be closed before priming a centrifugal pump and opened before or immediately after the pump is started.

4. The air vent ____________________ must be open during priming.

5. ____________________ is a condition that occurs when liquid is converted to a vapor as it passes through the pump.

Self Assessment Answers

1. Centrifugal

2. Foot valve

3. Discharge valve

4. Petcocks

5. Cavitation

Post Assessment

Explain the priming of a centrifugal pump when the pump is located below the source of supply. List the steps in the order that you would perform them.

Instructor Post Assessment Answers

The general steps for priming a centrifugal pump when the pump is below the source of supply are:

1. Close discharge valve.
2. Open air vent petcocks.
3. Open suction valve (slowly).
4. Close air vent petcocks when liquid comes through them.
5. Open discharge valve before starting.

Supplementary References

* Correspondence Course. Lecture 6. Third Class. Section 3. Southern Alberta Institute of Technology. Calgary, Alberta, Canada.

INSTRUCTIONAL LEARNING SYSTEMS

9.6

PUMPS -- MONITORING AND TROUBLESHOOTING

Goal:

The apprentice will be able to describe monitoring and troubleshooting of pumps.

Performance Indicators:

1. Describe installation as it relates to troubleshooting.
2. Describe troubleshooting requirements of pumps.
3. Describe monitoring requirements of pumps.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.

* Read the vocabulary list to find new words that will be used in package.

* Read the introduction and information sheets.

* Complete the job sheet.

* Complete self-assessment.

* Complete post-assessment.

Vocabulary

* Installation
* Monitoring
* Troubleshooting

Introduction

The installation of a pump is very important to monitoring and troubleshooting it while in operation. The manufacturer of the pump should be consulted about installation and their recommendations should be followed.

Once installed, the pump must be closely watched during its operation. This is called monitoring. When a problem occurs in the operation of the pump, the operator must be able to correct the problem. Problem identification and correction is called troubleshooting. Troubleshooting is a "quick fix" type of repair that involves simple operations such as replacing wear rings or seals.

This package is designed to introduce the apprentice to the basic concepts of installation, monitoring and troubleshooting. Preventive maintenance will be discussed in greater detail in a separate package.

Information

Installation

A pump should be installed in a location that is easily accessible for inspection and repair. Room should be allowed for removing the casing and rotor. Reciprocating pumps should allow room for removal of piston and rods. A pump should be located close to the supply to minimize the length of the suction line. Discharge lines should be short and with a minimum of fittings to reduce cavitation problems.

Where a pump is to work on suction lift, a foot valve should be installed along with a suction strainer. A gate valve should be placed in the discharge line close to the pump. Also a check valve should be installed between the gate valve and the pump.

Reciprocating pumps may require a surge chamber on the suction or discharge line. This chamber should be kept charged with air. A water level gauge is needed to check the amount of air in the chamber.

The pump manufacturer should be consulted about the installation of new pumps. Technical assistance should be requested from the manufacturer on installation procedures. Installation and alignment of pumps is a complex procedure and cannot be fully explained in this learning package. Additional information will be needed for proper installation.

Troubleshooting

The operator should always keep spare parts for pumps. The parts must be ordered in advance and catalogued for easy reference. The instruction manual should be close at hand and used as a guide for troubleshooting the specific pump that is giving trouble. Spare valves and packing should be available for troubleshooting/reciprocating pumps. Bearings, shaft sleeves, wearing rings and packing will be needed for repairing centrifugal pumps. The instruction manual for each pump will provide guidelines for troubleshooting.

Monitoring Pumps

The best way to avoid pump outages is to establish a schedule of operational checks and a preventive maintenance program. Operating checks should be made hourly, monthly, quarterly, semi-annually and annually. These checks are made in much the same way as automobiles are maintained.

Information

In addition to the operations checks for maintenance purposes, the operator should listen to the pumps and make visual inspections on a continual basis. Unusual noises should alert the operator to problems. Loss of pressure on pressure gauges should be detected and action taken quickly.

Monitoring pumps requires an operator to use their senses of hearing, sight, smell and feeling of bearings that might be overheating. They must possess a sense of responsibility for the equipment and be alert to operating problems.

Assignment

* Read pages 27-32 in supplementary reference.

* Complete job sheet.

* Complete self-assessment and check answers with answer sheet.

* Complete post-assessment and ask instructor to check your answers.

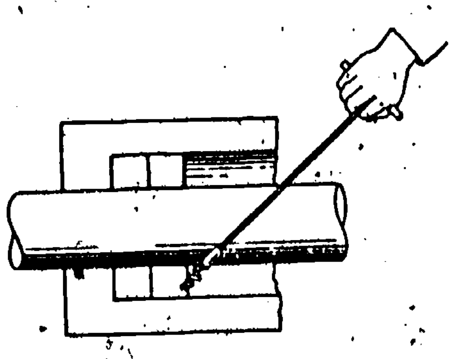
Job Sheet

REPLACE PUMP PACKING ON RECIPROCATING OR CENTRIFUGAL PUMP

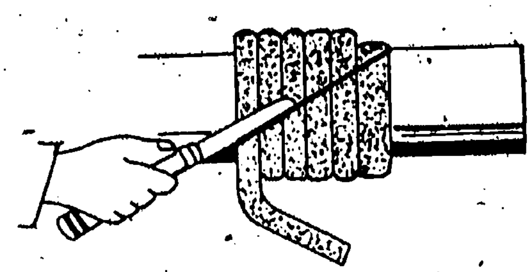
1. Shut down and drain pump.
2. Remove gland adjusting nuts and slide gland away from packing.
3. Remove all old packing with a packing puller tool.
4. Check condition of shaft or shaft sleeve and replace or resurface the shaft or replace shaft sleeve.
5. Determine correct size of packing to be used by:

   $$\text{Correct Size} = \frac{\text{Bore of stuffing box} - \text{Diameter of shaft or sleeve}}{2}$$

6. Wrap packing around shaft and cut the needed number of rings by diagonnally cutting packing coil with knife.
7. Place packing rings on shaft one at a time. Use oil or grease on the inside of each ring.
8. Tamp the rings into the stuffing box. Use metal ring to push each packing ring into place. Stagger the ring joints.
9. Replace gland and tighten gland nuts to squeeze packing. Slacken off on gland nuts to finger tight.
10. Prime and start pump.
11. Allow packing to leak for few minutes and then tighten gland nut to reduce leakage.



Removing Packing



Cutting Packing Rings

Self Assessment

1. When should a foot valve be installed on a pump line?

2. A ________________ valve should be located between the gate valve and pump.

3. A water level gauge is needed to check the amount of ________________ in a surge chamber of a reciprocating pump.

4. Which spare parts should be kept for reciprocating pump troubleshooting?

5. Which spare parts should be kept for centrifugal pump repair?

Self Assessment Answers

1. When pump works on suction lift.

2. Check valve.

3. Air.

4. Spare valves and packing.

5. Bearings, shaft sleeves, wearing rings and packing.

Post Assessment

1. What is the best way to avoid pump outages?

2. Where can troubleshooting information be obtained for specific types of pumps?

3. Why should a pump be located so that it is easily accessible?

4. Spare valves and packing should be kept for ____________ pumps.

5. Bearings, shaft sleeves and wearing rings are good spare parts for ____________ pumps.

Instructor Post Assessment Answers

1. Preventive maintenance operations check schedule.

2. Instruction manual for each pump. Obtained from pump manufacturer.

3. For inspection and repair.

4. Reciprocating.

5. Centrifugal.

Supplementary References

* Correspondence Course. Lecture 9. Section 2. First Class. Southern Alberta Institute of Technology. Calgary, Alberta, Canada.

INSTRUCTIONAL LEARNING SYSTEMS

9.7

PUMPS -- MAINTENANCE

Goal:

The apprentice will be able to describe maintenance procedures for pumps.

Performance Indicators:

1. Describe schedules for preventive maintenance of pumps.
2. Describe lubrication of pumps.
3. Describe maintenance of pump packing and seals.

Study Guide

* Read the goal and performance indicators to find what is to be learned from package.
* Read the vocabulary list to find new words that will be used in package.
* Read the introduction and information sheets.
* Complete the job sheet.
* Complete self-assessment.
* Complete post-assessment.

Vocabulary

* Gland
* Mating ring
* Mechanical seals
* "O" rings
* Preventive maintenance
* Pump packing
* Roller bearings
* Rotating mechanical seal
* Sealing ring
* Shaft sleeves
* Sleeve bearings
* Stationary mechanical seal
* Stuffing boxes
* Wearing rings

Introduction

Preventive maintenance is the key to success in pump operation. Most of the pump outages can be prevented by proper maintenance. A good maintenance schedule will assure that maintenance takes place before problems arise.

Lubrication of pumps will prevent wear of parts. Packing and seals must be replaced to avoid leakage and loss in pump efficiency. The apprentice should know how to care for and maintain pumps in a way that avoids costly outages. Otherwise, simple maintenance needs become major repair items.

Information

Maintenance Schedule

Preventive maintenance checks should be made to determine if the pump parts are working as they should work. The following items should be checked hourly during operation:

* Bearing temperatures (by hand)
* Suction pressure
* Discharge pressure
* Lubricating oil pressure and temperature
* Balancing disc leakoff
* Stuffing box leakoff
* Cooling water flow
* Cooling water inlet and outlet temperatures
* Amperage of driver motor
* Oil ring operation
* Recirculation or bypass flow

When any of the above items are not functioning normally, the problem should be corrected as quickly as possible.

Monthly checks should be made on the following:

* Bearing temperatures (by thermometer to get an accurate check)
* Correct hot bearing problems by adjusting the lubrication or alignment of pump and driver. Ball and roller bearings may run hot due to overlubrication. This problem can be corrected by removing lubricant. Sleeve bearings may not be receiving enough lubricant and run hot. Additional lubricant will correct the problem. Realignment of pump and driver may be needed to correct problems of hot bearings.

Quarterly checks should be made on:

* Dismantle, clean and change oil in sleeve bearings.
* Check all grease packed bearings for contamination. If contaminated, flush, clean and repack.
* Measure all bearings for wear and replace of needed.

Semi-annual checks should include:

* Check stuffing box leakage and renew packing.
* Check shaft sleeves for wear.
* Check for bent shafts, worn bearings and rotor balance.

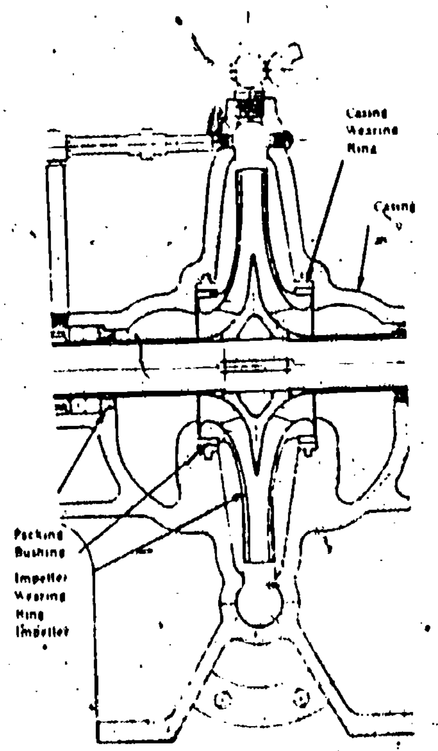
Information

Annual checks may involve a complete dismantling of the pump if it is giving poor performance. Such annual checks would include:

* Checking the casing for corrosion and wear.
* Checking rotor for corrosion and wear.
* Measuring wear ring clearance and replacing rings.
* Replacing worn shafts and sleeves.
* Flushing and cleaning coolant connections.
* Recalibration of pressure gauges.
* Checking bypass and recirculating valves for wear and replacing them when needed.
* Checking suction and discharge valve assemblies on reciprocating pumps.

Wearing Rings

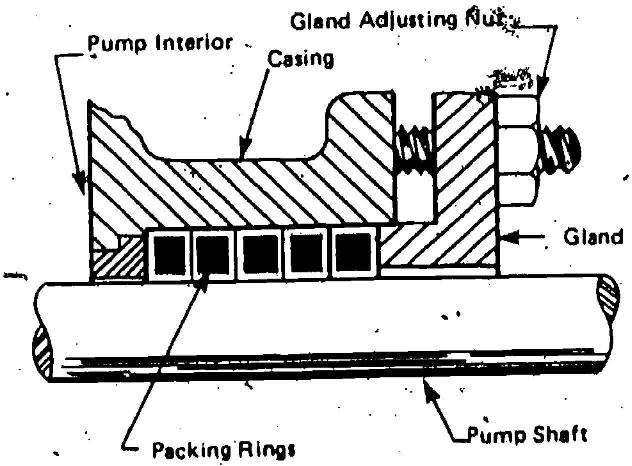
The wearing ring seals the impeller of a centrifugal pump into the casing. Rings may be mounted on either the impeller or casing or both. The rings are made of softer material than that of the surface it will be wearing against so that the impeller or casing does not wear. Wear rings are usually made of bronze or cast iron so that the wear will be smooth. The rings are set into the impeller rim by threading and held in place by set screws. Rings can be purchased as continuous or half rings. When fit on the casing, grooves hold the ring in place. The diagram below shows the location of wearing rings in a pump.



Information

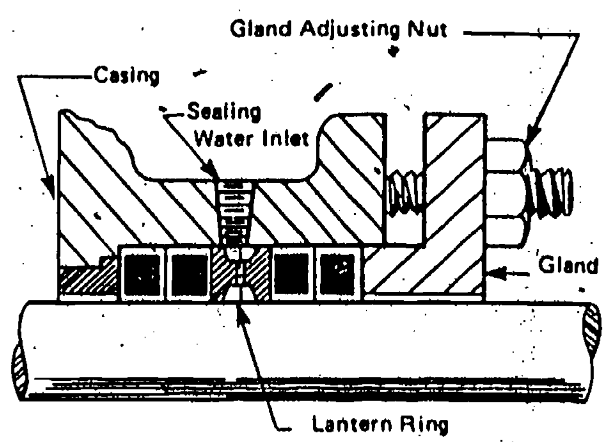
Stuffing Boxes

A seal is required between the casing and shaft of a pump. A stuffing box is a groove on the shaft that holds packing rings. The packing is held in place by an adjustable gland.



Stuffing Box with Packing

A lantern ring supplies sealing liquid to the packing to exclude air and provide lubrication. The lantern ring is needed by pumps that handle sand or other gritty materials. The sealing liquid keeps the sand from "eating up" the packing.

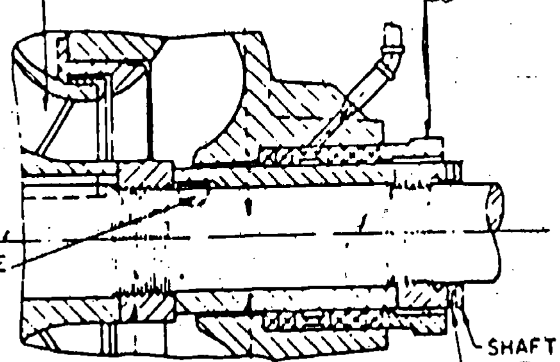


Stuffing Box with Lantern Ring

Information

Shaft Sleeves

A pump shaft is subject to wear and corrosion. Large pumps use shaft sleeves to take the wear instead of the shaft. When wear occurs, the sleeve is replaced. The sleeve is keyed on the shaft and held in place by the shaft nut.



Pump Packing

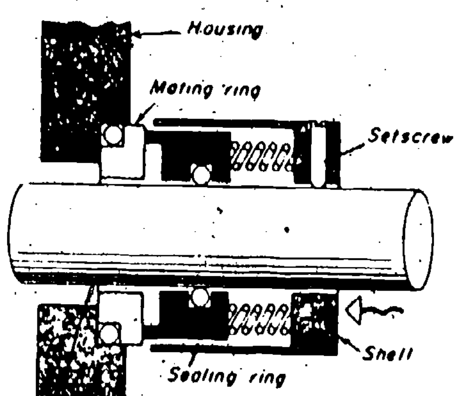
Pump packing is usually replaced every 3-6 months, depending on the operating conditions. Packing rings are cut from a coil and tamped into the stuffing box. The details of replacing pump packing are found in the Pump-monitoring and Troubleshooting package.

Mechanical Seals

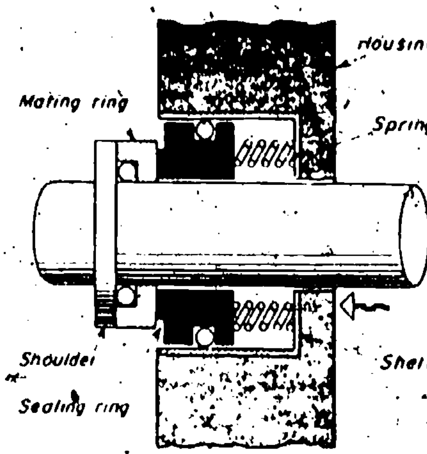
On pumps that handle gasoline, acids and other touchy liquids, a mechanical seal is used in place of stuffing boxes. Mechanical seals reduce pump leakage and make it easier to work with such materials. A mechanical seal is two flat rings that rotate at right angles to the pump shaft. One ring is called a sealing ring and the other is a mating ring. The two rings are held in contact with each other by springs. On a stationary mechanical seal, the sealing ring is attached to the pump casing and the mating ring turns on the shaft. A rotating mechanical seal has the sealing ring attached to the shaft and the mating ring on the casing. A seal between the rings and casing are provided by "O" rings.

Information

In the maintenance of mechanical seals, the operator should make certain that the pump is never operated without being filled with liquid. All air should be vented from the seal housings before starting the pump. A flow of cooling liquid must be kept over the seals. Mechanical seals may leak due to scoring, grooving, distortion, misalignment or vibration. Manufacturers instructions should be carefully followed in maintenance of pumps with mechanical seals.



Rotating Seal



Stationary Seal

Bearings

Sleeve or shell bearings should be oil lubricated by drop lubricators. Ball or roller bearings may be lubricated by oil or grease. Ball or roller bearings should be lubricated with a high grade of lubricant and should never be overlubricated. They should be cleaned and lubricated on a regular, scheduled basis. Ball bearings are also called anti-friction bearings.

Assignment

* Read pages 27-32 in supplementary reference.
* Complete the job sheet.
* Complete the self-assessment and check answers with answer sheet.
* Complete the post-assessment and have instructor check your answers.

Job Sheet

COMPLETE AN HOURLY CHECK OF AN OPERATING PUMP

* Check the following:

  - Check bearing temperatures by hand
  - Check suction pressure
  - Check discharge pressure
  - Check lubricating oil pressure and temperature
  - Check leakoff on balancing disc
  - Check stuffing box leakoff
  - Check cooling water flow
  - Check cooling water inlet and outlet temperature
  - Check amperage of driver motor
  - Check recirculation or bypass control

* List those problems that need to be corrected. Keep a written list of your readings.

* Ask instructor to validate your findings in regard to the maintenance problems of the pump.

* Discuss (with instructor) the best ways to correct problems.

Self Assessment

Indicate whether the following pump items should be part of an hourly, monthly, quarterly, semi-annually or annually operations check for preventive maintenance.

1. Cooling water flow
2. Stuffing box leakoff
3. Bearing temperatures by thermometer
4. Bearing temperatures by hand
5. Clean and change oil in sleeve bearings
6. Renew packing in stuffing boxes
7. Check grease packed bearings
8. Measure bearings for wear
9. Suction pressure
10. Amperage of driver motor

Self Assessment Answers

1. Hourly
2. Hourly
3. Monthly
4. Hourly
5. Quarterly
6. Semi-annually
7. Quarterly
8. Quarterly
9. Hourly
10. Hourly

Post Assessment

1. Packing rings are held in a stuffing box by the ____________________.

2. Sealing liquid is supplied to packing (on some pumps that pump sand or gritty materials) by a ______________________ ring.

3. Pump packing should be replaced every _________________ months.

4. List two types of mechanical seals.

5. When are mechanical seals used?

6. A seal is provided between the rings of a mechanical seal and the pump casing by _________ rings.

7. _________________ bearings are also called anti-friction bearings.

8. Shaft _______________ are used on large pumps to reduce wear on the shaft itself.

9. A complete dismantling of a pump is often a part of the ______________ operations check.

10. Wear rings are usually made of _____________ or ________________.

Instructor Post Assessment Answers

1. Gland

2. Lantern

3. 3 - 6 months

4. Rotating and stationary

5. When pumping gasoline or acid and excersive leakage is a problem.

6. "O" rings

7. Ball

8. Sleeves

9. Annual

10. Bronze or cast iron

Supplementary References

* Correspondence Course. Power Engineering. Lecture 9. Section 2. First Class. Southern Alberta Institute of Technology. Calgary, Alberta, Canada.

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Correspondence Courses
Power Engineering

13.1
13.2
13.4
13.6
13.7

SECTION 2

First Class
Lecture 9

STEAM GENERATION

POWER PLANT PUMPS

The purpose of a pump is to impart energy to a fluid in order to move it from one point to another. Because of the many purposes and variety of services for which a pump is required in a power plant it can be regarded as the most widely used item for power plant auxiliaries. Examples of pump applications in the power plant are: boiler circulating pumps, feedwater pumps, fuel-oil pumps, chemical feed pumps, condensate pumps, circulating water pumps, and vacuum pumps.

PUMP CLASSIFICATION

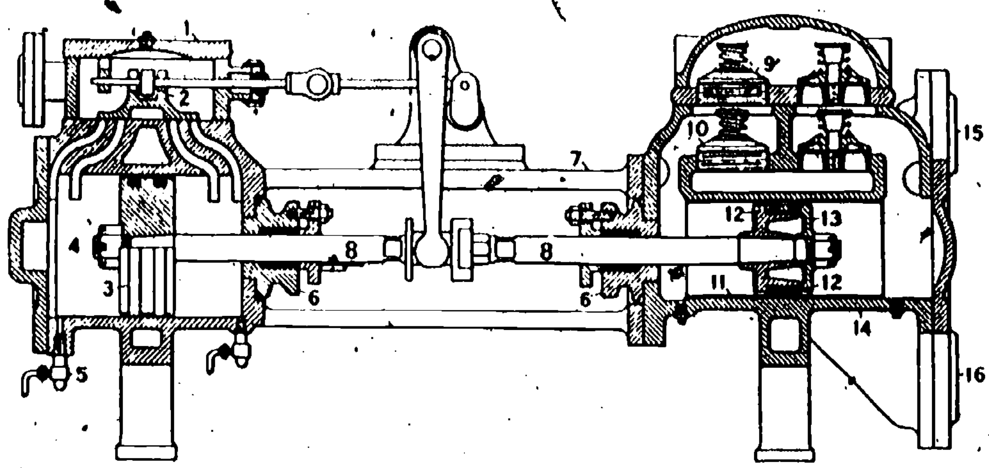
Pumps can be classified, according to their method of operation, as reciprocating, centrifugal, and rotary.

1. RECIRROCATING PUMPS

Reciprocating pumps are positive displacement pumps which use the reciprocating motion of pistons, plungers, or diaphragms to move the fluid through the pump. The ability of the reciprocating pump to produce high pressures and closely controlled flow makes them particularly adaptable for such applications as chemical feeding. They are also used as boiler feedpumps in small installations where moderate capacities and high pressures are required. In addition, fuel-oil pumps are frequently the reciprocating type.

The following sections discuss and illustrate some commonly used types of reciprocating pumps.

1. Direct Driven Duplex



1. steam chest
2. slide valve
3. piston rings
4. steam cylinder
5. drain cock
6. stuffing box
7. cradle
8. piston rod
9. discharge valve
10. suction valve
11. liner
12. packing ring
13. liquid piston
14. liquid cylinder
15. discharge port
16. suction port

Horizontal Duplex Pump Cross-Section
(Worthington Corporation)

Fig. 1

The duplex pump in Fig. 1 uses drive pistons operated by steam or air to drive the pumping pistons. The two pumping pistons, which are double acting, are arranged so that their operation overlaps and when the output from one piston reaches zero, the output from the other piston will be at a maximum. This arrangement tends to smooth out the pulsating discharge inherent with reciprocating pumps.

Direct driven pumps have good efficiency over a wide range of capacity. However, they are usually high in first cost and require a large floor space and supervision during operation.

2. Direct Driven Simplex

The simplex pump shown in Fig. 2 is another type of direct driven pump. It features one driving piston and one double acting pumping piston. Due to the single pumping piston, the discharge of this pump is more pulsating than that of the duplex pump.

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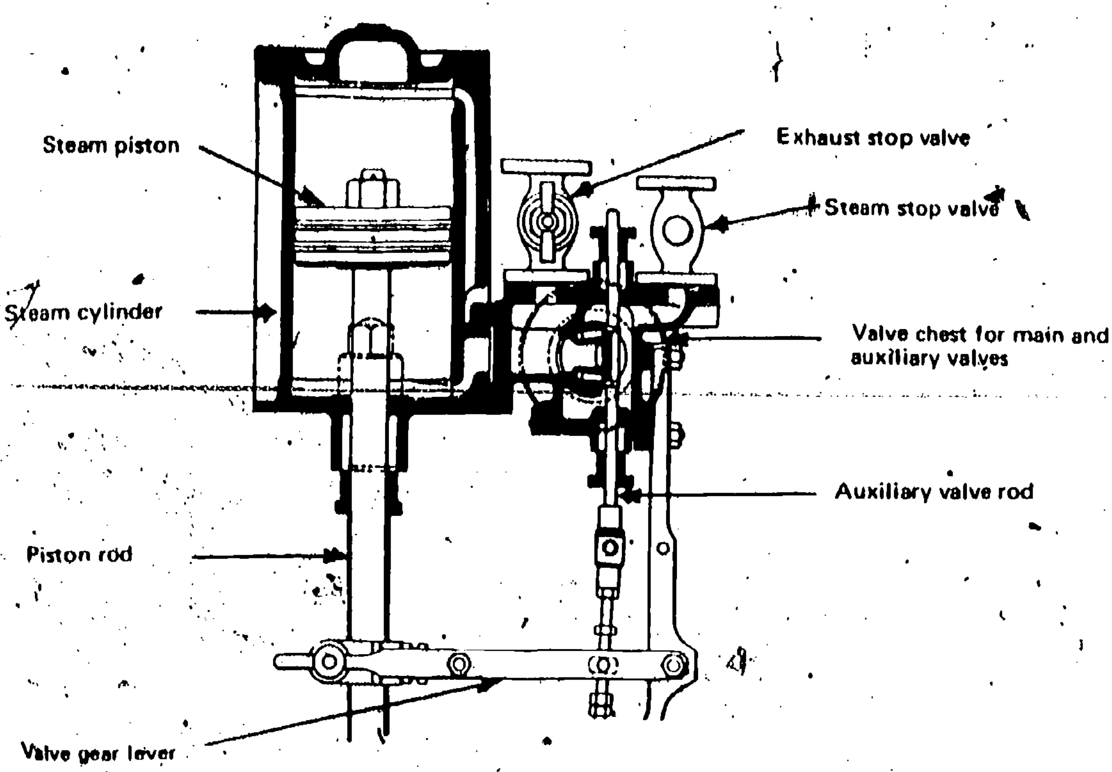


Vertical Weir Boiler Feed Pump

Fig. 2

Simplex pumps may be vertical as in Fig. 2 or they may be the horizontal type. Their advantages and disadvantages are much the same as those of the duplex pump. The vertical simplex however, has the added advantage of not requiring a large floor space and in addition will not be subject to the same cylinder and piston wear as the weight of the piston is not carried by the cylinder wall.

3. Power Driven Pumps

Power pumps are those which have the pumping pistons driven by an external power source through a crankshaft. The power source is usually an electric motor but internal combustion engines are also used.

Normally the power pump is driven at constant speed and therefore produces a constant flow rate over a wide range of discharge pressures. All power pumps should be equipped with relief valves on the discharge to prevent damage from overpressure which could occur if the discharge valve was closed during operation or if the discharge was blocked for some reason.

Fig. 3 shows a motor driven power pump having three single acting cylinders. The term "single acting" is used because water is discharged from each cylinder on the downstroke only as opposed to a double acting pump which discharges during each stroke.

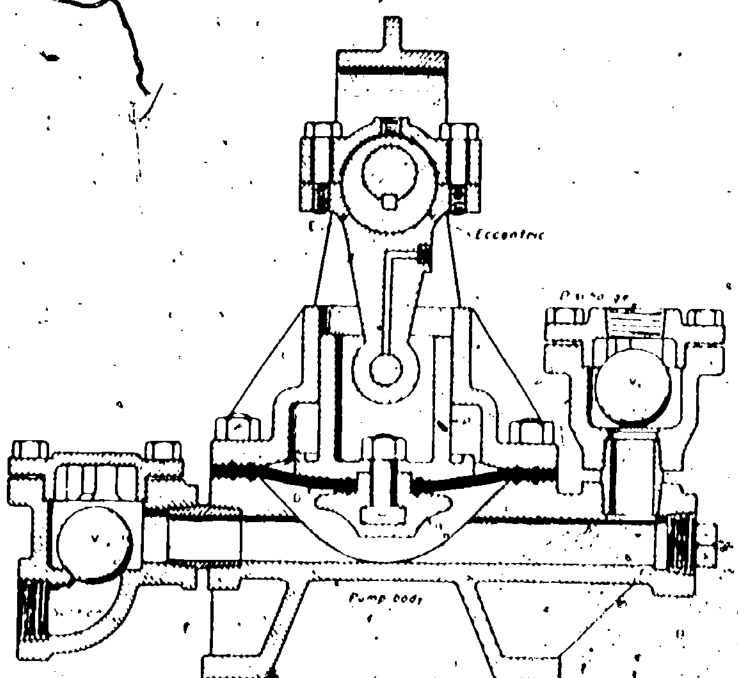
The drive is supplied to the three cylinders through an overhead crankshaft, gearing and belt. Because of the three cylinders, this type is called a triplex pump.

4. Diaphragm Pumps

Diaphragm pumps differ from piston type reciprocating pumps in that the fluid being pumped is completely isolated by the diaphragm from the reciprocating mechanism thereby eliminating leakage and contamination problems.

The diaphragm is a flexible membrane which acts as the liquid displacing component. It may be made from metal, plastic or more elastic materials such as rubber depending upon the particular application.

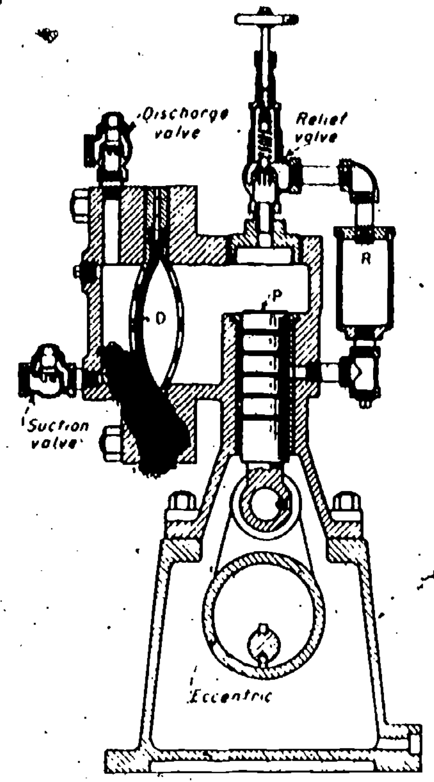
The diaphragm may be actuated mechanically or hydraulically. The mechanically operated type is limited to discharge pressures below 850 kPa because of the stress developed in the diaphragm. The hydraulic type uses a fluid to move the diaphragm. This method develops an even pressure over the entire surface of the diaphragm resulting in lower stresses and allowing higher discharge pressures.



Mechanically Actuated Diaphragm Pump

Fig. 4

A mechanically actuated diaphragm pump appears in Fig. 4. The diaphragm D which is of rubber or synthetic rubber is connected to the piston P by means of the disc B. An eccentric is used to produce the reciprocating motion which flexes the diaphragm causing pumping to occur. Discharge pressure in this pump is limited to 350 kPa.



Hydraulically Actuated
Diaphragm Pump

Fig. 5

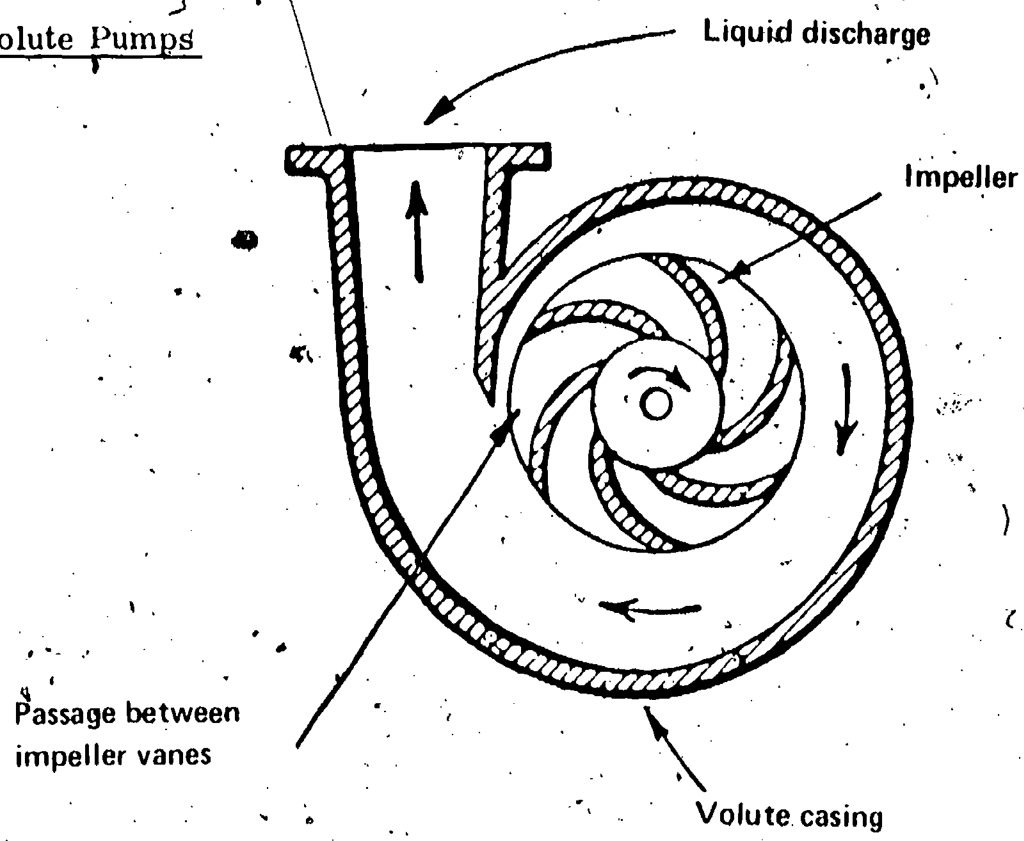
The hydraulic type of diaphragm pump shown in Fig. 5 is suitable for discharge pressure to 2000 kPa. The diaphragm D is caused to flex by means of a hydraulic fluid contained in the space between the piston P and the diaphragm. The piston is driven by an eccentric and when it moves upward it produces a hydraulic pressure on the diaphragm causing the diaphragm to move to the left. When the piston moves downward, a vacuum is formed and the diaphragm moves to the right. In this way a pumping action is produced in the chamber to the left of the diaphragm and the liquid being pumped is drawn in through the suction valve and discharged through the discharge valve.

Diaphragm pumps are well suited for use as controlled volume or metering pumps as their capacity can be adjusted by varying the stroke length or the stroke frequency.

2. CENTRIFUGAL PUMPS

A centrifugal pump may be defined in a general way as a pump which uses centrifugal force to develop velocity in the liquid being handled, which velocity being consequently converted to pressure. The centrifugal classification, however, can be subdivided into the following types: volute, diffuser, axial flow, mixed flow, and regenerative.

1. Volute Pumps



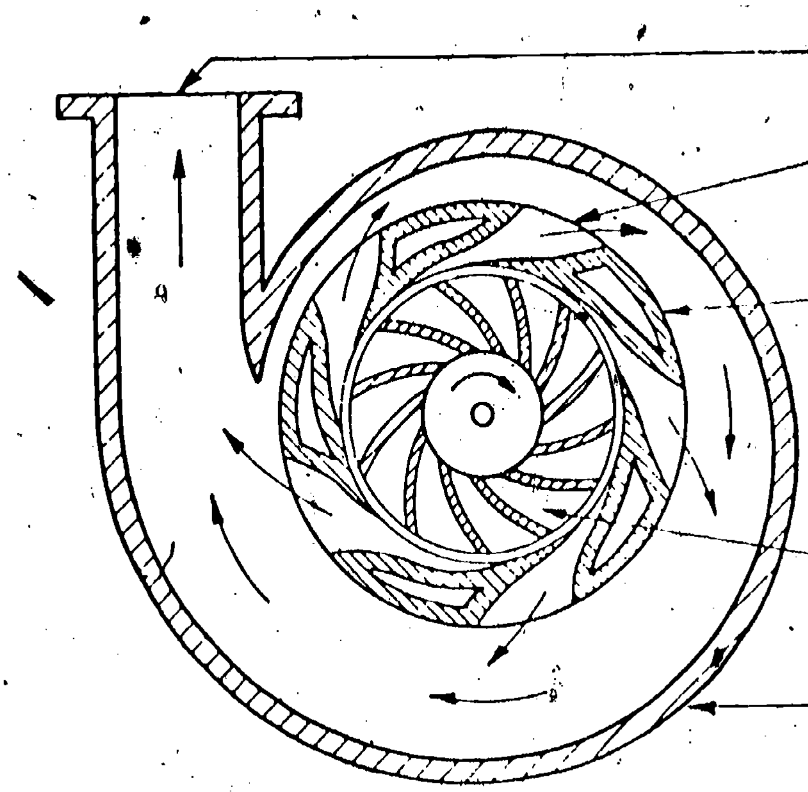
Volute Centrifugal Pump

Fig. 6

The general construction of the volute centrifugal pump is sketched in Fig. 6. The liquid being pumped is drawn into the centre or eye of the impeller and is discharged from the impeller periphery into a volute or spiral casing which has a gradually increasing cross-sectional area. This volute casing converts the velocity energy of the liquid created by the impeller to pressure energy. This pressure varies around the circumference of the volute and causes a radial unbalance or thrust which may be sufficiently large to cause vibration and shaft deflection. Because of this some pumps use twin volutes which are located so that they are diametrically opposed thus balancing the radial thrust.

Volute pumps may be either single or multistage design. In general, single stage pumps are used for heads of 120 m or less while the multistage design is usually necessary for heads of above 120 m.

2. Diffuser Pumps

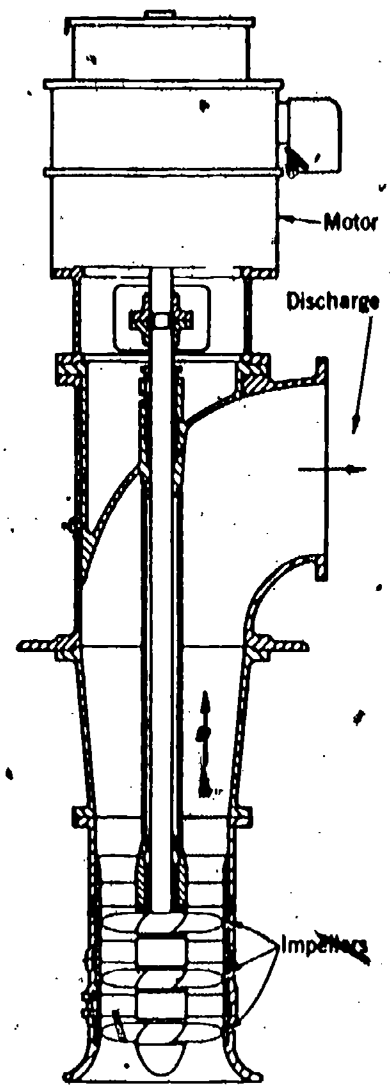


Diffuser Centrifugal Pump

Fig. 7

The construction of a diffuser centrifugal pump is sketched in Fig. 7. The diffuser pump features guide vanes or diffusers located between the impeller rim and the casing. The high velocity energy of the liquid leaving the impeller rim is converted to pressure energy as the liquid passes through the diffuser vanes. As these diffuser vanes are spaced uniformly around the impeller circumference there is no radial unbalance developed. In addition, in the diffuser pump the velocity energy of the liquid is more completely converted into pressure energy than it is in the volute pump. As a result, the diffuser pump is commonly used for high capacity, high pressure service.

3. Axial Flow Pumps



Vertical Axial Flow Pump

Fig. 8

Axial flow pumps, also referred to as propellor pumps, use impellers with blades similar to those of an aircraft propellor. The pump head is developed by the propelling or lifting action of the blades on the liquid.

The arrangement of the pump is usually vertical as in Fig. 8 but horizontal and inclined shaft arrangements are also available. For the smaller pumps, fixed blade type impellers are used but larger pumps may use impellers with adjustable or variable-pitch blades which can be used to maintain efficiency at loads which differ from the design load.

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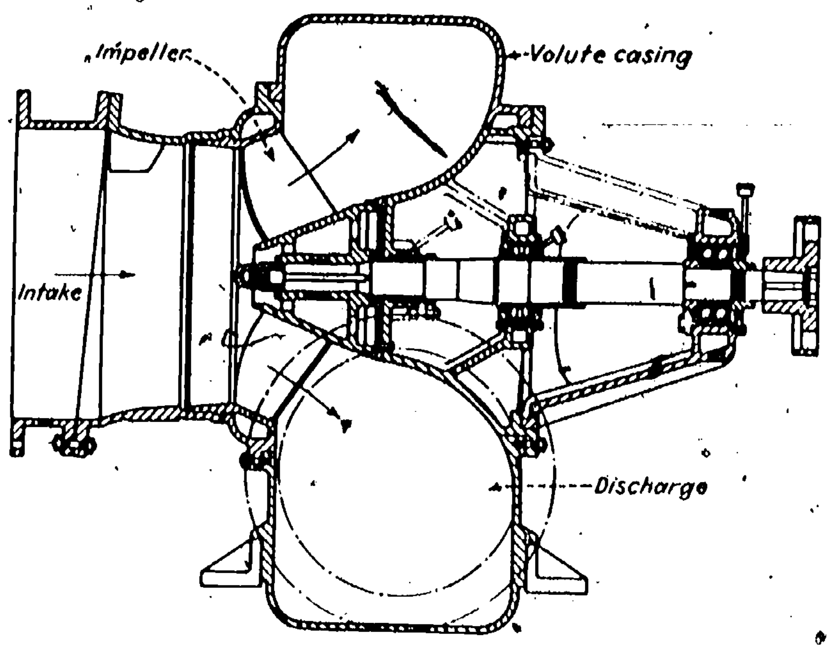
Axial flow pumps have the advantages of compact size and ability to operate at high speeds while their disadvantages include low suction lift capacity and relatively low discharge head capability. They are used mainly for low head, high capacity applications and are available in the single stage design or the multistage design as in Fig. 8.

4. Mixed Flow Pumps

Mixed flow pumps combine some of the characteristics of the volute and diffuser pumps together with some axial flow pump features. The head developed by this pump is produced partly by centrifugal force and partly by the lift of the impeller vanes on the liquid.



Mixed Flow Pump

Fig. 9

The mixed flow pump shown in Fig. 9 has a single inlet impeller with the flow entering the pump in an axial direction and leaving the pump in a direction somewhere between axial and radial.

Although the mixed flow pump in Fig. 9 is arranged horizontally, this type of pump, like the axial flow type, is frequently arranged for vertical operation. With the vertical arrangement the pump can be placed directly in the suction well and thus be primed at all times.

Like the axial flow pump, the mixed flow type is used mainly on low head, high capacity service and like the axial flow pump it may be fitted with variable pitch impeller vanes.

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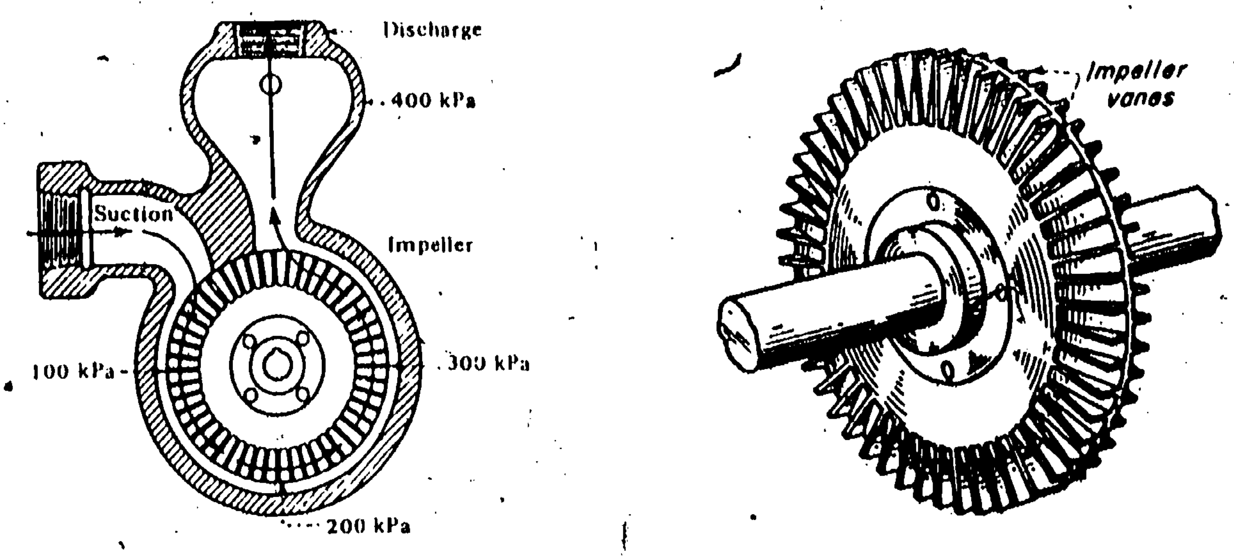
5. Regenerative Pumps



Turbine Pump Casing and Impeller

Fig. 10

The regenerative pump, or turbine regenerative pump as it is also called, features an impeller having a double row of vanes cut in the rim as illustrated in Fig. 10. The liquid being pumped enters at the periphery of the pump and circulates almost 360 degrees before being discharged at the periphery.

The impeller vanes travel in a channel in the pump casing and as the impeller rotates, the liquid being pumped recirculates between the impeller vanes and receives a number of impulses from the vanes. This series of impulses has the same effect as multistaging in a centrifugal pump and the liquid pressure will increase uniformly around the pump periphery from suction to discharge.

The regenerative pump can develop several times the discharge pressure of a centrifugal pump having the same size and speed. The head produced may be in the range of 550 kPa or higher depending on flow and design. A relief valve should be installed on the discharge line as excessive pressure can be developed if the pump is operated against a closed discharge.

The shaft speed in this type of pump may be as high as 6000 rev/min in some units. However, clearances are close and rapid wear will occur if the pumped liquid contains any abrasives.

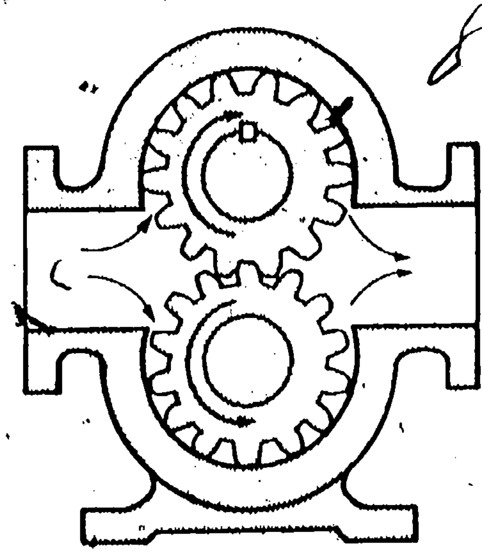
Although the efficiency of the regenerative pump is low, its compact size and low mass can be considered advantages. It is best suited for low capacity, high pressure service and this type is often used for boiler feed pumps for small boilers, condensate return pumps, liquified petroleum pumps and for pumping refrigerants.

3. ROTARY PUMPS

Unlike the centrifugal pumps discussed previously, rotary pumps are positive displacement units. Instead of imparting high velocity to the liquid due to centrifugal force as in a centrifugal pump, rotary pumps trap the liquid and push it around a closed casing to the discharge. However, due to their rotary characteristic, they do produce a continuous and smooth flow like the centrifugal pump and unlike the other positive displacement pump, the reciprocating.

A great variety of rotary pump designs are in use, a few of which are described as follows.

1. Spur Gear Pump



Gear Pump

Fig. 11

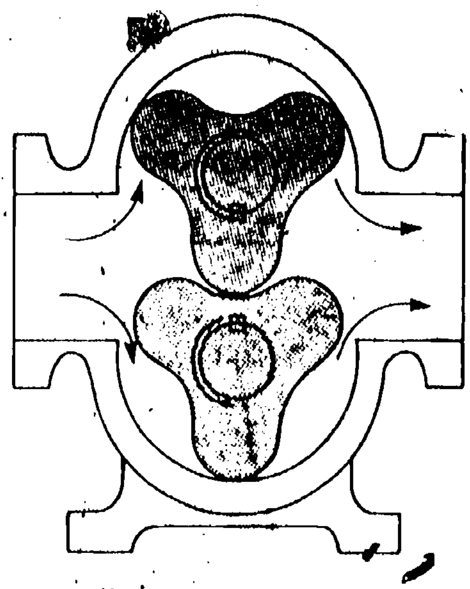
The spur gear pump shown in Fig. 11 consists of a housing containing two gears, the driving gear at the top and an idler or driven gear at the bottom.

As the gears rotate, the liquid is trapped between their teeth and the casing and is carried around to the discharge. The meshing teeth prevent escape of the liquid back to the suction.

The top or driven gear is keyed to a shaft which may be driven directly by an electric motor or indirectly by means of belting or gearing.

The spur gear type is generally used as a high pressure pump for low viscosity liquids. They are designed for speeds not exceeding 600 rev/min and for pressures up to 10 000 kPa. Capacity is not usually above 450 litres per min.

2. Lobe Pump



Lobe Pump

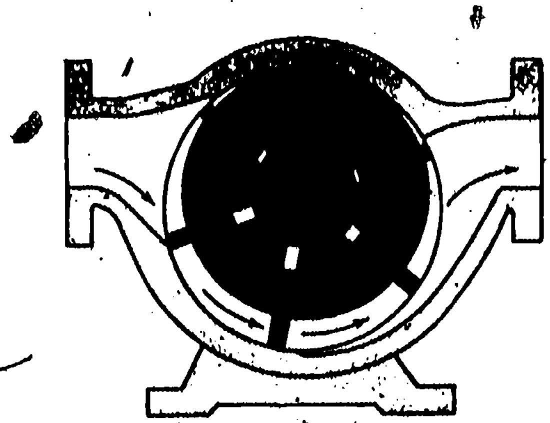
Fig. 12

The lobe pump in Fig. 12 uses two rotors, each of which has three lobes. The rotors are synchronized and driven by external gears and as they turn, the liquid is trapped in pockets formed by the lobes and the housing and is carried around and forced out the discharge.

Clearance between the lobes, and between the lobes and the housing must be kept to a minimum to prevent leakage and maintain efficiency.

The lobe pump is suitable for capacities up to 12 000 L/min and heads of up to 76 m.

3. Sliding Vane Pump



Sliding Vane Pump

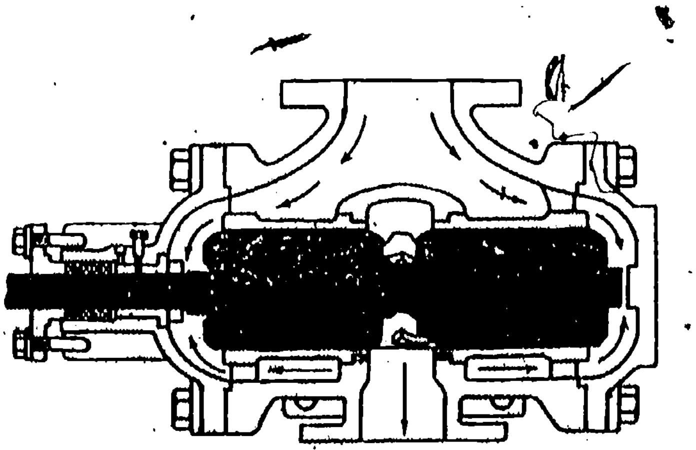
Fig. 13

In the sliding vane pump, Fig. 13, the rotor, which is off centre with the housing, contains a number of sliding vanes. These vanes are free to move radially within the rotor and tend to move out against the housing due to centrifugal force. As the rotor turns, the liquid is trapped between the vanes and the housing and is carried around to the discharge.

This type of pump can be built for pressures up to 7000 kPa when operating at 1200 rev/min.

There are several other different designs of sliding vane pumps. In one type the vanes are held in position by spacer rings that are concentric with the casing. In another type the vanes are pushed out against the casing by liquid pressure which is bled into the spaces behind the vanes.

4. Screw Pump



Screw Pump

Fig. 14

The screw pump in Fig. 14 features a power rotor situated between two idler rotors. The liquid is drawn into both ends of the rotor where it is trapped in the pockets formed by the threads. The liquid is carried along between the screw threads along the axes of the screws as in a screw conveyor. The idler rotors are driven by liquid pressure and there is no metal to metal contact between idlers and power rotor. This design may operate at pressures up to 7000 kPa and at speeds up to 7000 rev/min.

PUMP APPLICATION

As mentioned previously, some examples of pump applications in the power plant are: boiler circulating pumps, feedwater pumps, fuel-oil pumps, chemical feed pumps, condensate pumps, circulating water pumps, and vacuum pumps. These applications will be discussed briefly in the following sections.

1. Boiler Circulating Pumps

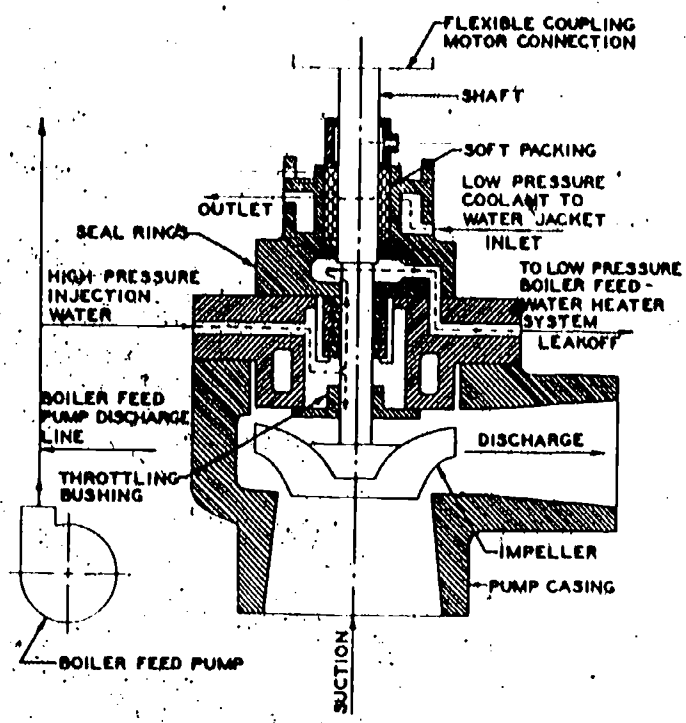
Forced circulation boilers, such as those described in Lecture 1, Section 2, require a pump or pumps to produce the flow through the boiler tubes. This is necessary for boilers operating at and above the critical pressure and this method is often used for boilers operating above 14 000 kPa.

Two types of boiler circulating pumps are in common use; the conventional drive type, and the submerged motor type.

Conventional Drive Type

This type usually uses an electric motor although steam turbines are sometimes used. The driver is connected to the pump shaft by means of a flexible coupling and the pump itself may be either a single-stage or two-stage volute type centrifugal.

In industrial applications where pressures and temperatures are not excessively high, the pump shaft is sealed by means of a packing gland or a mechanical seal. In central station practice, however, where pressures and temperatures are higher, a special type of shaft seal is used and this seal is shown in Fig. 15.



Boiler Circulating Pump Seal
(Combustion Engineering)

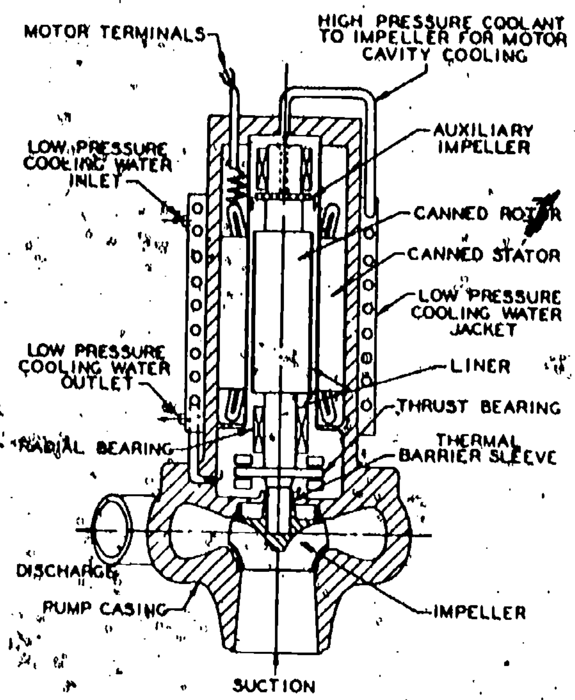
Fig. 15

In this type of seal a sealing water labyrinth is used between a throttling bushing and the soft packing. The sealing water for this labyrinth, however, cannot be taken from the pump casing because this high temperature water would flash in the seal and erosion would result. Therefore, cooler high pressure injection water is taken from the boiler feed pump discharge before the final feedwater heaters when the water is at a temperature and pressure suitable for the seal.

Submerged Motor Type

Two designs of submerged motor pumps are used. One design, known as the wet type, has the motor housed within the same casing as the pump proper. The pumped liquid surrounds and contacts the stator, the rotor, and the bearings. Waterproof insulation is used for the windings and the material used is usually polyvinyl chloride.

The other design of submerged motor pump is the canned motor type illustrated in Fig. 16.



Canned Motor Pump
(Combustion Engineering)

Fig. 16

In the canned motor pump the pumped liquid is allowed to enter the motor casing but contact with the stator and rotor is prevented by means of sealing jackets or cans. High pressure cooling water is circulated through the space between the stator and rotor cans by means of an auxiliary impeller on the motor shaft. This high pressure water then passes through an external cooler where it is cooled by means of low pressure cooling water.

In the submerged motor pump, a thermal barrier is required to retard the flow of heat from the pumped water into the motor portion of the pump. This barrier, in Fig. 16, is located immediately above the main impeller and consists of a close fitting sleeve and bushing with an extended surface.

2. Boiler Feedwater Pumps

The type of pump used for boiler feedwater service depends largely upon the capacity and pressure of the boiler which it serves. In general, feedwater pumps are either the reciprocating type or, more commonly, the centrifugal type.

Reciprocating Feedwater Pumps

The direct steam driven reciprocating pump is generally limited to plants having a capacity of 100 000 kg per hour and under and pressures less than 2750 kPa and for this type of service either the horizontal or the vertical design may be used.

Steam driven pumps have the unique advantage of being able to vary their capacity from zero to maximum independent of the discharge pressure plus the ability to vary their discharge pressure from zero to maximum independent of the capacity.

Power driven reciprocating pumps are sometimes used in feedwater service in medium pressure plants and in high pressure plants may be used to supply feedwater to the desuperheater.

When used for high pressure, high temperature service, reciprocating pumps are subject to increased wear on valves, seats, cylinders and pistons.

Power driven pumps cost more than direct steam driven types and are more compact than the horizontal steam pumps. The steam driven pumps have high reliability and low maintenance costs but unless the exhaust steam can be used for feed heating or process they are less economical than the power driven types.

Centrifugal Feedwater Pumps

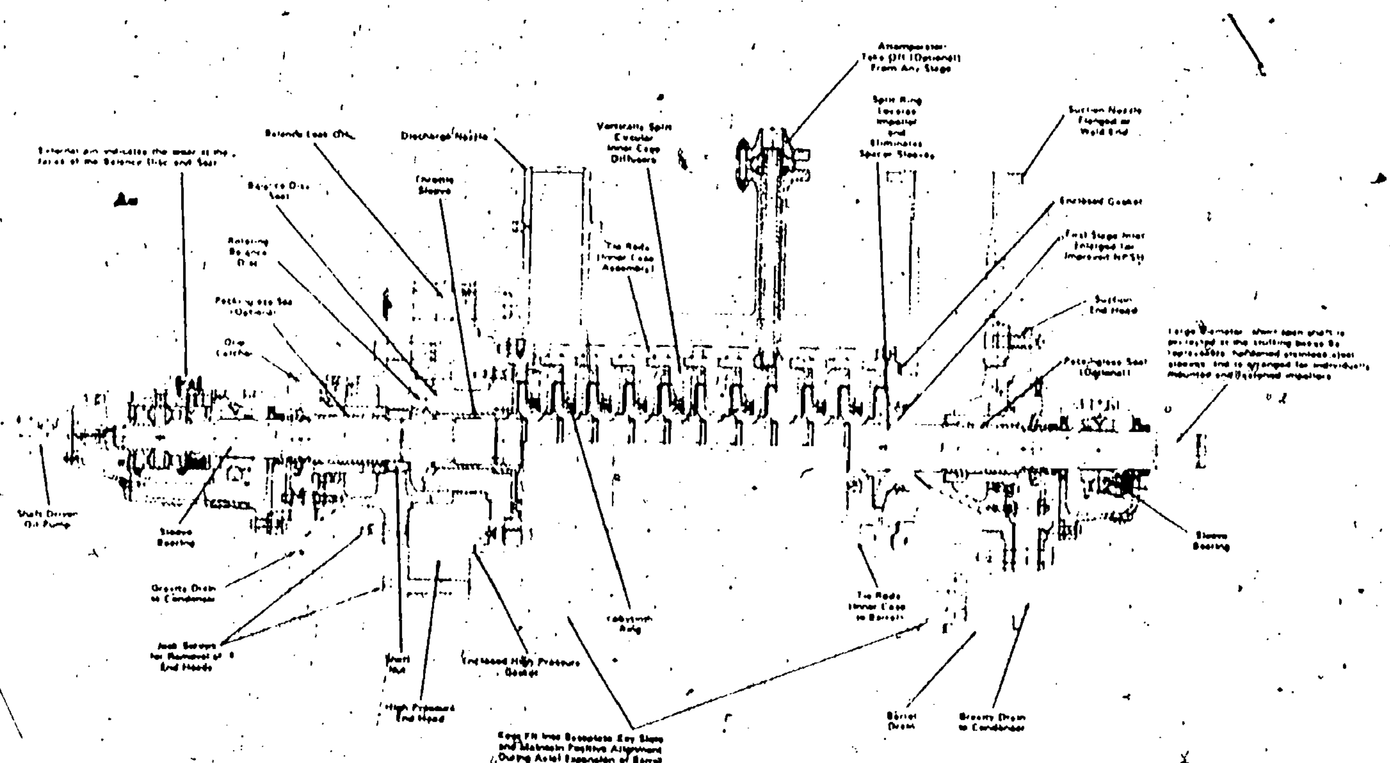
Medium and large-sized plants use centrifugal type boiler feedwater pumps of either the volute or the diffuser design. The regenerative pump, which also can be considered as a type of centrifugal pump is frequently used for feedwater service in small low pressure plants.

The volute and the diffuser pumps may be of the split case design for service up to 10 000 kPa. Above this pressure, the barrel type of casing is normally employed.

Horizontal Split Case Pump
(DeLaval)

Fig. 17

The split case pump in Fig. 17 contains six stages and is suitable for pressures in the range of 8000 kPa.



Barrel Type Pump (Allis-Chalmers)

Fig. 18

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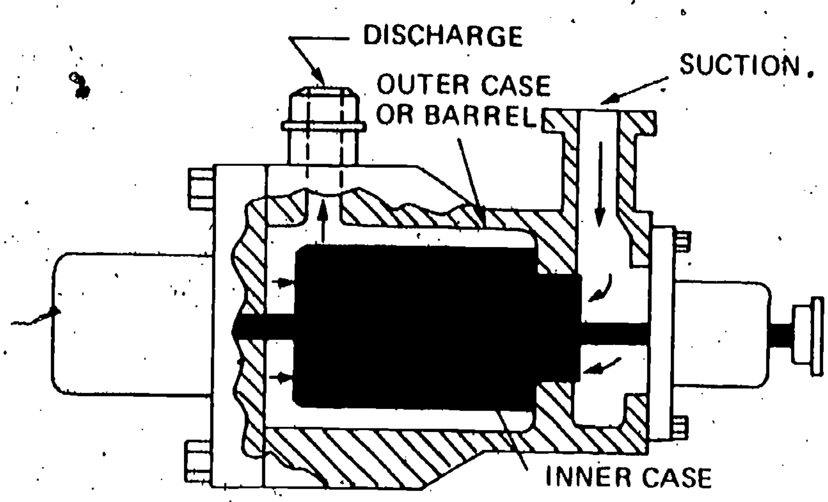
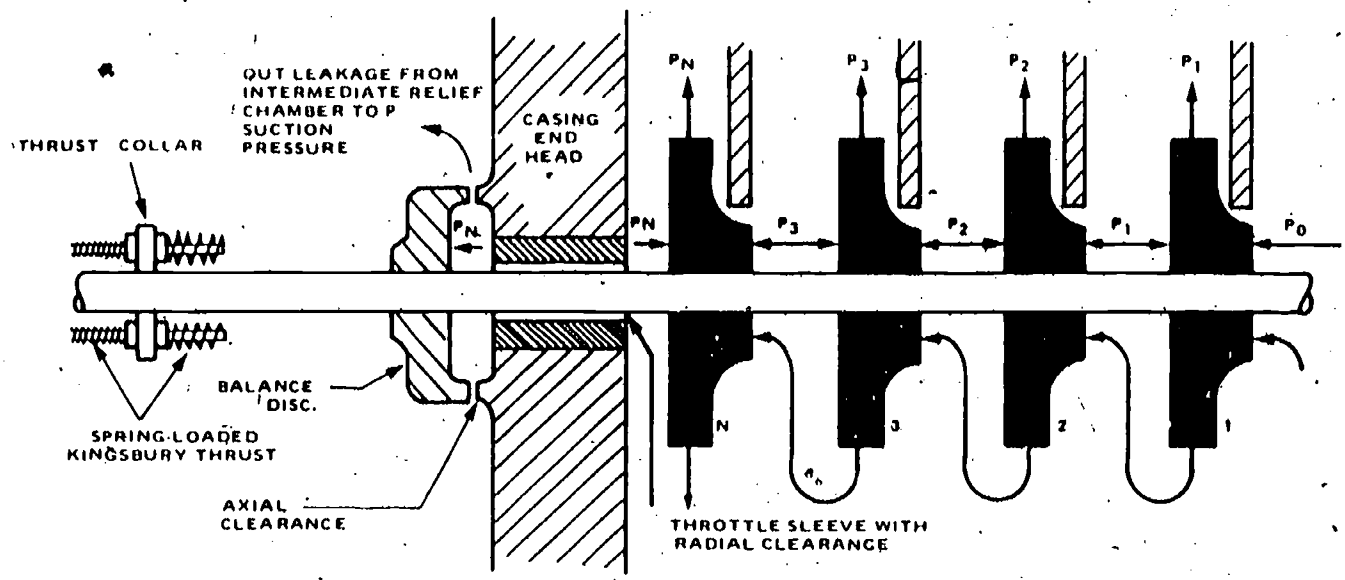


Barrel Pump Casing Arrangement

Fig. 19

A multi-stage pump such as that shown in Fig. 18 and Fig. 19 must be equipped with some device to provide axial balance. A single-suction impeller is subjected to axial hydraulic thrust caused by the pressure differential between its two faces. A multistage pump with all its single-suction impellers facing in one direction generates a hydraulic thrust equal to the sum of the individual impeller thrusts. To counteract this total thrust a balance disc and throttle sleeve may be used and this arrangement is sketched in Fig. 20.



Balance Disc and Sleeve
(Allis-Chalmers)

Fig. 20

Referring to Fig. 20, the radial clearance at the throttle sleeve remains constant while the axial clearance at the balance disc face varies with rotor position. At startup, the differential pressure created by the impellers will move the rotor to the right or suction end of the pump. This movement simultaneously reduces the axial clearance at the balance disc face, causing a pressure increase in the intermediate relief chamber, forcing the balance disc and rotor towards the left until the proper balance of pressures and forces is established. Conversely, movement of the rotor to the left will increase the axial clearance, reducing the pressure in the intermediate relief chamber until normal balance is achieved. The disc, with an area larger than that of the unbalanced area of the impellers overrides the impeller thrust and maintains a precise clearance to provide pressure breakdown and axial balance. It is sized so as to maintain balance under maximum possible loading and even with wear, is self adjusting. The system of balance is unaffected by varying the number of stages or by changes in impeller diameter.

A spring loaded Kingsbury type thrust bearing is employed only to locate the rotor axially during startup, shutdown and during transient operating conditions. In normal operation, the thrust bearing does not supplement the balance disc.

The leak-off from the relief chamber should not be returned to the suction of the pump as this may cause flashing at low flows. Instead the leak-off should be piped to an open heater ahead of the pump. There should be no valve of any kind between the leak-off connection and the open heater.

3. Condensate Pumps

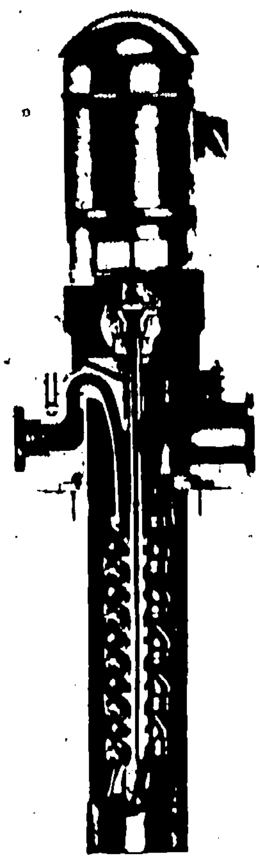
In power plants where low pressure steam is produced for building heating, a common arrangement is to have a unit which serves as both condensate pump and boiler feedpump. The unit usually consists of one or two single stage centrifugal pumps arranged to take their suction from a receiver tank into which the condensate returning from the system flows. The condensate pumps discharge directly into the boiler or boilers.

Although centrifugal pumps are most frequently used for this service some rotary, regenerative, and reciprocating designs may also be used.

In high pressure steam plants which supply steam to condensing turbines, the pump which removes the condensate from the condenser is known as a condensate or extraction pump. This pump, which usually discharges through low pressure heaters to a deaerator, must be of a special design having a low suction head requirement. This is because the turbine condenser is usually located in the power plant basement and the condensate pump cannot be supplied with much suction head without raising the condenser or installing the pump in a pit.

Centrifugal pumps are used for this type of service and, because the condensate is near the flashing temperature, the pump first stage impeller is designed with a large inlet or eye which reduces the possibility of flashing and cavitation.

Either horizontal or vertical centrifugal pumps may be used. The vertical type is often favored as it can be set into a pit in the basement floor and in this way obtain a few metres of suction head. Fig. 21 shows a multi-stage condensate pump of the vertical type.



Vertical Condensate Pump

Fig. 21

The shaft glands of condensate pumps must be water sealed to prevent air leaking into the pump and the pump vent must lead to the condenser as the pump is under condenser pressure when standing idle on standby duty. The usual arrangement as to the number of condensate pumps installed is two 100% capacity pumps, one in service and one standby. Alternatively, three 50% capacity pumps may be installed in plants which operate at low loads frequently.

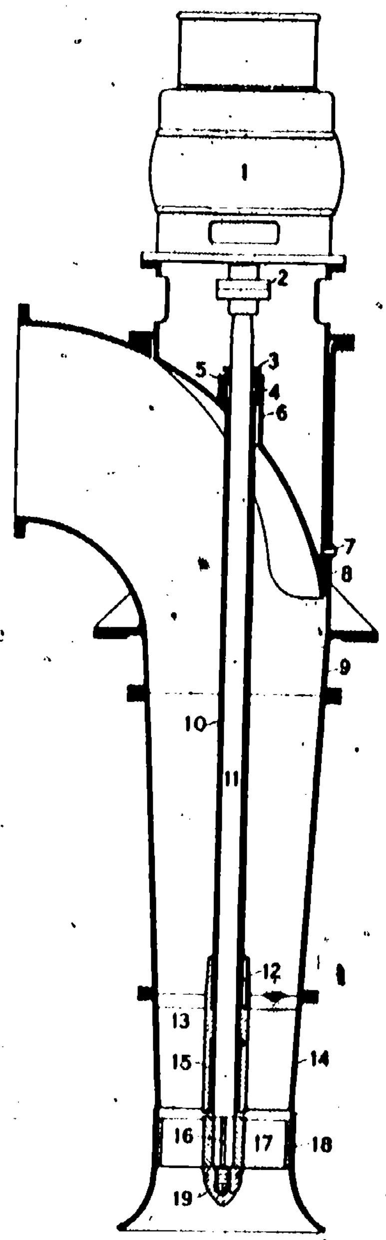
4. Circulating Water Pumps

Circulating water pumps are required to move large quantities of cooling water through the turbine condenser.

They are generally of the low head, large volume type featuring low speeds and single stage design. Both the vertical and the horizontal pump design may be used for this service. The horizontal type used is usually a volute centrifugal pump employing either a single or a double inlet. Vertical designs favored include the volute type, the propeller type, and the mixed flow type.

A propeller type circulating water pump is illustrated in Fig. 22.

1. motor
2. coupling
3. gland
4. gland spacer
5. gland packing
6. shaft sleeve key
7. gland drain
8. pump body bracket
9. pump discharge elbow
10. shaft stationary sleeve
11. shaft
12. shaft sleeve key
13. guide vanes
14. pump body
15. bearing
16. propeller key
17. propeller
18. pump body liner
19. propeller nut



Propeller Type Circulating Water Pump
(Westinghouse)

Fig. 22

Frequently two 50% capacity pumps are used for circulating water service as at times of partial turbine load it is economical to run only one pump rather than both. This practice is also feasible during cold weather when, because of the low temperature of the circulating water, the capacity of one pump is sufficient even at full turbine load.

5. Miscellaneous Pumps

Under this heading can be included fuel oil pumps, chemical pumps, vacuum pumps, and ash handling pumps.

Fuel oil pumps are usually some form of rotary positive displacement type. This type requires a relief or bypass valve to protect the pump and discharge lines from excessive pressure in the event that flow is restricted. Direct acting steam driven pumps are sometimes used for fuel oil service in smaller plants while in large stations centrifugal fuel oil pumps may be used.

Chemical feed pumps are usually the motor driven reciprocating plunger type. The capacity, or volume pumped, of this type can be varied by adjusting the stroke of the pump and in this way the amount of chemical fed to the boiler can be closely controlled. This type of pump should also be equipped with a relief valve on the discharge in order to avoid damage from over pressure.

Vacuum pumps which remove air and noncondensable gases from the turbine condenser may be the positive displacement type or the jet type. The positive displacement type may use a reciprocating piston or its design may feature a rotor with lobes or vanes. The jet pump utilizes a jet of high pressure steam as its operating medium and this high pressure steam may be applied to two or three stages in order to compress the air and gas from condenser pressure to atmospheric.

Ash handling pumps, which have to pump ash laden water, are usually single stage centrifugal using flat bladed impellers. Wear resistant alloy is used for their construction.

PUMP DRIVES

Pumps may be driven by any type of prime mover but the most common driver for power plant pumps is the electric motor. Steam turbines are favored under certain conditions while internal combustion engines, steam engines and gas turbines may occasionally be used for a power plant pump.

1. Electric Motors

The most simple arrangement for pump drive is to use a constant speed induction motor directly connected to the pump. This method can be used with centrifugal, rotary or reciprocating pumps.

Another constant speed driver is the synchronous motor which is not only more efficient than the induction motor but which can be used to improve the plant power factor.

A wound rotor induction motor may also be used for pump drive with the advantage of controlling pump output by speed variation. They are often used for pumps which are required to operate at reduced output only periodically.

Speed variation may also be obtained with a constant speed motor by means of a variable speed fluid or magnetic coupling. This method is often used for boiler feedpumps.

2. Steam Turbines

The use of a steam turbine as a pump driver provides the advantage of simple speed control plus the possibility of economical use of exhaust steam for process or feedwater heating. Usually such a steam turbine is used to drive a centrifugal pump but occasionally is used for rotary pumps and even reciprocating pumps.

For feedpump service in large central stations the steam turbine is preferred when kW requirements exceed about 5500. Various arrangements may be used in regard to the number of feedpumps required. In some plants three 50% capacity pumps are installed and at full load two pumps would be in service and one on standby. Other plants use only two 50% capacity pumps and in this case failure of one pump at full load would mean reducing load to half. Another method used by many large plants is to have only one 100% capacity pump which is required to have the same reliability as the turbo-generator itself. In the latter case, the feedpump turbine for a 1300 megwatt turbo-generator would be in the range of 50 MW.

Another method used in some large generating plants is to connect the feedpump through a variable speed coupling to the shaft of the main turbine or generator.

3. Steam Engines, I.C. Engines, Gas Turbines

The only steam engine driven pumps found to any extent are the direct acting steam pumps such as the duplex and simplex types. These are used in some power plants for feedwater service, fuel oil service, etc.

Internal combustion engines are frequently used for portable pumps and for emergency fire pumps.

Although gas turbines are becoming popular for a variety of pump drive services such as petroleum pipeline pumping, they are seldom used for auxiliary power plant pumps.

PUMP INSTALLATION, OPERATION, AND MAINTENANCE

In order to ensure satisfactory operation, considerable attention must be paid to the installation of the pump. The unit should be located where it is easily accessible for repair and inspection and sufficient headroom should be provided for removal of casing and rotor. In the case of a reciprocating pump, enough room should be provided for the removal of pistons and rods. The location should be as near as possible to the source of liquid supply in order that a short direct suction line can be used. Similarly, the discharge line should be short and direct with a minimum of elbows and other fittings so as to reduce friction losses. The piping should be supported independently of the pump to avoid strain on the casing and if an expansion joint is used in the piping there should be an anchor installed between the pump and the joint.

If the pump is to work on a suction lift then a foot valve should be installed in the suction line and this valve should have a flow area at least equal to that of the suction line.

A suction strainer should be installed having a flow area of three to four times that of the suction line.

A gate valve and check valve should be installed in the discharge line close to the pump with the check valve between the gate valve and the pump. If the pump is a positive displacement type then a relief valve should be installed in the discharge line as close to the pump as possible and before any check valve or stop valve.

In the case of a reciprocating pump where a surge chamber may be required on the suction or discharge line, provision should be made to keep the surge chamber charged with air and a water level gage is desirable in order to check on the amount of air in the chamber.

The foundation upon which the pump is to be placed should be heavy enough to absorb vibration and to provide adequate support for the pump base plate. Before the foundation concrete is poured, the foundation bolts should be located by means of a template and placed within pipe sleeves that are several sizes larger than the bolts.

If the pump to be installed is a large expensive unit, it is advisable to obtain the services of the manufacturer's erection engineer to assure proper installation and alignment.

If the pump and driver are mounted on the base plate when received from the manufacturer then the coupling halves should be disconnected and the units should be aligned after installing the base plate on the foundation. The base plate should be set on metal shims or wedges with a gap of about 25 mm between the base plate and the foundation for grouting. The metal shims should be adjusted until pump and driver shafts and suction and discharge flanges are level.

The flexible coupling between pump and driver is not intended to absorb misalignment but rather to compensate for temperature changes and to allow for some end play.

The coupling faces should be spaced far enough apart so that they do not contact each other when the driver rotor is pushed toward the pump as far as it will go. Also space must be allowed for eventual wear of the thrust bearings.

The pump and the driver may be misaligned angularly with the shafts concentric but not parallel, or they may be misaligned with the shafts parallel but not concentric.

A check for angular alignment is made by inserting a taper gage between the coupling faces at four points spaced at 90 degree intervals around the coupling. The coupling faces should be the same distance apart at all points for correct angular alignment.

Parallel alignment is checked by placing a straight edge across both coupling rims at the top, bottom, and both sides. The straight edge should rest evenly on the coupling rims at all positions.

Any misalignment, either angular or parallel can be corrected by inserting shims under the driver feet.

When the pump driver is delivered separately to the site and is to be mounted on the pump base plate in the field, then the base plate with the pump is set on the foundation and levelled with shims leaving a space for grouting. The driver is then placed on the base plate so that the coupling faces are the correct distance apart. The pump and driver should then be aligned as described previously and the holding down bolt holes for the driver marked off on the base plate. The driver is now removed and the bolt holes drilled and tapped. The driver is then replaced on the base plate, the bolts are inserted and tightened after re-aligning the driver and pump.

When the alignment of pump and driver is correct, the unit can then be grouted in. The base plate is completely filled with grout, with the levelling shims and wedges left in place. After the grout is hardened, about 48 hours after pouring, the foundation bolts can be fully tightened and the alignment checked once more.

The alignment should be checked again after the piping has been connected. The unit should then be operated under normal conditions until temperatures have reached operating condition then the unit should be shut down and alignment checked once more.

A final alignment check is made after the unit has been running for one week and then the pump and driver can be dowelled to the base plate.

Before the pump is put into operation, the stuffing boxes should be inspected. These are usually packed by the manufacturer before shipping the pump. If the stuffing boxes are not already packed then they should be cleaned and packed. If the liquid to be pumped is dirty or corrosive then the stuffing boxes should be sealed with a clean sealing liquid from some other source. The packing should be quite loose when the pump is first started and later tightened carefully. There should be a slight leakage from the stuffing box during normal running.

If the pump is equipped with mechanical seals then the manufacturer's instructions regarding these must be carefully followed.

Sleeve bearings should be cleaned thoroughly before starting the pump and should be filled with the proper lubricant. When the pump is running, the bearings should be checked to see that the oil rings are turning and the bearing temperature should be checked frequently until the pump is run in.

If the pump is equipped with a Kingsbury-type thrust bearing, make sure that enough oil is supplied to protect the thrust shoes before starting the pump.

Anti-friction bearings should not be overlubricated and only the best grade of lubricant should be used. They should be cleaned and lubricated at the required intervals.

Before the pump unit is started for the first time, it should be checked for proper direction of rotation.

Centrifugal pumps must be primed before starting and priming is recommended for rotary and reciprocating pumps as well. Priming can be done by means of an ejector or exhauster, driven by steam, compressed air or water pressure, which removes air from the pump and suction line. This method does not require a foot valve.

If the pump is equipped with a foot valve then an exhauster is not required and the pump can be filled with liquid from some outside source.

Still another method of priming is to use a vacuum pump to remove the air from the pump and suction line and so cause the pump to fill with liquid.

<u>Under no circumstances is a centrifugal pump to be started unless the casing and suction are filled with liquid.</u>

Most centrifugal pumps should be started with the discharge gate valve shut, however in the case of mixed flow or axial flow pumps more power may be required with the discharge valve shut than with it open and these pumps should be started with the discharge valve open or partially open.

Pumps must not be throttled by the use of a valve in the suction line.

Liquid moving through a pump will vaporize when the local absolute pressure falls to or below the liquid vapor pressure and this formation of vapor is called cavitation. Cavitation will reduce pump capacity and will cause erosion of metal, vibration, and pressure pulsations due to collapse of vapor pockets when arriving at higher pressure regions of the pump.

Cavitation is caused by:

Too high suction velocity.

Too many sharp changes in direction of suction line.

Too high temperature of pumped liquid.

Too high suction lift.

In order to provide for adequate maintenance of a pump, an adequate stock of spare parts should be kept on hand. These parts should be identified and catalogued with reference to the pump instruction manual. When ordering spare parts the manufacturer should be given the pump serial number, size, and type and the part name and identifying number as well as any additional markings to be found on the old part.

For reciprocating pumps it is usually only necessary to have spare valves and packing on hand.

For centrifugal pumps it is recommended that the following be kept on hand: set of bearings, set of shaft sleeves, set of wearing rings and an adequate supply of packing.

In order to avoid pump outages, a schedule of preventative maintenance should be set up. This schedule may be based on the number of hours the pump is in operation or it may be based simply on time. For example, a schedule based on time might involve the following intervals and operations:

Hourly - The operating checks that should be made every hour are: bearing temperatures (by hand), suction pressure, discharge pressure, lubricating oil pressure and temperature, balancing disc leakoff, stuffing box leakoff, cooling water flow, cooling water inlet and outlet temperatures, driver motor amps, bearing oil levels, oil ring operation, and recirculation or bypass flow if pump is operating at low capacity.

Monthly - An accurate check of the temperature of each bearing should be made with a thermometer. Ball or roller bearings that are running hot may be overlubricated and this can be checked by removing some lubricant. Hot sleeve bearings may be the result of dirty oil or insufficient oil. Faulty alignment of pump and driver is another cause of hot bearings.

Quarterly - At three month intervals sleeve bearings should be dismantled, cleaned and the oil changed. Grease packed bearings should be checked for contamination of the grease by the pumped liquid and if contamination is present, the bearing should be flushed out, cleaned and repacked. All bearings should be measured for wear.

Semi-annually - Stuffing box leakage should be carefully measured and the packing renewed if necessary. Shaft sleeves should be checked for scoring and wear. If shaft sleeves are not worn but packing wear is excessive, this is an indication of a bent shaft, or worn bearings, or an out of balance rotor.

In addition to the stuffing box inspection, the alignment of the pump and driver should be measured and the condition of the bearing lubricant should be checked.

Annually - Some pump manufacturers recommend an annual dismantling of their pumps while others do not recommend this until the necessity is indicated by poor performance, noise, vibration, or overloading of the driver.

If disassembly of the pump is carried out, the following should be inspected:

The casing should be examined for corrosion and wear and should be thoroughly cleaned.

The rotor should be examined for wear and corrosion.

Wearing ring clearance should be measured and rings replaced if necessary.

Worn bearing shafts and shaft sleeves should be replaced.

All sealant and coolant connections should be thoroughly flushed out and cleaned.

Pressure gages and other instruments should be recalibrated.

Bypass or recirculating valves should be checked for wear and repaired or replaced.

Suction and discharge valve assemblies on reciprocating pumps should be checked and pistons and cylinders inspected.

PUMPING THEORY

Definitions

1. Slip - In reference to a reciprocating pump this is the difference between the quantity of water actually delivered and the piston displacement or theoretical discharge all expressed in litres or m^3 per minute (L/min). Slip is due to leakage past valves, pistons and stuffing boxes and is expressed in percentage of piston displacement.

   Example: If during one stroke the pump piston displaces 2 litres but only 1.9 litres of the liquid is forced into the discharge then the slip = 2.0 - 1.9 = 0.1 L. Expressed as a percentage of piston displacement the slip $= \frac{0.1}{2} \times 100 = 5\%$

2. Volumetric Efficiency - In reference to a reciprocating pump this is the ratio of the volume of liquid delivered to the piston displacement. In the foregoing example the volumetric efficiency $= \frac{95}{100} = 0.95$ or 95%.

3. Capacity - This is the quantity of liquid handled by the pump in a given period of time. It is usually stated in litres/min or cubic metres per minute (m^3/min).

4. Total Static Head - This is equal to the vertical distance from the surface of the supply source to the free surface of the liquid in the discharge well or to the point of free discharge.

5. Static Suction Lift - This exists when the source of supply is below the centre line of the pump and it is the vertical distance from the surface of the liquid in the suction well to the centre line of the pump.

6. Static Suction Head - This exists when the supply is located above the centre line of the pump and is the vertical distance from the pump centre line to the surface of the liquid in the source of supply.

7. Static Discharge Head - This is equal to the vertical distance from the pump centre line to the surface of the liquid in the discharge well.

8. Friction Head - This is the equivalent head expressed as metres of liquid required to overcome the friction caused by the flow through the pipe and fittings in the system.

9. Velocity Head - This is the equivalent head in metres through which the liquid would have to fall to acquire the pumping velocity.

10. Pressure Head - This is the head in metres of liquid in a closed vessel from which the pump takes its suction or against which the pump discharges.

11. Total Head - This is the sum of the static head plus velocity head plus friction head plus pressure head.

12. Net Positive Suction Head - This is the total head in metres of liquid absolute at the suction nozzle of the pump, minus the vapor pressure of the liquid in metres absolute.

$$\text{N.P.S.H.} = \frac{0.10148\ (Pa - Pv)}{R.D.} + He - H_f$$

Pa	=	the pressure of the atmosphere or the pressure in the suction vessel in kPa
R.D.	=	the relative density of the liquid at pumping temperature
He	=	the suction head in metres, either positive or negative, depending on whether the pump is above or below the source of supply.
H_f	=	the friction head in metres of the suction piping
Pv	=	the vapor pressure of the liquid at the pumping temperature in kPa, as given in the dry saturated steam table, column 2 if liquid is water.

Examples:

1. A pump located 4.5 m above the source of supply is pumping 30°C water of R.D. of 1.0. The atmospheric pressure is 101.325 kPa and the friction in the suction piping is equal to 0.3 m of head. Calculate the available net positive suction head.

Solution: Pa = 101.325 kPa, Pv = 4.246 kPa, R.D. = 1.0,

He = -4.5 m, H_f = 0.3 m

$$\text{N.P.S.H.} = \frac{0.10148\ (101.325 - 4.246)}{1.0} - 4.5 - 0.3$$

$$= 9.8516 - 4.8$$

$$= \underline{\underline{5.85\ m}} \text{ (Ans.)}$$

2. The pump is pumping under the same conditions as in Example 1 except that the water is at a temperature of 80°C and has a relative density of 0.975. Calculate the available N.P.S.H.

Solution: P_a = 101 kPa, P_v = 47.39 kPa, H_e = −4.5 m, R.D. = 0.975, H_f = 0.3 m

$$N.P.S.H. = \frac{0.10148\ (101.325 - 4739)}{0.975} - 4.5 - 0.3$$

$$= 5.6137 - 4.8$$

$$= \underline{\underline{0.8137\ m}}\ \text{(Ans.)}$$

3. A boiler feed pump is supplied with 110°C water with R.D. of 0.945 from a deaerator operating at 170 kPa. The surface of the water in the deaerator is 30 m above the pump. Suction line friction is equal to 1 m. Calculate the available N.P.S.H.

Solution: [illegible] = 170 kPa, P_v = 143 kPa, H_e = 30 m, [illegible]$_f$ = 1 m, R.D. = 0.945

$$N.P.S.H. = \frac{0.10148\ (170 - 143)}{0.945} + 30 - 1$$

$$= 2.9 + 29$$

$$= \underline{\underline{31.9\ m}}\ \text{(Ans.)}$$

N.P.S.H. may also be defined as the head in metres at the pump suction nozzle that prevents vaporization of the liquid being pumped.

Each pump has a required or limiting N.P.S.H. which is determined experimentally by the pump manufacturer. It is, therefore, necessary that the suction system for the pump be able to supply a N.P.S.H. which is greater than the required or limiting N.P.S.H.

13. Cavitation - If the available [illegible] S.H. of the system is reduced below the required N.P.S.H. of th[illegible] then the liquid will begin to flash in the pump. This conditio[illegible]n as cavitation. Small bubbles of vapor will form in the liqu[illegible] these bubbles subsequently collapse causing pitting and erosion of impeller and casing.

14. Liquid Power, kW - This is equal to the number of kilograms of liquid delivered per minute times the distance through which liquid is lifted, divided by 6115.94.

$$\text{Liquid kW} = \frac{Wh}{6115.94}$$

W = kilograms of liquid per minute

h = head in metres

15. Mechanical Efficiency E

For centrifugal pumps $E = \frac{\text{Liquid kW}}{\text{Brake kW}}$

For steam driven pumps $E = \frac{\text{Liquid kW}}{\text{I kW of steam cylinder}}$

Centrifugal Pump Performance -

Effects of Speed Change -

1. The quantity of water pumped varies directly as the impeller diameter.

2. The head produced varies with the square of the impeller speed.

3. The power needed to drive the pump varies as the cube of the impeller speed.

For example if the impeller speed is doubled then the quantity pumped will double. The head developed will be four times as great and eight times as much power will be required to drive the pump.

Effects of Change in Impeller Size -

1. The quantity of water pumped varies directly as the impeller diameter.

2. The head produced varies as the diameter of the impeller squared.

3. The power needed to drive the pump varies as the cube of the impeller diameter.

The above rules can be summarized by the following equations in which:

kW = pump power required

H = head developed by pump, m

D = impeller diameter, mm

E = pump efficiency

n = pump speed in rev/min

Q = quantity pumped in L/min

In the equations the subscript 1 refers to the original conditions and the subscript 2 refers to the new conditions.

$$Q_2 = Q_1 \times \frac{n_2}{n_1} \times \frac{D_2}{D_1}$$

$$H_2 = H_1 \times \left(\frac{n_2}{n_1}\right)^2 \times \left(\frac{D_2}{D_1}\right)^2$$

$$kW_2 = kW_1 \left(\frac{n_2}{n_1}\right)^3 \times \left(\frac{D_2}{D_1}\right)^3$$

$$E_1 = E_2$$

Example:

A centrifugal pump delivers 13 600 L/min of water against a head of 50 m when running at 1760 rev/min. The pump efficiency is 81 percent and the power required to drive the pump is 125 kW. The impeller diameter is 343 mm. What will be the performance of the pump if the impeller diameter is reduced to 330 mm and the pump, at the same time is speeded up to 1800 rev/min?

Solution:

$$Q_2 = Q_1 \times \frac{n_2}{n_1} \times \frac{D_2}{D_1}$$

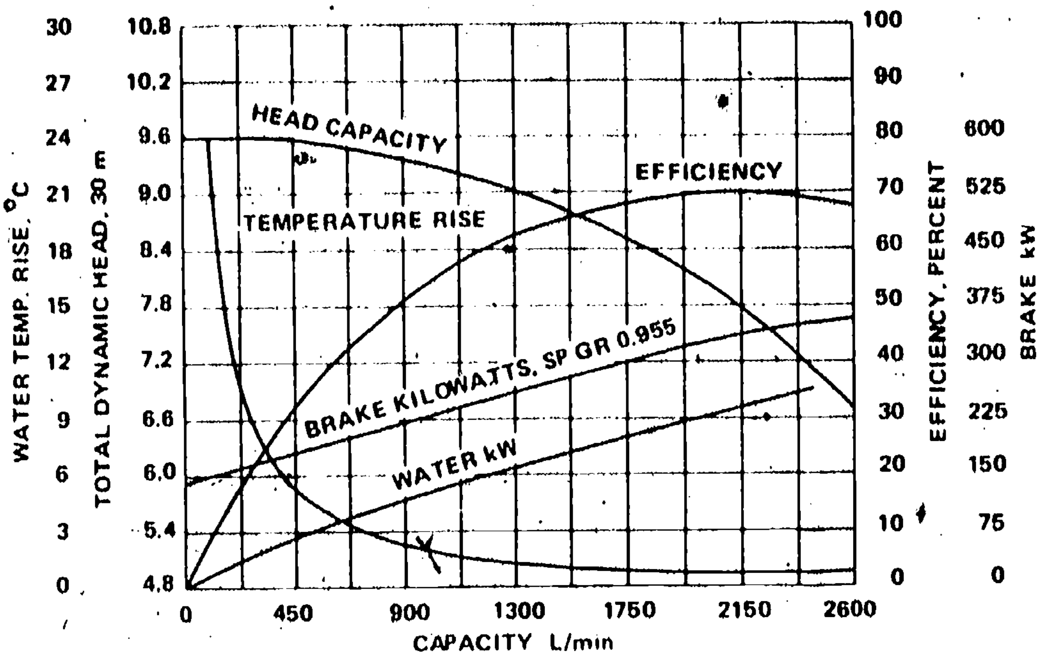
$$= 13\,600 \times \frac{1800}{1760} \times \frac{330}{343}$$

$$= \underline{13\,382 \text{ L/min}} \quad \text{(Ans.)}$$

$$H_2 = H_1 \times \left(\frac{n_2}{n_1}\right)^2 \times \left(\frac{D_2}{D_1}\right)^2$$

$$= 50 \times \left(\frac{1800}{1760}\right)^2 \times \left(\frac{330}{343}\right)^2$$

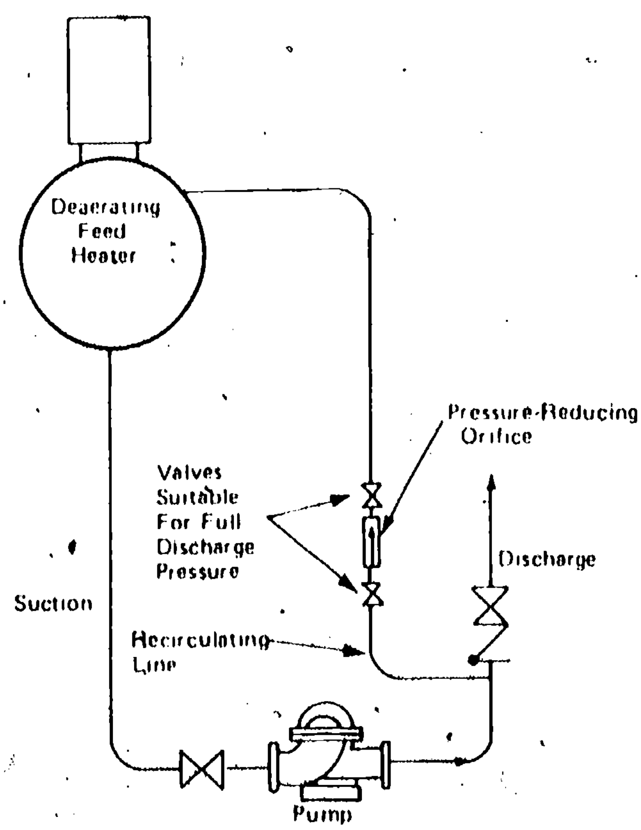
$$= \underline{48.41 \text{ m}} \quad \text{(Ans.)}$$



Temperature Rise Versus Flow

Fig. 25

To prevent this rapid temperature rise at low flows a recirculation line from the pump discharge to the suction source is used and this arrangement appears in Fig. 26.



Feed Pump Recirculation

Fig. 26

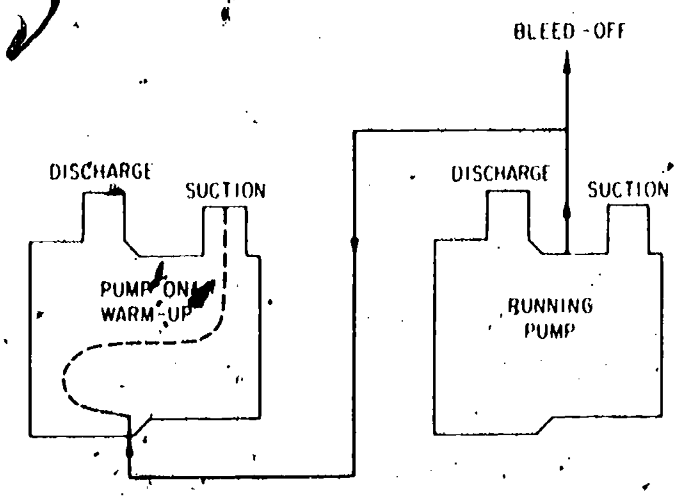
The recirculation line in Fig. 26 has an orifice designed to pass the minimum flow required to prevent overheating in the pump. The valves in the recirculation line may be operated manually or automatically but they must be open on starting and stopping the pump and when the pump is operating at low flows.

Pump Warm-Up Procedure

In the case of boiler feedpumps or other pumps which handle liquid at high temperatures, it is vital that the proper warm-up procedure be carried out before starting the pump. If this is not done then temperature gradients will be present within the pump which will cause rotor distortion.

To avoid these temperature gradients, the standby boiler feedpump is supplied with warm-up water which is bled off from an intermediate stage of the in-service boiler feedpump. This warm-up water enters at the bottom of the standby pump casing and leaves through the suction nozzle.

The arrangement is sketched in Fig. 27.



Pump Warm-Up Arrangement

Fig. 27

QUESTION SHEET

POWER ENGINEERING

First Class
Sect. 2, Lect. 9

1. Discuss in general terms the uses of the following classes of pumps:

   (a) reciprocating

   (b) centrifugal

   (c) rotary

2. Describe a type of pump which would be suitable as a boiler circulating pump and explain how sealing problems are overcome with this type.

3. Describe with the aid of a simple sketch, some method whereby axial balance is provided for in a single suction multi-stage centrifugal pump.

4. Discuss pump installation in terms of location, space required, fittings and piping required.

5. Describe the method of aligning and grouting-in of a centrifugal pump which has been delivered to the site with the driving motor separate from the pump and base plate.

6. Discuss the following in regard to a centrifugal pump:

   (a) priming

   (b) starting

   (c) cavitation

7. A pump is required to handle water at 50°C with a relative density of 0.986. The atmospheric pressure at the suction is 90 kPa and the friction in the suction piping is equivalent to a head of 2 metres.

   The required N.P.S.H. for this pump is 2.75 metres. What would be the maximum negative suction head (suction lift) that the pump can handle?

(continued)

8. A centrifugal pump has a maximum capacity of 9000 L/min. The impeller diameter is 550 mm. If the maximum capacity is to be reduced by 5 percent, what will be the new impeller diameter assuming the pump speed remains the same?

9. Flows below a certain minimum may cause problems in a centrifugal pump. Explain what these problems are and how they may be avoided at times of low demand.

10. A pump is to move 22 500 L/min of water of relative density 0.996. The pump is 1.5 m above the water supply and the point of discharge is 18 m above the pump. The friction in the suction piping is equivalent to 1 m of head and the friction in the discharge piping is equivalent to 4.5 m of head. If the pump has an efficiency of 80 percent, what motor power in kW will be required to drive the pump?

SOUTHERN ALBERTA INSTITUTE OF TECHNOLOGY
CALGARY, ALBERTA

Correspondence Courses
Power Engineering

SECTION 3

STEAM GENERATION

Third Class
Lecture 6

PUMPS

A pump can be defined as a device used to impart energy to a fluid in order to move it from one point to another. Because of the many purposes and variety of services for which a pump is required in power and industrial plants, it can be regarded as one of the most important plant auxiliaries. Examples of pump applications in the power plant are: boiler feedwater pumps, condensate pumps, fuel oil pumps, chemical feed pumps, cooling water circulating pumps, fire pumps, etc.

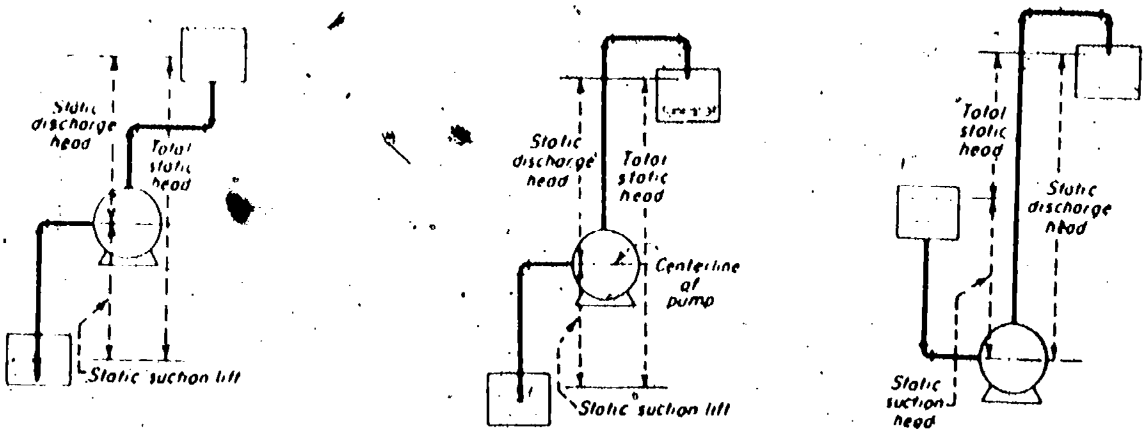
THEORY OF PUMPING

For the proper understanding of the pumping process, pump selection, the calculation of pump capacity and the power required to drive a pump, it is necessary that an engineer be fully familiar with the terminology used in pumping technology. Below follows a short discussion of most of the common terms in use.

Pump Head

Pump head refers to the pressure a pump has to overcome in order to be able to move the liquid through the system. This pressure is sometimes expressed in kPa but, more commonly, as the height (expressed in metres) of a column of the liquid pumped that would produce the same pressure. The height of this column is known as "head".

Pump head comprises several components which will be described with the aid of Figs. 1 and 2.



(A) (B) (C)

Fig. 1

1. Static Suction Lift - the vertical distance, in metres, from the liquid supply level to the pump centre line when the pump is above the supply level, Figs. 1 (A) and (B).

2. Static Suction Head - the vertical distance, in metres, from the liquid supply level to the pump centre line when the pump is below the supply level, Fig. 1 (C).

3. Static Discharge Head - the vertical distance, in metres, from the centre line of the pump to the free surface of the liquid in the tank pumped into , Fig. 1 (A); or to the point of free discharge, Figs.1(B) and (C).

4. Total Static Head - when pump is mounted above source of supply, total static head is the vertical distance, in metres, from surface of source of supply to surface in discharge tank, Fig. 1 (A), or to the point of free discharge, Fig. 1 (B). Thus total static head is static suction lift plus static discharge head.

   When pump is mounted below source of supply, total static head is the vertical distance, in metres, from surface of source of supply to surface in discharge tank, or to point of free discharge, Fig. 1 (C). Hence, total static head is static discharge head minus static suction head.

   While static head is always present in a filled system, whether the liquid is in motion or not, the following heads must be considered when the liquid is moving through the piping.

(PE3-3-6-2)

5. Friction Head - this is the pressure, expressed in metres of head, required to overcome friction caused by liquid flow through piping, valves and fittings in the system.

6. Velocity Head - the pressure, in metres of liquid head, required to give the liquid its motion through the system at a given velocity.

7. Pressure Head - the pressure, in metres of liquid head, in a closed vessel from which the pump takes its suction or against which the pump discharges.

8. Dynamic Suction Lift - the sum of static suction lift and suction friction and velocity head, Fig. 2.

9. Dynamic Suction Head - static head minus suction friction and velocity head.

10. Dynamic Discharge Head - static discharge head plus discharge friction and velocity head, Fig. 2.

11. Total Dynamic Head - the sum of dynamic suction lift and dynamic discharge head, Fig. 2. Where there is suction head, total dynamic head is the difference between dynamic suction and discharge head.

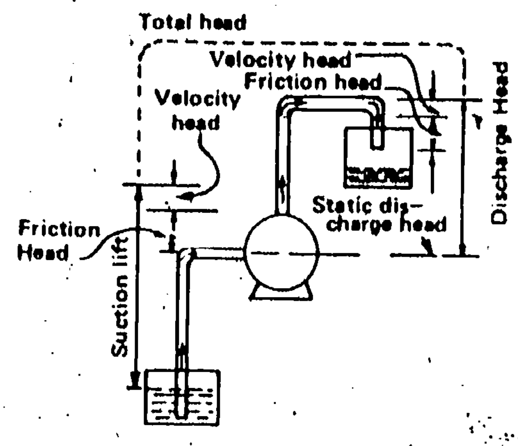


Fig. 2

When source of supply and discharge tank are both under atmospheric pressure, pressure head will be nil, but if either one or both are under pressure, the difference in pressure head must be added to the total dynamic head.

12. Vapor Pressure - all liquids form vapors at their free surface creating a pressure, known as vapor pressure, which increases in value with rising liquid temperatures.

In a closed system completely filled with liquid no vapors will form as long as the liquid is subjected to a pressure that is above the vapor pressure corresponding with the temperature of the liquid. However, should the pressure exerted on the liquid be allowed to drop below the vapor pressure, some of the liquid will flash into vapor.

This is an important factor to consider in a pumping system where the pressure on the suction side of the pump could drop below the vapor pressure of the liquid due to insufficient suction head, high suction

(PE3-3-6-3)

lift, excessive friction head or high liquid temperature. Should this occur, the liquid will form vapor which could partially or completely stop liquid flow into the pump. The pump is then said to be vapor-bound.

13. Cavitation - when the pressure at any point inside a centrifugal pump drops below the vapor pressure of the liquid, vapor bubbles will be formed which create cavities in the liquid flow. These bubbles are carried along with the flow until they reach a region of higher pressure where they collapse, producing a shock wave. This phenomenon is called cavitation. When the bubbles are carried onto the surface of the impeller and collapse there, the impact of the liquid suddenly filling the void and hitting the metal will damage the surface by gouging out small pieces. When this action is repeated in rapid succession, it is accompanied by noisy operation and vibration. Prolonged operation under these conditions may result in mechanical destruction of the pump.

14. Net Positive Suction Head - to prevent cavitation and vapor-binding and to ensure maximum flow through a pump, it is necessary to provide sufficient head on the pump suction so that the suction pressure will always be greater than the vapor pressure of the liquid handled.

    This pressure available or required at the pump suction is expressed in metres of liquid head and is called the " net positive suction head ".

15. Slip - referring to reciprocating and rotary pumps, the term " slip " means the difference between the actual volume of liquid discharged by the pump and its theoretical capacity. Slip is caused by leakage past valves and pistons in reciprocating pumps and the stationary and rotary members of rotary pumps. It is usually expressed as a percentage of the theoretical capacity.

16. Volumetric Efficiency - again referring to reciprocating and rotary pumps, the volumetric efficiency is the ratio of the actual volume discharged to the theoretical capacity of the pump. It is also expressed as a percentage of the theoretical capacity.

PUMP CLASSIFICATION

According to their method of operation, pumps can be divided into three main classes: reciprocating, rotary and centrifugal.

Each class can be further subdivided into a number of different types.

A description of the basic operating principle of the pumps in each class will follow, as well as a more detailed description of some of the more common types of pumps in each class used in power and industrial plants.

Reciprocating Pumps

In this type of pump the pumping action is produced by the to and fro (reciprocating) movement of a plunger, piston or diaphragm within a cylinder. The liquid being pumped is drawn into the cylinder through one or more suction valves and is then forced out through one or more discharge valves by direct contact with the plunger, piston or diaphragm.

Reciprocating pumps can be divided into two classes according to the pump drive:

1. The direct acting steam driven pump in which the movement of the piston in the water cylinder is produced by a steam piston in a steam cylinder. The pump is called direct acting because the piston rods of steam and water piston are directly connected together.

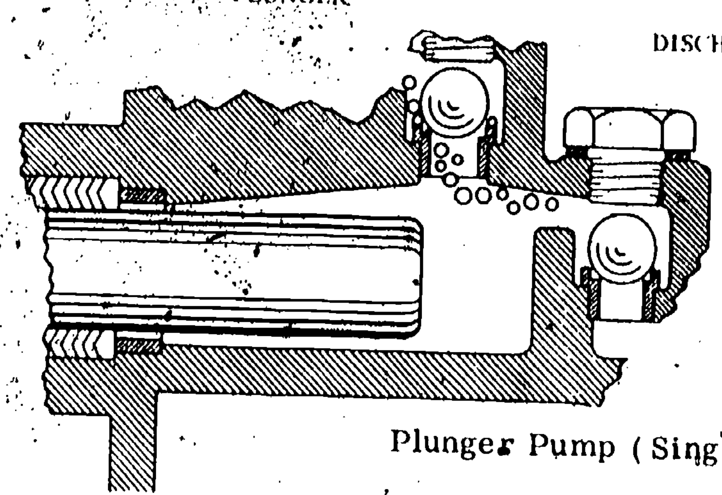
2. The power driven pump which has a crankshaft driven by a separate power source, usually an electric motor.

Reciprocating pumps can also be classified as single-acting or double-acting depending on whether pumping action takes place only on one side of plunger, piston or diaphragm or on both sides.

1. Plunger Pumps

The basic design of the plunger type reciprocating pump is shown in Fig. 3. The action of the pump is as follows:

When the plunger starts moving from right to left, the pressure in the cylinder drops below that in the suction line and the liquid is drawn into the cylinder via the suction ball check. The high pressure in the discharge line keep the discharge ball check firmly on its seat. At the end of its travel the plunger reverses direction and starts moving from left to right. This causes the pressure in the cylinder to rise above that in the discharge line and the liquid is forced out via the discharge ball check, while the suction ball check is forced to close.



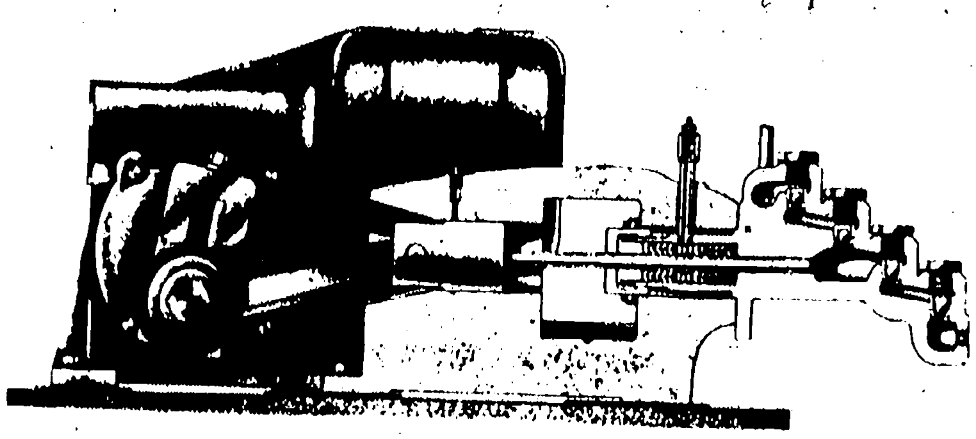
Plunger Pump (Single Acting)

Fig. 3

The movement of the plunger in one direction is called the stroke of the plunger. The distance the plunger moves in and out of the cylinder is the length of the stroke.

As can be seen in the sketch, only one side of the plunger takes part in the pumping action and liquid is only discharged during one out of every two strokes. Hence, the pump is called single-acting.

Fig. 4 shows a cross-sectional view of a power driven plunger pump. This pump is widely used as a chemical feed pump. It has an adjustable stroke for volume control and a double set of suction and discharge ball checks in step arrangement for high pressure applications.

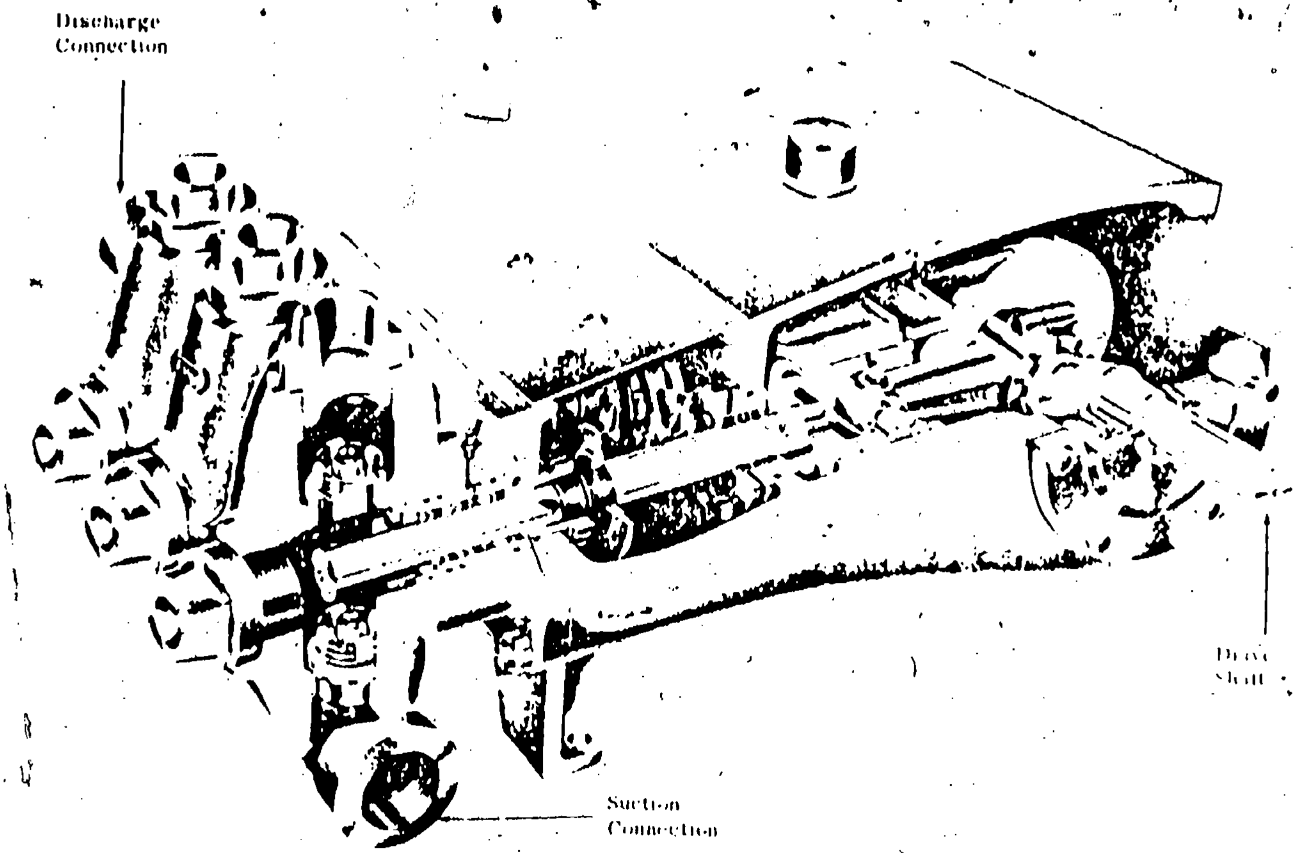


Power Driven Plunger Pump (Cross Section)

Fig. 4

(PE3-3-6-6)

Fig. 5 shows a large capacity triplex plunger pump. As the name imp it has three cylinders. The pump is single-acting and its plungers are driven t a crankshaft with three cranks placed 120 degrees apart.



Power Driven Triplex Pump
(Frank Wheatly Industries)

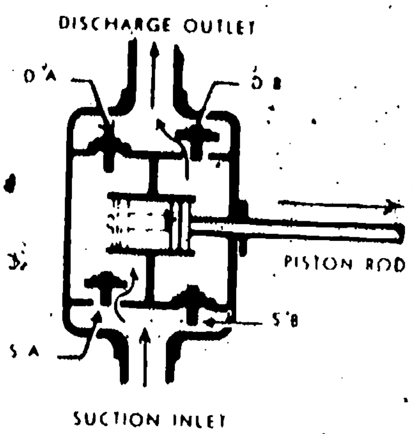
Fig. 5

2. Piston Pumps

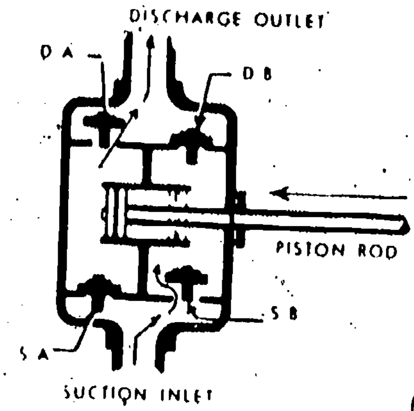
The basic operating principle of a double-acting piston pump is shown in Fig. 6. The pump has two discharge valves, D.A. and D.B., and two suction valves, S.A. and S.B.

When the piston moves from left to right, (a) the liquid is drawn into the left side of the cylinder via suction valve S.A. At the same time the piston forces liquid out of the right side via discharge valve D.B.

(PE3-3-6-7)



(a)



(b)

Double-Acting Piston Pump

Fig. 6

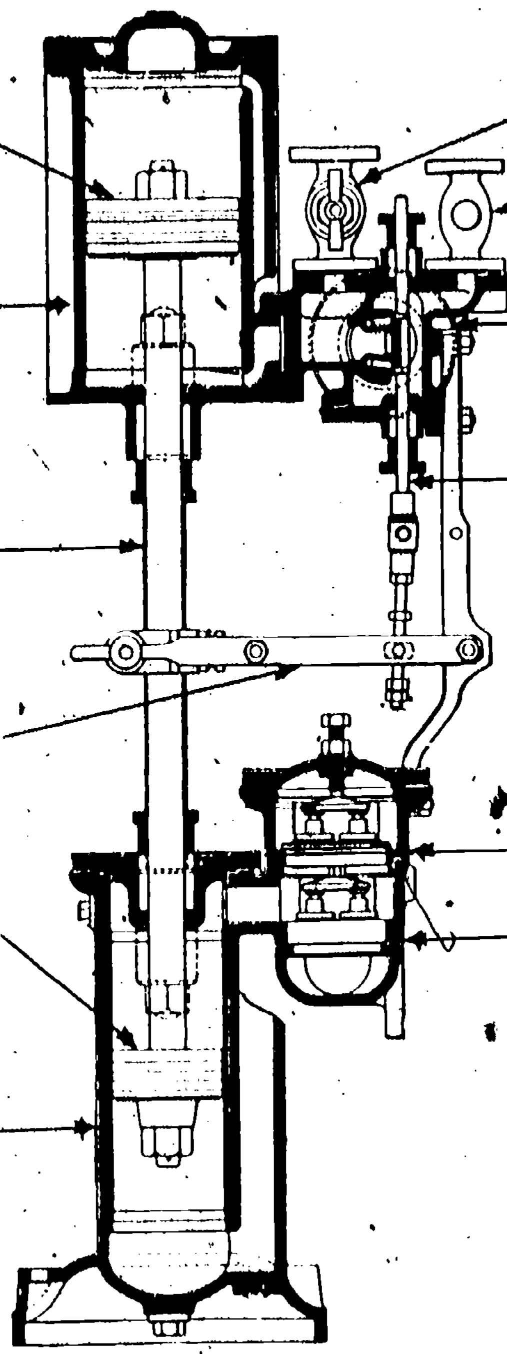
When the piston reverses direction and moves from right to left, (b) liquid is drawn into the right side of the cylinder via suction valve S.B. and discharged from the left side via discharge valve D.A.

With the above arrangement, both sides of the piston take part in the pumping action and liquid is discharged when the piston moves in either direction, hence the name "double-acting".

(a) Direct-Acting Steam Driven Pumps

(i) Simplex Pump

Fig. 7 shows a vertical direct-acting steam driven pump, commonly known as a simplex pump. The pump has a single, double-acting water piston driven by a single, double-acting steam piston; the pistons are connected by a common piston rod. The suction and discharge valves of the pumping cylinder are mounted in a common valve housing connected by channels to both ends of the cylinder. In the sketch, only the suction and discharge valves for the upper end of the cylinder are shown. The operation of the pumping cylinder is similar to the basic operating principle described above.



Vertical Direct-Acting Steam Driven Pump

Fig. 7

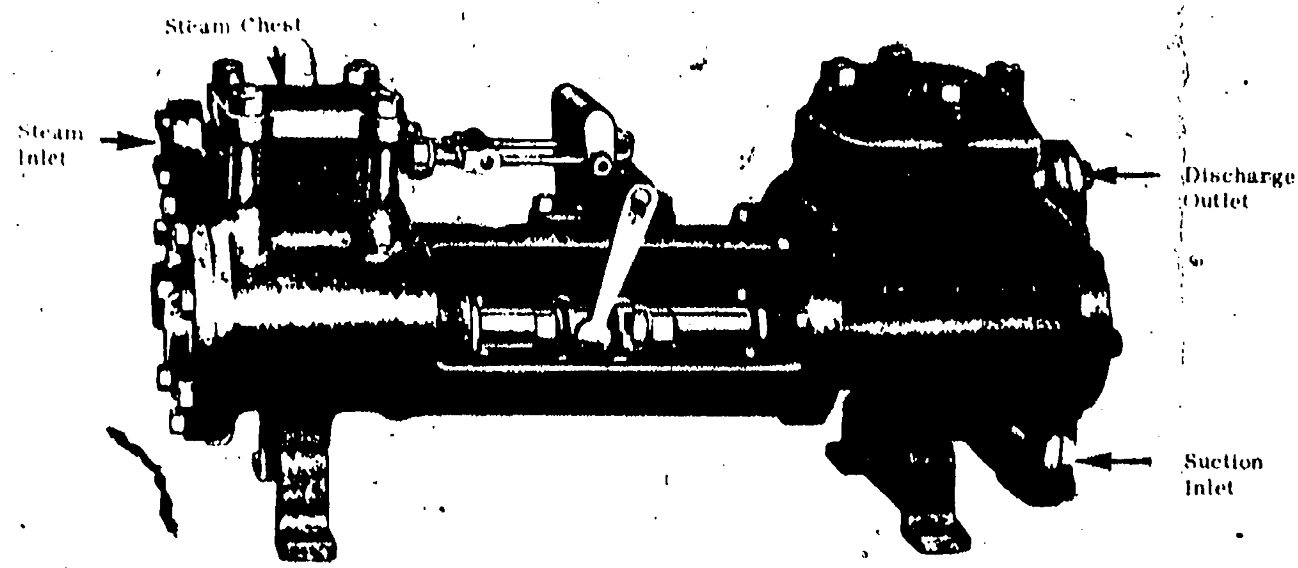
The steam piston is driven up and down by high pressure steam controlled by the main steam valve which moves horizontally across the cylinder steam admission and exhaust ports in the valve chest. When the valve is in its extreme right position it admits high pressure steam under the piston and simultaneously

(PE3-3-6-9)

connects the upper part of the cylinder to exhaust, causing the steam piston to rise. At the end of the upward stroke, the valve moves over to the extreme left, now admitting steam above the piston and allowing the steam in the lower part of the cylinder to exhaust. This forces the piston to move downwards again.

The movement of the main valve is controlled by the auxiliary valve which is moved up or down at the end of each stroke by the piston rod by means of the valve gear lever and the auxiliary valve rod. When placed in its upper and lower position, the auxiliary valve admits live steam to the space behind one end of the main valve and it connects the space on the other end of the valve to exhaust, causing the main valve to move horizontally from one extreme position to the opposite, placing it in the proper position for steam admission to and exhaust from either end of the cylinder.

(ii) Duplex Pump



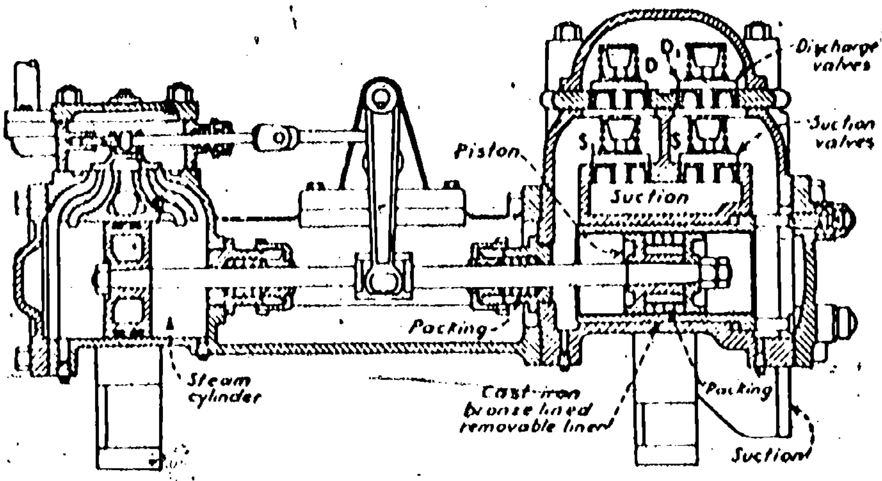
Horizontal Duplex Pump (Worthington)

Fig. 8

The duplex pump, illustrated in Fig. 8, is a horizontal, direct-acting steam driven pump. It has a double set of steam and pumping cylinders mounted side by side. The steam cylinders have a common steam chest, the pumping cylinders a common valve chest. A cross-section of one side of this pump is shown in Fig. 9.

The operation of the liquid pumping end of this pump is similar to that of the simplex piston pump described above.

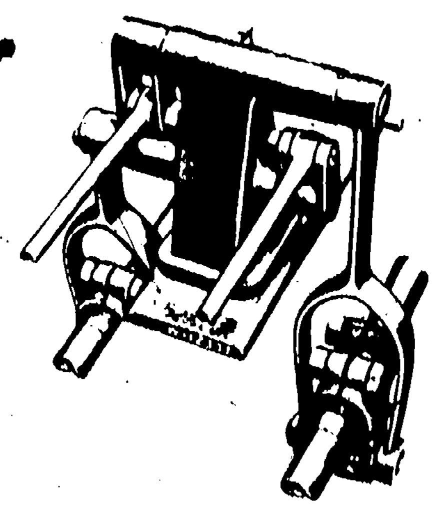
(PE3-3-6-10).



Duplex Pump Cross-Section

Fig. 9

The steam required to drive the steam pistons is supplied to the common steam chest which contains two slide valves, one for each cylinder. Each slide valve distributes live steam alternately to either side of the piston. The slide valve on one side of the pumping unit is moved to and fro by means of a lever mechanism actuated by the piston rod on the other side. A view of this slide valve actuating mechanism is shown in Fig. 10. It consists of a class I lever system (pivot in center) which causes the slide valve on one side to move in opposite direction of the piston on the other side, and a class II lever (pivot at end) which moves the second slide valve in the same direction as the opposite piston.



Slide Valve Actuating Mechanism for Duplex Pump (Worthington)

Fig. 10

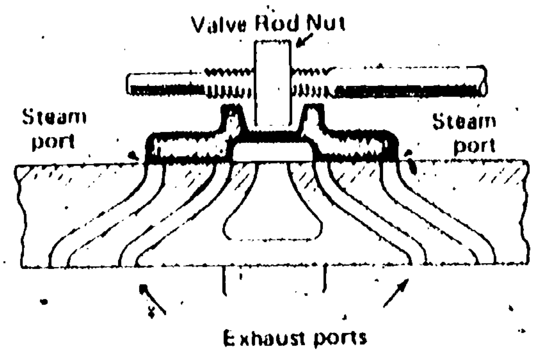
(PE3-3-6-11)

Each steam cylinder has four ports, Fig. 9. The outer ports are steam admission ports, the inner ports exhaust ports. A triangular fifth port, the exhaust steam outlet, can be connected to either one of the inner ports by means of the hollow centre of the slide valve.

The operation of the duplex pump is as follows. Referring to Fig. 9, the slide valve of one of the steam cylinders is shown in mid-position covering all ports. The steam piston however, should be at the extreme left end of the cylinder. When the slide valve is moved to the right by the movement of the opposite piston rod, it uncovers the left steam admission port and the right exhaust port. This allows live steam to enter the left side of the cylinder and spent steam to exhaust from the right side. The resulting pressure difference forces the piston to start its stroke to the right.

Near the end of the stroke the piston will slide over the right exhaust port trapping the remaining steam on the right side of the cylinder and continuous movement of the piston will then compress the steam. At nearly the same time, the movement of the opposite piston rod will move the slide valve back to mid-position, cutting off steam supply to left end of cylinder. This, combined with the compression of the steam on the right side causing a cushioning action, will bring the piston to a smooth stop at the end of its stroke. After a short stop the slide valve is moved to the left, opening steam admission on the right side of the cylinder and exhaust on the left side; causing the piston to start its stroke to the left. The same action takes place in the second steam cylinder, the movement of its slide valve being controlled by the piston rod of the first cylinder.

If the slide valves were rigidly connected to the valve rods, they would not stay open for steam admission and exhaust long enough for the pistons to complete their stroke and the pump would short-stroke, resulting in reduced capacity. To overcome this difficulty, the valve gear is given lost motion. Lost motion is the clearance between the valve rod nut or nuts and the lugs on the back of the valve against which the nut (s) press in order to move the valve. One lost motion arrangement using a single nut is shown in Fig. 11. Lost motion allows the valve to remain stationary until the piston has nearly completed its stroke. It also allows one piston to pause at the end of its stroke until its steam valve is actuated by the movement of the second piston since the pistons do not complete their strokes at the same time.



Slide Valve in Central Position
with Lost Motion

Fig. 11

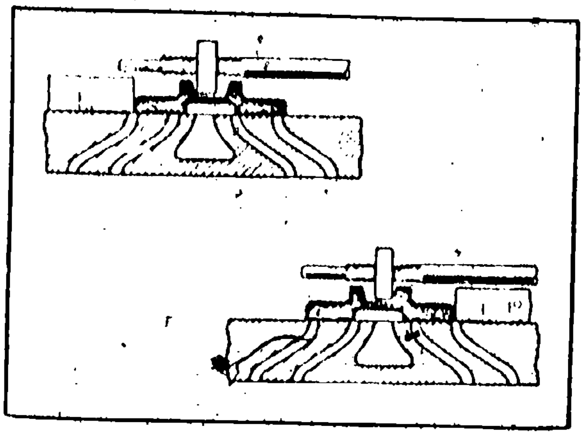
If the duplex pump is to work properly, the slide valves and linkage must be adjusted to be set in correct relation to the steam pistons. The proper procedure is as follows:

1. Shut down and isolate the pump at both the steam and water ends. Open the steam cylinder drain cocks and drain the water cylinder.

2. Place both steam pistons in the centre of their cylinders. To do this accurately, the piston is pushed over until it strikes the cylinder head and a mark is made on the piston rod at the face of the stuffing box gland. Then the piston is pushed back until it strikes the head at the other end of the cylinder and another mark is made on the piston rod at the gland face. The distance between the two marks is divided equally and a centre mark is made. The piston is then moved until the centre mark on the piston rod lines up with the gland face and the piston will now be centered. The other piston is then centered in a similar manner.

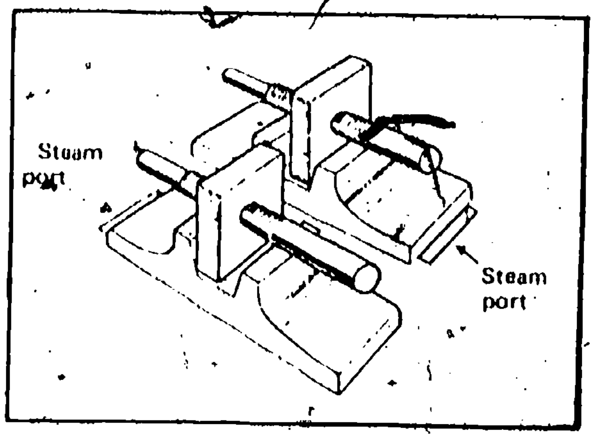
3. Set the slide valves in the centre of their travel. This is done by removing the steam chest cover and moving each valve so that the valve ends just cover the steam ports. With the valve in this position, the valve rod nut must be exactly half way between the valve horns. This can be checked by sliding the valve in one direction until it strikes the nut and then measuring the amount of port opening. Then slide the valve in the other direction until it strikes the nut and measure the amount of port opening at the other end. Fig. 12 illustrates this procedure. When the port openings are equal, the valve is correctly set. If the port openings are unequal, then the valve rod should be unlinked and screwed into or out of the valve rod nut as required.

4. Before replacing valve chest cover move each valve to give a port opening to steam at opposite ends so that the pump will be able to start. See Fig. 13.



Measuring Steam Port Openings

Fig. 12

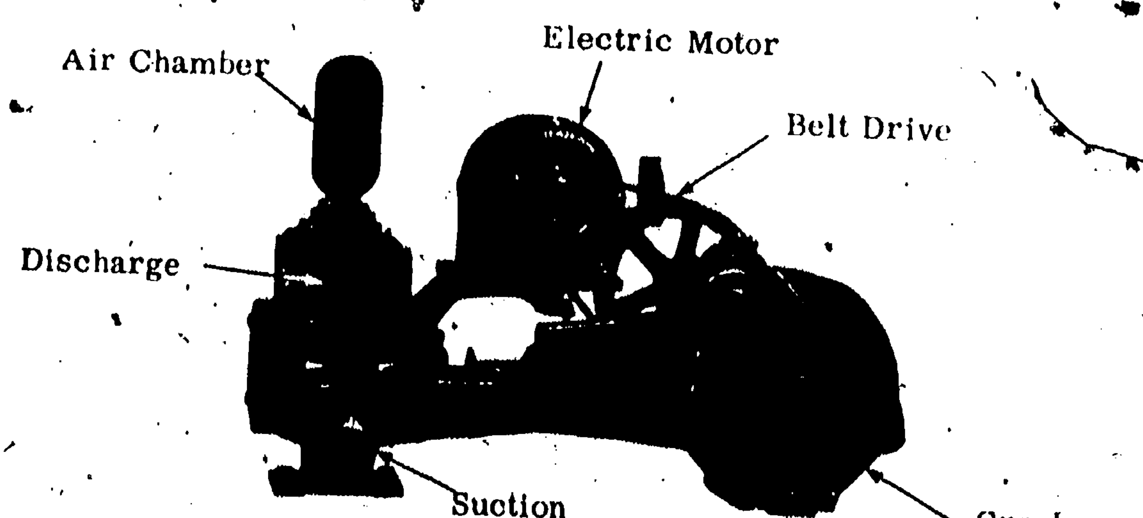


Opening Steam Ports before Starting

Fig. 13

(b) Power Driven Piston Pump

A power driven, double-acting reciprocating piston pump is shown in Fig. 14. The pumping end is similar to that of a steam-driven pump but the piston is moved back and forth by a crankshaft. Power is supplied to the low-speed crankshaft by an electric motor via a V-belt drive and a reducing gear.



Power Driven Piston Pump

Fig. 14

(PE3-3-6-14)

When a piston of a reciprocating pump stops and reverses at the end of each stroke, there is a momentary interruption of the liquid flow which causes a pressure drop in the discharge line. To dampen pressure fluctuations, the pump is often equipped with an air chamber (Fig. 14). This chamber contains air pressurized by the liquid in the discharge line. When the liquid is discharged from the pump, the pressure in the line tends to increase and some liquid is forced into the chamber, increasing the pressure of the trapped air. When the pump stops at the end of the stroke, the discharge stops momentarily and the discharge pressure drops off. The compressed air then forces the liquid out of the chamber and so maintains the flow and dampens the pressure fluctuation.

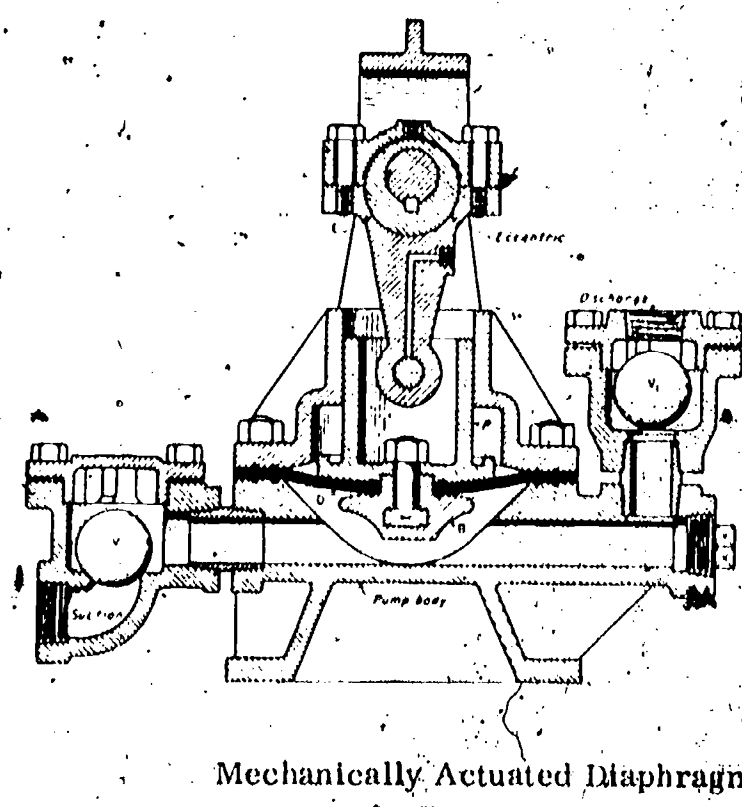
Air chambers are commonly used on single-piston pumps, they are not required on multi-piston pumps because these pumps are designed in such a way that the pistons do not reach the end of their stroke at the same time so that the flow is never completely stopped and pressure fluctuations are much smaller.

3. Diaphragm Pump

The diaphragm pump differs from the piston or plunger type reciprocating pump in that the fluid being pumped is completely isolated by the diaphragm from the reciprocating mechanism thereby eliminating leakage along piston rod and plunger.

The diaphragm is a flexible membrane which acts as the liquid displacing component. The diaphragm can be made of flexible metal or non-metallic materials such as plastic, rubber or neoprene, depending on the fluid being pumped.

A cross-sectional view of a mechanically actuated diaphragm pump is shown in Fig. 15. The diaphragm D is attached to the piston guide P by the disc B. An eccentric is used to produce reciprocating motion of the guide P, causing the diaphragm to move to and fro, resulting in pumping action.



Mechanically Actuated Diaphragm Pump
Fig. 15

(PE3-3-6-15)

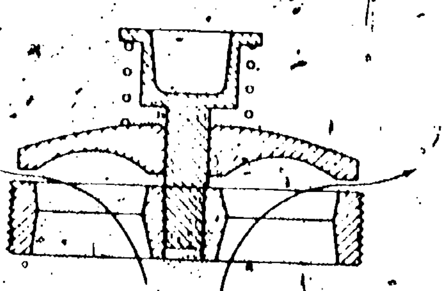
The amount of liquid pumped per stroke by a reciprocating pump is determined by the area of the piston, plunger or diaphragm and the length of the stroke, or in other words, by the volume displaced per stroke. This amount remains constant regardless of discharge pressure. For this reason, the reciprocating pump is classified as a positive displacement pump. The pump capacity depends on the number of pumping strokes per minute.

Reciprocating Pump Components

1. Pump Valves

Valves used for the liquid end of reciprocating pumps are opened and closed by the pressure difference of the liquid above and below the disc caused by the pumping action.

There are many different designs of valves. Generally, the type of valve to be used in a pump is determined by the operating pressure-low, medium or high and the properties of the liquid handled, such as viscosity, temperature, clear or containing suspended solids. The valves can be stem-guided, generally used for low-pressure service, or wing-guided, used for moderate or high pressures. The face of the valve can be flat or beveled. Some of the valve designs are shown in Figs. 15 to 18.



Stem-Guided Disc Valve

Fig. 16

Flat Disc Valve with Inclined Ribs

Fig. 17

Fig. 16 shows a stem-guided disc valve with flat face. The disc seat and stem are usually made of bronze, but other alloys may be used. The valve is suitable for hot and cold water service at moderate pressures.

(PE3-3-6-16)

Fig. 17 shows a flat disc valve with synthetic insert. The seat has inclined ribs which direct the liquid so that it rotates the disc slightly at each stroke, equalizing wear on the disc.

A wing-guided valve with beveled face used for high pressure clear liquids is shown in Fig. 18.

Ball valves are used where free opening of suction and discharge is required, Fig. 15.

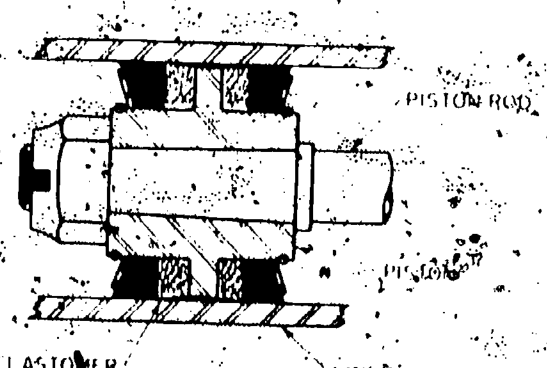
2. Piston and Rod Packing

To prevent leakage between the piston and cylinder wall, the steam piston is usually equipped with cast iron rings fitted in grooves machined in the perimeter of the piston. The water piston is usually sealed in the cylinder by square hard fibrous rings, or by rings made of a softer pliable material such as duck packing (asbestos core with canvas outer layer), Fig. 9. Two other means of sealing are shown in Fig. 19. A shows a piston fitted with moulded cup packing. The cup is made of rubber reinforced with fabric. B shows a piston equipped with rings made of solid rubber and reinforced elastomer.

Wing-Guided Valve

Fig. 18

(A)



(B)

Packing for Pump Pistons

Fig. 19

(PE3-3-6-17)

3. Relief Valves

When a power driven reciprocating pump is started accidentally with the discharge valve closed, or a valve in the discharge line is closed inadvertently during operation, the pump pressure will build up excessively and rupture of pump parts or piping could occur. To safeguard the pump against possible damage due to over pressure, it must be equipped with a relief valve mounted on the discharge of the pump ahead of the first stop valve.

A relief valve is not necessary on the discharge of direct-acting steam driven pumps because, with the discharge valve closed, the pressure in the water cylinder can only build up a limited amount. Once the force on the water piston equals the force acting on the steam piston, the pump simply stops.

Rotary Pumps

The name " rotary pump " is given to those pumps which consist of a closed casing in which gears, lobes, vanes or screws rotate with a minimum of clearance. These rotating parts trap the liquid and push it around the casing from suction to discharge. Unlike in the reciprocating pump, the flow of the liquid through the rotary pump is continuous and the discharge is smooth without pressure fluctuations.

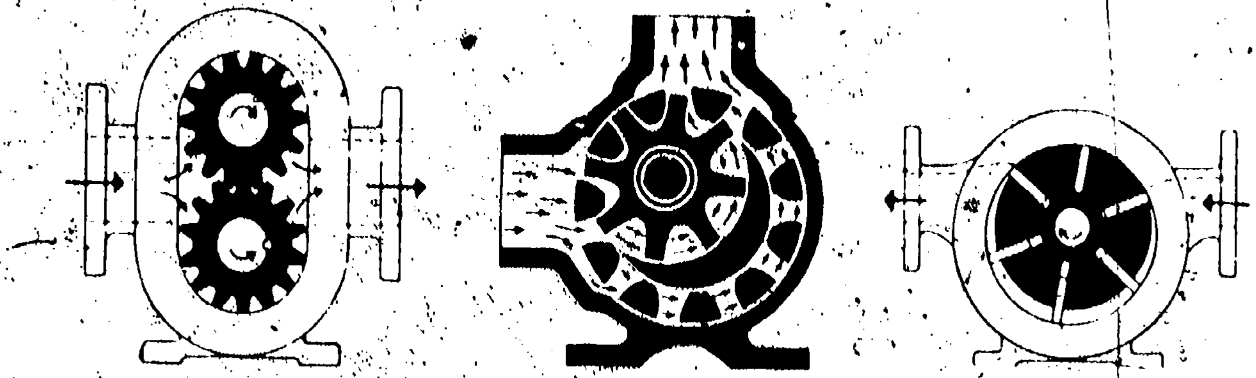
Rotary pumps are used for fuel, lubricating and hydraulic oil systems but also for many other liquids of various viscosities such as liquefied gases (propane, butane, ammonia, Freon, etc.).

Rotary pumps are available in many different designs. Five common types are shown in Fig. 20 and a description of these pumps is given below.

The external gear pump (a) has two gears which rotate in opposite directions inside the casing. Liquid drawn in through the inlet is trapped between the teeth of the gears and the casing wall and is carried to the discharge side. The meshing teeth in the centre act as a valve preventing liquid from flowing back to the inlet side.

The internal gear pump (b) has an externally-cut gear which meshes with an internally-cut gear on one side and is separated from this gear on the other side by a crescent-shaped partition which prevents liquid from passing back from discharge to suction side. Liquid from the suction fills the spaces between the teeth of both gears when they unmesh and it is forced out of these spaces into the discharge when the gears mesh again.

(PE3-3-6-18)



(d)
Three-Lobe

(e)
Two Screw

Rotary Pumps

Fig. 20

The sliding-vane pump (c) has a rotor containing vanes within slots. The rotor is mounted off-centre in the casing with minimal clearance on one side. The vanes are forced out against the casing wall by the centrifugal force and the liquid trapped between the vanes is carried around from suction to the discharge.

The three-lobe pump (d) has two rotors each with three lobes. The rotors are driven by external gears which synchronize the lobes. The liquid trapped in the pockets formed by the lobes and the casing is carried to the discharge.

The two-screw pump (e) has two rotors each with two opposing spirals or screw threads. The liquid is carried between the screw threads of the rotors and is forced axially towards the discharge as the screws rotate and mesh.

Rotary pumps are positive displacement pumps and, therefore, should be protected against excessive pressures by a relief valve on the discharge side of the pump.

Centrifugal Pumps

A centrifugal pump may be defined as a pump which uses centrifugal force to impart energy to a fluid by giving the fluid high velocity and then converting this velocity into pressure.

Because there are many different designs of centrifugal pumps, they can be divided into a number of types according to specific characteristics. The main division according to the method of imparting energy to the fluid gives us the following types: volute, diffuser, mixed flow, axial flow and regenerative.

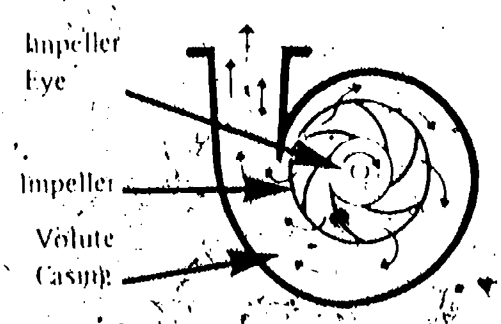
They can also be divided according to the:

number of stages - single or multi-stage
suction inlet - single or double suction
position of shaft - horizontal or vertical
type of casing - horizontal or vertical split
mounting - in-line or base-mounted

Centrifugal pumps can also be classified according to the application such as: boiler feed pump, general purpose pump, vacuum pump, circulating pump, etc. Each application requires a different design of pump.

1. Volute Pump

Basically, the volute centrifugal pump consists of an impeller made up of a number of vanes, which rotates in a volute stationary casing, Fig. 21. The term "volute" refers to the gradually increasing cross-sectional area of the spiral casing.

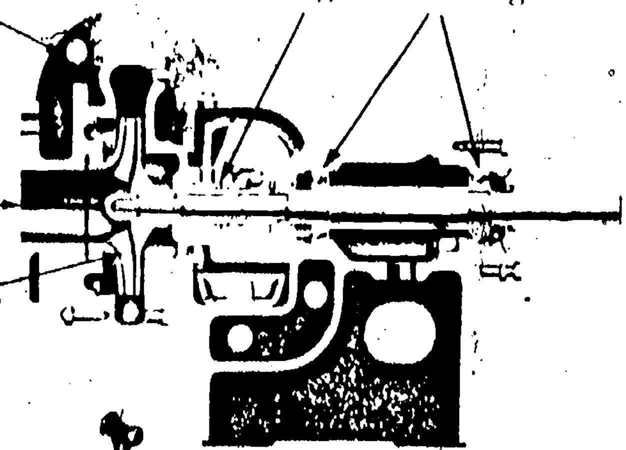


Volute Centrifugal Pump

Fig. 21

(PE3-3-6-20)

The liquid being pumped is drawn into the centre or eye of the impeller. It is picked up by the vanes and accelerated to a high velocity and discharged into the casing by centrifugal force. As the liquid travels through the volute casing to the discharge, its velocity energy is converted into pressure energy. Since the liquid between the vanes is forced outward, a low pressure area is created in the eye and more liquid is drawn in through the suction inlet. As a result, the flow of liquid through the pump is constant. A cross-sectional view of the volute pump is shown in Fig. 22.



Single-stage, Single-inlet Volute Pump
(Goulds Pump Inc.)

Fig. 22

2. Diffuser Pump

In the diffuser centrifugal pump, the high velocity liquid leaving the impeller passes between a number of vanes in a stationary diffuser ring. These vanes are shaped in such a way that the channels between them gradually increase in area, Fig. 23. As the liquid passes through these channels, its velocity energy is converted into pressure energy. The liquid is then discharged either into a concentric casing (A) or into a volute casing (B) where further velocity-pressure conversion takes place.

Since the flow of liquid in volute and diffuser pumps is away from the centre, these pumps are often classified as radial flow centrifugal pumps.

(PE3-3-6-21)

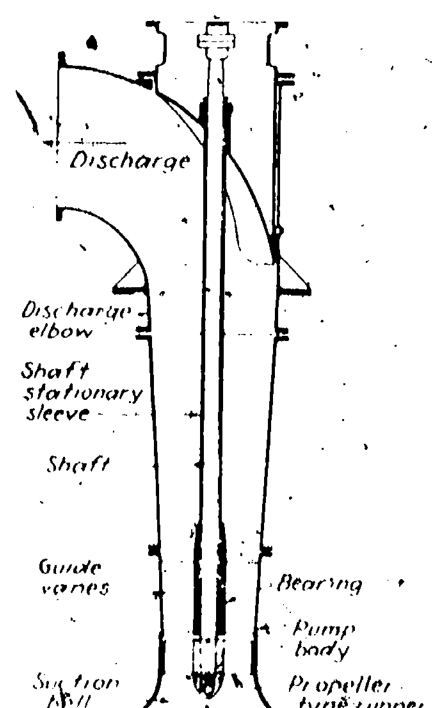
Diffuser Pumps

Fig. 23

3. Axial Flow Pump

The axial flow pump, Fig. 24, often called propeller pump, uses an impeller with vanes similar to a ship's propeller. The pump develops its head by the propelling or ~~lifting~~ action of the vanes on the liquid and the flow of the liquid is through the casing, thus parallel to the shaft. It is usually of vertical design but horizontal units are available.

As compared to a radial flow pump, the axial pump has a low suction lift and develops a relatively low discharge head but a large flow capacity.

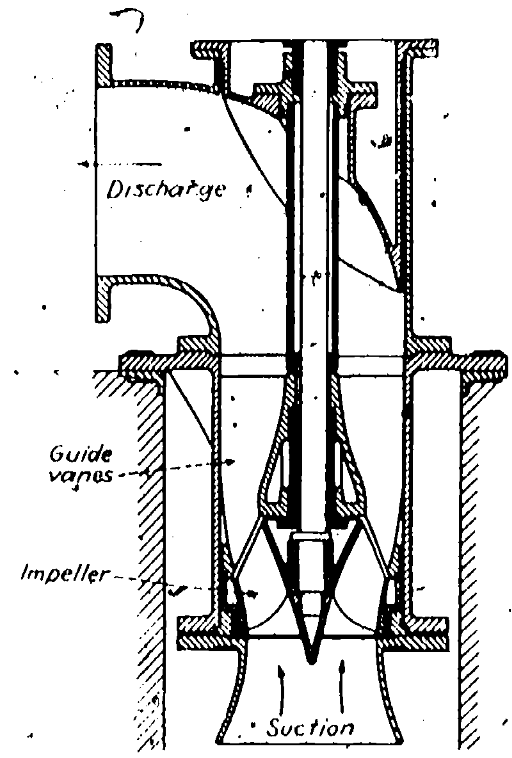


Vertical Axial Flow Pump

Fig. 24

4. Mixed Flow Pump

The mixed flow pump, Fig. 25 combines some of the characteristics of the radial flow and axial flow pumps. It develops its discharge head by using both centrifugal force and lift of the vanes on the liquid. The pump is built for vertical and horizontal applications, and it is commonly used for low head, high capacity operation.

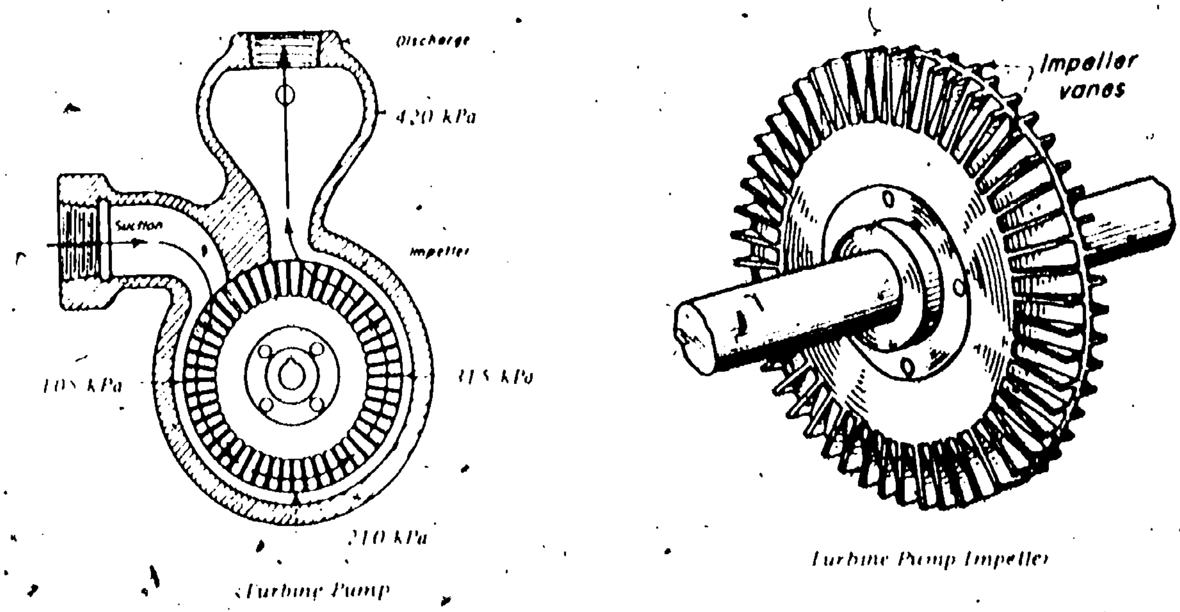


Mixed Flow Pump

Fig. 25

5. Turbine (Regenerative) Pump

The turbine or regenerative pump has an impeller which has a double row of vanes cut in the rim. It is mounted concentrically in the pump casing, Fig. 26.



Turbine Pump Casing and Impeller

Fig. 26

(PE3-3-6-23)

The liquid being pumped enters the periphery of the impeller and travels almost 360^{o} around the casing to the discharge. The impeller vanes travel in a channel machined in the casing and as the impeller rotates, the liquid is given forward motion. As the liquid speeds up, it is thrown into the channel by centrifugal force but, due to the shape of the channel, the liquid is returned again between the vanes, Fig. 27. This process is repeated several times and, as a result, the liquid follows a spiral like path around the periphery of the casing. Each time the liquid enters the vanes, it receives an impulse, this series of impulses causes the pressure to increase gradually from suction to discharge.

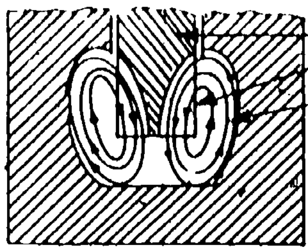
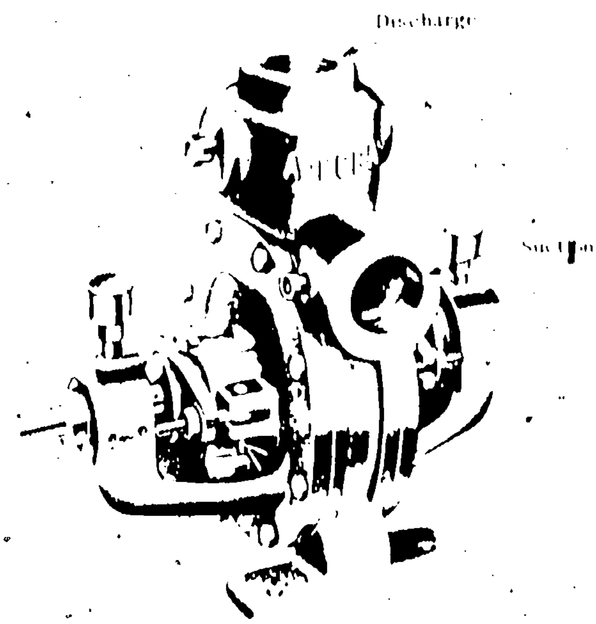


Fig. 27

The turbine pump can develop several times the discharge pressure of a centrifugal pump having the same impeller diameter and speed. A relief valve should be installed on the discharge as excessive pressure can be developed if the pump is operated against a closed discharge.

Turbine pumps are best suited for low capacity, high pressure service. They are often used as boiler feedwater pumps for small boilers, condensate return pumps, hot water circulating pumps, etc.

An outside view of a turbine pump is shown in Fig. 28.



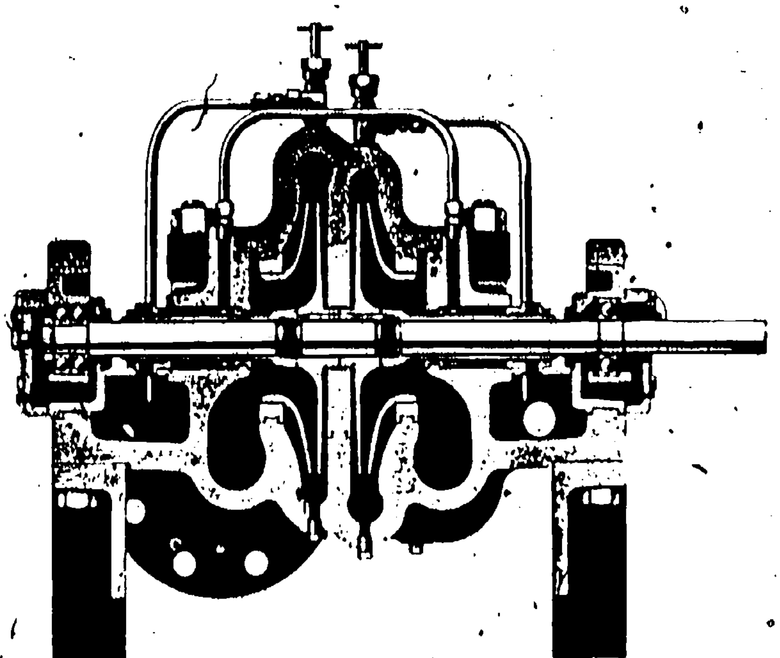
Turbine Pump
(Aurora Pump Division)

Fig. 28

(PE3-3-6-24)

6. Multi-Stage Pumps

The pressure developed by a centrifugal pump with a single impeller is usually limited to about 1000 kPa. Boiler feedwater pumps, however, are usually required to develop much higher discharge pressures. To obtain these higher pressures, centrifugal pumps are equipped with two or more impellers operating in series, that is, the discharge of one impeller is connected to the suction of the next impeller. These pumps are known as multi-stage pumps.

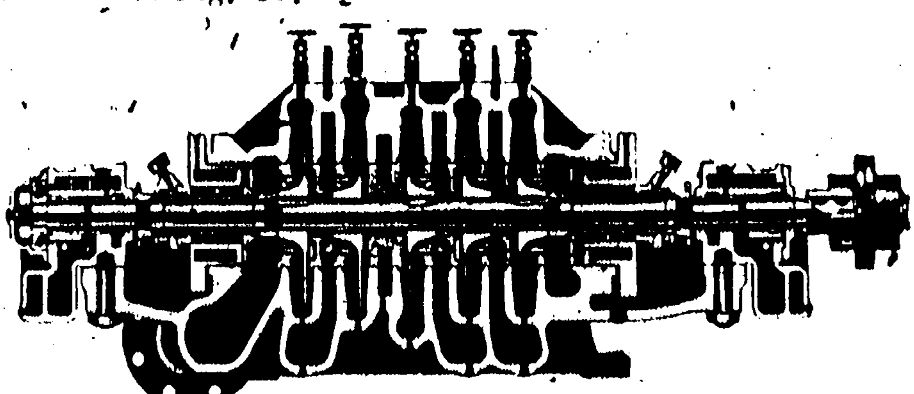


Two-stage Volute Pump with Opposed Impellers (Goulds Pump Inc.)

Fig. 29

Fig. 29 shows a cross-sectional view of a two-stage volute pump. The suction of the first stage is on the left. Liquid discharged from this stage is discharged through a volute into the suction of the high pressure impeller on the right. This impeller delivers the liquid through a second volute to the discharge outlet.

A cross-sectional view of a five-stage volute pump for heavy duty service is shown in Fig. 30.



Five-stage Volute Pump with Opposed Impellers

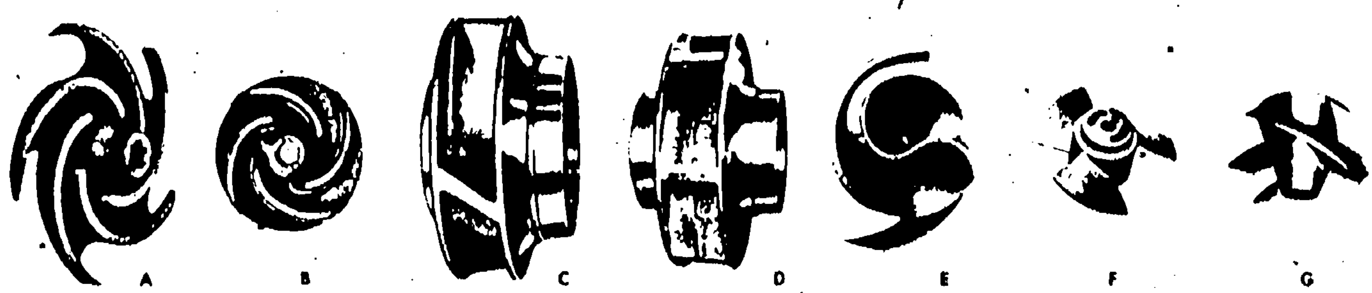
Fig. 30

(PE3-3-6-25)

CONSTRUCTION DETAILS OF CENTRIFUGAL PUMPS

Impeller Types

Impellers vary considerably in design. They can be classified according to specific speed, the way the liquid is drawn into the eye, vane design and pump application. Some common designs are illustrated in Fig. 31.



Impeller Designs

Fig. 31

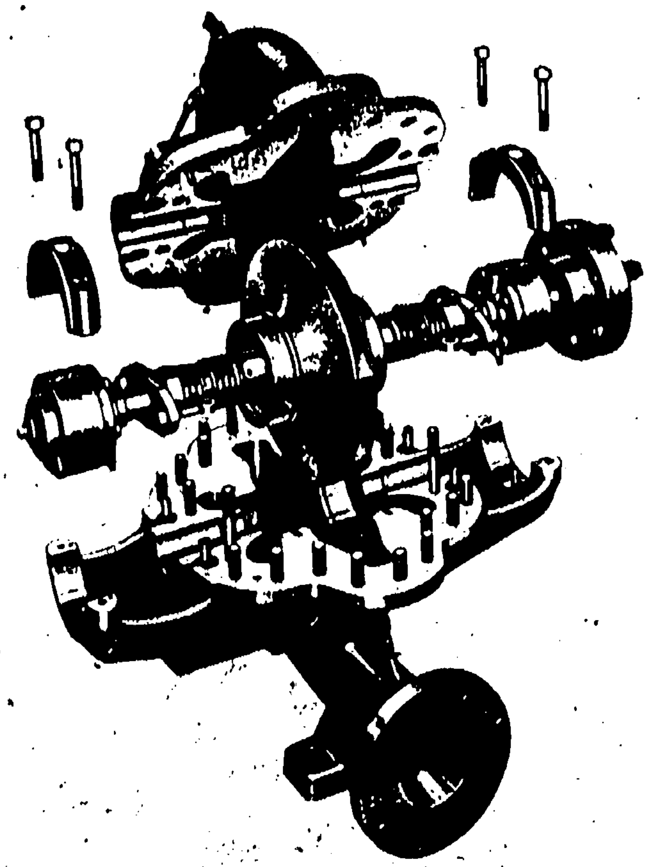
The open impeller, A, has vanes attached to a central hub with a relatively small shroud on one side. It is of end suction or single inlet design, thus the water enters the eye from one side only. B shows a semi-closed, single inlet impeller. A full shroud closes off one side. An enclosed, single inlet impeller is shown in C. The liquid passages between the vanes are closed off by the shrouds on both sides. Impeller D is also enclosed but it has a double inlet, thus water enters the eye from both sides. Design E is used in paper-stock pumps handling liquids containing solids. Impeller F is used in mixed-flow pumps while G is a propeller type impeller.

Pump Casings

Centrifugal pump casings may be split horizontally, vertically or diagonally. A horizontally split casing, also called axially split casing, is shown in Fig. 32. The suction and discharge nozzles are usually in the lower half of the casing. The upper half can be easily lifted for inspection.

A pump with vertically split casing, also called radially split, is shown in Fig. 22. It is used for pumps with end suction.

For multi-stage pumps of the volute or diffuser type with discharge pressures above 10 000 kPa barrel casings are used to avoid the difficulty in maintaining a tight joint between the halves of a horizontally split casing and the sections of radially split casings.

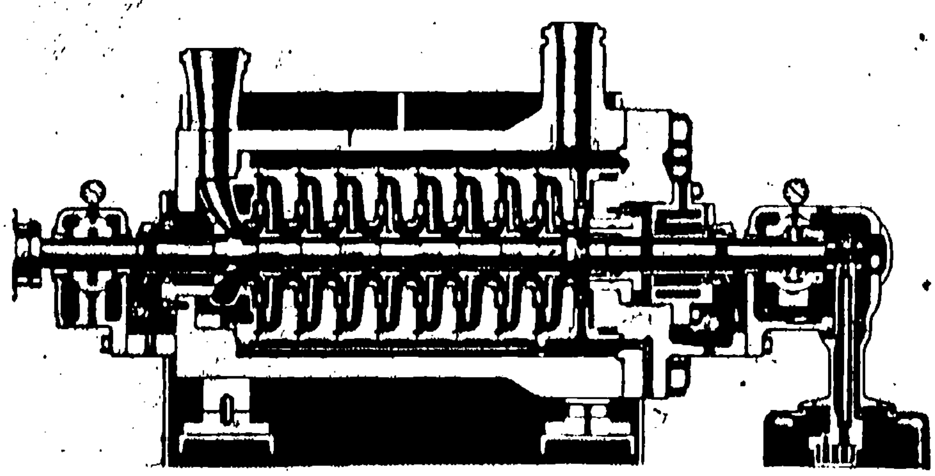


Volute Pump with Double-inlet Impeller

Fig. 32

The barrel casing consists of an inner casing fitted in an outer casing. The space between the two casings is subjected to discharge pressure which tends to hold the sections of the inner casing together. The inner casing may be made up of two halves, horizontally joined, or a number of sections with circumferential joints. The outer casing, the barrel, has no horizontal joints. It is closed by heads on either end.

A cross-sectional view of a barrel type boiler feed pump is shown in Fig. 33. The inner casing is made up of circumferentially joined ring sections. It is fitted into the outer casing through one end which is then closed by a head.

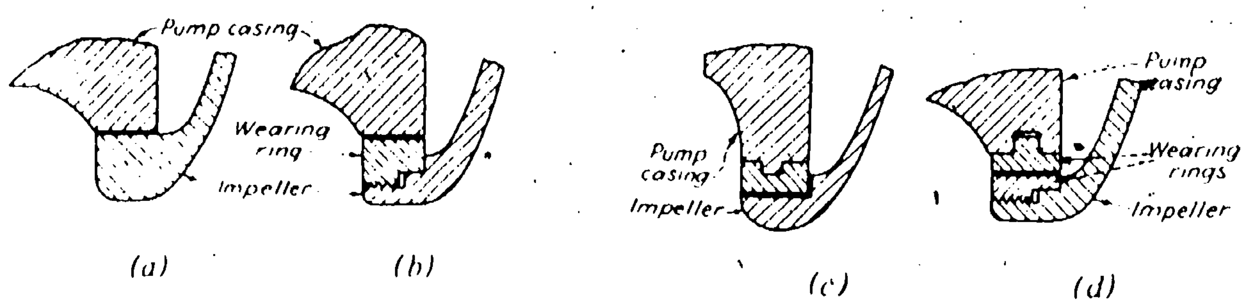


High Pressure 9-Stage Barrel Type Feed Pump - Fig. 33

Wearing Rings

The rotating impeller of the centrifugal pump must be sealed in the stationary casing with a minimum of clearance in order to keep leakage from discharge to suction as small as possible. This seal is provided by the flat joint formed by the rim around the impeller eye and a matching flat circular surface in the casing, Fig. 34 (a). However, during operation, the continuous leakage of the liquid through the joint will slowly wear away the surfaces of this joint and pump efficiency will drop off. When the clearance becomes too large, restoration of original clearance will be necessary, either by building up the worn surfaces or by replacing casing and impeller. This, however, will be quite costly for all but the smallest of pumps.

The cost of restoration can be considerably reduced by installation of wearing rings on impeller, in casing or both. The rings are renewable and can be replaced at a relatively low cost.



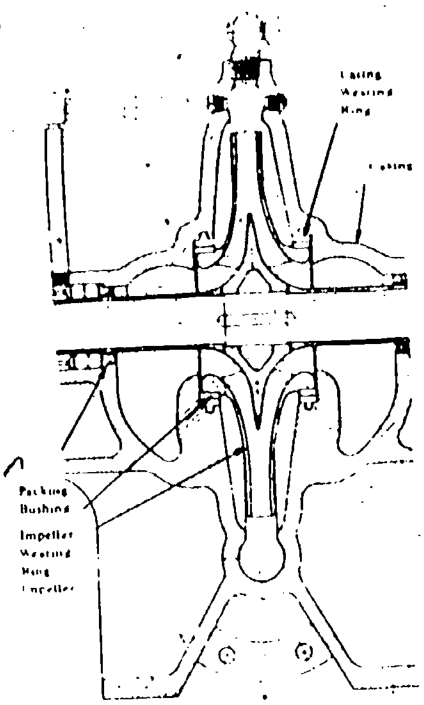
Wearing Rings

Fig. 34

When a wearing ring is mounted only on the impeller, Fig. 34 (b), it is made of a softer material than that of the casing so that practically all wear is on the ring. Similarly, when a ring is mounted in the casing only (c), its material will be softer than that of the impeller. Most larger pumps are equipped with wearing rings on the impeller as well as in the casing (d). A cross-sectional view of a centrifugal pump with double inlet impeller having wearing rings on impeller and in casing, is shown in Fig. 35.

Wearing rings are often made of bronze or cast iron since these materials tend to wear in a smooth manner.

They are installed on the rim of the impeller by either threading or shrinking and set screws are used to prevent them from working loose. Casing wearing rings consist of either a continuous ring used in vertically split casings, or of two half rings for horizontally split ridge or into a groove of the casing which the ring work loose.



Pump Shaft Sealing

In order to minimize leakage a round the pump shaft where it passes through the casing, the following means are used:

1. Stuffing boxes
2. Mechanical seals

1. Stuffing Boxes

A stuffing box consists of a cylindrical recess around the shaft that holds a number of rings of packing, which provide a seal between the casing and shaft. The packing is held in place by a gland that can be adjusted to compress the rings in order to obtain the desired fit by tightening the adjusting nuts. The bottom or inside end of the stuffing box may be formed by either the pump casing itself or by a bottom bushing. The basic construction of a stuffing box holding five rings of packing is shown in Fig. 36.

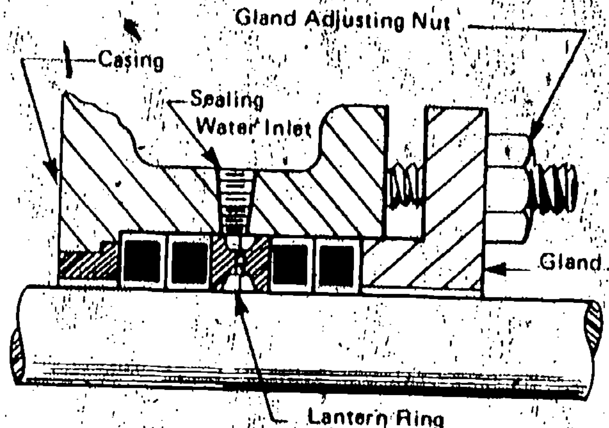
(PE3-3-6-29)

Wearing Rings

The rotating impeller of the cent stationary casing with a minimum of clea discharge to suction as small as possible formed by the rim around the impeller ey the casing, Fig. 34 (a). However, dur the liquid through the joint will slowly we pump efficiency will drop off. When the of original clearance will be necessary, or by replacing casing and impeller. Th but the smallest of pumps.

The cost of restoration can be wearing rings on impeller, in casing or relatively low cost.

Fig. 36



Stuffing Box with Lantern Ring

Fig. 37

Packing rings are made of pliable, yet durable materials such as woven asbestos, nylon , flax or teflon. Metals such as lead, copper or aluminum are also used, in which case they are wound as a foil around an asbestos or plastic core. The packing is usually impregnated with a lubricant which makes the packing self-lubricating during the startup period. Packing is supplied in continuous coils of square cross-section, or in preformed die-molded rings.

Packing in stuffing boxes should never be compressed so tightly that leakage is completely stopped. The resulting friction would cause excessive heat build-up, the packing would burn up and the shaft could be severely damaged by scoring. Instead, a slight leakage of liquid should be allowed to provide lubrication between packing and shaft.

When a pump operates with a negative suction pressure, a fully-packed stuffing box as in Fig. 36 will not provide proper sealing since air would be drawn into the casing along the shaft stopping the required leakage of liquid. To provide proper sealing, the stuffing box is then fitted with a lantern ring and a sealing water connection as shown in Fig. 37.

The lantern ring (also called seal cage) is a metal ring with channels machined in its inside and outside perimeter, connected by radially drilled holes. It serves to distribute sealing liquid under pressure to the packing thus preventing air infiltration and providing lubrication. This sealing liquid is usually provided by the high pressure section of the pump casing, either through an external connection, Fig. 38, or through an internally drilled passage in the casing.

(PE3-3-6-30)

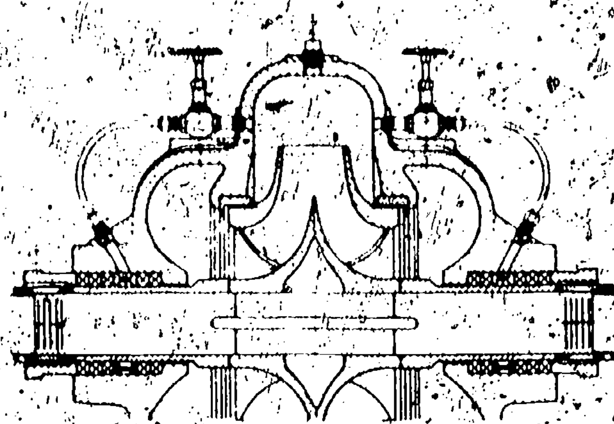


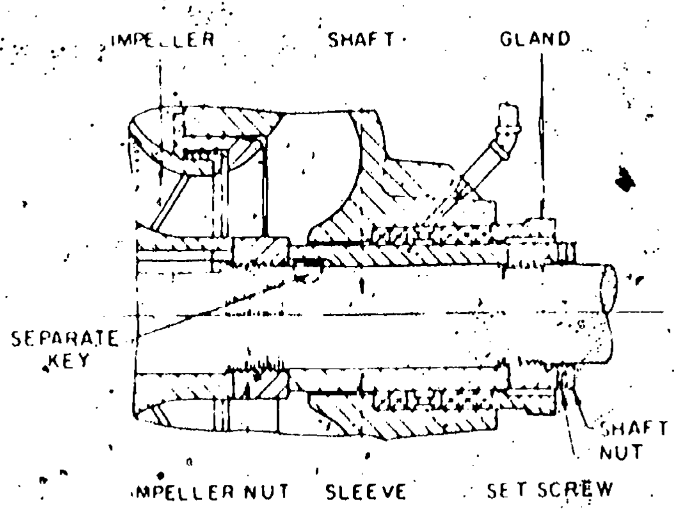
Fig. 38

Lantern rings are also used on pumps handling liquids containing sand, grit or other abrasives which could damage the shaft and shorten the life of the packing when allowed to enter the stuffing box. Clean sealing liquid provided by a separate source or by the discharge side of the pump via a filter or separator will then keep the gritty substances out of the stuffing box.

(a) Shaft Sleeves

Shafts are subjected to corrosion, erosion and wear at the stuffing boxes which will affect their strength and make effective sealing with packing rings difficult.

Shafts of smaller pumps are usually made of corrosion and wear-resistant materials for longer life. Larger pump shafts, however, are usually protected by renewable sleeves, as shown in Fig. 39. The sleeve is secured on the shaft by the shaft nut and sleeve rotation is prevented by a key.



Shaft Sleeve

Fig. 39

(b) Replacing Pump Packing

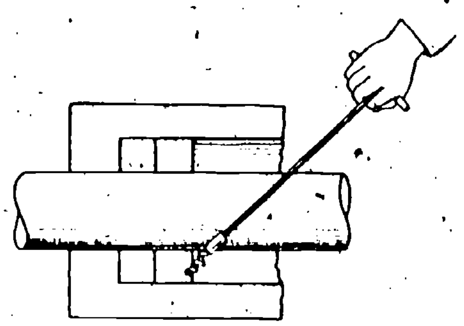
Pump packing has to be replaced periodically due to deterioration from wear and loss of saturant. The frequency of packing replacement will depend on operating conditions, quality of packing, and the care with which the packing was installed and adjusted. It may vary from three to six months in case of severe

(PE3-3-6-31)

operating conditions to several years under more moderate conditions. The procedure recommended for replacement of the packing is briefly described below.

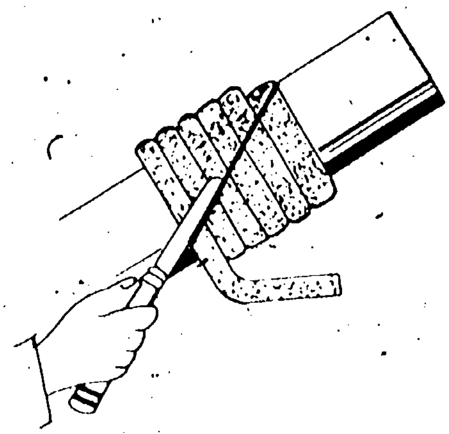
1. Shut down, isolate and drain pump. If pump is electrically driven, lock open motor switch and put warning tag on switch. If steam driven, chainlock steam supply valve and tag.

2. Remove gland adjusting nuts and slide gland away from the stuffing box. Then remove all the old packing using some type of packing puller, Fig. 40. Make sure the stuffing box is thoroughly clean and free of any small pieces of old packing. Check that the sealing water connection to stuffing box is clear.



Removing Packing

Fig. 40



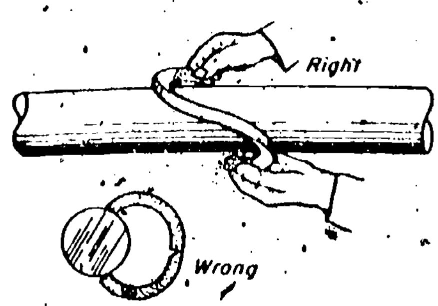
Cutting Packing Rings

Fig. 41

3. Check the condition of the shaft or shaft sleeve. If the surface of the shaft is grooved or scored, it should be resurfaced or the shaft should be replaced. If the surface of the shaft sleeve is damaged, replace the sleeve.

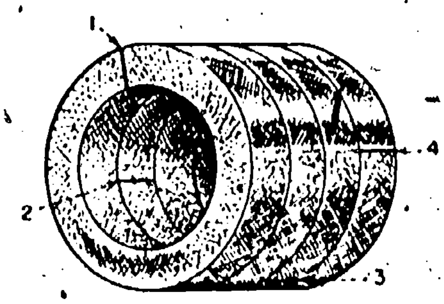
4. Determine the correct size of the packing to be used by subtracting the diameter of the pumpshaft or sleeve from the bore of the stuffing box and dividing the difference by two.

5. Wrap a coil of the correctly sized packing around the pumpshaft or, if not possible, a substitute shaft of the same size, and cut the required number of rings with a diagonal cut as shown in Fig. 41.



Sliding Rings onto Shaft

Fig. 42



Staggering Packing Rings

Fig. 43

6. Install the packing rings one at a time after putting a light coating of oil or grease on the inner diamete made of stiff material, slide them in Fig. 42, to prevent breaking of stuffing box one by one using a spl push each ring into place. Make s Fig. 43, and ensure that the lanter sealing water inlet.

7. Put gland into place and compress the gland nuts. Then slacken them

8. Prime and start up the pump. All some minutes, then gradually tight duced to that necessary for lubrica

The above described procedure of repacking the stuffing box of a pump can be used for a centrifugal pump as well as for a reciprocating pump.

2. Mechanical Seals

Loakage from stuffing boxes is objectionable on pumps handling liquids such as gasoline, acids, ammonia, etc. Instead, these pumps are equipped with mechanical seals which reduce leakage to a minute amount. They are also used on pumps where stuffing boxes cannot offer adequate leak protection such as high pressure pumps.

Basically a mechanical seal consists of two flat rings each with a polished flat sealing surface. The rings are perpendicular to the pumpshaft, the sealing faces rotate on each other. One of the rings is called the sealing ring and it is held in position by a spring. The other ring, its face in contact with that of the sealing ring, is called the mating ring.

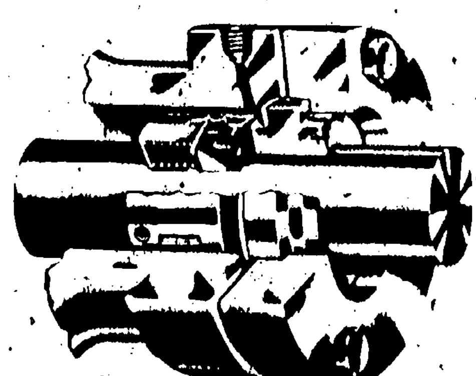
Mechanical seals may be divided into two general types: the rotating seal and the stationary seal.

(a) Rotating Mechanical Seal

The basic design of a rotating seal is illustrated in Fig. 44. The mating ring is held stationary in a recessed part of the pump housing or the seal housing cover. An "O" ring provides a seal between ring and casing to prevent leakage. A shell secured to the shaft by set screws holds the sealing ring so that it turns with the shaft. Leakage between shaft and sealing ring is prevented by a second "O" ring. As the pump shaft turns, the sealing ring is held against the mating ring by a number of small springs contained in the shell, thus preventing leakage between the faces. The springs allow the sealing ring enough flexibility to maintain full face contact with the mating ring at a constant pressure during slight shifts in shaft position.

Fig. 44

A cut-away view of a rotating mechanical seal is shown in Fig. 45. In this seal, leakage between sealing ring and shaft is prevented by a teflon wedge ring; between mating ring and seal housing cover by a flat teflon ring. The seal housing is provided with a quenching liquid inlet required on pumps operating with a negative suction pressure. The liquid supplied to the seal prevents air infiltration and provides lubrication and cooling. If the liquid pumped is clear, the quenching liquid can be drawn directly from the pump discharge but if the liquid contains particles of foreign matter, a separator should be installed in the quenching line.



Rotating Seal
(John Crane Co.)

Fig. 45

(PE3-3-6-34)

(b) Stationary Mechanical Seal

In this type of seal, the shell containing the springs and sealing ring is held stationary in the annular space of the pump housing as sketched in Fig. 46. The mating ring is fastened rigidly to the shaft, usually against a shoulder, so that it rotates with the shaft. The springs force the sealing ring against the mating ring so leakage between the faces is prevented. "O" rings are used to prevent leakage between sealing ring and shell and between mating ring and shaft.

The choice of materials used for sealing and mating rings depends on many factors such as type of liquid pumped, temperature, pump speed and seal design. The friction between the faces of these rings should be kept as small as possible. Materials commonly used are bronze, carbon graphite, ceramics, stellite and tungsten carbide.

When a pump is equipped with mechanical seals, the following precautions should be taken before and during operation:

1. Never run the pump unless it is completely filled with liquid.
2. Vent all air out of the seal housings before start up.
3. Make sure an adequate flow of quenching or cooling liquid is flowing to the seals.

It is extremely important that the seals never run in dry condition because this causes the faces to score and become grooved. Dry running seal faces are often indicated by a squealing sound but absence of this sound should not be interpreted as an indication that sufficient liquid is supplied to the seals.

A leaking seal may be caused by:

1. Seal faces that are scored or grooved.
2. Distortion of the rings due to unevenly tightened bolts of the seal housing gland.
3. "O" ring or other type gaskets that are cut or nicked during installation.
4. Misalignment of [illegible]

[illegible]

Pump bearings [illegible]

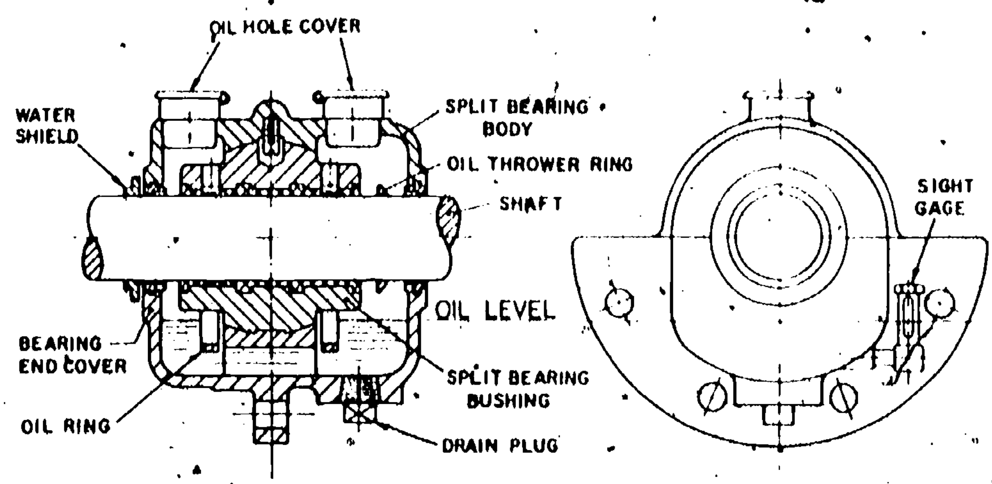
1. Sleeve and shell bearings
2. Ball and roller bearings

1. Sleeve and Shell Bearings

The bearings of small pumps usually consist of bronze bushings or sleeves fitted around the shaft with a small clearance, and held in place by the bearing brackets attached to the casing. On larger pumps the sleeve-type bearing consists of two half-shells made of cast-iron or steel and lined with babbitt, Fig. 47.

This bearing is usually self-aligning so that it adjusts itself automatically to small changes in shaft position.

Sleeve and shell bearings are usually oil-lubricated. On small pumps the oil is supplied to the bearings by drip lubricators. Medium-sized pumps use the lower part of the bearing housing as oil reservoir and the oil is supplied to the bearing by endless chains or rings riding on the shaft, Fig. 47. Large pumps are usually equipped with a shaft-driven oil pump which supplies the bearings with oil under pressure.

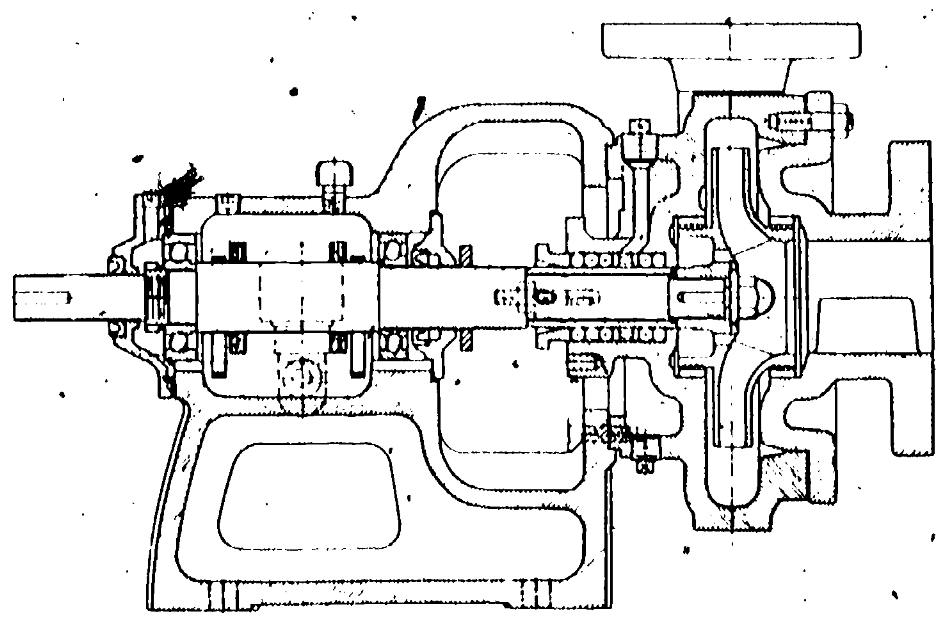


Self-aligning Shell Bearing

Fig. 47

2. Ball and Roller Bearings

Ball and roller bearings, also called anti-friction bearings have replaced sleeve bearings in many modern pump designs. Ball bearin s of single- or double-row design are mostly used on small and medium sized shafts; roller bearings are widely used on larger shafts. Anti-friction bearings may be lubricated either by oil or grease. Fig. 48 shows a single-stage centrifugal pump fitted with oil lubricated, single-row, ball bearings.



Single-stage Centrifugal Pump with Ball Bearings

Fig. 48

Axial Thrust

During operation a single-inlet impeller is subjected to hydraulic forces which create an axial unbalance. This is illustrated in Fig. 49 which shows that the area of the eye of the impeller is subjected to suction pressure while the partial shroud on that side and the full shroud on the opposite side are subjected to discharge pressure. The resulting imbalance causes an axial thrust towards the suction that tends to move the impeller out of its proper position in the casing.

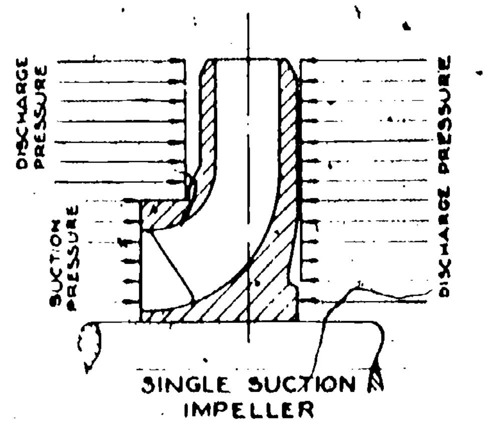


Fig. 49

On low capacity, single-stage pumps, axial movement of the impeller is usually prevented by installation of a thrust bearing on the shaft. On larger capacity, single-stage pumps, however, the axial imbalance is eliminated by one of the following methods:

1. Single-inlet Impeller with backside wearing ring and balancing holes

As shown in Fig. 48, the single-inlet impeller is equipped with a wearing ring on its backside with the same diameter as the one on the suction side. By connecting the space inside this ring to the suction side by means of balancing holes, axial balance is achieved.

2. Double-inlet Impeller

By using a double-inlet impeller the forces on the impeller are theoretically balanced, as shown in Fig. 50. In practice, the flow to each eye is not always equal so a light thrust bearing is still required.

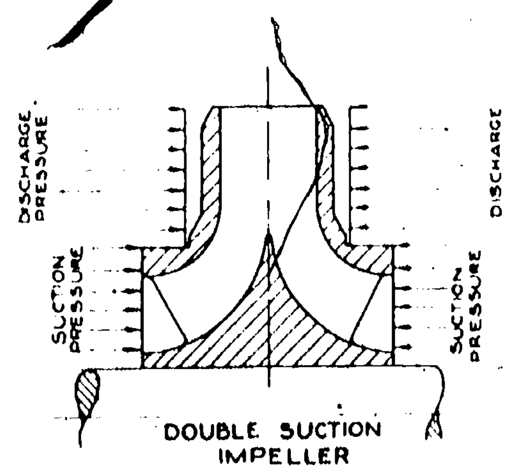


Fig. 50

3. Opposing Single-inlet Impellers

On multi-stage pumps with single-inlet impellers, the axial thrust can be eliminated by the use of opposed impellers. The inlets of one half of the impellers face in one direction, the other half in opposite direction, Fig. 29 and 30. With this arrangement, axial thrust on the first half of the impellers is counter-acted by the opposing axial thrust on the second half.

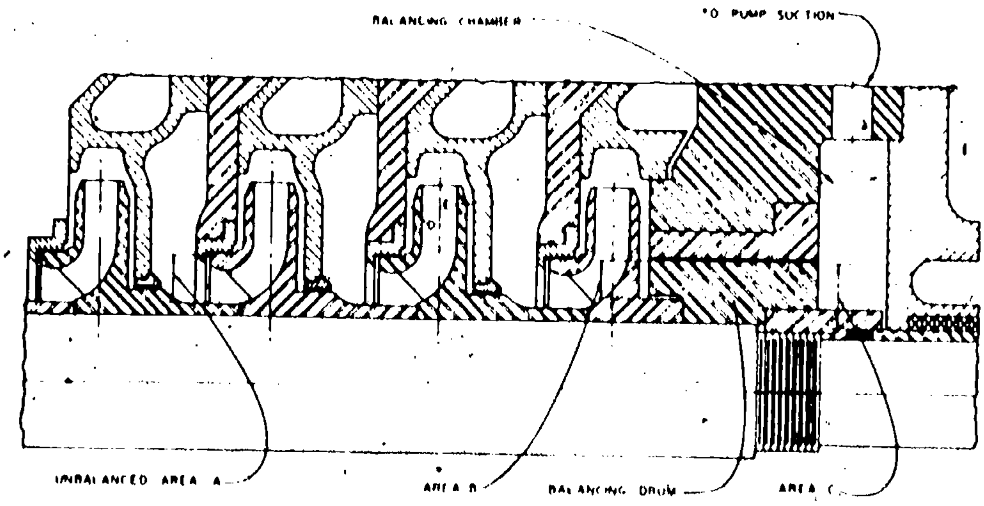
On multi-stage pumps having the single-inlet impellers all facing in one direction, the axial thrust toward the suction end of the pump will be theoretically equal to the sum of the individual impeller thrusts. This total thrust is partially or fully counter-acted by one of the following hydraulic balancing devices: a balancing drum, a balancing disc or a combination of drum and disc.

4. Balancing Drum

A balancing drum, illustrated in Fig. 51, is installed on the shaft between the last impeller and the balancing chamber which is connected to the suction side of the pump. The drum rotates inside the stationary member of the balancing device, the balancing drum head. Drum and head are separated by a small clearance allowing some leakage from the high pressure side of the pump to the low pressure chamber.

Balancing Drum

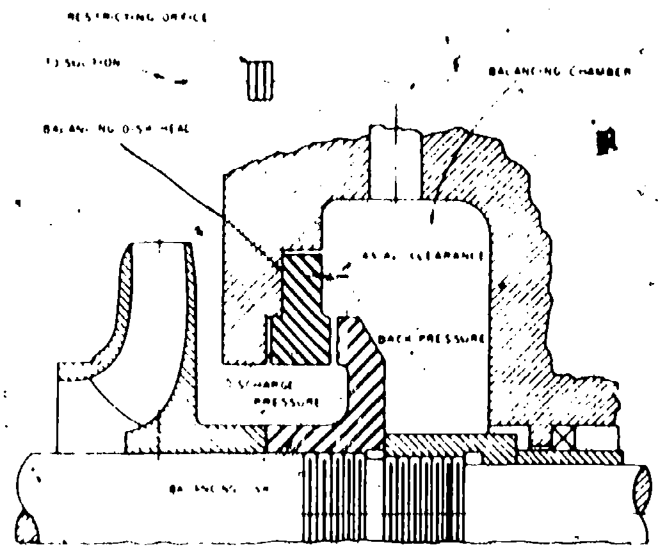
Fig. 51



The drum is subjected to two forces: the discharge pressure acting on area B and the suction pressure acting on area C. Since the first force is greater than the second, an axial thrust is produced toward the discharge side of the pump. This thrust counter-acts the axial thrust exerted on the impellers.

5. Balancing Disc

The simple balancing disc consists of a disc mounted on, and rotating with the shaft. It is separated from the balancing disc head attached to the casing by a small axial clearance. The leakage from the high pressure side of the pump flows through this clearance into the low pressure balancing chamber and from there to the suction of the pump via a restricting orifice that normally keeps the pressure in the balancing chamber well above the suction pressure. A simple balancing disc is shown in Fig. 52.



Simple Balancing Disc

Fig. 52

The back of the disc is subjected to the balancing chamber back pressure while the centre part of the front of the disc is subjected to full discharge pressure and the ring area facing the head, to a pressure gradually dropping from discharge pressure to balancing chamber back pressure. The difference in forces acting on the front and back of the disc produces an axial thrust which balances the axial thrust on the single-inlet impellers. When the thrusts are balanced, the clearance between disc and head will be a specific amount and the back pressure will be maintained at a specific value.

Should, during operation, the axial thrust on the impellers increase and exceed the thrust acting on the disc, the shaft would move slightly over toward the suction side of the pump causing the clearance between disc and head to be reduced. This will reduce the liquid leakage resulting in a drop in back pressure on the disc which, in turn, causes the thrust on the disc to increase so that it moves away from the head, increasing the clearance again. The increased leakage builds up the back pressure again until an equilibrium in thrusts is reached. The opposite will happen when the thrust on the impellers decreases below that on the disc.

While the balancing drum provides only counter-thrust, the balancing disc provides not only counter-thrust but it also restores automatically, the position of shaft and impellers if it changes position due to variations in axial thrust. The use of a simple balancing disc, however, has certain disadvantages and it is therefore seldom used. Most multi-stage pumps are now equipped with a combination of balancing drum, and disc. This combination has all the advantages of both hydraulic devices without any of their disadvantages.

PUMP DRIVES

Pumps may be driven by any type of prime mover. Most pumps in power plants, industrial plants, and commercial buildings are driven by electric motors. Steam turbines are also favored in many plants, but internal combustion engines such as gas turbines and gasoline, natural gas and diesel engines are also used for specific applications.

Electric Motors

The electric motor provides the simplest arrangement for a pump drive. It can be directly connected to centrifugal and rotary pumps while reciprocating pumps usually require some type of speed reduction such as V-belt or gear drive.

The most common type of motor used is the squirrel-cage induction motor. It operates at a nearly constant speed. The synchronous motor is often used for large capacity pumps. This motor also operates at constant speed. Where control of pump output by speed variation is required, a wound rotor induction motor is used. Speed variation over a wide range can be provided by the use of a constant speed motor driving the pump by means of a variable speed fluid or magnetic coupling.

Steam Turbines

Steam turbines are often used to drive centrifugal pumps and occasionally rotary pumps. They are directly connected to the pumps. The use of a steam turbine has the advantages of simple, wide range speed control and the possibility of the economical use of its exhaust steam for process or feedwater heating.

Internal Combustion Engines

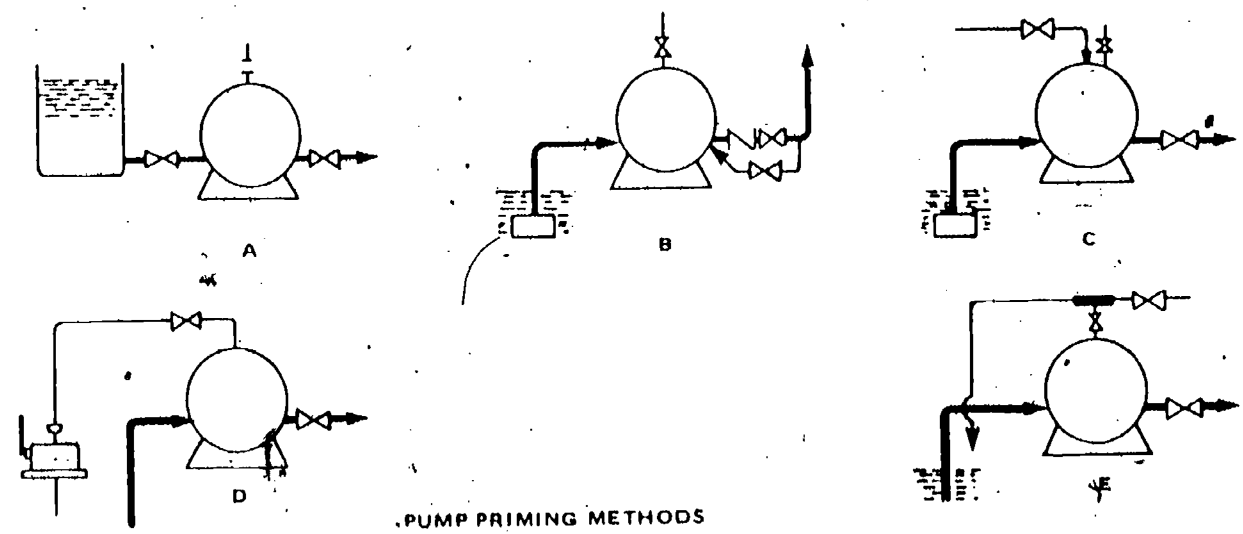
Internal combustion engines are frequently used to drive portable pumps and emergency fire pumps. Gas turbines are seldom used to drive pumps in power and industrial plants, but they are used for special services such as driving the pumps in crude oil pipeline pressure booster stations.

PRIMING OF PUMPS

The term "priming ", as used in connection with pumps, simply means the filling of pump casing and suction line with the liquid to be pumped, before the pump is started.

Positive displacement pumps - reciprocating and rotary are self-priming for total suction lifts up to about 8 metres at sea level when in perfect condition. But with long suction lines, high lifts, or poor mechanical condition, they must be primed.

Centrifugal pumps are not self-priming. They must be primed before start-up otherwise the impeller will simply churn air and no suction will be produced. Also, when the pump is started without proper priming, the mechanical seals will run dry causing the seal faces to score or, if stuffing boxes are used, shaft and packing rings may suffer. Some of the methods used to prime a centrifugal pump are shown in Fig. 53.



PUMP PRIMING METHODS

Fig. 53

During priming of a centrifugal pump, keep the discharge valve closed. When the pump is below the source of supply (pump has suction head), Fig. 53 A, open the air vent petcocks on the pump casing and slowly open the suction valve. The incoming liquid forces the air out of the casing. When the liquid appears through the vents, they can be closed. The pump is then primed and ready to be started.

When the pump is located above the source of supply, (pump has suction lift), various methods of priming can be used. The suction line should be equipped with a foot valve, a flap-type valve attached to the lowest part of the suction line acting as a check valve. The valve allows the liquid to enter the line but prevents it from draining out of the line.

Fig. 53 B shows how the pump can be primed by filling suction line and casing with liquid supplied through a bypass around the discharge valve. Vents are kept open until the liquid escapes. In C, suction line and casing are filled by liquid supplied through an auxiliary line. In D, a separate priming pump is used to draw the air from the casing, creating a vacuum which draws the liquid in through the foot valve. The same can be achieved by the use of an ejector as shown in E.

CAPACITY REGULATION OF PUMPS

Reciprocating and rotary pumps are classified as positive displacement pumps which means that, at a constant speed, they move a specific amount of liquid regardless of pump head. The capacity of these pumps is usually regulated by varying their speed. The capacity of centrifugal pumps, however, changes when the pump head is changed, hence, this pump is not a positive displacement pump. When the head is increased, the capacity of the pump decreases and when the head is lowered, the capacity increases. When the head is increased so much that it exceeds the design head of the pump, the output drops to zero.

The capacity of a centrifugal pump can be regulated by varying the speed but this requires a pump driver capable of varying its speed (steam turbine, internal combustion engine, etc.). Most centrifugal pumps, however, are driven by an electric motor, a constant speed driver.

When driven by an electric motor, the capacity of the most common centrifugal pump-the radial flow type (volute and diffuser pump) can be regulated by adjusting the discharge valve. Throttling the discharge valve increases the flow resistance, thus enlarging the friction head, and the flow will be reduced. The discharge pressure of the pump will increase moderately, but not enough to endanger the pump as with positive displacement pumps. Even with the discharge valve completely closed, the pressure increase will be well within safe limits.

When the flow is throttled, the power requirement of the radial flow centrifugal pump is also reduced notwithstanding the resulting pressure increase. Advantage is taken of this fact by starting large, electrical motor-driven centrifugal pumps with closed discharge. Since the no-flow power requirement is relatively small, excessive power surging during start-up can be avoided.

The power requirement of axial and mixed flow centrifugal pumps, when operated at low capacity, is actually higher than at full capacity. These pumps should always be started with the discharge valve wide open.

Caution

1. Never run a centrifugal pump continuously with the discharge valve completely closed. The mechanical power applied to the impeller is dispelled as friction to the water trapped and churned about in the casing. This friction causes overheating of the water to the point where it turns into steam which may result in damage to the pump.

2. Always operate a centrifugal pump with its suction valve wide open. Never use it for flow control. Throttling or closing of this valve starves the impeller of its water supply, the casing becomes partially empty resulting in excessive vibrations which may ruin the bearings. The lack of liquid may also damage mechanical seals and stuffing boxes.

GENERAL STARTING PROCEDURE FOR CENTRIFUGAL PUMPS

1. Check oil level in bearing housings if pump is equipped for oil lubrication.
2. Turn on cooling water for pump bearings, stuffing boxes and mechanical seals, if these parts are water cooled.
3. Open suction valve and close the discharge valve depending on method to be followed for pump.
4. Close all drains in casing, suction and discharge piping.
5. Prime the pump.

6. Start pump and bring it up to speed.
7. If pump is started with closed discharge valve, open this valve slowly.
8. Check leakage from stuffing boxes.
9. Adjust sealing liquid to stuffing boxes as required.
10. Check oil rings on sleeve bearings. They must turn freely.
11. Check suction and discharge pressures.
12. Feel pump bearings for overheating.

In case of a new pump being started for the first time, or a pump being started after an overhaul, the following items should be checked in addition to the above items:

1. Pump rotor should turn freely.
2. The alignment of pump and driver before pump is started and again after operating temperature is reached.
3. Direction of rotation of driving motor.

General Stopping Procedure

1. Close discharge valve slowly (large radial flow centrifugal pumps).
2. Stop pump driver.
3. Shut off cooling water.
4. Close suction valve.

CODE REQUIREMENTS FOR BOILER FEEDWATER PUMPS

In paragraphs PG 61.1 and PG 61.2 of Section I of the A.S.M.E. Code it is stated that boilers having more than 47 m^2 (500 square feet) of water heating surface shall have at least two means of feeding water, and each source of feeding shall be capable of supplying water to the boiler at a pressure of 3% higher than the highest setting of any safety valve on the boiler. It is also stated, that for boilers with solid fuel not in suspension and boilers whose setting or heat source can continue to supply sufficient heat to cause damage to the boiler if the feed supply is interrupted, one of the means of feeding shall be steam driven. However, boilers fired by gaseous liquid, or solid fuel in suspension may be equipped with a single means of feeding water, provided the heat input can be shut off prior to the water dropping to the lowest permissible water level.

The most common arrangement in power and industrial plants is to use two centrifugal pumps, each capable of supplying the boilers with the full feedwater requirement. While one pump is in operation, the other is kept on stand-by. A basic diagram of a boiler feedwater supply system with two centrifugal pumps in parallel and the necessary piping and valves is shown in Fig. 54.

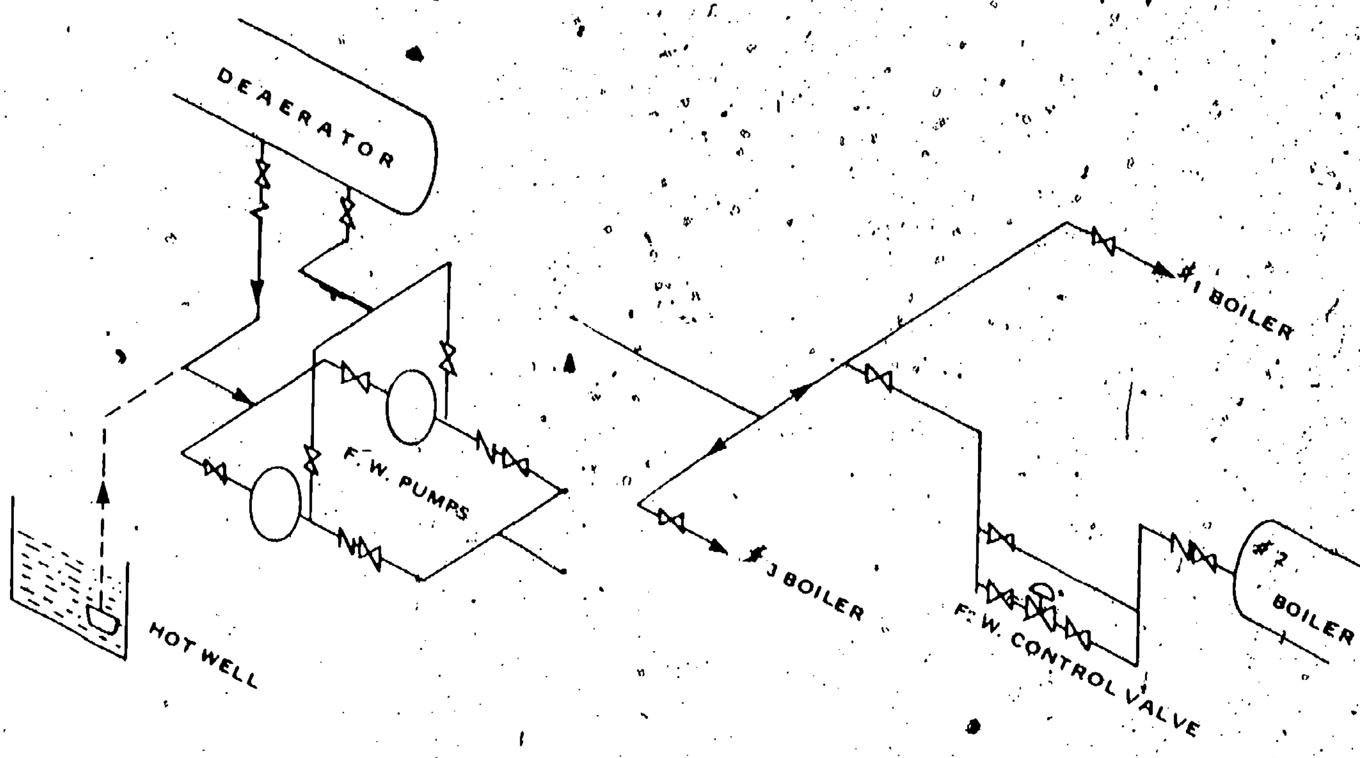
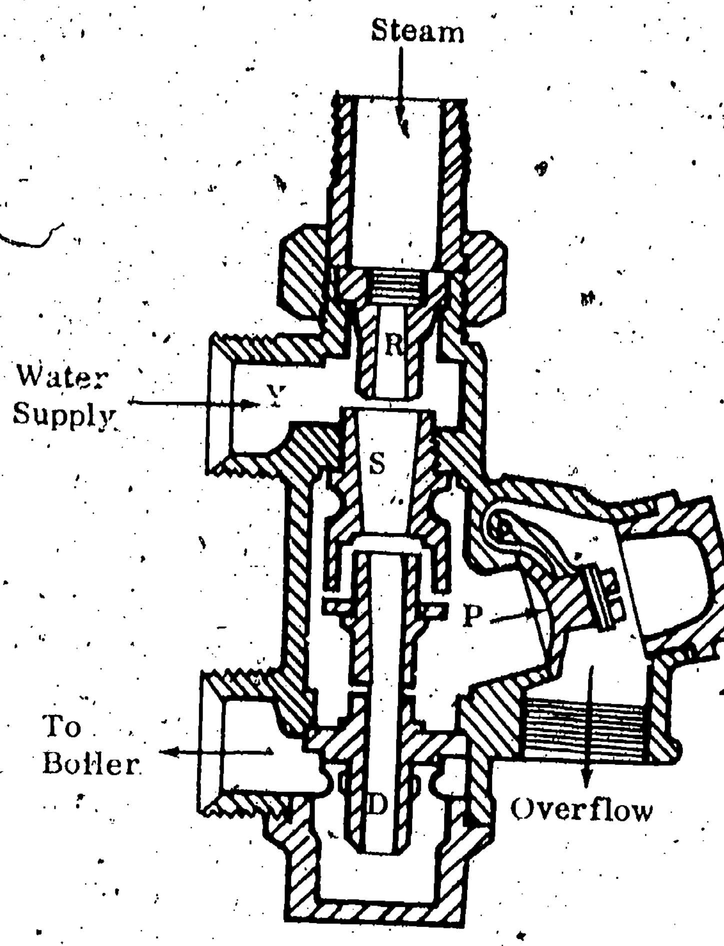


Fig. 54

The pumps are supplied with water through a common suction line from either a deaerator (suction head), or a hot well (suction lift). Each pump is equipped with a bypass from discharge to suction or to source of supply to provide sufficient flow through the pump to prevent overheating when it is operated at low load.

INJECTORS

The injector is a device used to feed water into a steam boiler under pressure. It is occasionally used in small plants as the secondary means of feeding water instead of a pump since the device is quite simple and relatively cheap. A cross-section of an injector is illustrated in Fig. 55 and the description of its operation follows.



Steam-Operated Injector

Fig. 55

Steam at boiler-pressure enters nozzle R. While passing through the nozzle, the steam drops in pressure, expands and attains a high velocity. This jet of high velocity steam then enters the suction nozzle S and, in doing so, it draws the air out of the suction chamber Y, creating a vacuum. This vacuum, in turn, causes the water to be drawn from the source of supply via the chamber into the suction nozzle. As the steam and water mix in this nozzle, the steam condenses, thus increasing the vacuum. It also imparts its velocity to the water. The condensed steam and water pass next into the combining and delivery nozzle, D. Here the velocity is converted into a pressure high enough to force the water into the boiler.

When the injector is first put into operation, it needs time to establish the proper jet flow and discharge pressure. During this time, the water is discharged via check valve P to the overflow. Once the water flows to the boiler, the check valve closes and the ring on the upper part of nozzle D is drawn upwards sealing the opening between nozzles S and D, preventing air from the lower injector housing to be drawn into the nozzle.

As a boiler feedwater device the injector is not very practical since it operates most efficiently at full capacity only. At reduced flows it is difficult to control and becomes unreliable. It is also unable to handle hot water, since the water would flash into steam due to the vacuum in the suction chamber and suction line. For these reasons, the use of the injector for boiler feed has been largely discontinued.

- QUESTION SHEET -

Power Engineering

Third Class
Sect. 3, Lect. 6

1. a) Define pump head and list all components comprising pump head.

   b) What is cavitation?

   c) Define the term "Net positive suction head".

2. a) Explain with the aid of a basic sketch, the operating principle of a reciprocating, double-acting piston pump.

   b) Explain why a relief valve is necessary on the discharge of a power driven reciprocating pump, but not on the discharge of a steam driven pump.

3. Describe briefly the steps involved in setting the slide valves of a duplex pump.

4. a) Explain with the aid of a simple sketch, the operating principle of a volute centrifugal pump.

   b) What is the structural and operational difference between a volute and diffuser centrifugal pump?

5. a) Explain why a radial flow centrifugal pump should not be run for an extended period of time with its discharge valve closed.

   b) Why should the output of this pump never be regulated by throttling the suction valve?

   c) What is a multi-stage pump and why is it used?

6. a) List two reasons for the use of wearing rings in centrifugal pumps.

   b) What is the purpose of shaft sleeves?

   c) Give two reasons for the use of lantern rings in stuffing boxes.

7. a) Describe briefly the difference between a rotating mechanical seal and a stationary mechanical seal.

   b) List the precautions to be taken in regard to mechanical seals.

(see over)

Question Sheet - continued

8. a) What causes axial thrust in a centrifugal pump?

   b) Name the various methods used to counter-act axial thrust.

9. Describe the step-by-step procedure of starting a large centrifugal pump equipped with stuffing boxes and water cooled, oil lubricated bearings.

10. Make a basic sketch of a turbine pump and explain briefly its operating principle.