INTERNSHIP REPORT

Bharat Petroleum

Bharat Petroleum Corporation Ltd.

OVERVIEW OF MACHINERY, STATIONARY AND ROTARY EQUIPMENT AT CENTRAL ENGINEERING WORKSHOP AND CASE STUDY OF MULTI STAGE CENTRIFUGAL PUMP

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PREFACE

This report is about the different machinery (such as Lathe, Milling, Grinding, etc.), rotary equipment (such as pumps, compressors, impellers, etc.) and stationary equipment (such as heat exchangers, valves, etc.) used in the Central Engineering Workshop and a case study report on Multi Stage, Single Suction Centrifugal Pump **143-P-01-A (RKB-32-9E/7, Job order – 50036758 used at ARU CCR N_2)**, at the machine shop of Bharat Petroleum's Mumbai Refinery. The case study report consists of the dismantling, cleaning, testing, assembly, replaced parts and recommendations to avoid further failures in pump. The report is made as a part of summer internship program from June to July 2017.

This report is made under the helpful guidance of, **Mr. K. PRADEEP** (Manager, Central Engineering Workshop) and **Mr. MAHESH J. UGHADE** (Assistant Manager, Central Engineering Workshop).

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1. OVERVIEW:

1.1. ABOUT BHARAT PETROLEUM CORPORATION LIMITED (BPCL):

Bharat Petroleum Corporation Limited (BPCL) is an Indian state-controlled oil and gas company headquartered in Mumbai, Maharashtra. The Corporation operates two large refineries of the country located at Mumbai and Kochi. The company is ranked 358th on the Fortune Global 500 list of the world's biggest corporations as of 2016.

Figure 1: B.P.C.L. Logo

Bharat Petroleum operates the following refineries:

Mumbai Refinery: Located near Mumbai, Maharashtra. It has a capacity of 13 million metric tonnes per year.

Kochi Refineries: Located near Kochi, Kerala. It has a capacity of 15.5 million metric tonnes per year.

Bina Refinery: Located near Bina, Sagar district, Madhya Pradesh. It has a capacity of 6 million metric tonnes per year. This refinery is operated by Bharat Oman Refineries Limited, a joint venture between Bharat Petroleum and Oman Oil Company.

Numaligarh Refinery: Located near Numaligarh, Golaghat district, Assam. It has a capacity of 3 million metric tonnes per year.

The company business is divided in seven SBUs (Strategic Business Units), like Retail, Lubricants, Aviation, Refinery, Gas, I&C and LPG.

1.2. ABOUT BHARAT PETROLEUM MUMBAI REFINERY (BPMR):

The Bharat Petroleum Mumbai Refinery (BPMR) is one of the most versatile refineries in India and excels in all aspects like quality, technology, fuel & loss, human relations, safety, environmental friendliness and operating cost.

With successful implementation of various projects and de-bottlenecking, the refineries currently process about 12 Million Metric Tons of crude oil per annum. BPMR has processed 61 different types of crudein five decades of its operations, making it one of the most flexible refineries in the country. The Refinery uses the latest microprocessor based Digital Distributed Control System (DDCS) and has been accredited with ISO 9002 (Quality Management System), the refinery laboratory has also been accredited with the unique distinction of a quality certification from NABL for “Quality Assurance Laboratory”.

It is the first Indian work site to achieve a Level 8 rating in the International Safety Rating System (ISRS) scale. ISRS is a tool owned by Det Norske Veritas, UK for the comparison, benchmarking and development of safety management systems worldwide. ISO 14001 (Environmental Management System) certifications has also been conferred to BPMR's for effective deployment of environmental care measures.

Figure 2: Refinery View

1.3. CRUDE REFINING UNITS IN BPMR:

The various process units in the BPMR are as follows:

i. Crude Distillation Unit (CDU – 1)

ii. Heavy Crude Unit (CDU – 2)

iii. New Crude Distillation Unit (CDU – 3)

iv. Feed Preparation Unit (FPU / HVU / VDU)

v. Fluid Catalytic Cracking Unit (CCU / FCCU)

vi. Hydro-Cracker Unit (HCR)

vii. Lubricating Oil Base Stock (LOBS)

viii. Reformer Feed Unit (RFU)

ix. Naphtha Hydro-Desulphurisation Unit

x. Catalytic Reforming Unit (CRU)

xi. Aromatic Extraction Unit

xii. New Solvent Unit (NSU)

xiii. Bitumen Blowing Unit (BBU)

xiv. Methyl Tertiary Butyl Ether (MTBE) Unit.

xv. Diesel Hydrodesulphurisation (DHDS) Unit

xvi. Sulphur Recovery Unit (SRU)

xvii. Treating Units

xviii. Utilities Network

xix. Waste Water Treatment Plant

xx. Tertiary Treatment Plant (TTP)

2. CENTRAL ENGINEERING WORKSHOP:

The Central Engineering Workshop located near the North Gate of the refinery is where the various equipment used in the process units of the refinery are brought for maintenance and other inspections. It is also the main maintenance workshop of the refinery.

The various sections in the workshop are as follows:

1. **CONSTRUCTION SECTION:** The construction shop is where the various fabrication/ manufacturing processes (such as welding, cutting, etc.) are carried out on the stationary (casing, bearing housing, various components of valves, heat exchangers) and rotating components (impeller, shaft, pumps, coupling, etc.) during their maintenance process.

2. **HEAT EXCHANGER SECTION:** This section looks after the maintenance and working of various heat exchangers (i.e. stationary components). Heat exchangers are one of the most commonly used devices in the crude refining processes of a refinery and hence require constant maintenance and check-up.

3. **VALVE SECTION:** This section carries out the testing and maintenance of the different types of valves (i.e. stationary components) used in the refining processes. The valves are first tested. In case any faults are detected, processes such as lapping are carried out on the valves.

4. **PUMP SECTION:** In the pump section, the maintenance of the various types of pumps (i.e. rotating/non-stationary components) used is carried out. The pumps are dismantled, cleaning is done, clearances are checked and various other tests such as dynamic balancing, shaft trueness, etc. are carried out before assembly of the pump.

5. **MACHINE SECTION:** The machine section consists of different types of machines such as Lathe Machine, Milling Machine, Drilling Machine, Computer Numerical Controlled (C.N.C.) Machines, etc. which are used in the maintenance and repair of equipment used in the refining process.

6. **TRANSPORT SECTION:** The transport section looks after the arrival and dispatch of the various machinery and components (stationary and rotary) brought in for maintenance in the Central Engineering Workshop. The section also does maintenance of various automobiles. This section is divided into subsections:

I. **RIGGING YARD:** Looks after components such as pulleys, chains, etc.

II. **E&STS:** Takes care of all types of Automobiles such as ambulance, cranes, fire trucks, lorries, cars, etc.

III. **TRANSPORT SECTION:** Looks after the transportation of the various static and rotating equipment from the installation site to the workshop and back.

7. **ROTARY CELL:** The rotary cell takes charge of the various non-stationary/rotating components such as the impellers of different pumps, shafts that are used in machinery, couplings, etc. This cell looks after the proper functioning of these components. The cell performs condition monitoring of the rotating components by vibration analysis.

Besides the above mentioned sections there are more cells/shops such as Instrument Shop, Electrical Shop, etc.

Different types of equipment used in the refinery are brought here for periodic maintenance, repair and cleaning.

3. MACHINES USED IN THE WORKSHOP:

3.1. LATHE MACHINE: The Lathe Machine is a machine that rotates the work-piece about an axis of rotation to perform various operations with tools that are applied to the work-piece to create an object with symmetry about that axis.

The Lathe Machine is used to perform operations such as:

a) Turning
b) Facing
c) Boring
d) Taper Boring
e) Chamfering
f) Drilling
g) Knurling
h) Cutting
i) Threading, etc.

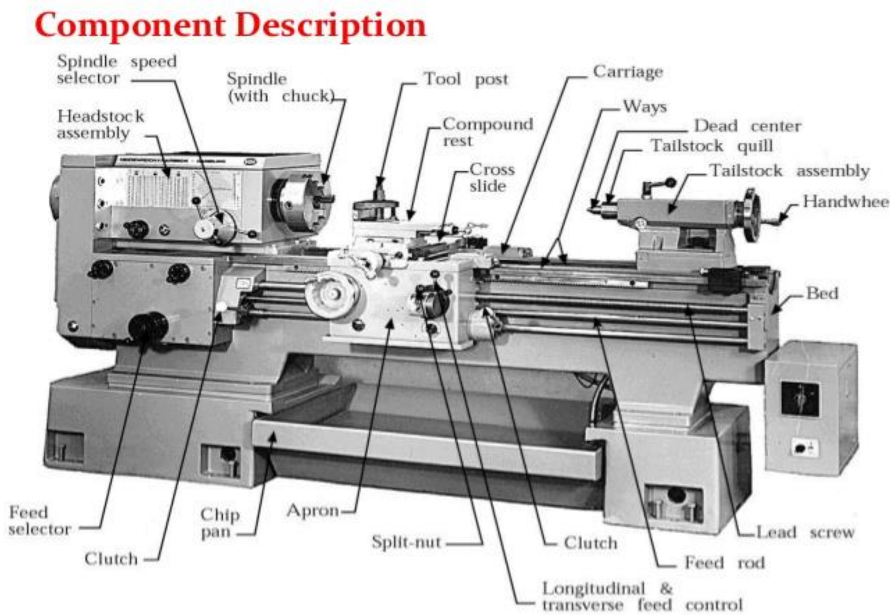


Figure 3: Lathe Machine

The Central Engineering Workshop uses around 8 Lathe Machines of varying bed lengths for a number of operations on the various stationary and rotary components.

3.2. MILLING MACHINE: Milling is the machining process of using rotary cutters to remove material from a work-piece by advancing (or feeding) in a direction at an angle with the axis of the tool. It covers a wide variety of different operations and machines, on scales from small individual parts to large, heavy-duty gang milling operations. It is one of the most commonly used processes in industry and machine shops today for machining parts to precise sizes and shapes.

Milling Machine is used to perform the following operations:

a) Face Milling

b) End Milling

c) Slab Milling

d) Plain Milling

e) Angular Milling

f) Drilling

g) Boring

h) Profile Milling

i) Threading

j) Gang Milling, etc.

The Central Engineering Workshop utilizes over 5 Milling Machines.

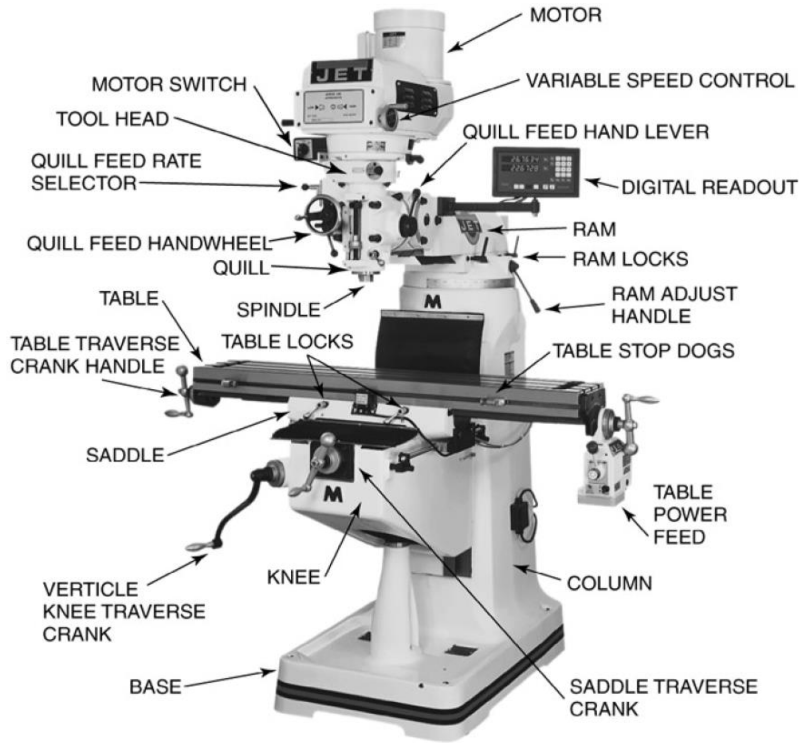


Figure 4: Milling Machine

3.3. DRILLING MACHINE: Drilling is a cutting process that uses a drill bit to cut a hole of circular cross-section in solid materials. The drill bit is usually a rotary cutting tool, often multi-point. The bit is pressed against the work-piece and rotated at rates from hundreds to thousands of revolutions per minute. This forces the cutting edge against the work-piece, cutting off chips (swarf) from the hole as it is drilled.

The drilling machine is used for the following operations:

a. Drilling
b. Boring
c. Counter-Boring
d. Counter-Sinking
e. Spot Facing
f. Tapping
g. Reaming
h. Trepanning

Figure 5: Drilling Machine

Different types of drilling machines are used in the

Central Engineering Workshop for machining different components of various assemblies.

3.4. COMPUTER NUMERICAL CONTROLLED MACHINES (C.N.C.) MACHINES: C.N.C. Machines is the automation of machine tools by means of computers executing pre-programmed sequences of machine control commands. This is in contrast to machines that are manually controlled by hand wheels or levers, or mechanically automated by cams alone. The coding of these machines is done using G.M. Codes.

In modern C.N.C systems, the designs of a mechanical part and its manufacturing program is highly automated. The part's mechanical dimensions are defined using computer-aided design (C.A.D.) software, and then translated into manufacturing directives by computer-aided manufacturing (C.A.M.) software.

Figure 6: C.N.C. V.T.L.

C.N.C. Machines can be broadly classified into the following types:

- Horizontal C.N.C. Machines
- Vertical C.N.C. Machines
- Universal C.N.C. Machines

Figure 7: C.N.C. Horizontal Boring Machine

The Central Engineering Workshop utilizes two C.N.C Machines viz. C.N.C. Vertical Turning Lathe Machine and C.N.C. Horizontal Boring Machine.

The C.N.C Vertical Turning Lathe (V.T.L.) Machine is used for performing turning operations on various components of large dimensions. The C.N.C. V.T.L. Machine is used instead of the traditional lathe machines when accuracy is an important factor and also the dimensions of the work-piece are large. The diameter of the chuck used id around 300 mm making it suitable for large work-piece.

The C.N.C. Horizontal Boring Machine is used for performing boring operations on work-pieces which require a hole of large diameter. The C.N.C. Horizontal Boring Machine provides greater accuracy and dimensional tolerances than the traditional drilling machines.

3.5. SHAPING MACHINE: The Shaping Machine or shaper is a type of machine tool that uses linear relative motion between the work-piece and a single-point cutting tool to machine a linear tool-path. It’s cut is analogous to that of a lathe, except that it is (archetypally) linear instead of helical.

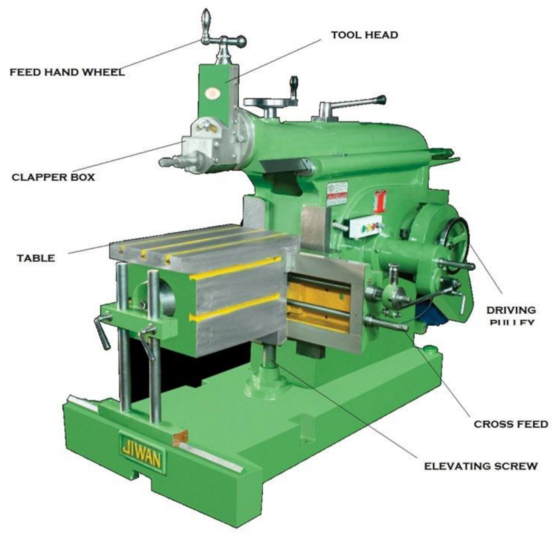


Figure 8: Shaper Machine

A metal-working shaper is somewhat analogous to a metal-working planer, with the cutter riding a ram that moves relative to a stationary work-piece, rather than the work-piece moving beneath the cutter.

The shaper is used to obtain horizontal, vertical as well as inclined flat surfaces. The vertical shaper is essentially the same thing as a slotter (slotting machine). The shaper machines use Whitworth Quick Return Motion Mechanism.

The shaper is used to manufacture keyways, dovetail slides, internal splines, gear teeth, etc. The Central Engineering Workshop utilizes around 2-3 shaping machines.

3.6. GRINDING MACHINE: A grinding machine, often shortened to grinder, is any of various power tools or machine tools used for grinding, which is a type of machining using an abrasive wheel as the cutting tool. Each grain of abrasive on the wheel’s surface cuts a small chip from the work-piece via shear deformation.

Figure 9: Grinding Machine

Grinding is used to finish work-pieces that show high surface quality (e.g. low surface roughness) and high accuracy of shape and dimension. As the accuracy in dimensions in grinding is of the order of 0.000025 mm, in most applications it tends to be a finishing operation and removes comparatively little metal, about 0.25 to

0.50 mm depth. However, there are some roughing applications in which grinding removes high volumes of metal quite rapidly. Thus, grinding is a diverse field.

Different types of grinding machines are used in the Central Engineering Workshop to perform grinding of cutting tools and various components.

3.7. ELECTRICAL OVERHEAD TRAVELLING (E.O.T.) CRANE: An overhead crane, commonly called a bridge crane, is a type of crane found in industrial environments. An overhead crane consists of parallel runways with a traveling bridge spanning the gap. A hoist, the lifting component of a crane, travels along the bridge. If the bridge is rigidly supported on two or more legs running on a fixed rail at ground level, the crane is called a gantry crane (USA, ASME B30 series) or a goliath crane (UK, BS 466).

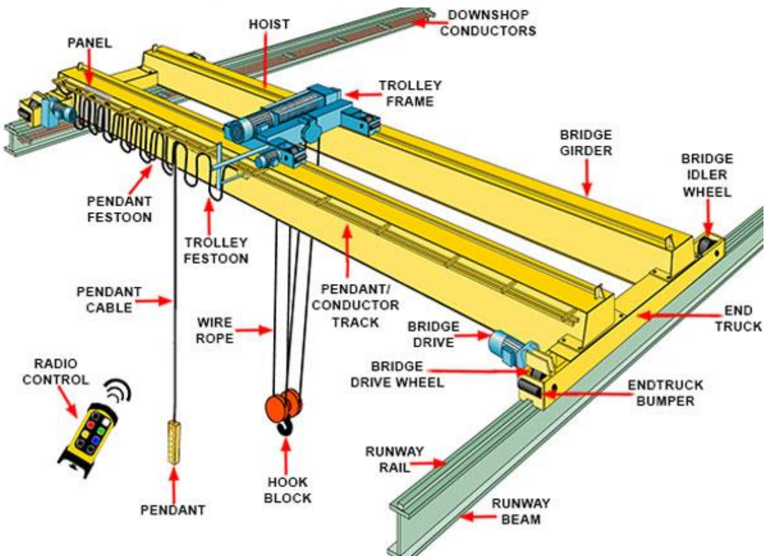


Figure 10: Electric Overhead Travelling Crane

Unlike mobile or construction cranes, overhead cranes are typically used for either manufacturing or maintenance applications, where efficiency or downtime are critical factors.

An Electric Overhead Travelling (E.O.T.) Crane is most common type of overhead crane, found in many factories. These cranes are electrically operated by a control pendant, radio/IR remote pendant, or from an operator cabin attached to the crane.

The Central Engineering Workshop uses 8 E.O.T.'s (as shown in figure) in-order to transport heavy machinery such as pumps, valves, heat exchangers and also many other equipment.

3.8. LAPPING MACHINE: Lapping is a machining process in which two surfaces are rubbed together with an abrasive between them, by hand movement or by using a machine.

This can take two forms. The first type of lapping (traditionally called grinding), involves rubbing a brittle material such as glass against a surface such as iron or glass itself (also known as the "lap" or grinding tool) with an abrasive such as aluminium oxide, jeweller's rouge, optician's rouge, emery, silicon carbide, diamond, etc. between them. This produces microscopic conchoidal fractures as the abrasive rolls about between the two surfaces and removes material from both.

The other form of lapping involves a softer material such as pitch or a ceramic for the lap, which is "charged" with the abrasive. The lap is then used to cut a harder material — the work-piece. The abrasive embeds within the softer material, which holds it and permits it to score across and cut the harder material. Taken to a finer limit, this will produce a polished surface such as with a polishing cloth on an automobile, or a polishing cloth or polishing pitch upon glass or steel.

Figure 11: Lapping Machine

Taken to the ultimate limit, with the aid of accurate interferometry and specialized polishing machines or skilled hand polishing, lens-makers can produce surfaces that are flat to better than 30 nanometres. This is one twentieth of the wavelength of light from the commonly used 632.8 nm helium neon laser light source. Surfaces this flat can be molecularly bonded (optically contacted) by bringing them together under the right conditions.

The Lapping Machine is used in the Workshop in-order to obtain perfectly surfaces on the various components of valves such as disc, lower blow-down ring, etc.

Besides the above mentioned commonly used machinery, there are other machine tools used such as large cutters for cutting of Heat Exchangers, etc.

4. PROCESSES CARRIED OUT IN THE CENTRAL ENGINEERING WORKSHOP:

4.1. WELDING: Welding is a fabrication or sculptural process that joins materials, usually metals or thermoplastics, by causing fusion, which is distinct from lower temperature metal-joining techniques such as brazing and soldering, which do not melt the base metal. In addition to melting the base metal, a filler material is typically added to the joint to form a pool of molten material (the weld pool) that cools to form a joint that is usually stronger than the base material. Pressure may also be used in conjunction with heat, or by itself, to produce a weld.

Figure 12: Welding Process

Although less common, there are also solid state welding processes such as friction welding or shielded active gas welding in which metal does not melt.

Many different energy sources can be used for welding, including a gas flame, an electric arc, a laser, an electron beam, friction, and ultrasound. While often an industrial process, welding may be performed in many different environments, including in open air, under water, and in outer space. Welding is a hazardous undertaking and precautions are required to avoid burns, electric shock, vision damage, inhalation of poisonous gases and fumes, and exposure to intense ultraviolet radiation.

Some of the best known welding methods include:

- **OXY-FUEL WELDING** – also known as oxyacetylene welding or oxy welding, uses fuel gases and oxygen to weld and cut metals.
- **SHIELDED METAL ARC WELDING (SMAW)** – also known as "stick welding or electric welding", uses an electrode that has flux around it to protect the weld puddle. The electrode holder holds the electrode as it slowly melts away. Slag protects the weld puddle from atmospheric contamination.

- **GAS TUNGSTEN ARC WELDING (GTAW)** – also known as TIG (tungsten, inert gas), uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by an inert shielding gas such as argon or helium.
- **GAS METAL ARC WELDING (GMAW)** – commonly termed MIG (metal, inert gas), uses a wire feeding gun that feeds wire at an adjustable speed and flows an argon-based shielding gas or a mix of argon and carbon dioxide (CO_2) over the weld puddle to protect it from atmospheric contamination.
- **FLUX-CORED ARC WELDING (FCAW)** – almost identical to MIG welding except it uses a special tubular wire filled with flux; it can be used with or without shielding gas, depending on the filler.
- **SUBMERGED ARC WELDING (SAW)** – uses an automatically fed consumable electrode and a blanket of granular fusible flux. The molten weld and the arc zone are protected from atmospheric contamination by being "submerged" under the flux blanket.
- **ELECTRO-SLAG WELDING (ESW)** – a highly productive, single pass welding process for thicker materials between 1 inch (25 mm) and 12 inches (300 mm) in a vertical or close to vertical position.
- **ELECTRIC RESISTANCE WELDING (ERW)** – a welding process that produces coalescence of laying surfaces where heat to form the weld is generated by the electrical resistance of the material. In general, an efficient method, but limited to relatively thin material.

Welding methods such as arc welding using Hydrogen iron powder electrode and gas welding are amongst the commonly used welding processes in the workshop.

4.2. PLASMA CUTTING: Plasma cutting is a process that cuts through electrically conductive materials by means of an accelerated jet of hot plasma. Typical materials cut with a plasma torch include steel, stainless steel, aluminum, brass and copper, although other conductive metals maybe cut as well. Plasma cutting is often used in fabrication shops, automotive repair and restoration, industrial construction, and salvage and scrapping operations. Due to the high speed and precision cuts combined with low cost, plasma cutting sees widespread use from large-scale industrial C.N.C. applications down to small hobbyist shops.

Figure 13: Plasma Cutter

The basic plasma cutting process involves creating an electrical channel of superheated, electrically ionized gas i.e. plasma from the plasma cutter itself, through the work piece to be cut, thus forming a completed electric circuit back to the plasma cutter via a grounding clamp. This is accomplished by a compressed gas (oxygen, air, inert and others depending on material being cut) which is blown through a focused nozzle at high speed toward the work piece. An electrical arc is then formed within the gas, between an electrode near or integrated into the gas nozzle and the work piece itself. The electrical arc ionizes some of the gas, thereby creating an electrically conductive channel of plasma. As electricity from the cutter torch travels down this plasma it delivers sufficient heat to melt through the work piece. At the same time, much of the high velocity plasma and compressed gas blow the hot molten metal away, thereby separating i.e. cutting through the work piece.

Plasma cutting is an effective means of cutting thin and thick materials alike. Hand-held torches can usually cut up to 38 mm (1.5 in) thick steel plate, and stronger computer-controlled torches can cut steel up to 150 mm (6 in) thick. Since plasma cutters produce a very hot and very localized "cone" to cut with, they are extremely useful for cutting sheet metal in curved or angled shapes.

Plasma cutter used in the Central Engineering Workshop for cutting casings, tubes, plates, etc. has the following specifications:

a) Current Rating: 70 A.

b) Frequency: 50/60 Hz.

c) Open Circuit Voltage: 58 V.

d) Phase: Single Phase.

e) Compressed Gas used: Air.

f) Pressure: 0.5 MPa, 5 bar.

g) Sheet/Plate thickness: 1-1.5 in.

Plasma cutting is used when dimensional accuracy and tolerances are the important factors.

Both the mentioned processes are used in the construction section inorder to repair various components such as casings, tubes, bars, etc. of different equipment such as pumps, valves, heat exchangers, etc.

5. HEAT EXCHANGERS:

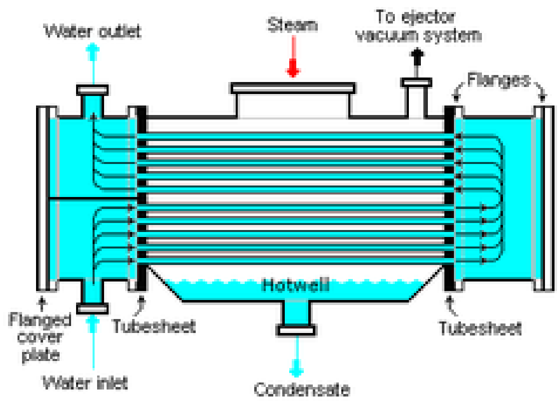


Figure 14: Heat Exchanger

5.1. INTRODUCTION: A heat exchanger is a device used to transfer heat between a solid object and a fluid, or between two or more fluids. The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact. They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing and sewage treatment. The classic example of a heat exchanger is found in an Internal Combustion Engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air. Another example is the heat sink, which is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant.

5.2. FLOW ARRANGEMENT: There are three primary classifications of heat exchangers according to their flow arrangement. In parallel-flow heat exchangers, the two fluids enter the exchanger at the same end, and travel in parallel to one another to the other side. In counter-flow heat exchangers the fluids enter the exchanger from opposite ends. The counter current design is the most efficient, in that it can transfer the most heat from the heat (transfer) medium per unit mass due to the fact that the average temperature difference along any unit length is higher. In a cross-flow heat exchanger, the fluids travel roughly perpendicular to one another through the exchanger.

For efficiency, heat exchangers are designed to maximize the surface area of the wall between the two fluids, while minimizing resistance to fluid flow through the exchanger. The exchanger's performance can also be affected by the addition of fins or corrugations in one or both directions, which increase surface area and may channel fluid flow or induce turbulence.

5.3. TYPES: Double pipe heat exchangers are the simplest exchangers used in industries. On one hand, these heat exchangers are cheap for both design and maintenance, making them a good choice for small industries. On the other hand, their low efficiency coupled with the high space occupied in large scales, has led modern industries to use more efficient heat exchangers like shell and tube or plate.

The different types of Heat Exchangers are:

A) Double Pipe Heat Exchangers:

1. Shell and Tube Heat Exchangers
2. Plate Heat Exchangers
3. Plate and Shell Heat Exchangers
4. Adiabatic Wheel Heat Exchangers
5. Plate Fin Heat Exchangers
6. Pillow Plate Heat Exchangers
7. Fluid Heat Exchangers
8. Waste Heat Recovery Units
9. Dynamic Scraped Surface Heat Exchangers
10. Phase-Change Heat Exchangers
11. Direct Contact Heat Exchangers
12. Micro-channel Heat Exchangers

B) Helical Coil Heat Exchangers

C) Spiral Heat Exchangers

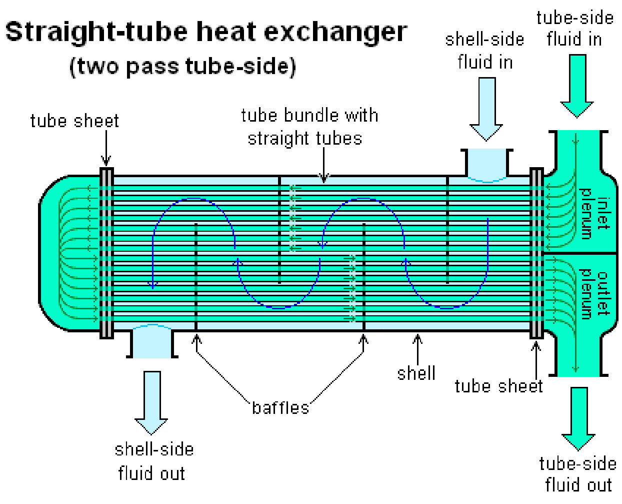


Figure 15: Shell and Tube Heat Exchanger

5.4. SHELL AND TUBE HEAT EXCHANGERS: This type of heat exchangers are the most commonly used in the petroleum refining industry. Shell and tube heat exchangers consist of series of tubes. One set of these tubes contains the fluid that must be either heated or cooled. The second fluid runs over the tubes that are being heated or cooled so that it can either provide the heat or absorb the heat required. A set of tubes is called the tube bundle and can be made up of several types of tubes: plain, longitudinally finned, etc. Shell and tube heat exchangers are typically used for high-pressure applications (with pressures greater than 30 bar and temperatures greater than 260 °C). This is because the shell and tube heat exchangers are robust due to their shape.

Several thermal design features must be considered when designing the tubes in the shell and tube heat exchangers: There can be many variations on the shell and tube design. Typically, the ends of each tube are connected to plenums (sometimes called water boxes) through holes in tube-sheets. The tubes may be straight or bent in the shape of a U, called U-tubes.

- **TUBE DIAMETER:** Using a small tube diameter makes the heat exchanger both economical and compact. However, it is more likely for the heat exchanger to foul up faster and the small size makes mechanical cleaning of the fouling difficult. To prevail over the fouling and cleaning problems, larger tube diameters can be used. Thus to determine the tube diameter, the available space, cost and fouling nature of the fluids must be considered.
- Tube thickness: The thickness of the wall of the tubes is usually determined to ensure:

1. There is enough room for corrosion
2. That flow-induced vibration has resistance
3. Axial strength
4. Availability of spare parts
5. Hoop strength (to withstand internal tube pressure)
6. Buckling strength (to withstand overpressure in the shell)

- **TUBE LENGTH:** Heat exchangers are usually cheaper when they have a smaller shell diameter and a long tube length. Thus, typically there is an aim to make the heat exchanger as long as physically possible whilst not exceeding production capabilities. However, there are many limitations for this, including space available at the installation site and the need to ensure tubes are available in lengths that are twice the required length (so they can be withdrawn and replaced). Also, long, thin tubes are difficult to take out and replace.
- **TUBE PITCH:** When designing the tubes, it is practical to ensure that the tube pitch (i.e., the centre-centre distance of adjoining tubes) is not less than 1.25 times the tubes' outside diameter. A larger tube pitch leads to a larger overall shell diameter, which leads to a more expensive heat exchanger.
- **TUBE CORRUGATION:** This type of tubes, mainly used for the inner tubes, increases the turbulence of the fluids and the effect is very important in the heat transfer giving a better performance.
- **TUBE LAYOUT:** Refers to how tubes are positioned within the shell. There are four main types of tube layout, which are, triangular (30°), rotated triangular (60°), square (90°) and rotated square (45°). The triangular patterns are employed to give greater heat

transfer as they force the fluid to flow in a more turbulent fashion around the piping. Square patterns are employed where high fouling is experienced and cleaning is more regular.

- **BAFFLE DESIGN:** Baffles are used in shell and tube heat exchangers to direct fluid across the tube bundle. They run perpendicularly to the shell and hold the bundle, preventing the tubes from sagging over a long length. They can also prevent the tubes from vibrating. The most common type of baffle is the segmental baffle. The semi-circular segmental baffles are oriented at 180 degrees to the adjacent baffles forcing the fluid to flow upward and downwards between the tube bundle. Baffle spacing is of large thermodynamic concern when designing shell and tube heat exchangers. Baffles must be spaced with consideration for the conversion of pressure drop and heat transfer. For thermo-economic optimization it is suggested that the baffles be spaced no closer than 20% of the shell's inner diameter. Having baffles spaced too closely causes a greater pressure drop because of flow redirection. Consequently, having the baffles spaced too far apart means that there may be cooler spots in the corners between baffles. It is also important to ensure the baffles are spaced close enough that the tubes do not sag. The other main type of baffle is the disc and doughnut baffle, which consists of two concentric baffles. An outer, wider baffle looks like a doughnut, whilst the inner baffle is shaped like a disk. This type of baffle forces the fluid to pass around each side of the disk then through the doughnut baffle generating a different type of fluid flow.

5.5. OPTIMIZATION: There are three goals that are normally considered in the optimal design of heat exchangers: (1) Minimizing the pressure drop (pumping power), (2) Maximizing the thermal performance and (3) Minimizing the entropy generation (thermodynamic).

5.6. SELECTION: To select an appropriate heat exchanger, the system designers (or equipment vendors) would firstly consider the design limitations for each heat exchanger type. Though cost is often the primary criterion, several other selection criteria are important:

- High/low pressure limits.
- Thermal performance.
- Temperature ranges.
- Product mix (liquid/liquid, particulates or high-solids liquid).
- Pressure drops across the exchanger.
- Fluid flow capacity.
- Cleaning-ability, maintenance and repair.
- Materials required for construction.

- Ability and ease of future expansion.
- Material selection, such as copper, aluminium, carbon steel, stainless steel, nickel alloys, ceramic, polymer and titanium.

5.7. FOULING: Fouling occurs when impurities deposit on the heat exchange surface. Deposition of these impurities can decrease heat transfer effectiveness significantly over time and are caused by:

- Low wall shear stress.
- Low fluid velocities.
- High fluid velocities.
- Reaction product solid precipitation.
- Precipitation of dissolved impurities due to elevated wall temperatures.

In commercial crude oil refining, crude oil is heated from 21 °C (70 °F) to 343 °C (649 °F) prior to entering the distillation column. A series of shell and tube heat exchangers typically exchange heat between crude oil and other oil streams to heat the crude to 260 °C (500 °F) prior to heating in a furnace. Fouling occurs on the crude side of these exchangers due to asphaltene insolubility.

6. VALVES:

6.1. INTRODUCTION: A valve is a device that regulates, directs or controls the flow of a fluid (gases, liquids, fluidized solids, or slurries) by opening, closing, or partially obstructing various passageways. Valves are technically fittings, but are usually discussed as a separate category. In an open valve, fluid flows in a direction from higher pressure to lower pressure. The word is derived from the Latin valva, the moving part of a door, in turn from volvere, to turn, roll.

Figure 16: Valve

The simplest, and very ancient, valve is simply a freely hinged flap which drops to obstruct fluid (gas or liquid) flow in one direction, but is pushed open by flow in the opposite direction. This is called a check valve, as it prevents or "checks" the flow in one direction. Modern control valves may regulate pressure or flow downstream and operate on sophisticated automation systems.

6.2. TYPES: Valves are quite diverse and may be classified into a number of basic types. Valves may also be classified by how they are actuated:

- Hydraulic
- Pneumatic
- Manual
- Solenoid valve
- Motor

Figure 17: Types of Valves

6.3. COMPONENTS:

A. **BODY:** The valve's body is the outer casing of most or all of the valve that contains the internal parts or trim. Valve bodies are usually metallic or plastic. Brass, bronze, gunmetal, cast iron, steel, alloy steels and stainless steel-sare very common. Seawater applications, like desalination plants, often use duplex valves, as well as super duplex valves, due to their corrosion resistant properties, particularly against warm seawater. Alloy 20 valves are typically used in sulphuric acid plants, whilst monel valves are used in hydrofluoric acid (HF Acid) plants. Hastelloy valves are often used in high temperature applications, such as nuclear plants, whilst inconel valves are often used in hydrogen applications. Plastic bodies are used for relatively low pressures and temperatures. PVC, PP, PVDF and glass-reinforced nylon are common plastics used for valve bodies.

B. **BONNET:** A bonnet acts as a cover on the valve body. The bonnet is the part of the encasing through which the stem passes and that forms a guide and seal for the stem.

It is commonly semi-permanently screwed into the valve body or bolted onto it. During manufacture of the valve, the internal parts are put into the body and then the bonnet is attached to hold everything together inside. To access internal parts of a valve, a user would take off the bonnet, usually for maintenance. Many valves do not have bonnets; for example, plug valves usually do not have bonnets. Many ball valves do not have bonnets since the valve body is put together in a different style, such as being screwed together at the middle of the valve body.

C. **PORTS:** Ports are passages that allow fluid to pass through the valve. Ports are obstructed by the valve member or disc to control flow. Valves most commonly have 2 ports, but may have as many as 20. The valve is almost always connected at its ports to pipes or other components. Connection methods include threading, compression fittings, glue, cement, flanges, or welding.

D. **HANDLE OR ACTUATORS:** A handle is used to manually control a valve from outside the valve body. Automatically controlled valves often do not have handles, but some may have a handle (or something similar) anyway to manually override automatic control, such as a stop-check valve. An actuator is a mechanism or device to automatically or remotely control a valve from outside the body. Some valves have neither handle nor actuator because they automatically control themselves from inside; for example, check valves and relief valves may have neither.

E. **DISC:** A disc or valve member is a movable obstruction inside the stationary body that adjustably restricts flow through the valve. Although traditionally disc-shaped, discs come in various shapes. Depending on the type of valve, a disc can move linearly inside a valve, or rotate on the stem (as in a butterfly valve), or rotate on a hinge or trunnion (as in a check valve).

F. **SEAT:** The seat is the interior

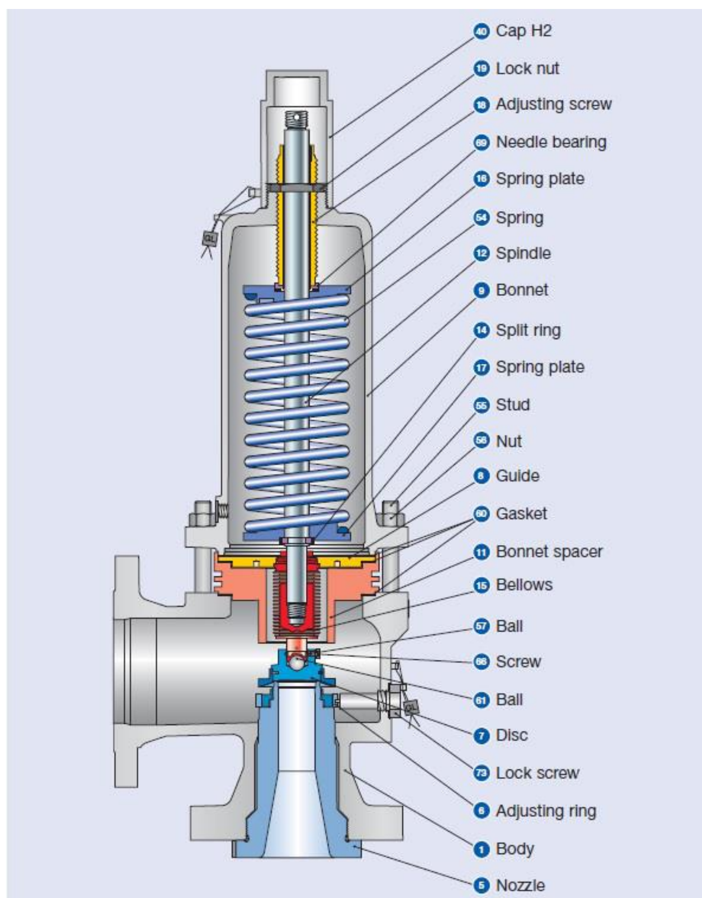


Figure 18: Valve Components

surface of the body which contacts the disc to form a leak-tight seal. In discs that move linearly or swing on a hinge or trunnion, the disc comes into contact with the seat only when the valve is shut. In disks that rotate, the seat is always in contact with the disk, but the area of contact changes as the disc is turned. The seat always remains stationary relative to the body.

Seats are classified by whether they are cut directly into the body, or if they are made of a different material:

1. Hard seats are integral to the valve body. Nearly all hard seated metal valves have a small amount of leakage.
2. Soft seats are fitted to the valve body and made of softer materials such as PTFE or various elastomers such as NBR, EPDM, or FKM depending on the maximum operating temperature.

A closed soft seated valve is much less liable to leak when shut while hard seated valves are more durable. Gate, globe, and check valves are usually hard seated while butterfly, ball, plug, and diaphragm valves are usually soft seated.

G. STEM: The stem transmits motion from the handle or controlling device to the disc. The stem typically passes through the bonnet when present. In some cases, the stem and the disc can be combined in one piece, or the stem and the handle are combined in one piece. The motion transmitted by the stem may be a linear force, a rotational torque, or some combination of these. The valve and stem can be threaded such that the stem can be screwed into or out of the valve by turning it in one direction or the other, thus moving the disc back or forth inside the body. Packing is often used between the stem and the bonnet to maintain a seal. Some valves have no external control and do not need a stem as in most check valves.

H. GASKETS: Gaskets are the mechanical seals, or packings, used to prevent the leakage of a gas or fluids from valves.

I. VALVE BALLS: A valve ball is also used for severe duty, high pressure and high tolerance applications. They are typically made of stainless steel, titanium, Stellite, Hastelloy, brass, or nickel. They can also be made of different types of plastic, such as ABS, PVC, PP or PVDF.

J. SPRING: Many valves have a spring for spring-loading, to normally shift the disc into some position by default but allow control to reposition the disc. Relief valves commonly use a spring to keep the valve shut, but allow excessive pressure to force the valve open against the spring-loading. Coil spring-sare normally used. Typical spring materials include zinc plated steel, stainless steel, and for high temperature applications Inconel X750.

6.4. SAFETY VALVE: Safety Valves are one the most commonly used pressure control valves in the refinery. The valve section looks after the maintenance of the safety valves.

A. **WORKING:** The pressure safety valve is a direct spring-loaded pressure-relief valve that is opened by the static pressure upstream of the valve and characterized by rapid opening or pop action. When the static inlet pressure reaches the set pressure, it will increase the pressure upstream of the disk and overcome the spring force on the disk. Fluid will then enter the huddling chamber, providing additional opening force. This will cause the disk to lift and provide full opening at minimal overpressure. The closing pressure will be less than the set pressure and will be reached after the blowdown phase is completed.

   The relief valve is designed or set to open at a predetermined pressure known as set pressure to protect pressure vessels and other equipment from being subjected to pressures that exceed their design limits.

   Once normal pressure conditions have been restored, the valve is required to close again, but since the larger area of the disc is still exposed to the fluid, the valve will not close until the pressure has dropped below the original set pressure. The difference between the set pressure and this reseating pressure is known as the blowdown and it is usually specified as a percentage of the set pressure.

B. **TESTING:**
   1. The pressure test of the safety valve is carried out by securing the inlet tract or the approach channel of the valve on the on the test fixture (which consists of the pressurized fluid, compressor, pressure gauges etc.).
   2. The relieving pressure of the pop test is noted down.
   3. If the POP pressure is higher than the set pressure the test needs to be repeated and if in the second effort it was near to the set pressure then it is because of deposit. If in the second effort it was not opened near to the set pressure either it was set wrongly or it was changed during the operation
   4. If the pressure safety valve was not opened in 150% of set pressure it should be considered as stuck shut. If the pressure safety valve was opened below the set pressure the spring is weakened.
   5. The leakage testing is carried out by partially filling the outlet tract with water.
   6. A pressure 10% less than the set pressure is applied at the inlet tract using the test fixture. If there are disturbances in the liquid film then there is a leak in the valve.
   7. If leakage is found then the valve is dismantled and various machining processes such as lapping are carried out the various components. The lapping process can be carried out either manually or on the machine although manually is preferred.

7. PUMPS:

7.1. INTRODUCTION: A Pump is a machinery or device that performs the function of increasing the total energy of a fluid in order to move it from one place to another i.e. the pump transfers energy to the fluid that it receives from the driver (electric motor, I.C. Engine, etc.). A pump is used for incompressible fluids (e.g. water, oil, etc.) whereas a compressor is used for compressible fluids such as air, other gases, etc. Pumps are one of the most often sold and used mechanical devices and can be found in almost every industry. Due to this there is a wide range of different pumps available.

7.2. NECESSITY: A pump is used for the following reasons:

1. To pump a liquid from lower pressure area to a higher pressure area.
2. To increase the flow rate.
3. To move a liquid from lower elevation to higher elevation.

Basically, a pump is used to increase the head of a fluid.

Within the petroleum industry pumps are necessary to process fluids especially hydrocarbons. Another important application within the petroleum industry is in the mud circuit on a drilling rig. On drilling rigs, mud which consists mainly of water and bentonite as well as of several different additives depending on many different factors is used. The heart of the mud circuit is the mud pump which is in general a high pressure piston pump. It provides the major part of head to overcome the systems resistance.

Other typical applications for pumps are pipeline applications. Pipelines are used for economical transport of hydrocarbons like oil and gas over long distances. At the beginning of a pipeline system, in most cases huge storage tanks can be found to ensure a continuous flow through the pipeline. The oil is forced through the pipe by a few powerful centrifugal pumps in serial. On its long way, pumping stations

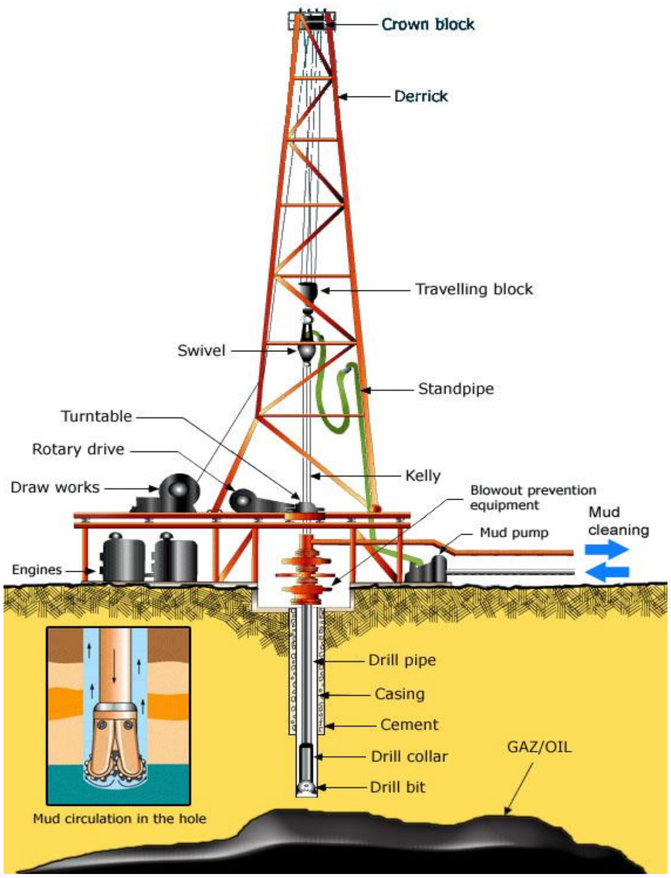


Figure 19: Pump used in Mud Circuit on Drilling Rigs

are required to overcome the resistance and heights. These pumping stations are distributed over the whole length of the pipeline, but can be found especially before mountains.
These are just examples for the wide range of applications of centrifugal pumps within the petroleum industry. Also important are applications within the hydrocarbon processing industry and on offshore rigs or distributing stations at harbours.

7.3. TYPES: There are two basic types of pumps: positive displacement and centrifugal. Although axial-flow pumps are frequently classified as a separate type, they have essentially the same operating principles as centrifugal pumps.

I. **POSITIVE DISPLACEMENT PUMPS:** A positive displacement pump makes a fluid move by trapping a fixed amount and forcing (displacing) that trapped volume into the discharge pipe. Some positive displacement pumps use an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pump as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is constant through each cycle of operation. A positive displacement pump can be further classified according to the mechanism used to move the fluid:

A. **ROTARY TYPE POSITIVE DISPLACEMENT:** These pumps move fluid using a rotating mechanism that creates a vacuum that captures and draws in the liquid. Rotary pumps are very efficient because they naturally remove air from the lines, eliminating the need to bleed the air from the lines manually. The nature of the pump requires very close clearances between the rotating pump and the outer edge, making it rotate at a slow, steady speed. If rotary pumps are operated at high speeds, the fluids cause erosion, which eventually causes enlarged clearances that liquid can pass through, which reduces efficiency. Rotary positive displacement pumps fall into three main types:

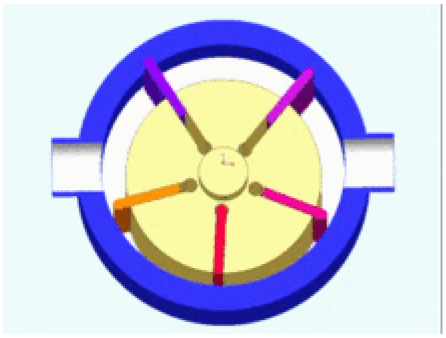


Figure 20: Rotary Type Positive Displacement Pump

- **GEAR PUMPS** – A simple type of rotary positive displacement pumps where the liquid is pushed between two gears. It consists of two meshed gears that rotate in a closely fitted casing. The tooth spaces trap fluid and force it around the outer periphery. The fluid does not travel back on the meshed part, because the teeth mesh closely in the centre.

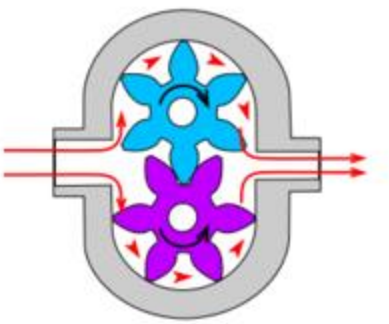


Figure 21: Gear Pump

Gear pumps see wide use in car engine oil pumps and in various hydraulic power packs.

- **SCREW PUMPS –** A screw pump is a more complicated type of rotary pump that uses two or three screws with opposing thread — e.g., one screw turns clockwise and the other counter-clockwise. The shape of the internals of this pump is usually two screws turning against each other to pump the liquid. The screws are mounted on parallel shafts that have gears that mesh so the shafts turn together and everything stays in place. The screws turn on the shafts and drive fluid through the pump. As with other forms of rotary pumps, the clearance between moving parts and the pump's casing is minimal.

Figure 22: Screw Pump

- **ROTARY VANE PUMPS –** Similar to scroll compressors, these have a cylindrical rotor encased in a similarly shaped housing. As the rotor orbits, the vanes trap fluid between the rotor and the casing, drawing the fluid through the pump.

B. RECIPROCATING POSITIVE DISPLACEMENT PUMPS: Reciprocating pumps move the fluid using one or more oscillating pistons, plungers, or membranes (diaphragms), while valves restrict fluid motion to the desired direction. Pumps in this category range from simplex, with one cylinder, to in some cases quad (four) cylinders, or more. Many reciprocating-type pumps are duplex (two) or triplex (three) cylinder. They can be either single-acting with suction during one direction of piston motion and discharge on the other, or double-acting with suction and discharge in both directions. The pumps can be powered manually, by air or steam, or by a belt driven by an engine. Reciprocating pumps typically pump highly viscous fluids like concrete and heavy oils, and serve in special applications that demand low flow rates against high resistance. Reciprocating hand pumps were widely used to pump water from wells. Common bicycle pumps and foot pumps for inflation use reciprocating action. These positive displacement pumps have an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pumps as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. Typical reciprocating pumps are:

- **PLUNGER PUMPS –** A reciprocating plunger pushes the fluid through one or two open valves, closed by suction on the way back. These consist of a cylinder with a reciprocating plunger. The suction and discharge valves are mounted in the head of the cylinder. In the suction stroke the plunger retracts and the suction valves open causing suction of fluid into the cylinder. In the forward stroke the plunger pushes the liquid out of the discharge valve. With only one cylinder in plunger pumps, the fluid flow varies between maximum flow when the plunger moves through the middle positions, and zero flow when the plunger is at the end positions. A lot of energy is wasted when the fluid is accelerated in the piping system. Vibration and water hammer may be a serious problem. In general the problems are compensated for by using two or more cylinders not working in phase with each other. Triplex plunger pumps use three plungers, which reduces the pulsation of single reciprocating plunger pumps. Adding a pulsation dampener on the pump outlet can further smooth the *pump ripple*, or ripple graph of a pump transducer. The dynamic relationship of the high-pressure fluid and plunger generally requires high-quality plunger seals. Plunger pumps with a larger number of plungers have the benefit of increased flow, or smoother flow without a pulsation dampener. The increase in moving parts and crankshaft load is one drawback. The oil and gas drilling industry uses massive semi-trailer-transported triplex pumps called mud pumps to pump drilling mud, which cools the drill bit and carries the cuttings back to the surface.

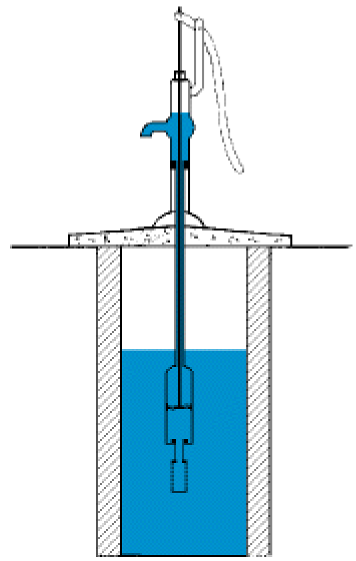


Figure 23: Plunger Pump

- **PISTON PUMPS DISPLACEMENT PUMPS** – A piston pump is a type of positive displacement pump where the high-pressure seal reciprocates with the piston. Piston pumps can be used to move liquids or compress gases. Usually simple devices for pumping small amounts of liquid or gel manually. The common hand soap dispenser is such a pump.
- **RADIAL PISTON PUMPS –** A radial piston pump is a form of hydraulic pump. The working pistons extend in a radial direction symmetrically around the drive shaft, in contrast to the axial piston pump.

II. **ROOTS TYPE PUMP:** Named after the Roots brothers who invented it, this lobe pump displaces the liquid trapped between two long helical rotors, each fitted into the other when perpendicular at 90°, rotating inside a triangular shaped sealing line configuration, both at the point of suction and at the point of discharge. This design produces a

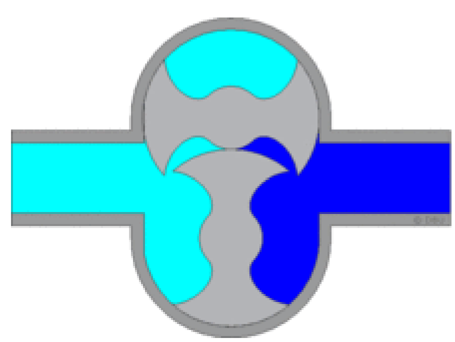


Figure 24: Roots Type Pump

continuous flow with equal volume and no vortex. It can work at low pulsation rates, and offers gentle performance that some applications require. Applications include:

- High capacity industrial air compressors
- Roots superchargers on internal combustion engines.
- A brand of civil defence siren, the Federal Signal Corporation's Thunderbolt.

III. **PERISTALTIC PUMP:** A peristaltic pump is a type of positive displacement pump. It contains fluid within a flexible tube fitted inside a circular pump casing (though linear peristaltic pumps have been made). A number of rollers, shoes, or wipers attached to a rotor compresses the flexible tube. As the rotor turns, the part of the tube under compression closes (or occludes), forcing the fluid through the tube. Additionally, when the tube opens to its natural state after the passing of the cam it draws (restitution) fluid into the pump. This process is called peristalsis and is used in many biological systems such as the gastrointestinal tract.

Figure 25: Peristaltic Pump

IV. **IMPULSE PUMPS:** Impulse pumps use pressure created by gas (usually air). In some impulse pumps the gas trapped in the liquid (usually water), is released and accumulated somewhere in the pump, creating a pressure that can push part of the liquid upwards.

Conventional impulse pumps include:

- **HYDRAULIC RAM PUMPS –** kinetic energy of a low-head water supply is stored temporarily in an air-bubble hydraulic accumulator, then used to drive water to a higher head.
- **PULSER PUMPS –** run with natural resources, by kinetic energy only.
- **AIRLIFT PUMPS –** run on air inserted into pipe, which pushes the water up when bubbles move upward.

Other than those mentioned above, there are many other types of pumps e.g. Velocity pumps, Rope pumps, Gravity pumps, Steam pumps, Axial flow and Radial flow pumps.

A subdivision of Velocity pumps is called as Radial flow pumps (Centrifugal Pumps). These pumps are one of the most commonly used pumps in the petroleum refinery.

8. CENTRIFUGAL PUMPS:

8.1. INTRODUCTION: Centrifugal pumps are a sub-class of dynamic axisymmetric work-absorbing turbo-machinery. Centrifugal pumps are used to transport fluids by the conversion of rotational kinetic energy to the hydrodynamic energy of the fluid flow. The rotational energy typically comes from an engine or electric motor. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radially outward into a diffuser or volute chamber (casing), from where it exits.In these pumps, Centrifugal force pushes the liquid outward from the eye of the impeller where it enters the casing. Differential head can be increased by turning the impeller faster, using a larger impeller, or by increasing the number of impellers. The impeller and the fluid being pumped are isolated from the outside by packing or mechanical seals. Shaft radial and thrust bearings restrict the movement of the shaft and reduce the friction of rotation.

Figure 26: Centrifugal Pump

8.2. CLASSIFICATION: Centrifugal Pumps can be classified as follows:

A. BASED ON NUMBER OF SUCTION:

i. **SINGLE SUCTION:** Single suction pump, also known as end-auction pump or single stage pump, working principle of which is: when the pump starts, the pump shaft drives the impeller for high speed rotary motion, forcing the pre-filling fluid between blades to rotate. With the effect of inertial centrifugal force, the fluid moves along radial direction from the impeller centre to the peripheral region. When the fluid obtains the energy in the movement through the impeller, the static pressure is increased and the flow rate is increased as well. After the fluid leaves the impeller and flows into the pump shell, it is slow down in the expanding tube within the shell, causing part of the kinetic energy converted to static pressure, and finally it is discharged from the pipeline along the tangential direction. When fluid from the impeller is pushed towards to the peripheral direction at the same time, low pressure area is formed in the centre of impeller. With the impact of total static pressure difference between fluid level of storage tank and the impeller centre, the fluid is sucked into the impeller centre. Relying on the continuous operation of the impeller, it is possible to make continuous fluid suction and discharge.

ii. **DOUBLE SUCTION:** Double suction pump is an important type of centrifugal oil pump. This type of pump impeller actually consists of two back-to-back impellers, from which the water flow into a volute. One double suction pump works just like two same diameter end-suction pumps work at the same time, so its flow quantity can be doubled by using the same outer diameter impeller. The horizontal split structure of pump shell makes easy inspection and maintenance possible. Meanwhile, the entry end and exit end of double suction pump are in the same direction, being perpendicular to the pump shaft, which is helpful for the layout and installation of pumps and water pipes; double suction pump is characterized by symmetrical impeller structure and non-axial force, so it can run more smoothly and can satisfy the operating requirement of mass flow and high lift.

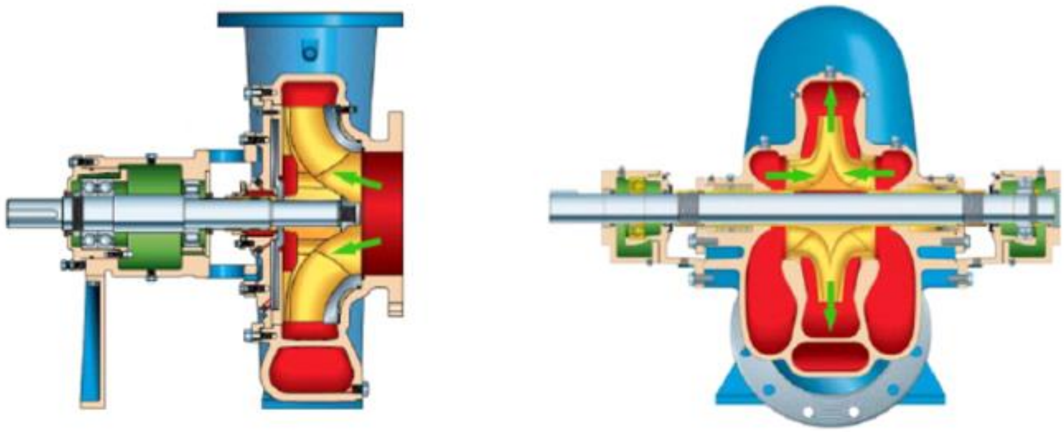


Figure 27: Single Suction and Double Suction Centrifugal Pump

B. BASED ON NUMBER OF STAGES:

i. **SINGLE STAGE:** If a pump consists of only one single impeller (stage), it is known as a single stage centrifugal pump. This type of pumps is simple in construction, design and maintenance. Here, there is no need of balancing disks/drums as the bearings are capable of withstanding the forces. It is the most commonly used pump in production operations.

Figure 28: Single Stage and Multi Stage Centrifugal Pump

They are used in pumping services of low-to-moderate TDH (Total Dynamic Head which is a function of the impeller's top speed). They have higher unbalanced thrust and radial forces at off-design flow rates than multistage designs and have limited TDH capabilities.

ii. **MULTI STAGE:** A pump consisting of two or more impellers is known as a Multi Stage Pump. The pumps are complicated in design. They are used in pumping services of moderate-to-high TDH. Each stage acts as a separate pump. All the stages are within the same housing and installed on the same shaft. Eight or more stages can be installed on a single horizontal shaft. There is no limit to the number of stages that can be installed on a vertical shaft. Each stage increases the head by approximately the same amount. As the pressure in these pumps is high, there may be a need to use a balancing disk/drum depending on the type of liquid.

C. BASED ON SECTION:

i. **HORIZONTAL SECTION:** In a horizontal centrifugal pump, the shaft is normally in a horizontal position. It is sometimes overhung or placed between bearing design. These pumps are easier to install and maintain because the internal parts like rotor are easily accessible. They can be directly coupled to electric motor, engine or turbine. For low suction pressure, it is possible to opt for an overhung design. For high suction

Figure 29: Horizontal Section and Vertical Section Centrifugal Pump

pressure, it is possible to opt for in between-bearing design. Various nozzle configurations that match the external site piping like end suction top discharge, top suction top discharge and side suction side discharge are available. It is suitable for almost all indoor applications due to its low headroom requirements. It's applications become limited where the net pump suction head (NPSH) required exceeds the NPSH available. It requires an auxiliary booster pump. The maximum allowable operating temperature as well as working pressure are both generally much lower than that in a vertical inline pump. A bigger footprint is required for horizontal designs.

ii. **VERTICAL SECTION:** A vertical pump is one whose shaft is in vertical position; it is always an overhang and of radial-split case type design. It requires a smaller footprint than that of horizontal pumps. It is suitable for spaces where the ground surface area is restricted. With a vertical centrifugal pump, the NPSH available can be increased. Such pumps are suitable for higher temperature and high pressure fluids. They require large headroom for installation and maintenance especially when it comes to multistage units or turbine pumps. Only when direct coupling with an electric motor is available, such pumps can be used. With types of drivers like engine or turbine are used, vertical centrifugal pumps will not be the perfect choice for your industry. Due to the overhang design, it becomes difficult to balance the hydraulic axial thrust especially while dealing with high suction pressures. A multistage vertical inline pump would normally require expensive barrel and pit. It will be prone various issues in its mechanical seals when it has to pump liquids with high dissolved gases since they will accumulate at the top of the seal chamber or the stuffing box. Here venting is difficult and less effective.

D. BASED ON IMPELLER DESIGN:

i. **OPEN IMPELLER**: The open impeller has a series of vanes attached to a central unit. This is done for the mounting on the shaft. However, this design is more sensitive to wear and tear of the blades. The efficiency of an open impeller can be maintained through clearance adjustment. In an open impeller, no pump disassembling is necessary while checking the status of the wear rings. An open impeller is less likely to get clogged and even if it does, it is easier to clean. In an open impeller, all the parts are visible, it thus becomes easy to inspect for damage. The open impeller is less costly to build. The vanes can be easily cut to improve the capacity in an open impeller. An open impeller provides a wide range of specific speed.

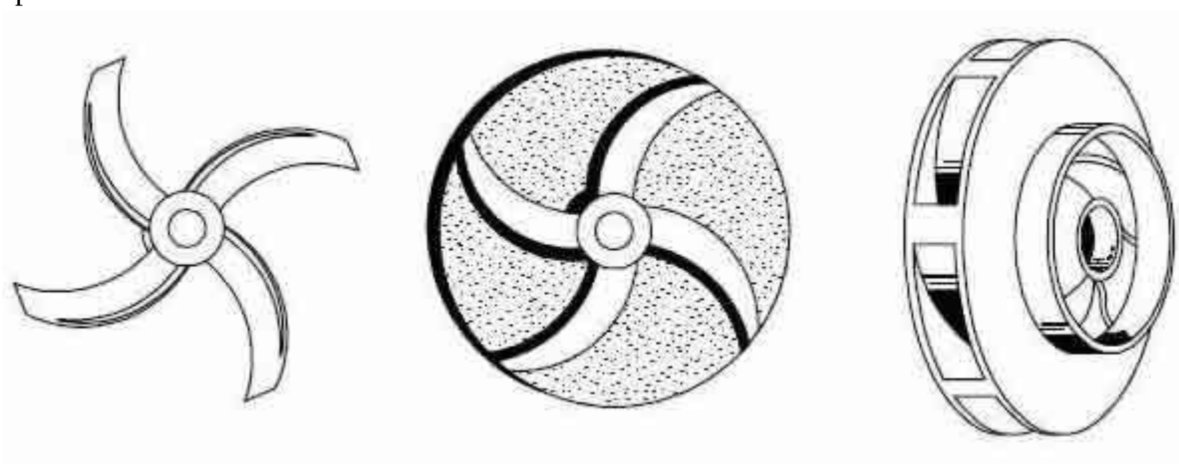


Figure 30: Different Types of Impellers

ii. **SEMI CLOSED IMPELLER**: The semi closed impeller is constructed with a circular plate (the web) attached to only one side of the blades. The design is less susceptible to wear and tear of the blades as compared to open impellers. The chances of the impeller getting clogged are more than open impeller as the dirt and waste particles can get accumulated on the web.

iii. **CLOSED IMPELLER**: The closed impeller has a side wall on the either sides (top and bottom) of the vanes. Closed impellers are the most commonly used impellers in the industry since they can deal with volatile and explosive fluids. The closed impeller is initially really efficient, but with time, loses its efficiency as the clearance of the wear ring increases. The pump had to be disassembled when it has a closed impeller to check the status of the wear rings. In a closed impeller, if stringy material or solids are pumped, the impeller can clog and it becomes really difficult to clean them. The internal parts of a closed impeller are hidden hence it is difficult to cast and inspect for flaws. The design of a closed impeller is more complicated and expensive since the additional wear rings are needed. It is not possible to easily modify a closed impeller so as to improve its performance. In a closed impeller, speed choices are limited.

8.3. WORKING PRINCIPLE: A centrifugal pump is a rotodynamic pump that uses a rotating impeller to increase the pressure of a fluid. The fluid enters the pump near the rotating axis, streaming into the rotating impeller. The impeller consists of a rotating disc with several vanes attached. The vanes normally slope backwards, away from the direction of rotation. When the fluid enters the impeller at a certain velocity due to the suction system, it is captured by the rotating impeller vanes. The fluid is accelerated by pulse transmission while following the curvature of the impeller vanes from the impeller center (eye) outwards. It reaches its maximum velocity at the impeller's outer diameter and leaves the impeller into a diffuser or volute chamber.

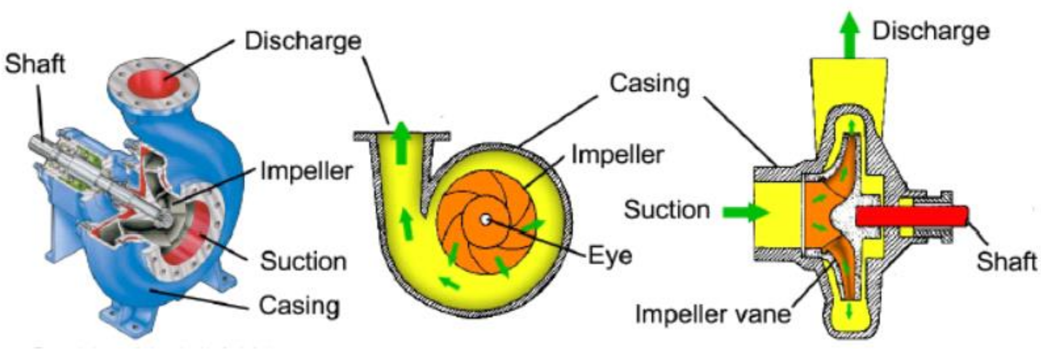


Figure 31: Working Principle of Centrifugal Pump

So the centrifugal force assists accelerating the fluid particles because the radius at which the particles enter is smaller than the radius at which the individual particles leave the impeller. Now the fluid’s energy is converted into static pressure, assisted by the shape of the diffuser or volute chamber. The process of energy conversation in fluids mechanics follows the Bernoulli principle (eqn.1) which states that the sum of all forms of energy along a streamline is the same on two points of the path. The total head energy in a pump system is the sum of potential head energy, static pressure head energy and velocity head energy.

$$z_1 + \frac{v_1^2}{2 \cdot g} + \frac{p_1}{\rho \cdot g} = z_2 + \frac{v_2^2}{2 \cdot g} + \frac{p_2}{\rho \cdot g}$$

As a centrifugal pump increases the velocity of the fluid, it is essentially a velocity machine. After the fluid has left the impeller, it flows at a higher velocity from a small area into a region of increasing area. So, the velocity is decreasing and so the pressure increases as described by Bernoulli's principle. This results in an increased pressure at the discharge side of the pump. As fluid is displaced at the discharge side of the pump, more fluid is sucked in to replace it at the suction side, causing flow.

8.4. PUMP ASSEMBLY:

A. CASING: The pump's casing houses the hole assembly and protects is from harm as well as forces the fluid to discharge from the pump and convert velocity into pressure. The casings design does not influence the total dynamic head but is important to reduce friction losses. It supports the shaft bearings and takes the centrifugal forces of the rotating impeller and axial loads caused by pressure thrust imbalance. Most of all centrifugal pumps are of simple spiral casing and are not equipped with a guide vane aperture. Even if this would increase efficiency due to the simplicity of spiral casings, this is the preferred type of construction. Only extraordinary big or multistage pumps do have guide vanes. The spiral pump casing has to be carefully designed to avoid turbulences resulting in a decrease in efficiency. The shape of the casing is defined by several factors; these are profiles angles, diameter and width. The whole amount of fluid flows through the discharge cross section, the amount of fluid is decreasing when going backwards in the spiral, from point of view of flow direction. Therefore, the area of the profiles is decreasing continuously as well, to fit the flow rate in the specific point of the pump casing. The result is a spiral shaped casing. The optimum properties of the spiral were found in experiments and expressed in formulae and diagrams. The fluid velocity is not uniformly distributed over a certain profile section. Modern Pumps are designed for a constant pressure and constant mean velocity in every profile section at the BEP. Apart from the BEP, the radial forces are out of balance resulting in a total radial force different to zero. This is important because the

Figure 32: Pump Casing

radial force bends the pump's shaft and results in higher wear at seals and could lead to shaft fatigue. To reduce most radial forces the pump casing can be designed as a double spiral casing. In this case the flow is splitted into two parts. Due to symmetry reasons, almost all radial forces cancel each other out. Another important part of the pump's casing are elbows in multistage pumps to deflect the flow from the previous stages discharge side to the suction side of the following. If a multistage pump is equipped with guide vanes, no elbows are necessary. As already mentioned, guide vane construction is only common at big or horizontal multistage pumps. Guide vanes work as a diffuser and convert the increased fluid velocity into pressure. It consists of extending channels arranged around the impeller. To ensure adequate pump life time, the pump's casing material should be selected carefully. Standard pump casings are made of cast iron but due to the fact that cast iron is not that resistant against cavitation, many pumps are coated or made from more wear resistant materials. Due to vibrations, the casing should have good damping properties. Pump casings are splitted either axial or radial to allow assembling and maintenance.

B. **IMPELLER:** The impeller is the essential part of a centrifugal pump. The performance of the pump depends on the impeller diameters and design. The pump's TDH is basically defined by the impeller's inner and outer diameter and the pump's capacity is defined by the width of the impeller vanes. In general, there are three possible types of impellers, open, enclosed and semi open impellers, each suitable for a specific application. Standard impellers are made of cast iron or carbon steel, while impeller for aggressive fluids and slurries require high end materials to ensure a long pump life. Impeller is a rotating component of a centrifugal pump, which transfers energy from the motor that drives the pump to the fluid being pumped by accelerating the fluid outwards from the centre of rotation. The velocity achieved by the impeller transfers into pressure when the outward movement of the fluid is confined by the pump casing. Impellers are usually short cylinders with an open inlet (called an eye) to accept incoming fluid, vanes to push the fluid radially, and a splined, keyed, or threaded bore to accept a drive-shaft.

Figure 33: Impeller

The impeller made out of cast material in many cases may be called rotor, also. It is cheaper to cast the radial impeller right in the support it is fitted on, which is put in motion by the gearbox from an electric motor, combustion engine or by steam driven turbine. The rotor usually names both the spindle and the impeller when they are mounted by bolts.

C. **SHAFT:** The shaft is the connection between impeller and drive unit which is in most cases an electric motor but can also be a gas turbine. It is mainly charged by a radial force caused by unbalanced pressure forces in the spiral casing and an axial force due to the pressure difference between front and backside of the impeller. Most common pump shafts are made of carbon steel. There are several cranks to support the bearings and seals. A high surface quality and small clearances are required. Especially in the areas of the bearing's, clearance and surface quality is important to ensure right positioning of the shaft in the casing and therefore close positioning clearances of the impeller. At the area of the seals, particularly the surface quality is important to ensure an adequate seal lifespan. In shaft design, it is also important to avoid small radius at cranks to minimize stress in these areas which are susceptible for fatigue.

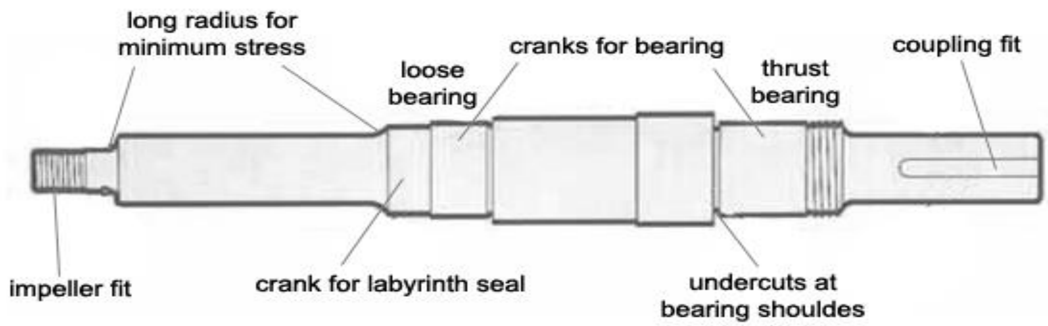


Figure 34: Shaft

D. **BEARINGS:** The bearings keep the shaft in place to ensure radial and axial clearance. The bearings lead radial and axial forces from the impeller into the casing. In double suction pumps bearings are located at both sides of the impeller as at single suction pumps all bearings are located behind the impeller. In horizontal process pumps, usually oil bath lubricated bearings are used. Medium and heavy duty process pumps are used in refineries, where highest reliability is required. In these pumps, axial loads are supported by universal single row angular contact ball bearings. In heavy duty process pumps, also matched taper roller bearings with steep contact angles, arranged face to face or back to back are used to support combinations of high radial and axial loads. In very high duty service and slurry pumps, spherical roller bearings can be used to support very high radial loads. A spherical thrust bearing is used to support axial loads. It is usually spring preloaded to ensure that sufficient load is applied during start up or pump shutdown. At vertical pumps, the thrust bearing can be a ball bearing with a spherical outer ring raceway, with the centre of the radius located on the bearing axis, providing a self-alignment capability. It is equipped with a 45° contact angle that enables the bearing to support large axial loads and moderate radial loads. If the pump is operated at its BEP, the bearing will only have to carry the rotating assemblies' weight, the stress due to interference fit of the shaft and in some cases manufacturer dependent preloads. Unfortunately, many bearings are overloaded because of wrong interference fit, shaft bend, solids, unbalanced rotating elements, vibrations, axial thrust and many more. This leads to increased stress and temperature and therefore to a decrease in lifespan. It is also important for the bearing's lifespan to protect it from fluid by adequate seals.

The different types of bearings are:

- **BALL BEARINGS:** Ball bearings are probably the most common type of bearing. They are found in everything from inline skates to hard drives. These bearings can handle both radial and thrust loads, and are usually found in applications where the load is relatively small. In a ball bearing, the load is transmitted from the outer race to the ball, and from the ball to the inner race. Since the ball is a sphere, it only contacts the inner and outer race at a very small point, which helps it spin very smoothly. But it also means that there is not very much contact area holding that load, so if the bearing is overloaded, the balls can deform or squish, ruining the bearing.

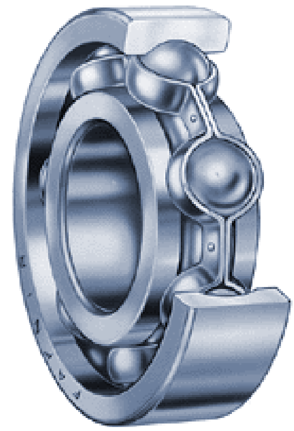


Figure 35: Ball Bearings

- **ROLLER BEARINGS:** Roller bearings are used in applications like conveyer belt rollers, where they must hold heavy radial loads. In these bearings, the roller is a cylinder, so the contact between the inner and outer race is not a point but a line. This spreads the load out over a larger area, allowing the bearing to handle much greater loads than a ball bearing. However, this type of bearing is not designed to handle much thrust loading. A variation of this type of bearing, called a needle bearing, uses cylinders with a very small diameter. This allows the bearing to fit into tight places.

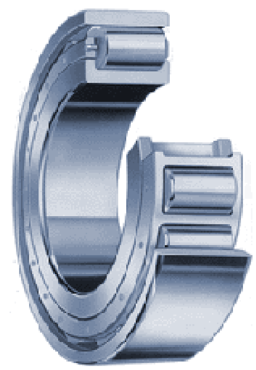


Figure 36: Roller Bearings

- **BALL THRUST BEARINGS:** Ball thrust bearings are mostly used for low-speed applications and cannot handle much radial load. Barstools and Lazy Susan turntables use this type of bearing.

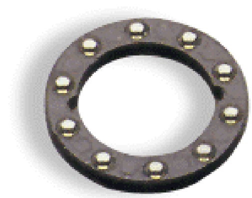


Figure 37: Ball Thrust Bearings

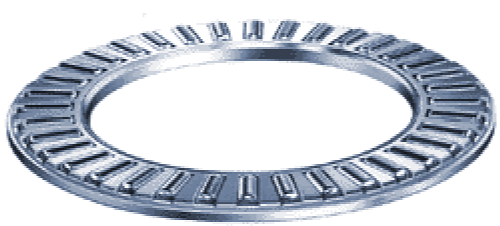


Figure 38: Roller Thrust Bearings

- **ROLLER THRUST BEARINGS:** Roller thrust bearings can support large thrust loads. They are often found in gear-sets like car transmissions between gears, and between the housing and the rotating shafts. The helical gears used in most transmissions have angled teeth, this causes a thrust load that must be supported by a bearing.

- **TAPERED ROLLER BEARINGS:** Tapered roller bearings can support large radial and large thrust loads. Tapered roller bearings are used in car hubs, where they are usually mounted in pairs facing opposite directions so that they can handle thrust in both directions.

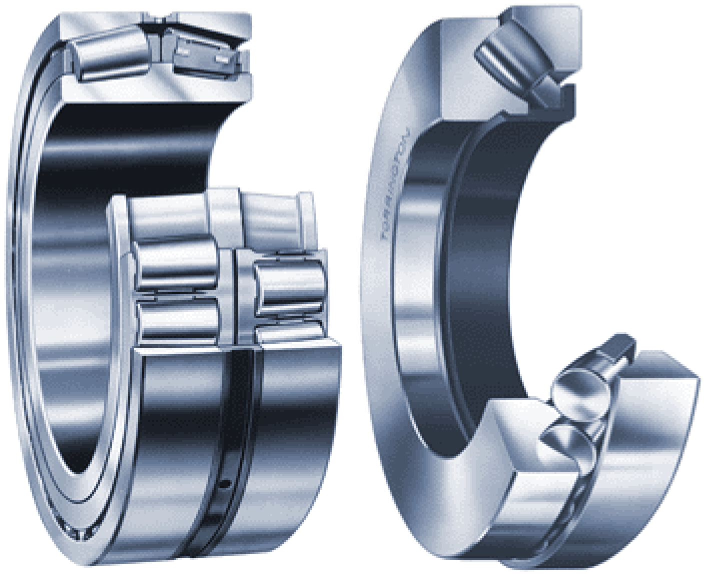


Figure 39: Tapered Roller Bearings

- **MAGNETIC BEARINGS:** Some very high-speed devices, like advanced flywheel energy storage systems, use magnet bearings. These bearings allow the flywheel to float on a magnetic field created by the bearing. Some of the flywheels run at speeds in excess of 50,000 revolutions per minute (rpm). Normal bearings with rollers or balls would melt down or explode at these speeds. The magnetic bearing has no moving parts, so it can handle these incredible speeds.

E. SEALING: To protect the bearings against fluid and prevent leakage, there are several seals fitted into the casing. Nowadays, rotary pumps are equipped with mechanical seals. A mechanical seal consists of primary and secondary sealing. In most cases the primary part, which is fitted to the casing, is made of a hard material like silicon carbide or tungsten carbide. The other, the rotating part of the primary seal is made of a soft material like carbon. Both parts are pressed against each other by e.g. a spring. The

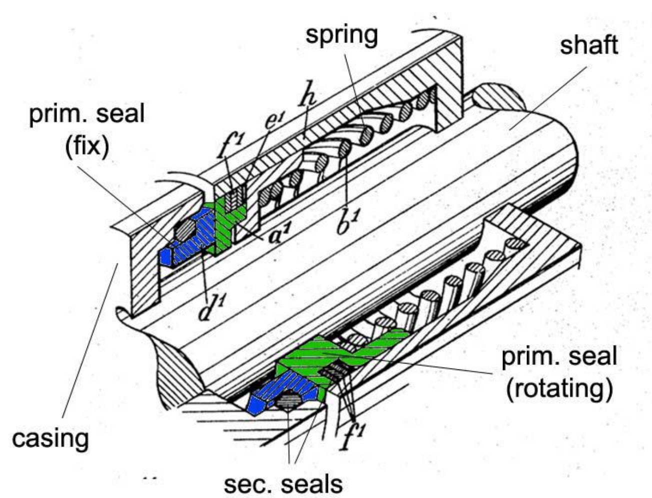


Figure 40: Mechanical Seal

secondary sealings are not rotating relative to each other and provide a fluid barrier. Mechanical seals can be separated into pusher/non-pusher seals, seal driving/spring compression, balanced/unbalanced and inside/outside mounting. Pusher seals will have a tendency to “hang up” when handling fluids which crystallize because the secondary seal member is not able to accommodate for travel. Whether applying a balanced or unbalanced seal will affect seal performance. Unbalanced seals see a high pressure at the impeller side and therefore have a reduced fluid film between the seal faces. This leads to overheating, rapid face wear and seal fatigue at early stages. To simplify maintenance many seals are available in cartridges which are pre-packed seal assemblies. To avoid any leakage when handling hazard fluids, double or tandem seals can be applied. In these seals, a secondary so called containment seal is placed after the primary one. The space in between is filled with a natural fluid called barrier or buffer fluid. These seals are very common in the petroleum industry. The difference between a tandem and a double seal is that in a double seal the barrier fluid is pressurised. Due to this, in case of primary seal fatigue the pressurised barrier fluid streams into the pumps instead of the hazard fluid into the atmosphere. The seal materials must fit the fluid to ensure accurate seal lifespan. The standards of modern mechanical seals are widely defined by API Standard 682 - Shaft Sealing Systems for Centrifugal and Rotary Pumps.

8.5. PUMP PARAMETERS AND SELECTION:

There are several parameters depending on impeller design, diameter, RPM etc., characterising a pump. The most important pump parameters are as follows:

I. **TOTAL DYNAMIC HEAD (T.D.H.):** Head in general is used to define energy supplied to a liquid by a pump and is expressed in units of length. In absence of any velocity it is equal to the height of a static column of fluid that is supported by a pressure in the point of datum. Total dynamic head (TDH) is the difference between total dynamic discharge head and total dynamic suction head. Total dynamic discharge (suction) head is practically the pressure read from a gauge at the discharge (suction) flange converted to length units and corrected to the pump centre line plus the velocity head at the point of the gauge. These two values represent the total amount of energy of the fluid at the discharge and suction flange of the pump. Mathematically it is the sum of static discharge (suction) head and velocity at the discharge (suction) flange minus total friction head in the discharge (suction) line. The difference of these values gives you the THD which represents the energy added to the fluid. TDH does not depend on the delivered fluids density. A higher density only increases the pressure and therefore the required power at a constant flow rate.

$$\boxed{\begin{aligned}&TDH=h_d-h_s\\&TDH=(z_2-z_1)+\frac{(p_2-p_1)}{\rho\times g}+\frac{(v_2^2-v_1^2)}{2\times g}\end{aligned}}$$

II. **FLOW RATE (Q):** (Volumetric) Flow rate is the volume of fluid passing through the pump per unit of time. It is calculated as area times fluid velocity. It depends on the impeller geometry and RPM. Impellers are optimised for highest outlet velocities. Multiplied by the useable impeller inlet area gives the flow rate. An impeller is designed for a maximised flow rate at a specific speed depending on its diameter. This is called the point of best efficiency.

$$\boxed{Q=A_1\cdot v_1=A_2\cdot v_2}$$

III. **NET POSITIVE SUCTION HEAD (N.P.S.H.):** NPSH is defined as total suction head above the suction nozzle and corrected to datum, less the vapour pressure of the fluid converted into length units. It analyses energy condition on the suction side of the pump to determine whether the liquid will vaporise at the lowest pressure point of the pump. Vapour pressure is a characteristic fluid property increasing with increasing temperature. It indicates the pressure at which a fluid starts boiling, causing bubbles which move along the impeller surface to an area of higher pressure where they collapse rapidly and cause significant harm to it. By decreasing the pressure, the temperature at which this happens also decreases. So, if the pressure is low enough it is possible to see this effect even at surrounding temperature. This effect is known as cavitation and should necessarily be avoided. It is obvious that in order to pump a fluid in an effective way it should be a liquid. Therefore, NPSH required ($NPSH_R$) is the total suction head required to prevent the fluid from vaporising at the lowest pressure point of the pump. $NPSH_R$ is a function of pump design as the pressure at the impeller decreases by accelerating the fluid along the impeller. There are also pressure losses due to shock and turbulences as the fluid strikes the impeller. To overcome all these pressure drops in the pump and maintain the fluid above vapour pressure a certain positive suction head is required. $NPSH_R$ varies with flow rate and speed within any particular pump. The available NPSH is a function of the system in which the pump operates. To avoid cavitation $NPSH_A$ must be bigger than $NPSH_R$. In practise the $NPSH_A$ can be determined by a gauge on the suction flange of the pump and the following formula. It is also common to add a certain safety value to the $NPSH_R$ to make sure that there is enough suction head to prevent the fluid from vaporising.

$$NPSH_A = NPSH_R + 0.5 \text{ m}$$

$$NPSH_A = \frac{\left(p_1 + p_e + \frac{v_1^2 \cdot \rho}{2}\right) - p_v}{\rho \cdot g} + \Delta z_{1,2}$$

IV. **SPECIFIC SPEED (N_S):** Specific speed is a value to characterise the shape of a impeller. Low specific speed characterises a radial impeller and is increasing up to high specific speed at axial impellers. Impellers in between are known as Francis-vane and mixed-flow impeller. Specific speed is only of designing engineering significance used to predict pump characteristics.

$$\boxed{n_s = n \cdot \frac{\sqrt{Q_{BEP}}}{TDH_{BEP}^{\frac{3}{4}}}}$$

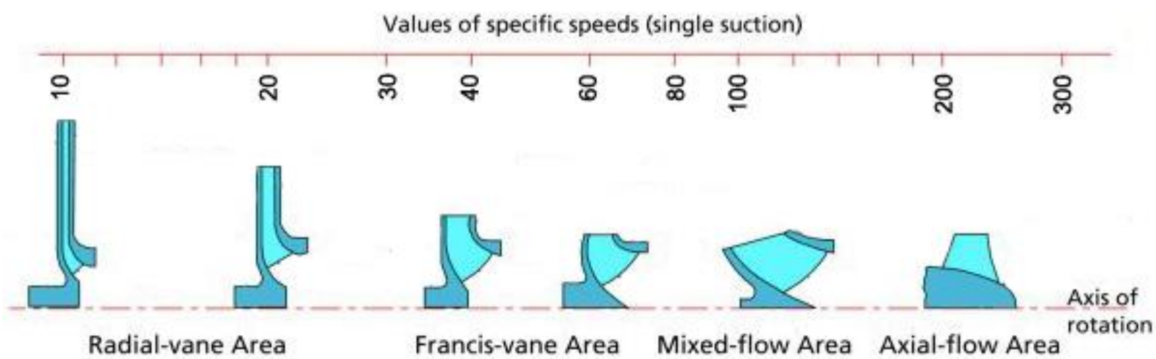


Figure 41: Impeller Types Based on Specific Speed

V. **POWER AND EFFICIENCY (P, η):** The work performed by a pump is a function of THD, flow rate and the specific gravity of the fluid. Pump input (P) or brake horse power (bhp) is the actual power delivered to the pump shaft. Pump output (P_{hydr}) or hydraulic horse power (whp) is the energy delivered to the fluid per time unit. Due to mechanical and hydraulic losses in the pump, P_{hydr} is always smaller than P. Therefore, efficiency is defined as P_{hydr} divided by P. The impeller geometry is optimized to provide highest flow rate at a certain speed at a given diameter at its point of best efficiency (BEP). If operating a pump off its (BEP), losses due to increasing turbulences and recirculation will increase and reduce efficiency. These effects are caused by a mismatch of the pump's design flow rate and the actual flow rate. The difference between inlet vane angle and approaching flow angle is increasing as moving away from the BEP as well as losses between impeller vane exit and the diffuser. Result of this is an increased flow between the impellers shrouds and the casing.

$$\boxed{P_{hydr} = \rho \cdot g \cdot Q \cdot TDH}$$

$$\eta = \frac{P_{hydr}}{P} = \frac{\rho \cdot g \cdot Q \cdot TDH}{P}$$

VI. AFFINITY LAWS: These laws express relationships between several variables involved in pump performance such as flow rate, impeller diameter, head and power. There are two ways to express these relationships: either holding the impeller diameter or the rotation speed constant. Affinity laws apply to radial pumps as well as axial pumps.

Constant Impeller Diameter:

$$\frac{Q_1}{Q_2} = \frac{n_1}{n_2} \qquad \frac{TDH_1}{TDH_2} = \left(\frac{n_1}{n_2}\right)^2 \qquad \frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3$$

Constant Rotation Speed:

$$\frac{Q_1}{Q_2} = \frac{D_1}{D_2} \qquad \frac{TDH_1}{TDH_2} = \left(\frac{D_1}{D_2}\right)^2 \qquad \frac{P_1}{P_2} = \left(\frac{D_1}{D_2}\right)^3$$

8.6. PROBLEMS IN CENTRIFUGAL PUMPS: A major problem at centrifugal pumps is, like at all fast moving parts in a fluid, cavitation. Other difficulties obtain solid handling, abrasives and corrosives as well as leakage. Most errors during pump operation can be avoided by selecting a quality pump designed for the application and adequate maintenance.

1) **CAVITATION:** Cavitation occurs when the static pressure in a fluid is lower than the fluid's vapour pressure, mostly caused by high velocities. Due to Bernoulli's law, static pressure decreases when velocity is increasing. If this happens, the fluid locally starts boiling and forms gas bubbles which need more space than the fluid would take. In a centrifugal pumps' impeller, the bubbles are moving to an area of decreasing pressure. If the pressure now exceeds the vapour pressure, the gas condensates at the bubble's inner surface and so collapse rapidly. This implosion of gas bubbles causes high, temporarily pressure fluctuations of up to a few 1000bar. As the fluid flows from higher to lower pressure, this flow causes a jet of the surrounding fluid, which may hit the surface. These high energy micro-jets cause high compressive stress weakening the material. Finally, crater-shaped deformations and holes known as cavitation pitting occur. Other reasons for cavitation can be a rise of fluid temperature, a low pressure at the suction side or an increase of delivery height. Cavitation in centrifugal pumps mainly occur at the impeller leading edges but also at the impeller vane, wear rings and thrust balance holes. To avoid cavitation, it is important to deliver sufficient NPSH and to keep fluid temperature low. High fluid temperatures can occur if the pump is on to keep the pressure up but no fluid is

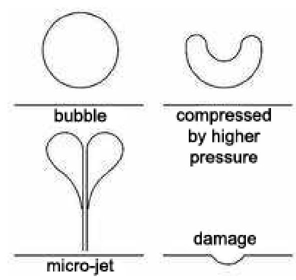


Figure 42: Cavitation

taken out. The harm of cavitation to the impeller and other parts of the pump is significant.

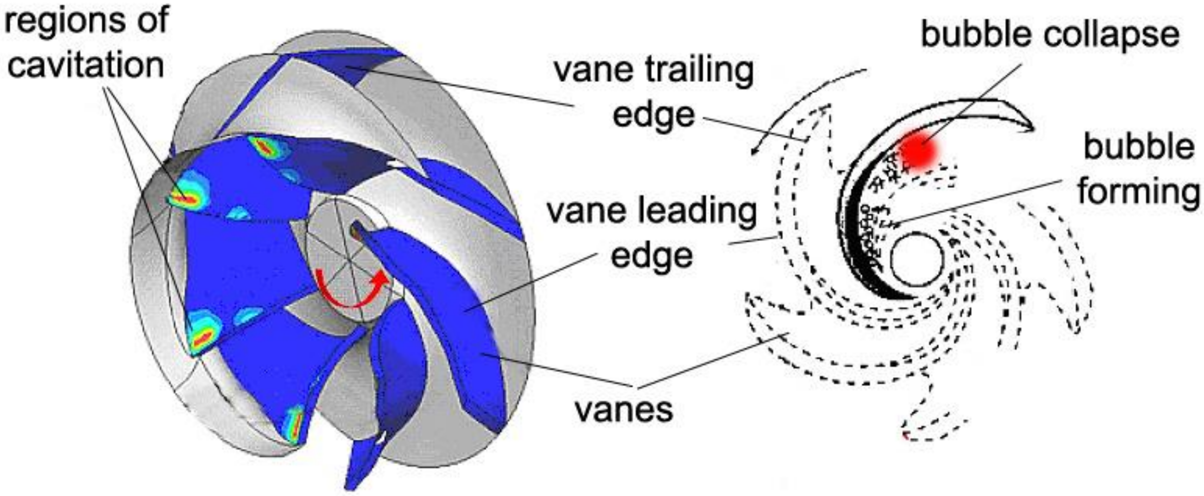


Figure 43: Cavitation Process

Figure 44: Cavitation Effect

2) **CORROSION:** Corrosion is breaking down of essential properties in a material due to chemical or electrochemical reactions with its surroundings. As there is a wide range of pump applications within the chemical industry, including the petroleum industry, handling oil and gas up to high aggressive acids it is important to provide pumps that can be operated under these difficult conditions. There are several types of corrosion and many factors it depends on, like fluid temperature, contained elements and pH-value. Most common and dangerous corrosion in pumps is the so called uniform corrosion. This is the overall attack of a corrosive liquid on a metal. The chemical reactions between fluid and metal surface lead to uniform metal loss on the moistened surface, known as

corrosive wear. To minimize corrosive wear, it is important to select a resistant pump material.

3) **SOLIDS AND SLURRY HANDLING (ABRASIVE MEDIA):** When expecting solids in the fluid or dealing with slurries, it is important to select a pump that is designed for this application. On the other hand, slurry pumps are much more expensive than a standard water pump, so the decision is not that easy. There is a very wide range of slurries which can be divided into three categories, light, medium and heavy slurries. To provide a pump that can be used with slurries, special design features must be made. Slurry pumps can be equipped with e.g. thicker wear sections, larger impellers, special material and semi-volute or concentric casing. All these features extend pump lifespan but also cause disadvantages like higher initial costs, higher weight or less efficiency. Slurry pumps can be separated into two main categories, rubber lined and hard metal pumps. At rubber lined pumps, the inner surface is covered by a layer of rubber, to absorb solid's impact energy. Rubber lined pumps have a limited application range. This type of wear prevention is only suitable for light at least for medium slurries at low head applications. Also, the fluid temperature should not exceed 150°C. Rubber lined pumps are not applicable for hydrocarbon based slurries. On the other hand, hard metal pumps are suitable for high power applications used at even heavy slurries. Hard metal slurry pumps can also handle sharp, jagged solids even at fluid temperatures above 150°C. Standard hard metal slurry pumps can be designed of hardened steel but for high corrosive fluids high alloyed steels are used. When selecting a hard metal pump, it is important that the pump material is harder than the solid particles. Cartable ceramics provide excellent resist to erosion but limit impeller tip velocity. The lifespan of a pump can be increased by selecting the correct materials of construction. Another important factor when handling slurries is speed. By decreasing the pump's R.P.M. the fluid speed is also decreasing and therefore the solid's speed is decreasing too. This leads to lower impact energy and less wear. Experiments by pump manufacturers have shown that a slurry pump's wear rate is proportional to speed raised by the power of 2.5. Therefore, by decreasing the speed of a slurry pump by half, this will lead to approximately 6 times lifespan. For this reason, most slurry pumps are operated at slowest speed possible equipped with impeller large in diameter to increase pump lifespan.

8.7. PRIMING: Priming in simple words means to get something ready for operation. For a centrifugal pump priming means that the pump casing must be filled with liquid before the pump is started, or the pump will not be able to function. If the pump casing becomes filled with vapours or gases, the pump impeller becomes gas-bound and incapable of pumping. To ensure that a centrifugal pump remains primed and does not become gas-bound, most centrifugal pumps are located below the level of the source from which the

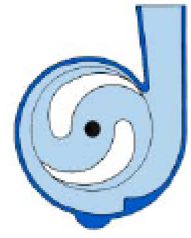


Figure 45: Priming

pump is to take its suction. The same effect can be gained by supplying liquid to the pump suction under pressure supplied by another pump placed in the suction line. 80% of centrifugal pump problems are caused by not priming a pump or not doing it properly. Priming a pump is probably the first and one of the most important thing that should be done before operating it. While centrifugal pumps are relatively inexpensive, the downtime of the system due to a malfunctioning pump might be costly.

Enough liquid for priming can be stored in a specially designed pump casing, resulting in a centrifugal pump that is self-priming. During priming the liquid is recirculated within the casing. Gas from the suction port mixes with the liquid in the pump. The impeller repeatedly ejects the mixture back into the casing. The liquid sinks to the bottom of the casing, where it re-enters the pump along with more gas from the suction port. Gradually the gas is expelled from the pump into the discharge line, and the suction line fills with liquid. Normal centrifugal pump operation begins thereafter. Most centrifugal pumps are not self-priming.

9. CASE STUDY ON MULTI-STAGE CENTRIFUGAL PUMP:

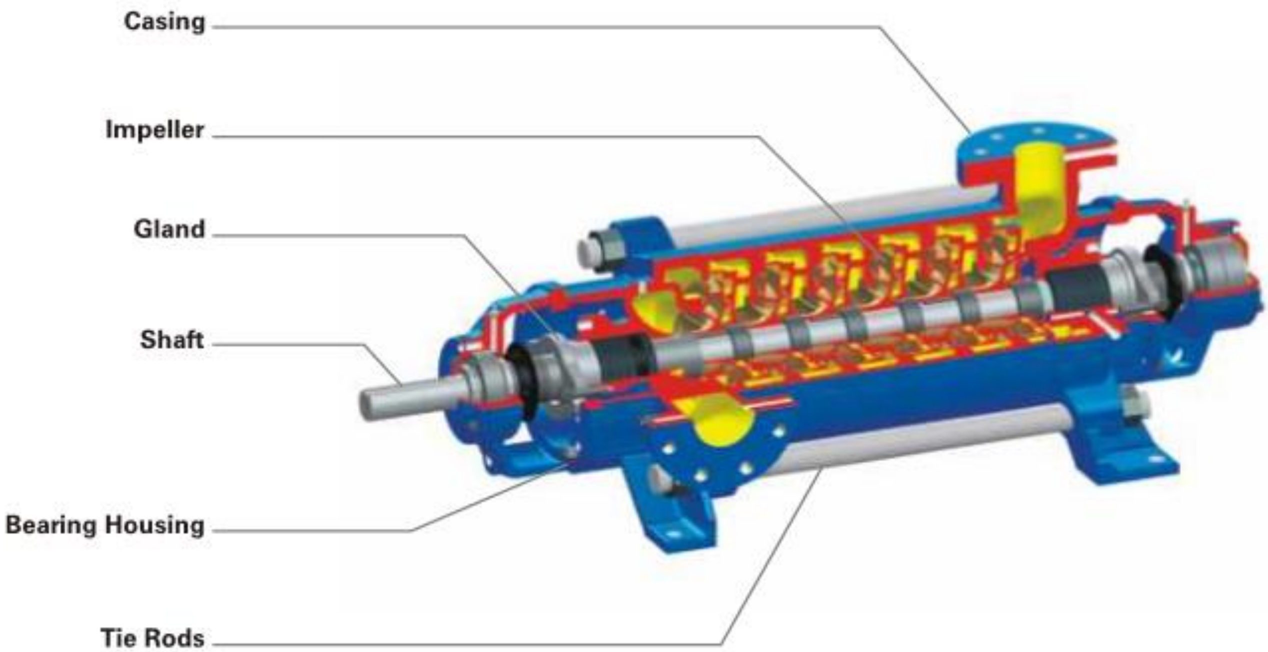


Figure 46: Multi Stage Centrifugal Pump

PUMP TYPE: RKB 32 – 9E.

PLANT: ARU CCR N_2.

JOB ORDER: 50036758.

9.1. PUMP SPECIFICATIONS:

- Company: Kirloskar Brothers Limited (K.B.L.).
- Number of stages/impellers: 7.
- Number of Vanes in impellers: 5.
- Section: Horizontal Section
- Suction type: Single Suction.
- Impeller Type: Closed Impeller (5 balancing holes).
- Impeller Diameter: 115 mm.
- Direction of Rotation: Clockwise when viewed from D.E.
- Suction Diameter: 40 mm.
- Delivery Diameter: 32 mm.
- Head Range: 5 – 70 m (1450 rpm, 50 Hz).
  35 – 210 m (2900 rpm, 50 Hz).
- Discharge Range: 1 – 6 m^3/hr (1450 rpm, 50 – Hz).
  4.5 – 5 m^3/hr (2900 rpm, 50 – Hz).
- Suction Velocity: (Discharge/Suction diameter) = (6/0.001256) = 4774.65 m/hr.
- Delivery Velocity: (Discharge/Delivery diameter) = (6/0.000804) = 7460.4 m/hr.
- Temperature range: -30^{o}C to 90^{o}C.
- Bearing details:
  1) D.E.: 6306 (Deep Groove Bearing).
  2) N.D.E.: NU 306 ECP (Roller Bearing).
  3) Lubrication used: Grease (AA 22S, MAK Lanthax EP2).
  4) Maximum Temperature: 80^{o}C.
- Gland Material: Graphite, Size = 10 mm square.
- Material of Construction:
  1) Impeller: Brass.
  2) Shaft: Chromium Plated Stainless Steel.
  3) Casing: Cast Iron.
- ‘O’ Ring Material: Nitrile Rubber.
- Key Sizes:
  1) Key for Coupling: 8 x 7 x 54L.
  2) Key for First Impeller: 6 x 4 x 25L.
  3) Key for Stage Impeller: 6 x 4 x 14L.
  4) Key for Last Impeller: 6 x 4 x 44L.
- Oil Seal:
  1) Material: Nitrile Rubber with Steel Springs.
  2) Size: 40 x 52 x 7 Thick.
- Torque for Tie Bar Nuts: 9 Kg. m.

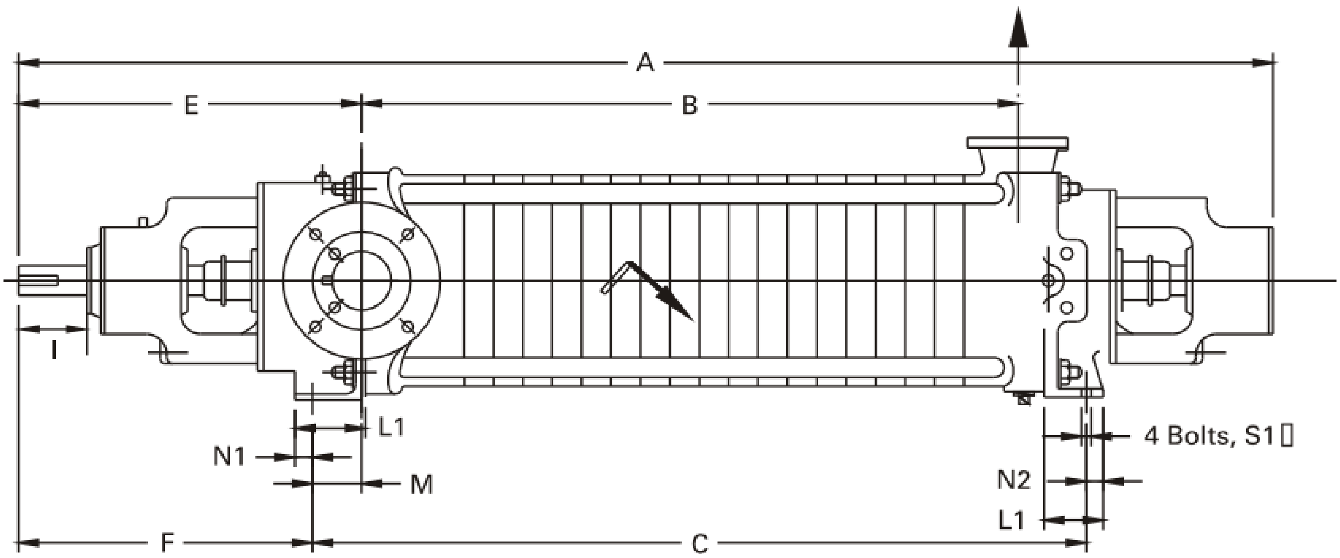


Figure 47: Pump Dimensions

- A = 817 mm.; B = 352 mm.; C = 442 mm.; E = 269.5 mm. F = 209.5 mm.
- Weight of the pump = 87 kg.

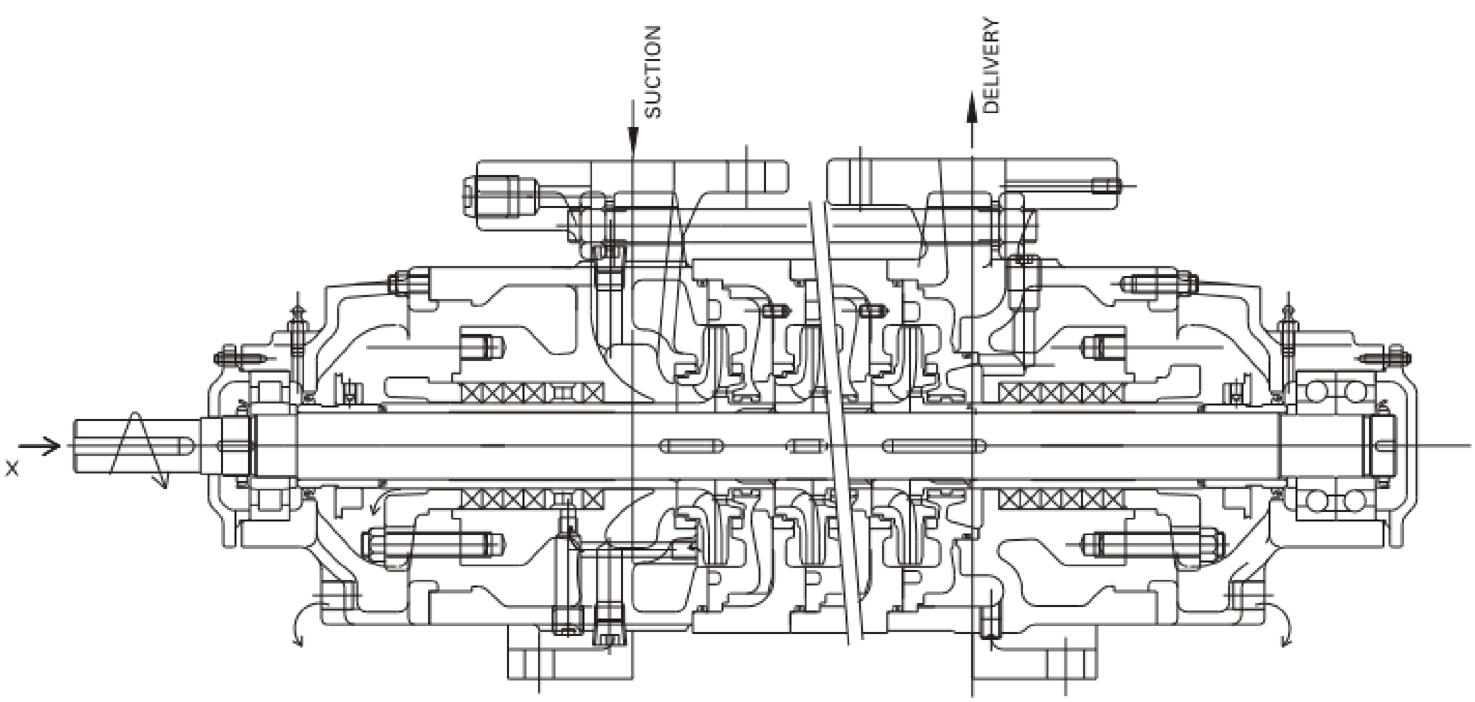


Figure 48: Sectional View

- Suction Flange: DIN ND – 10.
- Delivery Flange: DIN ND – 40 or ND – 64 (vertical).

- Application: Cooling water pump, Salt water pump

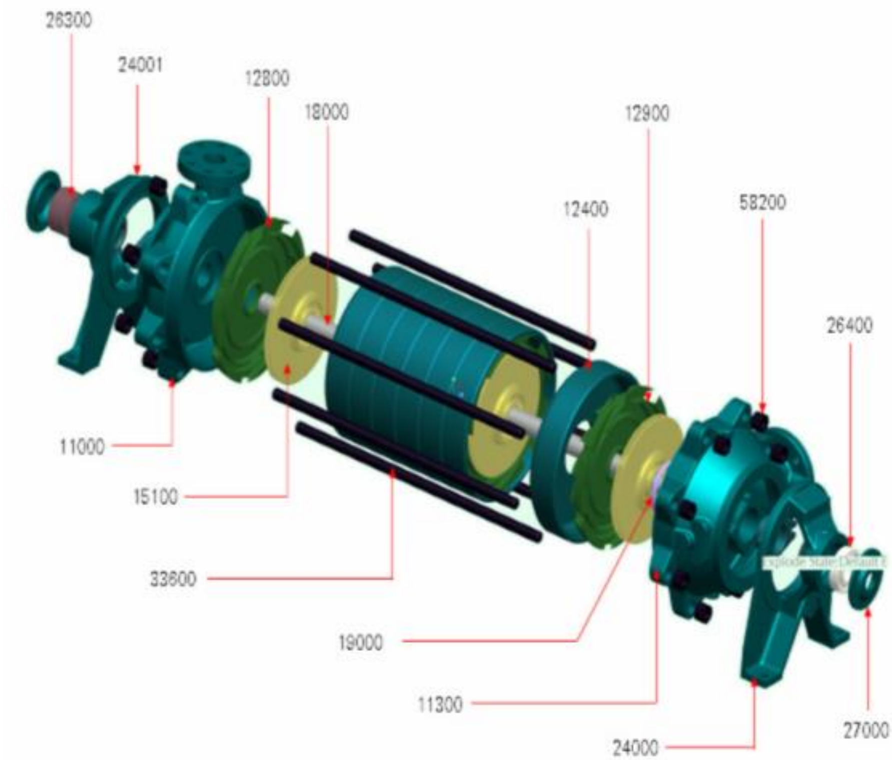


Figure 49: Exploded View

Where, 26300 – Deep Groove Bearing (1).
24001 – Bearing Housing N.D.E. (1).
11000 – Delivery Casing (1).
12800 – Diffuser (1).
15100 – Enclosed Impeller (7).
18000 – Pump Shaft (1).
33600 – Bearing Lock Nut (2).
12900 – Diffuser with guide vanes (6).
11300 – Suction Casing (1).
58200 – Hexagonal Nut for gland stud (4).
24000 – Bearing Housing D.E. (1).
26400 – Roller Bearing D.E. (1).
27000 – Bearing Cover D.E. (1).

9.2. PUMP HISTORY: Prior to the current maintenance, the pump was previously brought on 28/07/2016. It was found that both the sleeves had been badly rubbed. Hence, both the sleeves had to be replaced. All packing ('O' ring) had to be replaced.

9.3. PROBLEM AND PROBABLE CAUSES: At the operation site (i.e. Aromatic Reforming Unit or A.R.U.), it was detected that the pump does not provide adequate head (pressure). Hence, it was sent to the Central Engineering Workshop for check – up/maintenance. The probable causes for reduction in head are:

1. Air leaking through the suction line and stuffing box etc.
2. Insufficient venting.
3. Number of revolutions too high.
4. Number of revolutions too low.
5. Impeller clogged.
6. Impeller damaged.
7. Casing rings worn out.

9.4. DISMANTLING: After the arrival of the pump in the Central Engineering Workshop, the first step in the maintenance process is the dismantling of the pump. While dismantling and re-assembling, the cross-sectional assembly drawing and specification part list should be referred. The procedure for dismantling is as follows:

1. Ensure that the pump is drained out completely from the liquid by removing the drain plug or open the pump casing drain cock.
2. Remove all auxiliary tubing and piping and place the pump horizontally on a plain table/platform.
3. Loosen the coupling using rotary fitter and remove the pump half coupling.
4. Unlock the lock nuts followed by the End cover on the driving end and non-driving end of the pump.
5. Loosen the gland at D.E. and N.D.E.
6. Take out bearing cover at N.D.E.
7. Unlock lock washer and unscrew the lock nut.
8. Take out bearing housing along with bearings (deep groove bearings). For this purpose, use two jaw puller. Do not use hammer to remove the bearing/bearing housing.
9. Remove adjustable washer, liquid deflector, distance sleeve, gland, ‘O’ ring and shaft sleeve.
10. Unscrew the tie rod nuts, remove washers of tie bar.
11. Take out delivery casing and take out tie bars.
12. Remove diffuser from the delivery casing along with ‘O’ ring.
13. Take out impeller and then remove key. Remove stage casing along with ‘O’ ring.
14. Repeat the above step until the first stage impeller is reached.
15. Now start dismantling from D.E. Remove bearing cover.
16. Unlock lock washer and unscrew lock nut.
17. Take out bearing housing along with roller bearing outer race.

18. For gland packed pump, remove gland packing from stuffing box and take out the entire shaft out of suction casing along with shaft sleeve, distance sleeve, deflector, gland and inner race of roller bearing, etc.

9.5. PHOTOS OF THE DISASSEMBLED PUMP:

Figure 50: Discharge Casing

Figure 51: Roller Bearing & Bearing Housing

Figure 52: Shaft

Figure 53: Gland Pusher

Figure 54: Impeller


Figure 55: Diffuser

9.6. CLEANING: The next stage after dismantling is the cleaning of the different parts of the pump. The deposit and rust which were formed on the various parts of the pump is cleaned by using metallic buffer. It is used to clean each component of the pump. The equipment consists of metallic wire brush fixed on a rotating disc which rotates. As the disc rotates, the brush is rubbed against the component to be cleaned. The brush removes the deposits on the components thus performing the cleaning operation.

9.7. CHECK LIST: After cleaning of the various parts is done, the next step is to prepare the check list. The check list is prepared to find out the various tolerances of the pump. The check list of the prepared is as shown:

No. 039 **MACHINE SHOP** Date : 21/06/2017

MULTI - STAGE PUMP - CHECK LIST REPORT Name :

Pump No. CCR . N - 2 P-01A Unit ARU.CCR.

Make ______ No. of Vanes 5

Problem Reported Now ______ Impeller Dia. 115mm

Major Findings ______

GENERAL INFORMATION

Direction of rotation ~~CW/CCW~~ from DE

Impeller Distance from ND ______ mm / DE ______ mm

Casing / Drum gasket thickness ______ Material ______

PUMP COMPONENTS

1. Casing & Stuffing box condition O.K Stuffing box tested at ______
2. Bearing housing cooling jacket tested at ______ Circlip /Oil Ring / Oil Chain ______

   Deflector Condition O.K clearances on shaft ______

   Oil seal No. ______ & ______ Baffle / felt / bearing cover condition OK
3. Coupling type Love Jaw series ______ / fitment on shaft S-S / dist. from shaft face ______
4. Shaft run out ______ / locknut fitting ______ / impeller fitment on shaft ______
5. Bearing DE No. 306 EC fitment on shaft S-S in brg. housing ______

   NDE No. 6306 fitment on shaft S-S in brg. housing ______

   Bearing spacer DE ______ thk inner / outer race NDE ______ thk inner / outer race
6. Thrust balancing disc/ drum condition ______ counter balancing disc ______

   Fitment on shaft ______ balancing line condition ______

~~MECHSEAL~~ /GLAND PACKING

MECH SEAL TYPE : Single seal / Multi - spring / bellow / cartridge Make & Size ______

1. Mechanical seal faces condition DE ______ NDE ______
2. Secondary Packing Condition ______ / Comp. Unit Condition ______
3. Sleeve Condition ______ / fitment on shaft ______
4. GLAND PACKED PUMP :

   GLAND PUSHER (~~Split~~ / One Piece) ______ / lantern ring ______

Form No. : 10129

Figure 246: Check List Page 1

CLEARANCES

Existing Maintained

1. Neck Bush DE – 0.017" ND · 0.016"
2. Throttle Bush

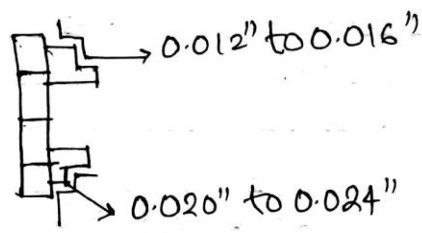
IMPELLER	Condition	Front Cls	Back Cls	Fitment on Shaft	BUSHES	Drum Cls	Fitment on Shaft
DE Impeller No. 1	O.K		0.008"	0.002" loose	Bush 1	0.012"	
Impeller No. 2	O.K		0.008"	0.002" lose	Bush 2	0.011"	
Impeller No. 3	O.K		0.008"	0.002" lose	Bush 3	0.012"	
Impeller No. 4	O.K		0.008"	0.002" lose	Bush 4	0.010"	
Impeller No. 5	O.K		0.008"	0.002" loose	Bush 5	0.011"	
Impeller No. 6	OK.		0.008"	0.002" loose	Bush 6	0.012"	
NDE Impeller No.7	OK		0.008"	0.002" loose			

Clearances to be maintained impeller front ____________ back ____________ Bush to drum cls ______________

ANY OTHER INFORMATION / SUGGESTION

1] Both thr. sleeves (N.D.E & D.E) to be replaced

2] Imp. front clearance



MACHINING / WELDING JOBS

Figure 57: Check List Page 2

9.8. SHAFT TRUENESS: Shaft Trueness is machine line up process carried out on the shaft of the pump. Shaft Trueness is carried out to ensure that the shaft of the pump is free from any defects such as bent, eccentricity, etc. and that it is perfectly straight. On rotating machinery such as a pump, runout is defined as the degree to which a shaft or coupling deviates from true circular rotation. Run out is caused by a bent shaft or by eccentricity of the coupling. Eccentricity is caused by if the coupling is not bored in its physical centre or if the bore is bigger that the shaft.

The shaft trueness is checked as follows:

1. The shaft is secured firmly between the head stock and tail stock of the Lathe Machine.
2. The dial indicator is mounted to a fixed point is space and perfectly perpendicular to the shaft.
3. The shaft is then rotated about its axis. Ensure that the shaft rotates only in one direction.
4. The total runout of the shaft is measured using the dial indicator. If the runout is within acceptable limits (0.002" or less) then the coupling must be bored properly enough and the shaft is reasonably straight and within acceptable limits.
5. If excessive runout is observed, then we have to find out if it is caused by the bent shaft or eccentric coupling or at times even both.
6. The measurement is carried out on the shaft and as close to the coupling as possible. If the dial indicator shows large deflection then the runout is caused by the bent shaft.
7. If the measurement at the shaft had been close to 0 then the problem would have been eccentricity of the coupling.
8. If excessive runout is observed then machining processes such as turning, welding, etc. have to be carried out before assembly.
9. At times, the measurement is even carried out along the axis of the shaft and on the coupling to determine if the shaft is skewed.

In this pump, there was no runout. Hence the shaft is perfectly straight.

9.9. BALANCING: The process of rectification of the different types unbalance is called as Balancing. As per the unbalancing, mass is either added or removed by machining processes such as welding and turning respectively.

A. STATIC UNBALANCING: Static Unbalance is the condition of unbalance for which the central principal axis is displaced only parallel to the shaft axis. It's a condition that exists when the centre of mass is not on the rotation axis. Static unbalance by itself is typically measured and corrected on narrow disc-shaped parts. To correct the static unbalance requires only one correction. The amount of unbalance is the product of the mass and radius. This type of unbalance is a vector, and therefore, must be corrected with a known mass at a particular angle.

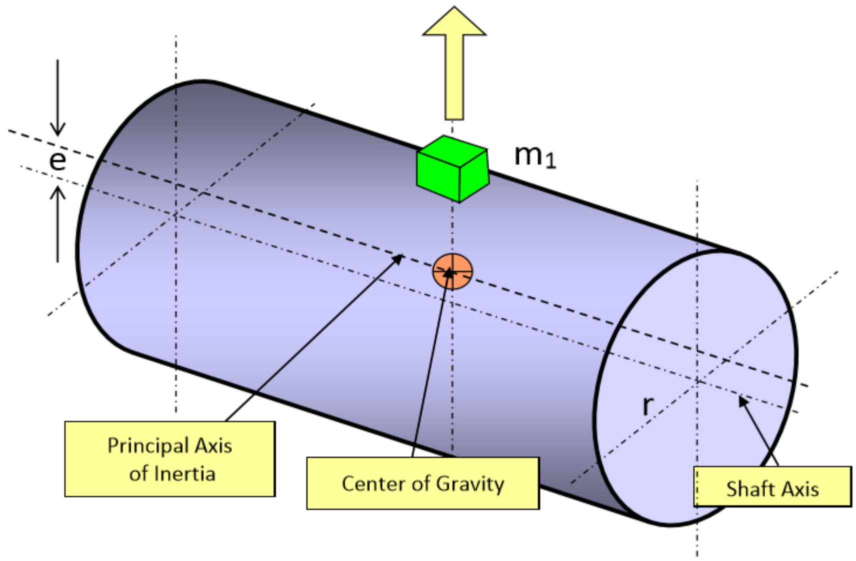


Figure 58: Static Unbalance

B. **COUPLE UNBALANCING:** Couple Unbalance is the condition of unbalance for which the central principal axis intersects the shaft axis at the centre of gravity. A couple is a system of two parallel forces, equal in magnitude and acting in opposite directions. A couple causes a moment or torque proportional to the distance between the parallel forces. Its effect is to cause a twisting or turning motion. It is a specific condition that exists when the principal inertia axis is not parallel with the axis of rotation. To correct the couple unbalance, two equal weights must be added to the rotor at angles 180° apart in two correction planes.

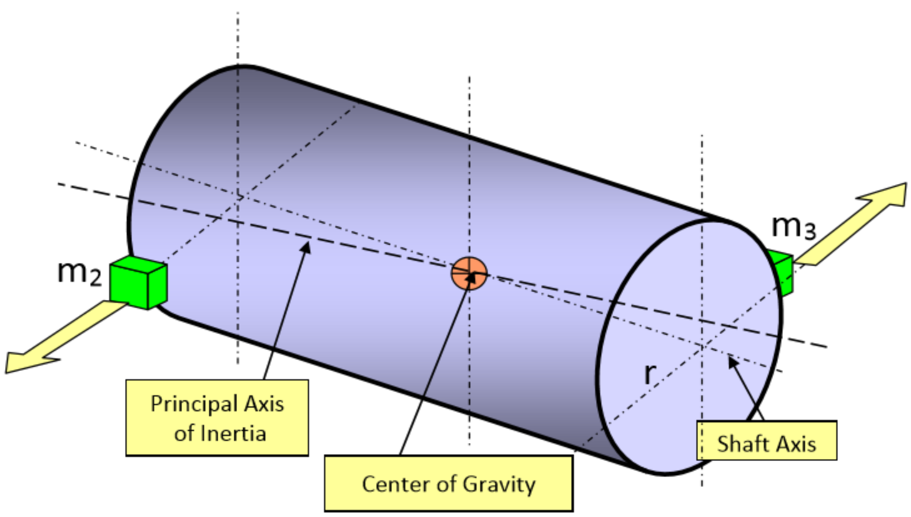


Figure 59: Couple Unbalance

C. **DYNAMIC UNBALANCING:** Dynamic Unbalance is the condition of unbalance for which the central principal axis is not parallel to and does not intersect the shaft axis. It may also be defined as a combination of static and couple unbalance at different angles.

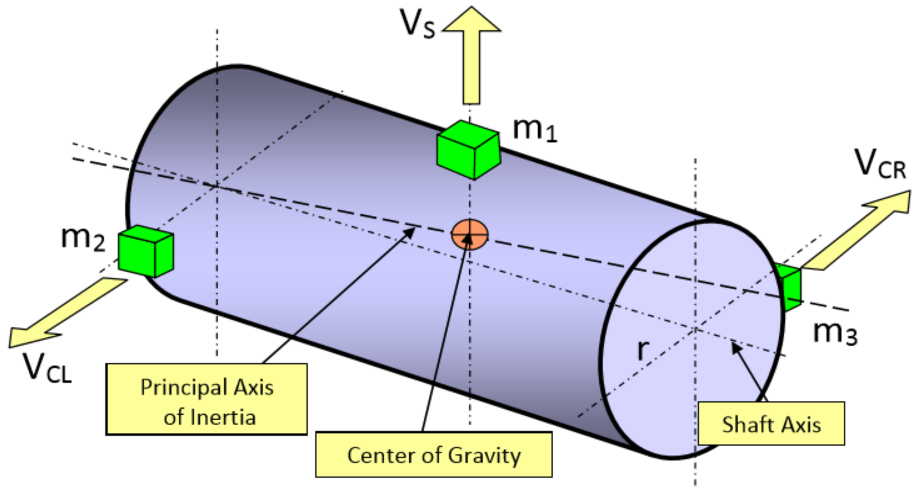


Figure 60: Dynamic Unbalance

9.10. RE-ASSEMBLY: After all the tests are carried out and the necessary rectification is done, the last stage is the re-assembly. Before re-assembly, all the parts should be thoroughly cleaned in kerosene, petrol or benzene to remove the dust, rust, etc. After cleaning, the necessary parts should be replaced.

1. Slide inboard ball bearing on shaft by hand, make sure that it is square with shaft. Press evenly the inner race of the bearing until bearing is seated firmly against the shaft shoulder.
2. Don’t use hammer to fit the bearings. Do not damage the shaft surface especially where it is in contact with oil seal.
3. All parts are free from burr and those are cleaned thoroughly with kerosene/ thinner.
4. Balancing holes provided on impellers are not chocked.
5. Replacement components such as ‘O’ rings, gland packing, keys etc. are of correct size.
6. Grub screw is fitted in the stage casings.
7. Drain plugs are fitted on suction casing & delivery casing body.
8. Air vent plug is fitted on suction casing body.
9. Check run out of shaft by dial gage. It should be within 0.05 mm.
10. Insert washer on the shaft.

9.11. MAINTENANCE PROCESS OF THE PUMP:

1. The maintenance process started with the dismantling of the pump as explained above.
2. Once the pump is completely dismantled, it’s each and every component i.e. rotary and static were cleaned with the metallic buffer.

3. Once the cleaning was done, the checklist of the various parts was prepared.
4. As per the checklist, parts such as sleeves, packing gland, bearings were changed.
5. Machine line up process such as Dynamic Balancing and Shaft Trueness were carried out on the shaft and impellers.
6. As there were no defects or errors detected through these tests, no machining processes were carried out on the components.
7. The horizontal re-assembly of the pump was carried out. However, it was found that there was no proper float given to the shaft (required float was 65 thou on each end of the shaft). Hence, the dismantling of the pump was carried out in the vertical position from the N.D.E. by placing the pump on a jack with a ball in between for proper grip. While doing so it was found that the key of 3rd impeller from the N.D.E. was not placed properly and also an extra impeller key was found. The re-assembly was carried out.
8. Later the dismantling again started from the N.D.E. and the extra key was found to be of the 4th impeller from the N.D.E.
9. Thereafter the regular re-assembly was carried out. Spacer of the required dimensions for the D.E. and N.D.E. were manufactured using the Lathe in order to get proper locking of the shaft. Graphite was used as the material for gland packing. The coupling was placed on the shaft at the D.E. and was tightened using the rotary fitter.
10. Pressure tests weren't carried out as gland packing was used in the pump.

9.12. CONCLUSION: After the completion of the maintenance process it was observed that there was no cause for the problem (i.e. decrease in head) in the pump as the clearances were also within limits. Hence it was concluded that the cause for problem must be on the operation site such as:

1. Suction pipe, foot valve choked.
2. Suction head too low (difference between pressure at suction connection and vapor pressure too low).
3. Nominal diameter of suction line too small.
4. Suction pipe not sufficiently submerged.
5. Too many bends in the suction line.
6. Clearance around suction inlet not sufficient.
7. Shut off valve in the suction line in unfavourable position.
8. Incorrect layout of suction line (formation of air pockets).
9. Valve in the suction line not fully open.
10. Joints in the suction line not leak-proof.
11. Suction lift too high.
12. Delivery liquid contains too much gas and/or air.
13. Delivery liquid too viscous.
14. Incorrect direction of rotation (electric motor incorrectly connected, leads of phases on the terminal block interchanged).

15. Separation of crystals from the flow of pumping liquid (falling below the temperature limit/equilibrium temp).
16. Type of pump unsuitable.
17. Incorrect choice of pump for existing operating conditions.
18. Voltage too low/power supply overloaded.

LIST OF FIGURES

REFERANCE

1. Instruction on Installation, Operation and Maintenance for Kirlosker Pump (Type RKB).
2. Catalogue for Multistage Pumps RKB Type by Kirlosker Brothers Limited.
3. Bachelor Thesis Centrifugal pumps by Christian Allerstorfer.
4. www.bharatpetroleum.com
5. Balancing Basic by MaintTech.
6. www.wikipedia.com
7. www.inspection-for-industry.com