Basics of Mechanical Engineering-3

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Week 11

Lecture 44: Basics of Turbines and Pumps

Welcome to the next lecture. In this course where we will try to see the Basics of Turbines and Pumps. These two are related.

Contents

- Turbomachinery
- Pumps
- Dynamic Pumps
- Positive Pumps
- Turbines
- Reaction Turbine
- Impulse Turbine

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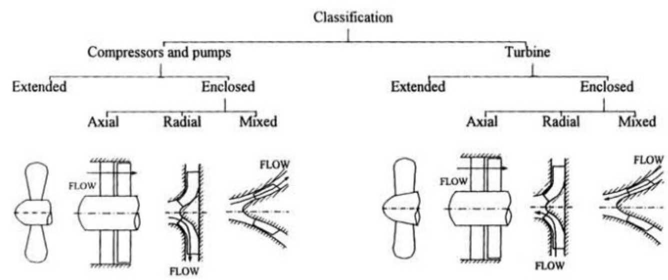
The content of the lecture will be: first, we will try to understand what turbomachinery is. Because there is a field exclusively in mechanical and aerospace engineering, they talk about turbomachinery. So we will try to see what turbomachinery is.

Then, pumps—what are the different types of pumps? We will try to focus on dynamic pumps and positive displacement pumps. And when we talk about turbines, we will try to look at reaction turbines and impulse turbines.

Turbomachinery

- Turbomachinery describes machines that transfer energy between a rotor and a fluid, including both turbines and pumps.
- While a turbine transfers energy from a fluid to a rotor, a pump transfers energy from a rotor to a fluid. It is an important application of fluid mechanics.



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Turbomachinery describes machines that transfer energy between a rotor and a fluid. It includes turbines and pumps. For example, when you try to extract water from your well, the water is sucked from the well and pushed to the overhead tank. So here, a rotor and a fluid interact with each other. The same way, when we talk about dialysis pumps, what happens is the liquid from one end is sucked inside, where it is purified and then injected or pushed back into the body. So you see that there is an interaction between the machinery and the fluid.

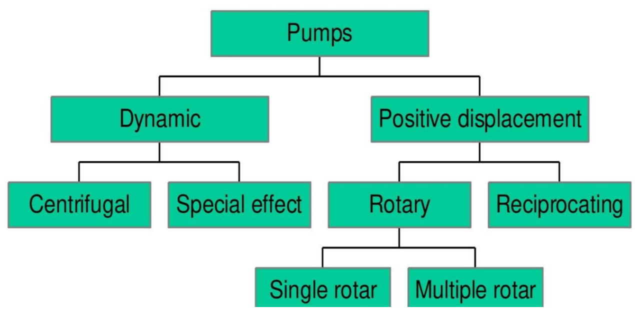
While a turbine transfers energy from a fluid to a rotor, a pump transfers from a rotor to a fluid. There is a difference. Friends, understand the difference. There is a transfer between fluid to rotor. When we saw the hydro power corporation and all, what they do is the fluid is used to push the rotor and then the rotor rotates from there they try to generate energy.

So, in pumps the electricity is given to the pump it rotates that is a rotor which rotates which tries to pressurize the fluid or take the fluid from a lower level to a higher level. It is an important application of fluid mechanics where both turbines and pumps are used. When we try to classify them they are classified into compressor and pumps the other one is turbine. They are equally classified if you see it is extended, it is enclosed. It is extended, it is enclosed.

That means to say it is open, it is closed. So then under enclosed you will try to see axial, radial and mixed. Here also you will try to see axial, radial and mixed. What is axial? Flowing along the axis is axial. When it is flowing along the radius, it is called radial. And the third one is a mix of these two, as they have said. So if you look at the flow, you can see it flows along. Here, the fluid flows along the radius. Here, it is a mix of both. Choosing this is very important because it dictates the efficiency of the machine.

Pumps

- Machines that deliver liquids are simply called pumps.
- The pump is the oldest fluid energy transfer device known.
- There are two basic types of pumps: positive-displacement and dynamic or momentum- change pumps.



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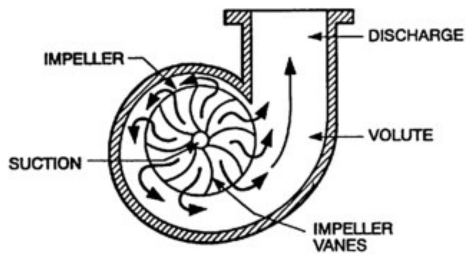
Pumps. Machines that deliver liquid are simply called pumps. This can have a very high flow rate. For example, it can be 100 liters per minute. From there, it can go to 10 ml per minute. Look at the range: 100 liters per minute and 10 ml per minute. It can go to both. In medical or microreactor applications, we go this low or even lower—down to 1 ml or less for delivery. So, machines that deliver liquid are simply called pumps. The pump is the oldest fluid energy transfer device known to us. There are two basic types of pumps. One is called a positive displacement pump, and the other is a dynamic or momentum change pump.

The dynamic is otherwise called a momentum change pump. Friends, we have seen what momentum is in our previous course. The classification of a pump. So, as I told you, it is positive and dynamic. Under positive, we further classify it into rotary and reciprocating. So, you have a piston where the piston is moving through a cylinder. So, it is moving through a cylinder. So, this is called reciprocating. When it is rotary, you will have a rotor. This rotor is rotated inside a casing. So, that is rotary. Again, in rotary, it is classified as single rotor and multiple rotor. When we talk about dynamic or momentum change pumps, they are classified as centrifugal pumps or special effect pumps. What are dynamic pumps?

Dynamic Pumps

- Dynamic pumps simply add momentum to the fluid by means of fast-moving blades or vanes or certain special designs.
- There is no closed volume.
- The fluid increases momentum while moving through open passages and then converts its high velocity to a pressure increase by exiting into a diffuser section.



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Dynamic pumps simply adds momentum to the fluid by means of fast moving blades or vanes or certain special design. So, here if you see, the discharge comes through this. If you see, this is a plane; it comes through this plane, right? So, when this fellow rotates—that is, when the impeller rotates—it is going to create something like a vacuum there.

So, now what happens is the water is sucked from or through a pipe on top of this impeller. Now, the impeller rotates. You can see when the impeller rotates, the distance between the impeller and the casing keeps increasing. So, this one is called a volute.

So, in the impeller, you will have vanes. These are vanes. The arc-like profile which is given—these are called vanes. So, water enters through this suction, then passes through these vanes, and then it is rotated inside the casing. This casing—the radius increases. So, the momentum increases when it is exiting out. So, that is why it is referred to as a certain special design. There is no closed volume. The fluid increases momentum while moving through the open passage. This is an open passage and converts its high velocity to a pressure increase by exiting into a diffuser section.

So here in fluid, you can do two things. One is you can increase or decrease the pressure. You can increase or decrease the velocity. You can either increase or decrease the velocity while keeping the pressure constant, or keep the velocity constant while adjusting the pressure. And apart from these two, you also have volume, which can be increased or decreased. So these are the three parameters you have. So within this, you try to play a lot. These are significant; by the way, there are other parameters also.

Dynamic Pumps

Dynamic pumps can be classified as follows:

A. Rotary

1. Centrifugal or radial exit flow
2. Axial flow
3. Mixed flow (between radial and axial)

B. Special Designs

1. Jet pump or ejector
2. Electromagnetic pumps for liquid metals
3. Fluid-actuated: gas lift or hydraulic ram

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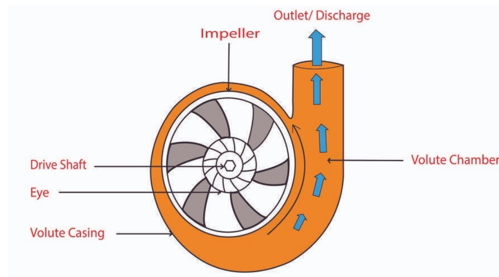
So the dynamic pump can be classified into rotary type and special design. Under rotary, it is always centrifugal. What is centrifugal? You have something which is there, rotating at a speed. So now the media will try to go to the extreme walls, to the extreme walls, and it is rotating. So this is called a centrifugal pump, or it is called radial exit flow. The other one is axial, which we saw. The third one is a mixture of both, called mixed flow.

When we go to special designs, we see a jet pump or an ejector. Jet pumps are used today in agricultural applications on farms. Electromagnetic pumps for liquid metals are also available today. Then, fluid-activated gas lifts or hydraulic arms are also there. These are all special types which exist, but the rotary ones are very common.

Centrifugal Pumps

A centrifugal pump consists of an impeller rotating within a casing.

- Fluid enters axially through the "eye" of the casing.
- It is then caught by the impeller blades and whirled tangentially and radially outward.
- The fluid exits through all circumferential parts of the impeller into the diffuser part of the casing.
- Impeller blades are typically backward-curved, but radial and forward-curved designs also exist, which can slightly alter the output pressure.



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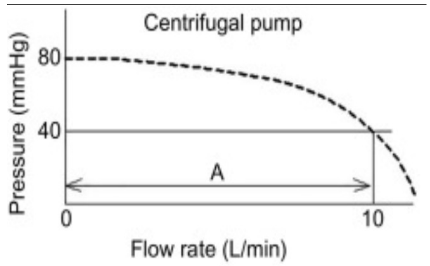
A centrifugal pump consists of an impeller rotating inside a casing. So, this is an impeller. The fluid enters axially through the eye. So, here is the eye. So, this is a drive shaft, entering through the eye of the casing. It is then caught by the impeller blade. This is an impeller, and these are all impeller blades. So, caught by the impeller blades and whirled tangentially and radially. So, what is tangential? This is tangential, and this is radial.

So it is whirled. When it rotates, the fluid is thrown. So it goes tangentially. It whirls tangentially and radially. Radially is when it rotates like this; the water also moves toward the casing. Radially outward. The fluid exits through all the circumferential parts of the impeller into the diffuser part of the casing. So this is the diffuser part of the casing. The impeller blades are typically backward-curved. But radial and forward-curved designs also exist.

So what they say is that this is backward-curved. So backward-curved, there can be radial straight and forward-curved designs, which can significantly alter the outward pressure. Through the volute chamber, when the discharge happens, you can still experiment by changing the impeller blade design.

Centrifugal Pumps



This image shows how a centrifugal pump works by displaying its pressure versus flow rate:

- When the pump is not moving any fluid (flow rate is zero), it produces the highest pressure this is called the "shutoff head."
- As the flow rate increases (more liquid is pumped out), the pressure the pump can create gradually decreases.
- This type of performance curve is typical for centrifugal pumps.
- Centrifugal pumps are best for moving fluids at moderate pressures and higher flow rates. They can't maintain high pressure at high flow.

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If you plot a graph between pressure and flow rate, as the flow rate increases, you can see the pressure drop. This image shows how a centrifugal pump works by displaying its pressure versus flow rate. So, pressure versus flow rate. Flow rate will always be liters per minute. It can be liters, kiloliters, or million liters. It can be there. So, when we talk about the usage of STP plants, we talk in million liters.

When the pump is not moving any fluid, it produces the highest pressure. This is called the shut-off head here. When the flow rate is not there, as the flow rate increases from 0 to 10, the pressure of the pump gradually decreases. This type of performance curve is typical for centrifugal pumps. So, you will see there, as and when the flow rate increases, the pressure drops. Maybe after 10 liters or 20 liters or maybe 100 liters, the pressure almost becomes zero, which is not possible, but it becomes very, very low.

Centrifugal pumps are best for moving fluid at moderate pressures and high flow rates. So, that is why we use these pumps in farms. In agricultural applications, we try to have moderate pressure, and we need a very high flow rate because the water has to be sucked from the well and dispersed, right? They cannot maintain high pressure at high flow.

They cannot measure. And for agricultural applications, you do not need tight requirements. So friends, this will try to tell you where and when to choose centrifugal pumps. So as the flow rate increases, the pressure decreases.

Centrifugal Pumps

Performance and Applications

- Centrifugal pumps are generally characterized as high-head, low-flow machines, meaning they deliver a high pressure rise but a relatively moderate flow rate.
- They typically provide a higher flow rate and a much steadier discharge compared to positive-displacement pumps.
- However, they are ineffective in handling high-viscosity liquids. High viscosity can lead to a dramatic drop in head and discharge, and an increase in power requirements, with efficiency dropping substantially.

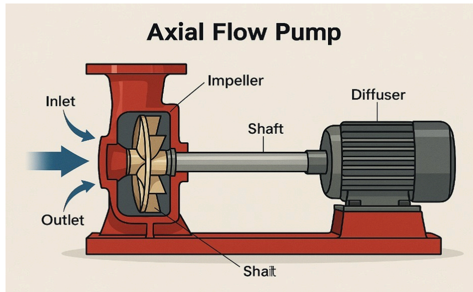
So the performance and application, if you see for centrifugal pumps, are generally characterized as high-head, low-flow machines. Meaning they deliver high pressure rise but relatively at a moderate flow rate. The same thing is displayed here. They typically provide a high flow rate and a much steadier discharge compared to positive displacement pumps. What are the classifications of positive displacement pumps? We will see that in detail.

But here, if you see positive displacement, I said reciprocatory. So what happens when you majority reciprocatory, what will happen is it reciprocates, it compresses and then it has a vacuum, or it has a dull period, so that's why they say these pumps are much better than the positive displacement pump. However, they are ineffective in handling highly viscous liquids. Suppose tomorrow you replace the water with a sugar solution, which is used in the process industry, pharma industry, sauce industry, or food industry.

Then highly viscous fluids can be thought of. These fluids oil there the centrifugal pumps are not very efficient. High viscosity can lead to a dramatic drop in head and discharge and an increase in power requirement, with efficiency dropping substantially. So for high-viscosity fluids, please don't use centrifugal pumps.

Axial Flow Pumps

- An axial-flow pump is a **type of dynamic pump** that falls under the rotary classification of fluid machinery.
- These pumps are designed to **add momentum to the fluid** using fast-moving blades or vanes, converting high velocity into a pressure increase as the fluid exits into a diffuser section.



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Axial flow pumps. Axial flow pumps: you can see that the water flows along the axis. An axial flow pump is a type of dynamic pump that falls under the rotary classification of fluid machinery. These pumps are designed to add momentum to the fluid, using fast-moving blades or vanes. So there is a diffuser, there is a shaft, right? There is an impeller. So this is an impeller. This impeller rotates. The impeller rotates.

These pumps are designed to add momentum to the fluid using fast-moving blades or vanes, converting high velocity into a pressure increase as the fluid exits into the diffuser section. So, high velocity is already there. If you want to further increase the pressure, we use these axial flow pumps.

Axial Flow Pumps

- Fluid flows almost straight through the pump, passing through fixed and moving blades.
- For gases, we often assume flow is incompressible because the pressure increase is small.
- Simplified models assume fluid exits blades at an angle and speed related to blade shape.
- The Euler turbomachinery formula is used to calculate theoretical head and power.
- Ideal head (H) is calculated using blade angles and speed, but real performance is usually lower due to losses.

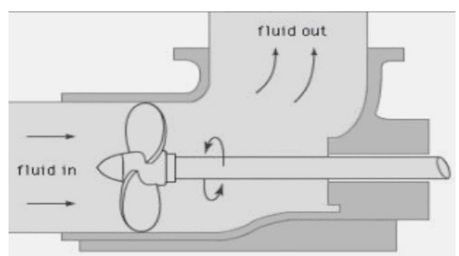
The flow moves almost straight through the pump. Passing through fixed and moving blades. These are the blades. The impeller has blades. Nowadays, it is pretty interesting. You can have blades as and when you need them, and you can try to change the orientation of the blades. All blades can be uniformly changed with respect to angle, or you can change only one blade.

So, the technology has advanced to that level. When you do that, what happens? You try to increase the flow rate and velocity. For gases, we often assume the flow is incompressible because the pressure increase is small. Simplified models assume the fluid exits the blade at an angle and speed related to the blade rotation speed.

The Euler turbomachinery formula is used to calculate the theoretical head and power, which we have already seen. In the tutorial, we will discuss it. The ideal head H is calculated using the blade angle and speed, but real performance is usually lower due to losses.

Axial Flow Pumps

- Axial pumps are low-pressure, high-flow machines (opposite of centrifugal pumps).
- The head drops fast as flow increases, meaning flow is stable even if pressure changes.
- Power demand decreases as head increases, but if flow suddenly drops, motor overload may happen.
- Efficiency is narrow and sharp, unlike centrifugal pumps which have a wider efficiency range.



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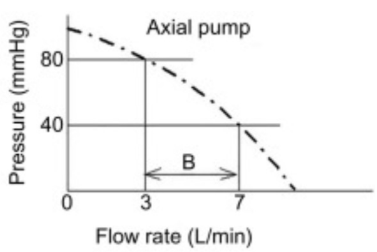
Now, you can clearly see the figure; the schematic figure shows the working of the axial flow pump. Axial pumps are low-pressure, high-flow machines, opposite to centrifugal pumps. Centrifugal pump—what we have is when there is high pressure, the flow rate decreases, right? So, here, low-pressure, high-flow machines—opposite to centrifugal—is the working style of axial flow pumps. The head drops fast as flow increases. Head is what? Pressure. The head drops fast as the flow increases, meaning the flow is steady even if the pressure changes.

The power demand decreases as the head increases. Head is the pressure. Head is the overhead, whatever you have. But if flow suddenly drops, motor overload might happen. And lastly, efficiency is narrow and sharp—unlike centrifugal pumps, where there is a wide range of efficiency. For axial flow pumps, it has a sharp curve. That means to say, if you cross the critical level, the efficiency falls down drastically.

Axial Flow Pumps



This image shows how an axial flow pump works with pressure and flow:

- When the pump isn't moving any fluid (zero flow), it creates the highest pressure.
- As the amount of fluid flowing through the pump increases, the pressure it can produce gets lower.
- Axial flow pumps are good for moving large amounts of fluid but not for creating very high pressure.
- So, the pump works best when you need to move a lot of liquid quickly, but it won't push it very hard.

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So, this is the curve which you see for axial flow pumps. So, pressure versus flow rate is shown here. You can see here there is a drop B between 3 liters per minute and 7 liters per minute. You see the slope falls down drastically where you can try to see the efficiency. This image shows how axial flow pumps work with pressure and flow. When the pump is not moving any fluid (zero flow), it creates the highest pressure. It is an idealistic case. The pump cannot be at zero flow, but you can approximate it. As the amount of fluid flowing through the pump increases, the pressure decreases.

But in centrifugal pumps, the drop was gradual. Here, the drop is steep. Axial flow pumps are good for moving large amounts of fluid but not for creating very high pressures. So, if you want to move a large amount of fluid, we always go for axial pumps. The pump works best when you need to move a lot of liquid quickly, but it will not push it very hard.

Here, this tries to clearly explain where we would use it: in flooding situations where water must be moved from one space to another, such as from a road to a sewage tank. In such cases, we use axial flow pumps. Here, it will move liquid very fast, but not very hard—the pressures will not be very high, which is what we wanted to explain.

Axial Flow Pumps

Design and Applications

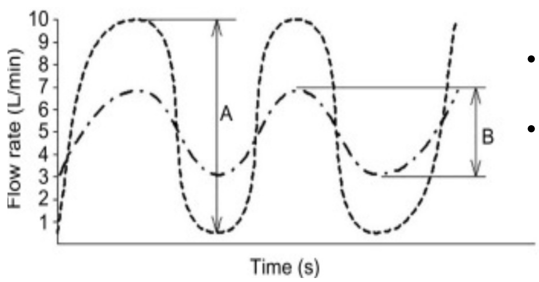
- Can be made in **multiple stages** to reach higher pressures.
- **CFD (Computational Fluid Dynamics)** is used for modern design due to complex 3D flows.
- Commonly used where **large amounts of fluid** need to be moved at **low pressure**: mine ventilation, irrigation, flood control, etc.
- **Free propellers** (like in boats or planes) are axial-flow devices too, but **less efficient** than ducted ones.

In terms of design and application, it can be made in multiple stages to achieve higher pressure. So why? Because here we try to say large amount of liquid can be moved. The pressure will be low. So you add one more pump. See, in trains, what happens is when the engine cannot pull all the bogies, they put a double engine. So, almost the same. It can be made in multiple stages.

So, it can be one more pump, or you can put multiple stages to increase pressure. CFD is used for modern designs due to complex 3D flow. Computational fluid dynamics is a software simulation we use to understand the flow and visualize it. Commonly used when a large amount of fluid needs to be moved at low pressure.

So, for example, in mine ventilation, irrigation, flood control, etc. Free propellers are axial flow devices too, but less efficient than the ducted ones. Free propellers, which are axial flow pumps, are used in boats or planes.

Centrifugal and Axial Flow Pumps



- The solid line represents the flow rate of the centrifugal pump.
- The dashed line represents the flow rate of the axial flow pump.

- The centrifugal pump's flow is relatively steady and smooth over time. Its output flow has smaller fluctuations, meaning it delivers a consistent amount of fluid.
- The axial flow pump's flow fluctuates more significantly, with higher peaks and dips. This means its flow rate varies more and is less steady.

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So, the centrifugal pump and axial flow pump, when we try to plot them against the flow rate and time, you can see here—this is the response we get. The solid line represents the flow rate of the centrifugal pump, whereas the dashed lines represents an axial flow pump.

From the graph, it is clearly visible what the response of the individual is with respect to time. The centrifugal pump flow is relatively steady and smooth over time. So that means to say, whatever the sinusoidal does, the amplitude is very low. The centrifugal pump is relatively steady and smooth over time. Its output flow has small fluctuations, meaning it delivers a consistent amount of fluid, which is the centrifugal pump.

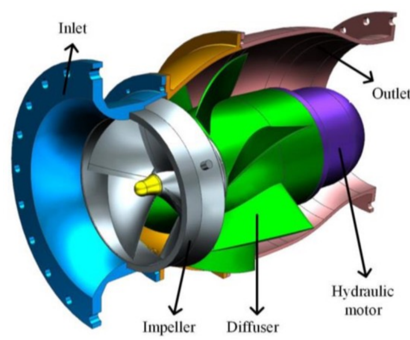
You see a large sinusoidal wave. So this large sinusoidal wave shows that there is a lot of fluctuation with respect to time. So if you want to have a steady state, what we do is attach this pump to a container where the water is filled and then ejected. So we can try to do that. That is how it happens in water jet cutting machines because the pressure required is very high.

So, the water is pushed into an intensifier. So, the intensifier is a tank wherein it amplifies and finally gives a steady flow out. The axial flow pumps show huge fluctuations, which is A, more significantly, showing that it can reach higher peaks in the flow rate, but it will also dip. So, this means the flow rate varies more and is less steady. So, you see the magnitude of A, which is very large. The flow rate at a given time can go high and low, but in the centrifugal pump, though it is sinusoidal, the magnitude is very low in terms of fluctuations.

Mixed Flow Pumps

They are classified under the rotary designs of dynamic pumps.

- In a mixed-flow pump, the fluid passes through the impeller with both an axial-flow component and a centrifugal (radial) component. This "part radial, part axial" flow gives them their name.
- To achieve higher flow rates, their passages are "opened up" more than a purely centrifugal design, which reduces the radial outlet velocity and consequently the head produced.
- Like other dynamic pumps, they generally offer higher flow rates and a steadier discharge.



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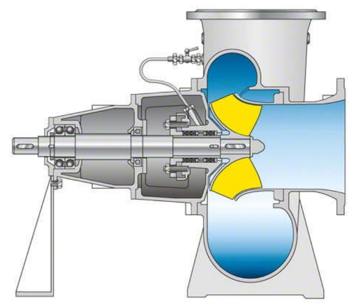
So, when we get into mixed flow pumps, they are classified under the rotary designs of dynamic pumps. The classification we saw in the beginning. In the mixed flow pump, the fluid passes through the impeller with both an axial flow component and a centrifugal component. This part radial, part axial gives the name, which is mixed flow. So you can see here, this is axial flow and then radial flow.

To achieve a high flow rate, their passages are open more than the purely centrifugal design, which reduces the radial outlet velocity and consequently the head produced. Like other dynamic pumps, they generally offer a high flow rate and steadier discharge, which is why we go for a mixed flow pump. So, here the inlet is given through this; this is the inlet, and then this is an impeller which rotates. Here is a diffuser. So, which tries to change the pressure diffuser, and then it tries to go to a hydraulic motor, and here is an outlet. So, mixed flow pumps are used.

Mixed Flow Pumps

Performance and Design Considerations:

- Mixed-flow pumps are designed for applications requiring low head and high discharge, addressing needs that centrifugal pumps might struggle to meet efficiently.
- Their optimum efficiency, like other pump types, is correlated with their specific speed and capacity.
- The theoretical understanding of these machines often relies on Euler's turbomachine formulas, which relate power and head to fluid velocity components and impeller speeds.



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The performance and the design consideration for a mixed flow. The mixed flow pumps are designed for applications where low head and high discharge are required, addressing the need that centrifugal pumps might struggle to display or demonstrate. So, wherever the centrifugal pump fails, we always look for a mixed flow pump.

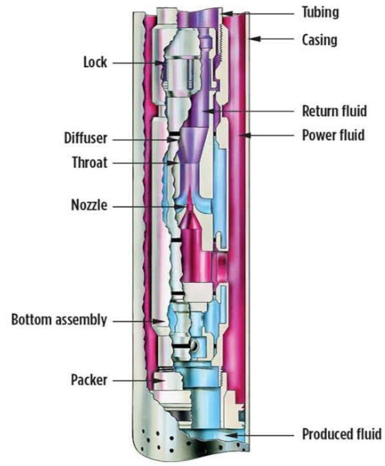
Their optimum efficiency, like other pump types, is correlated, and their specific speeds and capacity are high. The theoretical understanding of these machines often relies on Euler's turbomachinery formula, which relates power head to fluid velocity components and impeller speed.

So, when you look at a pump what else you will have? You will try to have one is the motor which rotates, right? So, there is a component called speed then there is a fluid which comes inside with a velocity. So, these two are there, right? You see here, then what you can do is try to talk about the power requirement for the motor.

So, these are the things you can talk about. So, that is what we try to put. And then in the Euler's turbo missionary formula: we will try to calculate the efficiency or we try to calculate the pressure, whatever it is, by going around directly or indirectly. Euler turbo machinery formulas will be discussed in the tutorials.

Jet Pumps

- A jet pump works by injecting a primary fluid through a nozzle, which then entrains a secondary fluid in an annular region around the primary jet.
- This process typically involves the Venturi effect, where the acceleration of the primary fluid in a narrowing section creates a lower pressure, leading to suction and entrainment of the secondary fluid.
- The two fluid streams subsequently become fully mixed downstream. The resulting mixed flow then typically slows down in a diverging section (diffuser), converting kinetic energy into pressure energy, potentially leading to a pressure increase



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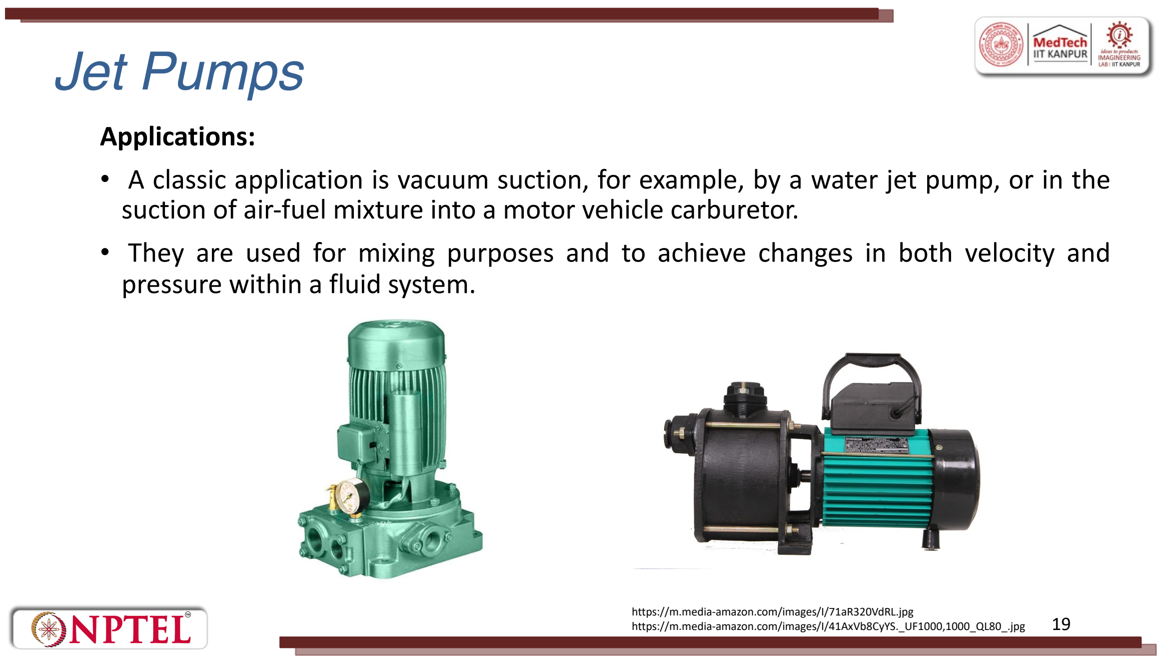
The next one is a jet pump. The jet pump works by injecting a primary fluid through a nozzle, which then entrains a secondary fluid in an annular region around the primary jet. So, this is a jet pump, right? So, you see here is a nozzle, and here is a throttle you have, this is a diffuser, ok.

So, the diffuser and here is the return fluid, which is there in the casing, and this is the tubing used in your bore wells. So, there are two fluids injecting a primary fluid through a nozzle. So, this is a nozzle, right, which then entrains a secondary fluid in an annular region around the primary jet.

This process typically involves the Venturi effect. Venturi effect is very common when there is a direction change direction change and when there is a flow change, Venturi effect where the acceleration of the primary fluid in a narrow section creates a low pressure leading to a suction and entrainment of the secondary fluid.

So, primary fluid, secondary fluid—when the acceleration of the primary fluid happens through a narrow section, it creates a low pressure, right? The two fluid streams subsequently become fully mixed downstream. So, the two fluids mix downstream. The resulting mixed flow then typically slows down in the diverging section—convergent-divergent—we saw that this is a nozzle where it is converging, then it is diverging. So, when it is diverging, it is called a diffuser.

So, the diverging section converts the kinetic energy into pressure energy, potentially leading to a pressure increase. A jet pump is a complex phenomenon, but it finds wider applications today. It has a primary fluid and a secondary fluid, right? So, the two fluids subsequently become fully mixed downstream, which results in a mixed flow—two fluids mixing flow. Typically, it slows down in the divergent section, converting the kinetic energy into pressure energy.



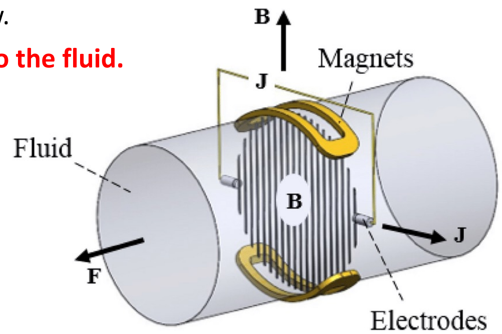
So, these are the applications—you will see a lot of these either used in hydraulic packs, or they can be used for agricultural applications, or they can be used in pharma and process companies. The classical application is in vacuum suction, for example, by a water jet pump, or in the suction of an air-fuel mixture into the motor vehicle carburetor—we use jet pumps. They are used. So that's why I said, if you read this, the two fluid streams subsequently become fully mixed downstream. Look at the examples.

I am talking about a vehicle carburetor. Then, vacuum suction is also used. For example, in your vacuum pumps, which are used in chemistry labs where you diffuse or try to suck all the air from a closed container, we use this vacuum suction. They are used for mixing purposes and to achieve changes in both velocity and pressure within a fluid system. The next one is the electromagnetic pump.

So, the electromagnetic pump is used to move a liquid, a fluid, using a magnetic field. Because when you use mechanical components, there is a possibility that you cannot go higher than a critical speed. Second, the mechanical components will have wear and tear. Third, there is always a weight component that comes into play. So, in order to avoid all these issues, we try to move to electromagnetic pumps.

Electromagnetic Pumps

- Electromagnetic pumps function by applying a magnetic field across a conducting fluid.
- The movement of the fluid within this magnetic field induces a voltage across two electrodes placed in or near the flow.
- **This mechanism adds momentum to the fluid.**



https://www.researchgate.net/publication/356023786/figure/fig1/AS:1088106157608980@1636436132360/The-structure-of-the-electromagnetic-pump.png

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In these electromagnetic pumps, a magnetic field is generated outside and it tries to move the valve inside, or it is used to change the direction while the fluid is flowing. An electromagnetic pump functions by applying a magnetic field across a conducting fluid, and it is used for conducting fluids. What are conducting fluids? For example, if you have a metallic paint, a conducting fluid, or you can have ion particles dispersed in a fluid for clear finishing applications and other uses. The movement of the fluid within this magnetic field induces a voltage across two electrodes, right?

So, these are electrodes; this is one electrode, and this is another electrode. The movement of the fluid is there, right, within the magnetic field, it induces a voltage. So, we try to apply a very high voltage. So, the induced voltage across the two electrodes placed in or near the flow happens, and the mechanism adds momentum to the fluid. So, here the magnetic field is created and here is the voltage which is applied.

Electromagnetic Pumps

Advantages:

- The electrodes can be streamlined or integrated into the wall, causing little to no flow resistance.
- They provide a very strong output for highly conducting fluids.

Disadvantages:

- Commercial electromagnetic flowmeters are available for most liquid flows, but they are generally relatively costly

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https://www.icmm.ru/images/files/commercial_offers/electro-magnet-pump/electro-magnet-pump-pic1.png

So, the advantage is that the electrodes can be streamlined or integrated into the wall, causing little or no flow resistance. They provide a very strong output for highly conducting fluids. That is what I said: fluid in a hydraulic power pack can be used. Commercially, electromagnetic flow meters are available for most fluid flows, but they are generally relatively costly compared to normal pumps.

Positive Displacement Pump

- Positive-displacement pumps (PDPs) are a fundamental type of pump that operate on a distinctly different principle from dynamic (or rotodynamic) pumps like centrifugal or axial-flow types.
- PDPs work by forcing the fluid along through successive volume changes.
- This means they trap a specific volume of fluid in a cavity, which then opens to admit fluid via an inlet, closes and finally squeezes the fluid out through an outlet.
- This mechanism results in a pulsating or periodic flow as the cavity changes volume.
- PDPs are one of the two basic types of pumps, with billions in use globally.
- They are broadly classified into reciprocating and rotary designs.

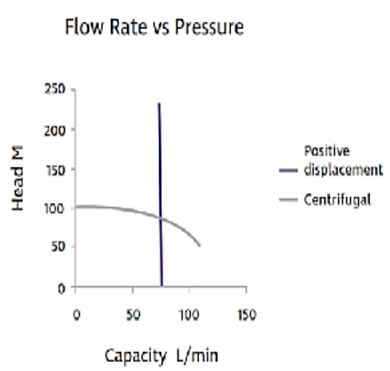
The next set of pumps are positive displacement pumps. So if you go back to our initial slides, it clearly says all these things. So, centrifugal pump—we have finished dynamic, centrifugal, special effect. Now we are trying to get into positive displacement pumps. Positive displacement pumps, which are shortly called PDP pumps, are a fundamental type of pump that operates on a distinctly different principle from dynamic pumps like centrifugal or axial flow types. They are completely different. The PDP pumps work by forcing the fluid through successive volume chains.

A fluid is pushed through successive volume chains. So, this means they trap a specific volume of fluid in a cavity, which then opens to admit fluid, right? So, you have a cylinder; there is a hole. So, when this fellow goes and when it comes down, when the piston comes down, there is a vacuum which is created; the fluid flows inside. This means they trap a specific volume of fluid in a cavity.

That means today you have a container, a bottle; a hole is there. When you move the piston down, the air is pushed inside. The container has a fixed volume. This means that they trap a specific volume of fluid into the cavity which then opens to admit fluid via an inlet closes, and finally squeezes the fluid out through the output. So, there is a closed volume; you suck it in, and now you are pressurizing it.

So, there is pressure that builds up. This mechanism results in pulsating or periodic flow because the piston goes up and down repeatedly as the cavity changes volume. Positive displacement pumps are one of the two basic pumps, with billions in use globally. They are broadly classified into reciprocating and rotary types.

Positive Displacement Pump



- This image shows how a positive displacement pump works. The straight vertical line means that the pump gives the same flow rate almost all the time, even if the pressure changes a lot.
- So, no matter how hard it has to push (even if the pressure goes up), the amount of fluid it moves every minute stays nearly the same. This is what makes positive displacement pumps special they deliver a steady flow, no matter what the pressure is.

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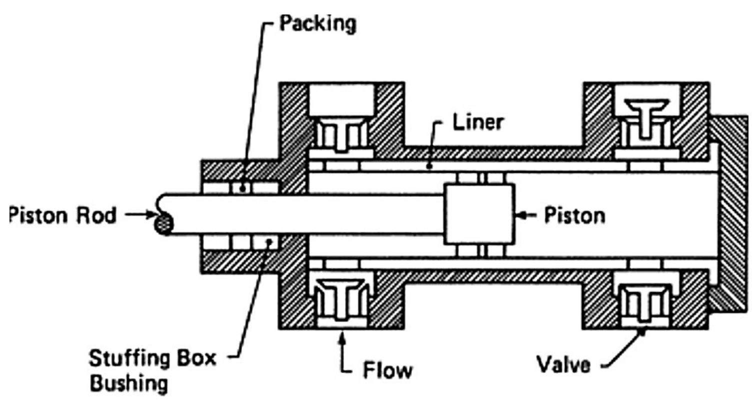
When you look at a positive displacement pump, considering pressure (e.g., MPa) and flow capacity, the image shows how it works. The straight vertical line means that the pump delivers the same flow rate almost all the time, even if the pressure changes significantly. This is what a positive displacement pump is. The curve that droops downward is the centrifugal pump, which we have already discussed. The image illustrates how a positive displacement pump works. The straight vertical line means the pump delivers the same flow rate almost all the time, even if the pressure changes significantly.

The flow rate is constant. Therefore, positive displacement pumps find many more applications. No matter how hard it has to push, the amount of fluid it moves every minute remains nearly the same. This is what makes positive displacement pumps special—they deliver a steady flow. No matter the pressure, they provide a constant flow rate.

Positive Displacement Pump



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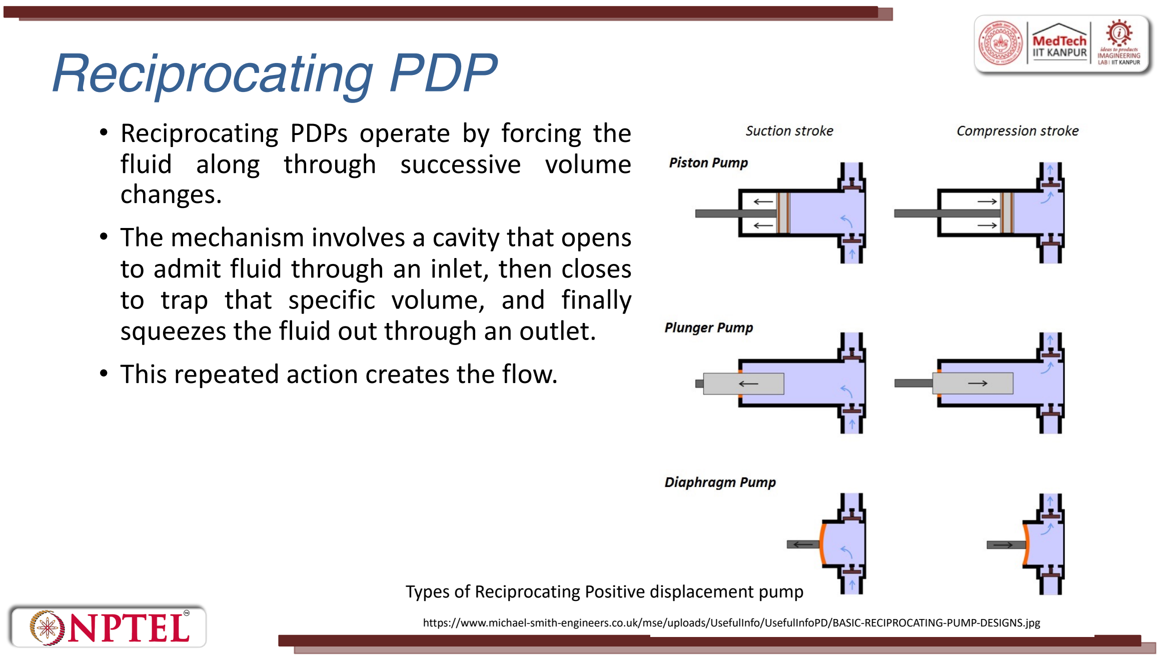
This is a typical example I gave you with respect to the bottle. There is a confined volume where a piston moves up and down. Fluid flows through this, then pressurizes, and then exits through the outlet. This is for a reciprocating-type positive displacement pump.



Reciprocating PDP pumps, which we will explore further, operate by forcing fluid through successive volume chambers. The working of reciprocating PDP is discussed in this slide. So, you can see here there is a suction stroke. So, there is a fluid which comes inside the piston, moves back, and then when the piston is compressed, it moves to the front side. So, this is a piston type; you can also have something called a plunger type. So, the piston is completely arresting the fluid and pressurizing it.

There can be a plunger type where the fluid is fully filled, and the plunger is pushed out. Then the plunger is pushed in, and the valve is opened on the other side so it can go. You can also have a diaphragm type. The diaphragm type is a hard-fixed vertical line, a solid line, the piston end, so that we can make it slightly elastic and then allow the fluid to flow inside and outside. The reciprocating PDP operates by forcing the fluid along through successive volume changes.

The mechanism involves a cavity that opens to admit fluid through an inlet, then closes to trap the specific flow, and finally squeezes the fluid out. So, this is in, and this is out.

Reciprocating PDP

A reciprocating positive displacement pump uses a piston moving back and forth to push fluid out, like a bicycle pump.

In the graph, the vertical line means:

- The pump delivers a steady amount of fluid every minute, no matter how hard it has to push (even if pressure increases).
- The flow rate stays nearly the same even as the pressure goes up a special feature of reciprocating PDPs.
- So, this image shows that a reciprocating PDP always pushes out the same amount of liquid, even if it has to work against higher pressure .

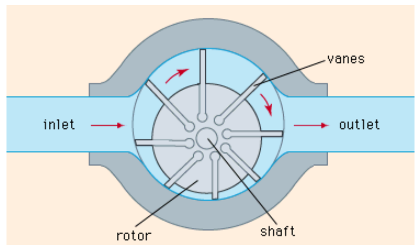
So, you can see for the reciprocating pump, how are the responses? So, the reciprocating pump uses a piston moving back and forth to allow fluid flow, like a bicycle pump. So, in the graph, this graph is discussed in the next slide.

The pump delivers a steady amount of fluid every minute, no matter how hard it has been pushed, even if the pressure increases. The flow rate stay nearly the same, even as the pressure goes up, special feature of reciprocating pump. So this image, whatever we have shown in the previous slide, shows the reciprocating pump are always pushes out the same amount of liquid, even it has to work against the higher pressure.

Rotary PDP

- Rotary pumps operate by mechanically trapping a fixed volume of fluid in a cavity and then moving that volume through the pump to the outlet.
- The "rotary" aspect refers to the motion of the internal components that create these changing cavities.

Operational Principle: A cavity opens to admit fluid, then closes to trap it and finally squeezes the fluid out through an outlet, resulting in a pulsating or periodic flow.

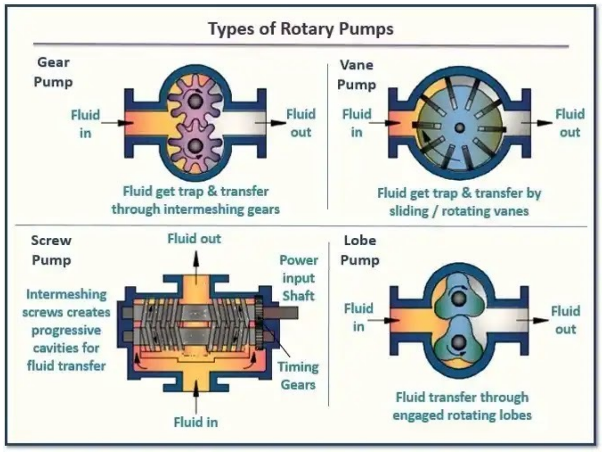


https://www.britannica.com/technology/pump/Positive-displacement-pumps

The rotary pump operate by mechanically trapping a fixed volume of fluid in the cavity and then moving that volume through the pump to the output so input so there is a trapping then you pressurize and then you exit out. The rotary aspect refers to the motion of the internal component that can create these change in cavities.

The principle is almost the same: the cavity opens to admit a fluid, then closes to trap it, and finally squeezes the fluid and outlet, resulting in a pulsating or periodic flow. Keep this in mind, friends: the flow rate will be constant for any pressure in both rotary and reciprocating pumps. The only difference is the pump size or the pump architecture, okay?

Rotary PDP



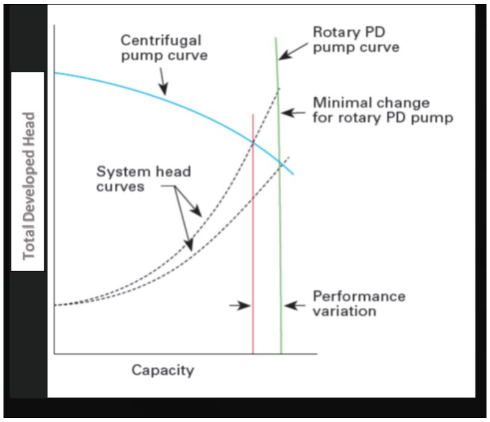
https://www.knowpipingfield.com/2024/02/rotary-pumps-the-right-choice-for-precise-fluid-transfer.html?m=1

So here is the typical rotary pump you can see a fluid flowing inside this is otherwise called as a gear pump it increases the pressure and there is a flow. You can also have vane pumps.

These are all vane pumps. So, vane pumps are like we have a vane. These two gears are meshing, and then you create— So, in a vane pump, what happens is the fluid flows inside, and there is a vane which is created. There is also a screw pump, right? There is a screw which can rotate, like a screw in a nut. So, the intermeshing screw creates a progressive cavity for fluid transfer.

So, fluid flows inside, fluid flows outside—this is a screw pump. Then you have a lobe. So, here the gear teeth are converted into lobes—tri-lobes, right? The fluid flows inside, the fluid flows outside, and the fluid transfers through the engaged rotating lobes. So, these are the different types of rotary positive displacement pumps. All of them find a lot of applications because the flow rate is constant for any given pressure.

Rotary PDP



- This image shows that rotary positive displacement pumps give a steady flow, almost unaffected by pressure changes in the system shown by the nearly straight vertical line. This is exactly how rotary PDPs behave: constant flow, minimal performance variation as pressure varies.

https://www.knowpipingfield.com/2024/02/rotary-pumps-the-right-choice-for-precise-fluid-transfer.html?m=1 27

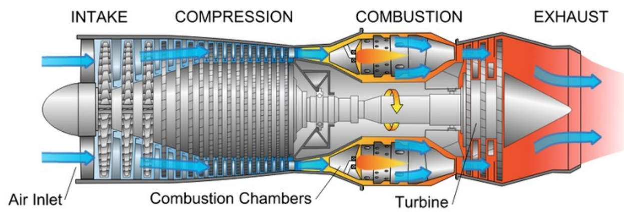
So, if you plot with respect to the total developed head—the pressure which is developed with respect to capacity—you can see the centrifugal pump performance falls down. Then you can see there is a rotary pump curve, which is a straight line, and then you can see there is a change in the rotary pump. You can try to have the rotary pump head; this is a change. And then here is a performance variation which can happen because of this change in the rotary. The system pressure head changes when we try to change the performance curve, right?

This image shows that the rotary positive pump gives a steady flow. There is a small variation. It is almost unaffected by the pressure change in the system. So, here is a pressure change in the system. So, here there is a head change, right? A system shown by a nearly straight vertical line.

This is exactly how a rotary pump behaves. A constant flow, minimal performance variation of the pressure happens. This is for rotary.

Turbines

- Turbines are machines fundamentally designed to extract energy from a fluid that possesses high head.
- They're a key part of "turbomachinery" a broader category of devices that are typically connected to a rotating shaft and deal with fluid energy transfer.
- It's a bit of a misnomer to simply say a turbine is "a pump run backward" because their operational principles and designs are distinct, although both deal with fluid mechanics and rotating elements.



https://energyeducation.ca/wiki/images/thumb/3/3d/Natgasturb.png/780px-Natgasturb.png

Now, let us move into the topic of turbine pumps—fluid coming in and getting it out, right? Turbines are machines fundamentally designed to extract energy when the fluid possesses a higher head.

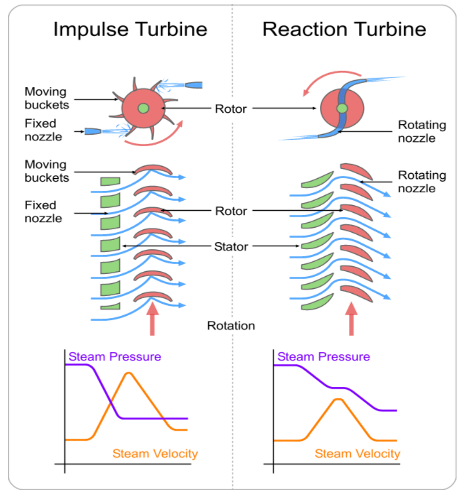
They are a key part of turbomachinery itself. A broader category of devices that typically connect a rotating shaft and deal with fluid energy transfer. It is a bit of a misnomer to simply say a turbine is a pump run backward. It is a misnomer. Please do not say that.

Because their operational principles and designs are distinct, although both deal with fluid mechanics and rotary elements. Please don't use this: a pump when it is rotated backward is called a turbine, no.

Turbines

Turbines are primarily classified into two main types based on how they convert fluid energy into mechanical work:

1. Reaction Turbines
2. Impulse Turbines



https://mechanicalbooster.com/wp-content/uploads/2017/01/Turbines_impulse_v_reaction-1.png

Turbines are primarily classified into two main categories. One is called a reaction-type turbine. The other one is called an impulse turbine. When you look at the impulse turbine, there is an impeller which rotates, and there are blades. The liquid tries to hit the blade, and then the blade or the bucket rotates. So, here I am calling it a blade, but in reality, it will be a bucket because a blade is a flat one, while a bucket is something three-dimensional. So, the moment the jet of water hits the blade, the blade starts rotating.

The nozzles are in a fixed position. The part that rotates is called the rotor. So, in a moving bucket, this is a bucket. So, there is a fluid that comes and hits the bucket and then flows out. When it hits the bucket, this bucket is attached to a rotor, and the rotor starts rotating. So, here it is called a flow; you can see how it happens.

The fluid flows, hits the bucket, and then enters. So, here these are rotating parts, and these are static parts. So, if you plot the pressure with respect to velocity, you can see how the steam pressure or the water pressure drops here. Instead of water, you can also inject steam. So, here it can be steam/water injection. So, you can see how the pressure drops and how the velocity increases, right?

This is for an impulsive type. In the reaction type, what happens is you have a rotor. Through the rotor, there is a fluid that flows and exits out. So, it has a rotating nozzle. So, here it is a fixed nozzle; here it is a rotating nozzle. So, here you can see how the stator looks and how the rotating nozzles are.

So, you see what the response of steam pressure falling down is with respect to the steam velocity increase. You can see how the steam velocity increases and how the pressure falls down.

Reaction Turbines

- In a reaction turbine, the fluid completely fills the blade passages, and the energy conversion, or head change/pressure drop, occurs within the impeller itself.
- These are dynamic devices engineered to efficiently admit high-energy fluid and extract its momentum.
- The flow through a reaction turbine is generally opposite to that in a pump, with fluid entering at the larger-diameter section and discharging through the eye after transferring most of its energy to the impeller.

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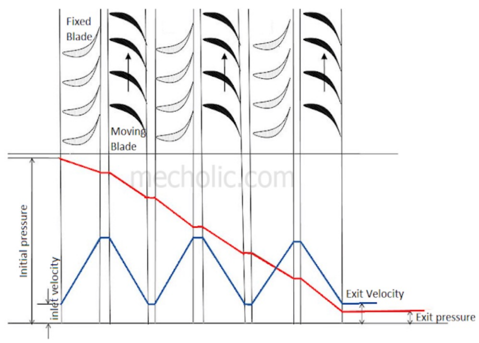
The reaction turbine is a turbine where the fluid completely fills the blade passage, and the energy conversion of head changes; the pressure drop occurs within the impeller itself. They are dynamic devices engineered to efficiently admit the high-energy fluid and extract its momentum. High-energy fluid can be a jet of water or it can be steam.

The flow through a reaction turbine is generally opposite to that of a pump. The fluid enters at a larger diameter section and discharges through an eye after transferring most of its energy to the impeller. So, what happens is this: the shaft is rotating, and this rotates. So, you have a blade which is there, and then the water hits it, and the rotor starts rotating.

Reaction Turbines



- The alternating blades and graphs illustrate continuous conversion of both potential energy (pressure) and kinetic energy (velocity) into rotational energy.
- The turbine reacts to fluid pressure drop across both blade types, generating force and making the shaft spin.
- The steadily falling pressure and cyclical velocity change shown in the image are key behaviors of reaction turbines.

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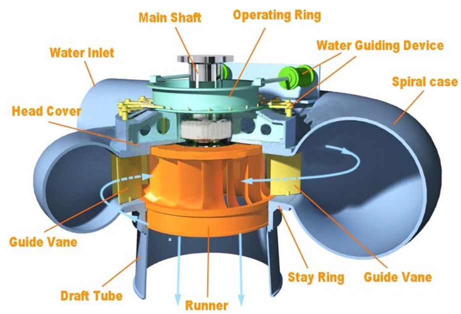
So, these alternating blades and graphical illustrations continue the conversion of both potential energy (pressure) and kinetic energy (velocity) into rotational motion. So, you can see here how the exit pressure falls and how the exit velocity changes. So, here are fixed blades and here are moving blades: fixed blades, moving blades. So, you see how the pressure falls down drastically. And the exit velocity is almost the same. The turbine reacts to the fluid pressure drop across both blade types, generating forces and making the shaft spin.

So it hits tangentially, making it spin. The steadily falling pressure and cyclic velocity change shown in the image are the key behaviors in a reaction turbine. So, a reaction turbine—this is a reaction turbine.

Reaction Turbines

Francis Turbines:

- These are radial-flow or mixed-flow designs.
- The earliest efficient inward-flow turbine was developed by James B. Francis in 1849, lending his name to this family of turbines.



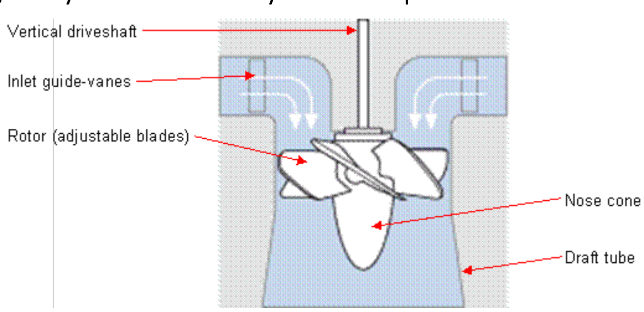
https://mechanicalbooster.com/wp-content/uploads/2018/01/Francis-turbine-main-components.jpg

So, the Francis turbine is part of the reaction turbine. So, here there is either a radial flow or mixed flow design. It was invented or developed in 1849, lending its name to his family of turbines—James Francis did that. So, here if you see, there is a runner, there is a vane—these are all vanes, OK? And here it rotates. Reaction turbine: we are seeing under reaction turbine—we saw Francis, now we saw Kaplan.

Reaction Turbines

Kaplan Type:

- For lower heads, a more compact axial-flow design is utilized.
- These can feature either fixed or adjustable blades, with the adjustable (Kaplan-type) blades providing greater efficiency at low-power settings, although they are mechanically more complex.

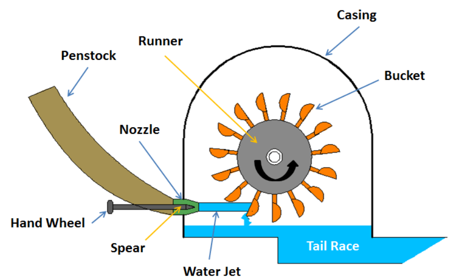


https://mechanicalbooster.com/wp-content/uploads/2018/02/Kaplan-turbine-main-parts-diagram.png

So, for lower head, a more compact and axial flow design is utilized. So, we use either a fixed or an adjustable blade. So, these are blades where we can fix the profile—in the sense, the slot angle—with the adjustable blade providing greater efficiency at low power settings.

Impulse Turbines

- An impulse turbine first converts the high head into a high-velocity jet through a nozzle.
- This jet then strikes the blades at one position as they pass by.
- The impeller passages are not fluid-filled, and the jet flow past the blades essentially occurs at constant (atmospheric) pressure.



https://mechanicalbooster.com/wp-content/uploads/2018/01/Impulse-Turbine-1.png 37

So, an impulse turbine is what I said earlier. There is a fluid flowing from a dam through a penstock. The fluid enters into it, and here you have a handwheel which can try to increase or decrease the length of the spear. So, the velocity can be controlled.

So, the velocity comes, and then they hit the bucket, which is attached to a rotor. So, this rotates. This is called the runner. This rotates, and when it rotates from here through a shaft, we try to generate electricity. So, this is the bucket. This entire thing is under casing. So, the water hits. After it hits, it falls down and goes into the tailrace, which gets back into the catchment area. So, this is a water jet. So, an impulsive turbine first converts a high head into a high-velocity jet through a nozzle, and the jet is allowed to strike the runner bucket.

So, and then it passes. The impeller passages are not fluid-filled, and the jet flow past the blade essentially occurs at a constant pressure. So, then the rest falls down and then it goes. So, this is the impulsive turbine. So, as an impulsive turbine, we see one example is the Pelton wheel.

Impulse Turbines

Pelton Wheels:

- They are ideally suited for high head and relatively low power applications.
- The high pressure is confined to the small nozzle, which reduces the need for a massive casing thickness in the main turbine.
- The theoretical power delivered is proportional to the fluid mass flow rate and a function of the jet velocity and bucket speed.
- Maximum power is achieved when the bucket linear velocity is approximately half the jet velocity.
- Nozzle losses are accounted for by a velocity coefficient, typically between 0.92 and 0.98.
- **While efficient, impulse turbines are generally not quite as efficient as Francis or propeller turbines at their best efficiency points (BEPs).**

They are ideally suited for high heads. So, the water comes through the penstock and relatively low-pressure application. The high pressure is confined to a small nozzle. So, which we saw here. Because of the head, the pressure comes through the nozzle, which reduces the need for massive casing thickness in the main turbine.

The theoretical power delivered is proportional to the fluid mass flow rate, the velocity, and the function of the jet velocity and the bucket speed. So, this in turn you try to drive it out. The maximum power is achieved when the bucket linear velocity is approximately half the jet velocity, the jet velocity, and the bucket velocity. The nozzle losses are accounted for. This is accounted for by a velocity coefficient, typically 0.92 to 0.98. While efficient, impulse turbines are generally not quite as efficient as Francis and propeller turbines, as their efficiencies are very high.

Impulse Turbines

So, this is how a Pelton turbine looks like.

To Recapitulate

- What is Turbomachinery?
- What are pumps? State different types of Pumps.
- What do we understand by Dynamic Pumps?
- Sate and describe Positive Pumps.
- What are Turbines?
- State the working principle of Reaction Turbine?
- How does an Impulse Turbine work?

To recap. In this lecture, we saw what turbo machineries are, what pumps are, their classifications, what a dynamic pump is, what a positive displacement pump is, what turbines are, and the different types of turbines, that is, reaction turbines and impulse turbines. This is a very important topic because when you see any electrical system, you will see there is a pump or there will be a motor.

So, from now onwards, you will start appreciating how these pumps and motors work and how they are making our lives easier. If you take an AC unit, you will have a compressor, and again, there will be a motor. If you look at a mixer, there will be a motor. So, there is a motor, and this motor will be attached to a pump. So, this pump is used for various applications.

When you take a desert cooler, there is a pump which is used to suck water and then take the water to higher heights or altitudes. From there, it is dispersed to the sawdust or any other medium, and when the air is blown, you get a cool feeling. So, there also we try to use pumps. You get pumps from 100 rupees to a few crore rupees. So, that is the variation depending upon the requirement you decide.

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These are the references which we have used, friends, and thank you very much.