Basics of Mechanical Engineering-1

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Week 11

Lecture 47

Clutches, Brakes and Flywheels

Welcome to the next lecture in the course Basics of Mechanical Engineering 1. We will discuss Clutches, Brakes and Flywheels in this course. I am Dr. Amandeep Singh. This course is co-taught by Professor Ramkumar with me. Clutches, Brakes, Flywheels.

These are common words that you have been listening, you have observed them being used at multiple places. Clutches are there to engage and disengage the stationary components with the rotating components. For example, in your automobiles, you pull the clutch wire, the clutch disengages. If you leave it, it engages once again and you can change the gear of your motorbike. You can change the gear of your automobile when you push the clutch pedal there.

Clutches are there in drills. In the drill bits, when the drill has to rotate, in what speed it should rotate, when it stops. It is not a sudden stop. It is not a brake immediately. It is through clutch only engaging and disengaging happens.

Yes, brakes are also there to stop the motion completely to stand still. For those, brakes are used. And to provide load to the rotating shaft, flywheels are used. We will discuss on this.

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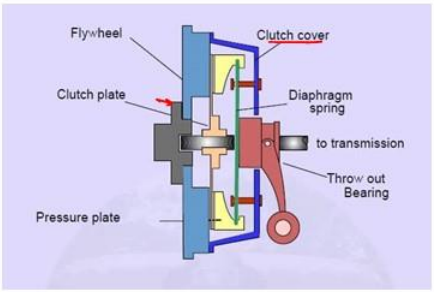
So, clutches we will try to discuss upon the working principle of after giving Introduction to Clutches. Torque Transmission in clutches we will discuss. Introduction to Brakes we will be putting some light upon. Types of Brakes we will see. Applications of Brakes in various industrial kinds we will see. Working principle of Brakes we will try to see. And Flywheels introduction would be given. After that we will see Types of Flywheels and their applications.

Introduction to Clutches

- A clutch is a mechanical device that connects and disconnects the power transmission from the driving shaft (engine or motor) to the driven shaft (gearbox or wheels).
- It allows for smooth engagement, power transmission, and disengagement, enabling machinery to start, stop or change speeds without shutting off the engine.

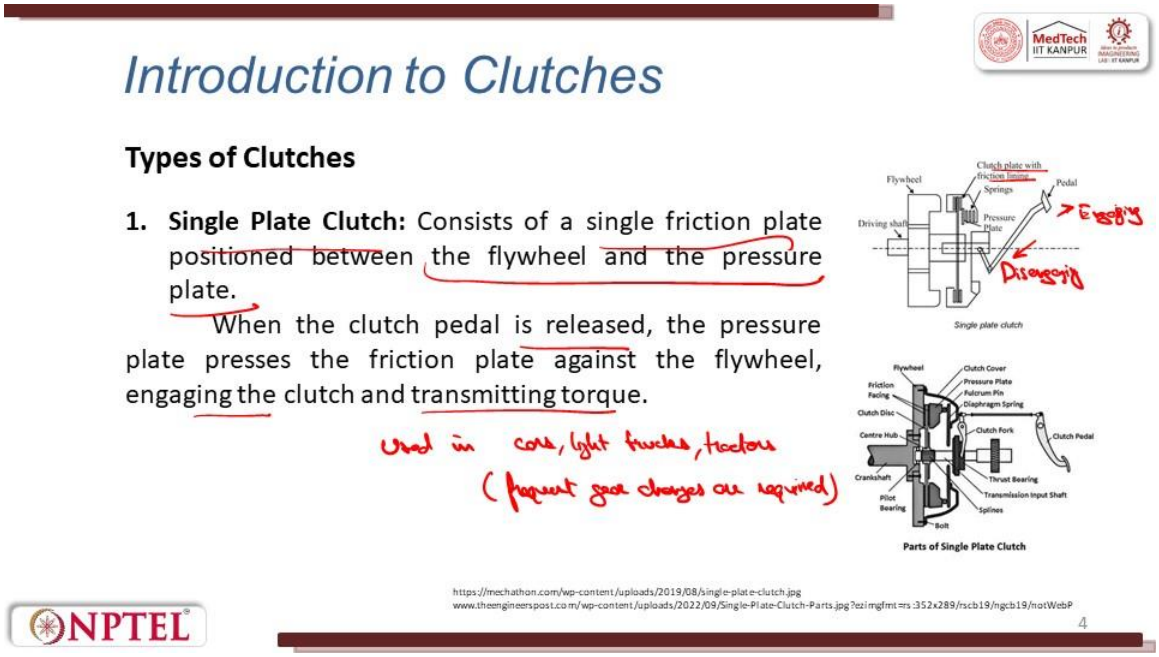


https://learnmech.com/wp-content/uploads/2015/09/clutch.jpg

When I say Clutches or Clutch, as a definition, it is a mechanical device that connects and disconnects. The power transmission from the driving shaft that is engine or motor to the driven shaft that is gearbox or wheels. This is a typical clutch being shown here.

This is a clutch cover and this is a clutch plate that engages and disengages and there is a flywheel that is connected to the clutch. Now, it allows for smooth engagement, power transmission and disengagement enabling machinery to stop, change speeds without shutting off the engine. So the keyword here is smooth engagement or disengagement. That is what is the purpose of a clutch, so that a smooth engagement and disengagement is there. There should not be shock, there should not be sudden stopping or everything.

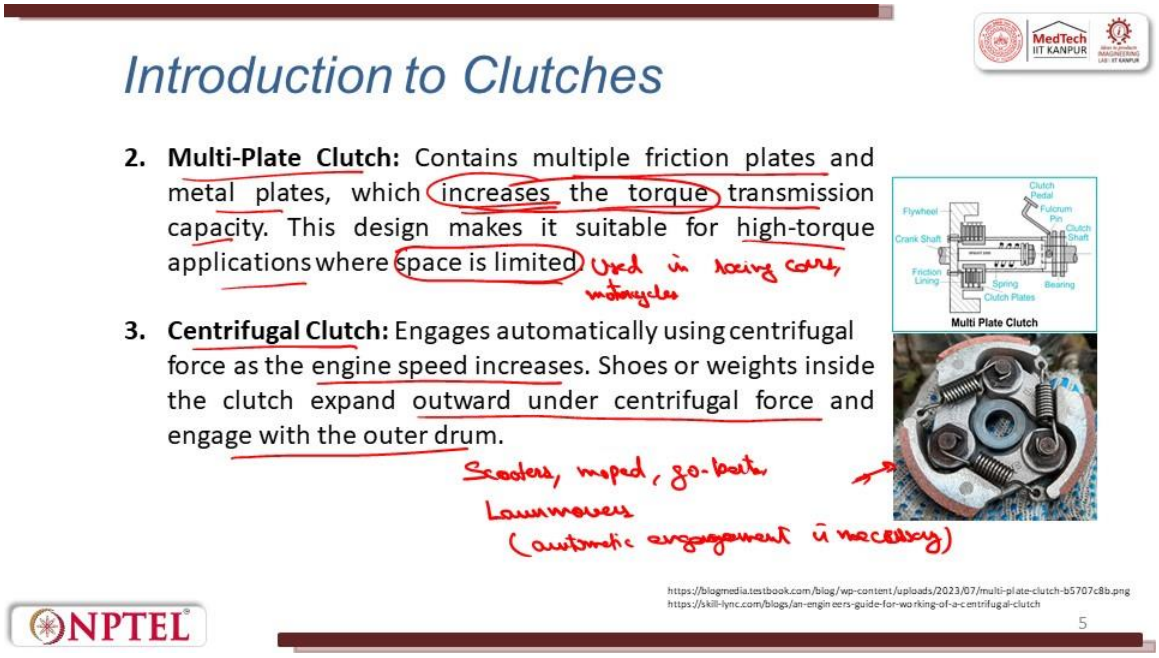
So, it could be multiple kinds of clutches such as dry clutch, centrifugal clutch. Nowadays, electromagnetic clutches are also there, wrap spring clutches are also there. Nowadays, multiple new technologies have come where fans and compressors are also using clutches in them.



To talk about the Types of Clutches, first is Single Plate clutch. A clutch with a single plate. Clutch plate with friction lining is shown here. There are springs here. But this is a single plate here. While pressing a pedal of your automobile, you try to disengage this clutch.

A single plate clutch. It consists of a single friction plate. Position between the flywheel and the pressure plate. When the clutch pedal is released, the pressure plate presses the friction placed against the flywheel and engaging of the clutch happens and transmitting of torque happens. That means pressing the pedal is disengaging and when we release it, it is engaging.

So, they are parts of a clutch system, I am not going to more details because this course is just basics of mechanical engineering, only trivial information is being given that what are the applications such as these single plate clutches are used in cars, light trucks, tractors where frequent gear changes are required.

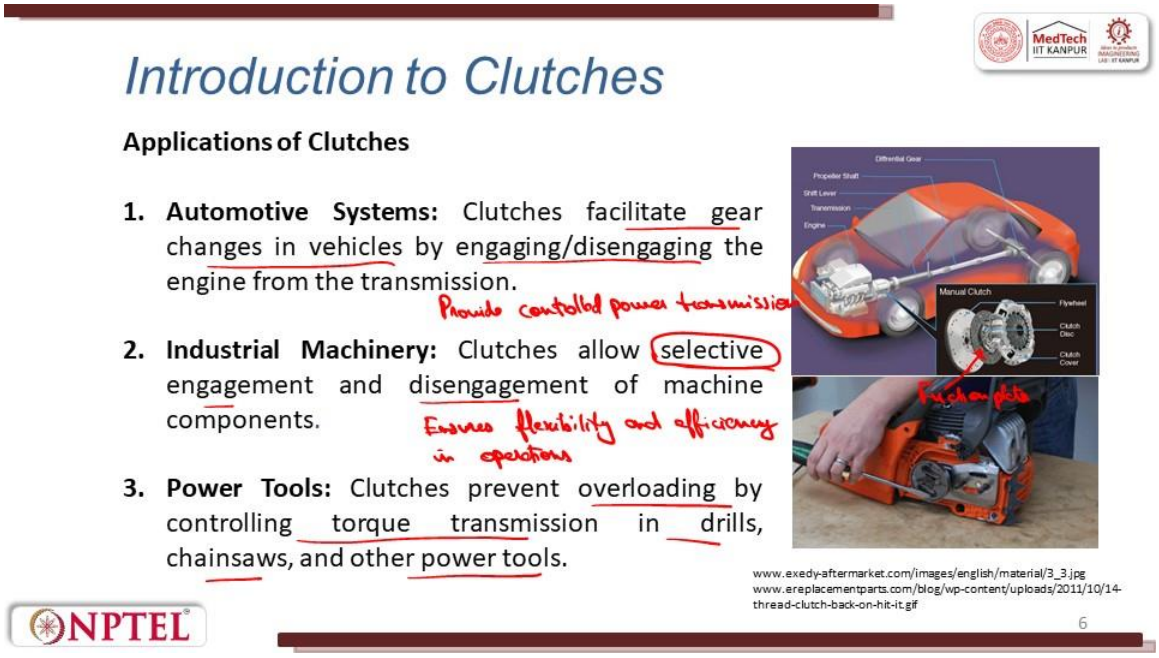


Other than single plate, there are multiple plate or Multi-Plate catches. These contain multiple friction plates and metal plates which increases the torque transmission. Increase of torque transmission is the need of having multiple plates to increase the capacity of the trunk transmission.

These are used. This design makes it suitable for high torque applications where space is limited. As I said, light trucks use the single plate clutches. For heavy trucks, for the racing cars, used in racing cars where the torque is high or for the motorcycles, that transmit heavy torque, but space is less.

Space is limited is a key word here and increasing the torque transmission is a key word here. There we use multiple plate clutches. Then comes Centrifugal clutch. This engages automatically using centrifugal force as the engine speed increases. Shoes or weights inside the clutch expand outward under centrifugal force and engage with the outer drum.

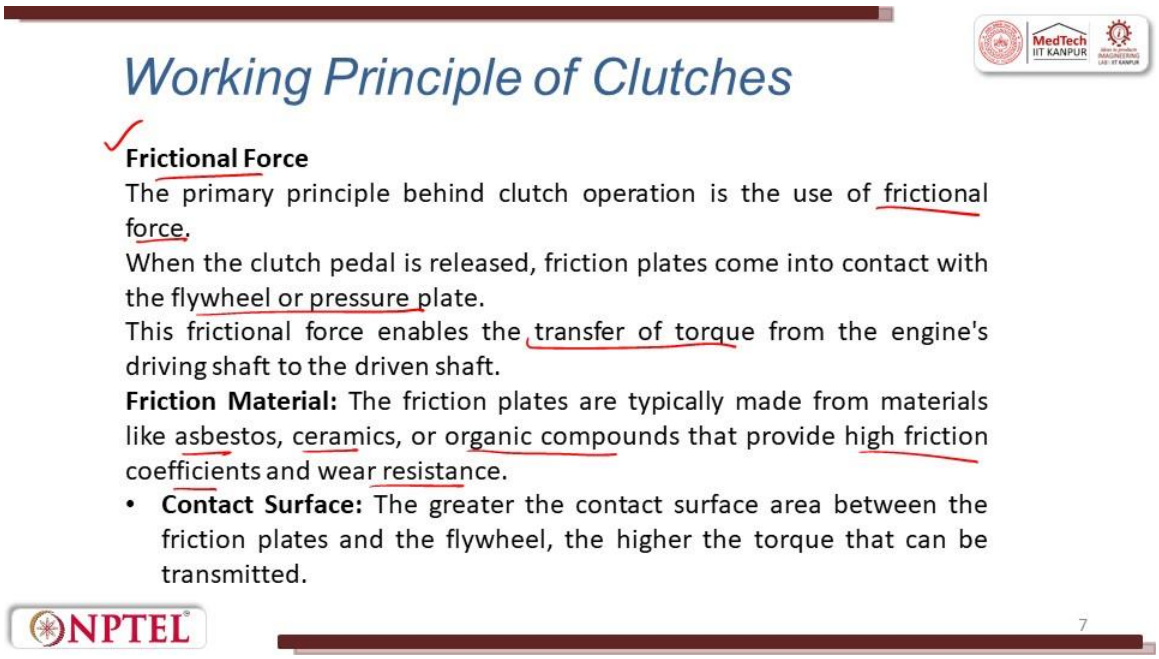
So this is a centrifugal clutch in which shoes or you call it clutch shoe, you call it clutch weight that expands so that it cracks a drum and engagement is there. So these are used in scooters. If you have got your scooter or moped service, you might have observed this kind of clutch system there. Or maybe for the go-karts, lawnmowers, where automatic engagement is necessary. Here we use the centrifugal clutch.



What are the applications specifically equipped to talk about? Applications of the Clutches are there in automotive systems. Crutches facilitate gear changes in vehicles by engaging, disengaging the engine from the transmission. That is, they provide controlled power transmission. Then we have industrial machinery where clutches are used heavily.

Clutches allow selective engagement and disengagement of machine components. When I say selective engagement, this means flexibility is allowed. I would say this ensures flexibility and efficiency in the operations. Then, clutches find their applications and power tools. Clutches prevent overloading by controlling torque transmission in drills, chainsaws and other power tools where clutches can help to control the power torque

transmission. Whenever the heavy torque is required, clutches would work to transmit heavy torque to make the hole bigger or deeper.



Working Principle of Clutches- Frictional Force. The primary principle behind clutch operation is the use of frictional forces. You have seen the clutch plates. These are also known as friction plates.

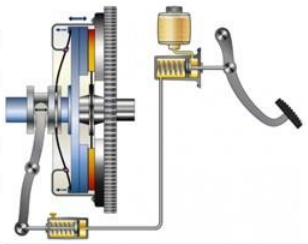
You can call it as friction plate or clutch plate. So, working principle always involves the frictional force. When clutch pedal is released, friction plates comes into contact with the flywheel or pressure plate. Frictional force enables the transfer of torque from the engine's driving shaft to the driven shaft. Friction material in the clutches could be multiple material, for example, a vestos, ceramics, organic compounds.

These provide high friction coefficient and wear resistance. So, when the clutch pedal is released, frictional resistance is there and it allows power transmission to occur. Frictional force is one point.

Working Principle of Clutches

Torque Transmission: Torque transmission in a clutch occurs as follows:

1. **Engagement:** When the clutch pedal is released, the pressure plate presses the friction plate(s) against the flywheel, creating a frictional grip between them.
2. **Power Transfer:** The frictional grip ensures that the rotational force (torque) from the driving shaft (engine) is transmitted to the driven shaft (gearbox).
3. **Disengagement:** Pressing the clutch pedal releases the pressure plate, separating the friction plate from the flywheel, thereby interrupting torque transmission. Allows the driver to change the gear



https://haynes.com/en-us/tips-tutorials/troubleshooting-common-clutch-issues-and-causes

Second point is Torque Transmission. Torque Transmission in a clutch occurs as follows. Engagement. When the clutch pedal is released, the pressure plate presses the friction plate against the flywheel creating a frictional grip.

Power Transfer is when the friction grip ensures that the rotational force that is the torque from the driving shaft that is engine is transmitted to the driven shaft that is gearbox. It is how the power transfer happens. Disengagement is when pressing the clutch pedal releases the press plate separating the friction plate from the flywheel thereby interrupting the torque transmission and this allows the driver to change the gear.

Torque Transmission in Clutches

To derive the formula for torque transmission in clutches, we analyze how frictional forces contribute to torque transfer between the driving and driven components.

Given relationship:
The formula for torque transmission in clutches is:

$$T = \mu F r$$

Where:

- T = Torque transmitted by the clutch
- μ = Coefficient of friction between the friction surfaces
- F = Axial force applied by the pressure plate (normal force)
- r = Mean radius of the friction surface

Next is Torque Transmission in Clutches. To derive the formula for the torque transmission in clutches, we analyze how frictional forces contribute to torque transfer between the driving and the driven components. This is the given relationship

$T=\mu W r$

Where:

- T = Torque transmitted by the clutch
- μ = Coefficient of friction between the friction surfaces
- W = Axial force applied by the pressure plate (normal force)
- r = Mean radius of the friction surface

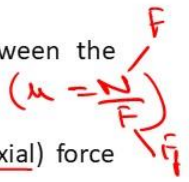
Torque Transmission in Clutches

Given relationship:

1. **Assumptions and Basics:**
   - The frictional force generated between the friction surfaces is responsible for transmitting torque.
   - The clutch consists of friction surfaces pressed together by an axial force F, and these surfaces have a coefficient of friction μ.
2. **Normal Force (*F*):** The pressure plate applies an axial force F to the friction plates, pressing them against the flywheel.
3. **Frictional Force (F_f):** The frictional force F_f developed between the contact surfaces is given by:

   $$F_f = \mu F$$

   Here, μ is the coefficient of friction, and F is the normal (axial) force acting on the friction surfaces.



In this relationship, there are certain Assumptions and Basics. Frictional force generated between the friction surfaces is responsible for transmitting torque. This is first. Second is the clutch consists of a friction surfaces pressed together by an axial force F and these surfaces have coefficient of friction μ. Normal force pressure plate applies an axial force F to the frictional plates, pressing them against the flywheel.

Frictional force is Ff. The frictional force Ff developed between the contact surfaces is given by $F_f = \mu W$. It is normal force by the friction force. If you recall mu was normal force by the friction force. Here normal force is F, frictional force is Ff.

Here mu is a coefficient of friction and F is the normal axial force acting on the friction surfaces.

Torque Transmission in Clutches

4. **Torque Transmission:** Torque is the product of the frictional force and the mean radius at which the force acts. Therefore, the torque T transmitted by the clutch is:

$$T = F_f \times r$$

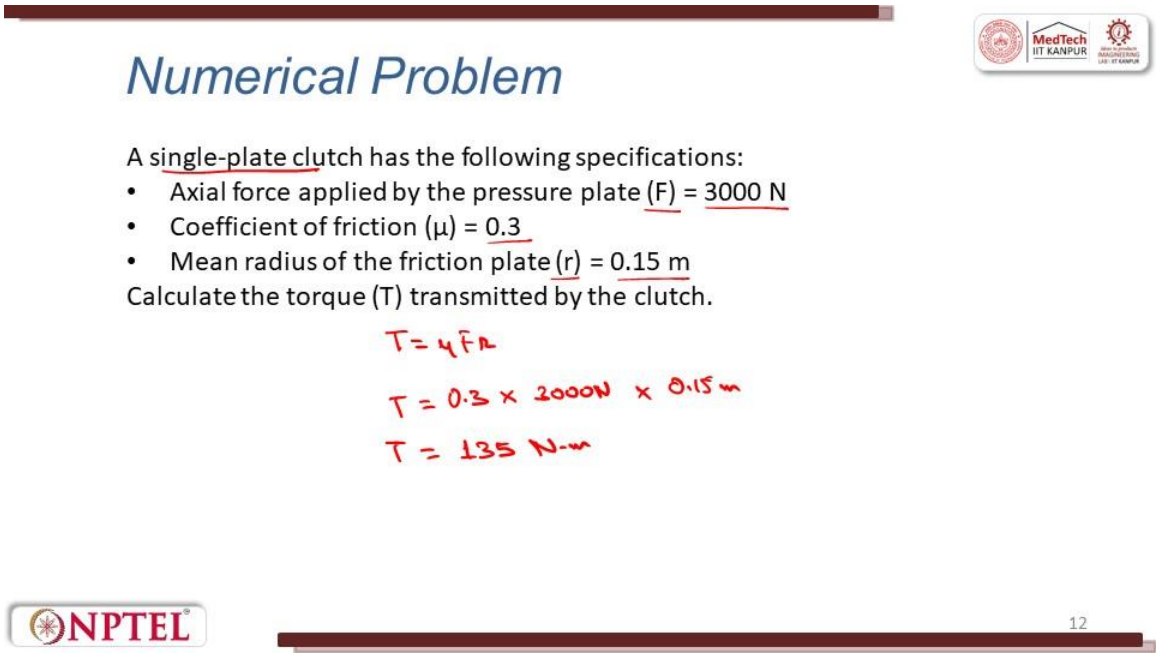
Substituting $F_f = \mu F$:

$$T = \mu F r$$

The derived formula $T = \mu F r$ shows that the torque transmitted by a clutch depends on the coefficient of friction, the axial force applied by the pressure plate, and the mean radius of the friction plate.

In torque transmission, how does that happen? Torque is the product of the frictional force and the mean radius. So torque is equal to frictional force into mean radius. This is the radius at which the force acts.

Therefore, the torque T transmitted to the clutch is $T = F_f \times r$. If we put the friction force as product of the coefficient of friction and the nominal force, $T=\mu F r$. This is how we have come to this relationship, $T=\mu F r$. This shows that the torque transmitted by a clutch depends on the coefficient of friction, the axial force applied by the pressure plate and the mean radius. There are three factors 1, 2 and 3.



Let us try to look at a quick numerical statement. A single plate clutch is a single plate has the following specifications. Axial force applied by the pressure plate F is 3000 Newton. Coefficient of friction is 1000. 0.3 mean radius of friction plate r is 0.15 meters that calculate the torque transmitted.

We will use the formula derived earlier:

$T=\mu Wr$

Substituting the given values:

T= 0.3 × 3000N × 0.15m

T = 135Nm

Introduction to Brakes

- A brake is a mechanical device used to slow down, stop, or control the speed of a moving object by applying a resistive force.
- Brakes convert the kinetic energy of a moving object into heat energy through friction. Reducing the motion of the object

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www.brake-cylinder.com/Content/uploads/2020537014/20200819155910739cd60814324882b2ab2d507eb255b4.jpg

Next is Brakes. When we talk about brakes, brakes are a part of an automobile system. If I talk about an example of a drill, again brakes are used there. Brake is typically a mechanical device. That inhibits motion by absorbing energy of the moving system. It tries to slow down, it tries to stop a moving vehicle, a moving axle or anything that is in motion.

So, this is generally again accomplished with the help of friction only. Mostly the brakes are there, those use friction between the two surfaces. That is they convert the kinetic energy into heat and they try to stop the vehicle or the motion. So, there are other systems as well for braking nowadays. For example, hydraulic brakes are there, electromagnetic brakes are there, hydraulic brakes use oil and a piston system, electromagnetic brakes use the eddy currents or so.

So, multiple kinds of brake systems are there. The point is the force is there, force when it is at a peak position, it has to be slowed down, it has to be stopped. It is the purpose of a mechanical brake. So, as a definition, a brake is a mechanical device used to slow down stop or control the speed of a moving object by applying a resistive force. Brakes convert the kinetic energy of a moving object into heat energy through friction. So that is how it tries to slow down and it reduces its motion. It could be slowing down, it could be stopping, anything.

Types of Brakes

1. **Disc Brakes:**

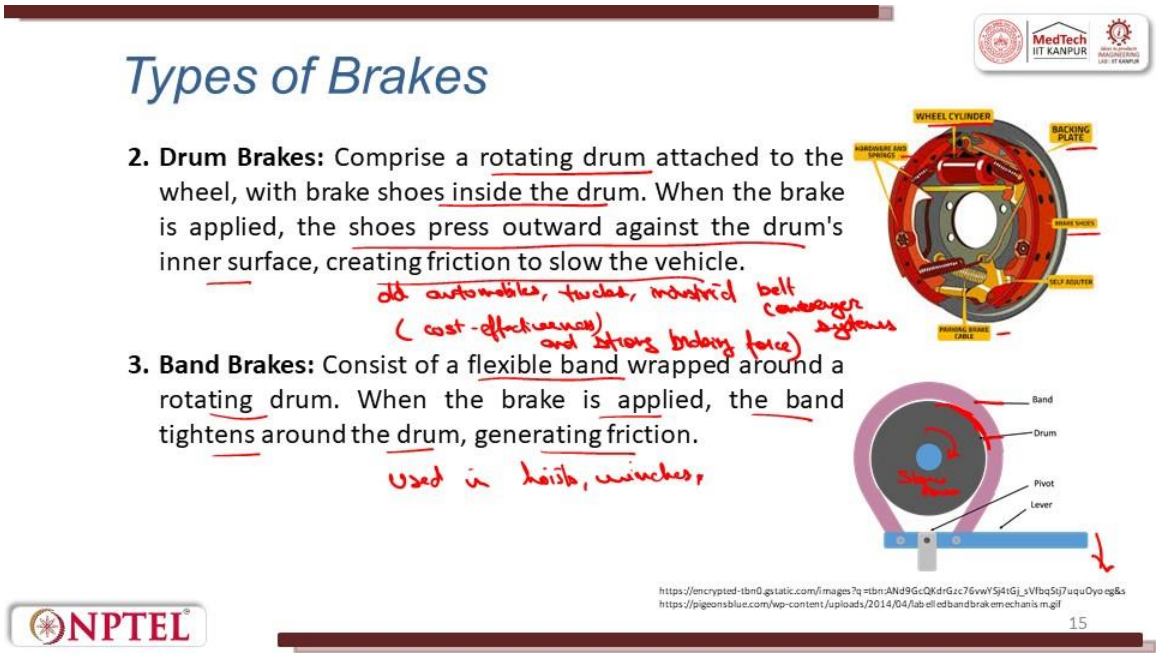
- Utilize a disc (rotor) and caliper mechanism. When the brake is applied, brake pads inside the caliper squeeze against the spinning disc, generating friction and slowing down the vehicle.

Automobiles (motorcycles, cars)
Bicycles

www.akebono-brake.com/english/product_technology/img/product/automotive/disc/ph07.png
https://bikeadvice.in/wp-content/uploads/2018/02/Hero-Xtreme-200R-pics-disc-brake-abs.jpg
www.rei.com/dam/up_2019-08-keener_062415_0001.jpg

Disc brakes is one of the types of the brakes which utilize disc or rotor and caliper mechanism. When the brake is applied, brake pads inside the caliper squeeze against the spinning disc. This generates friction and slowing down the vehicle.

So when the brake is applied, brake pads inside the caliper squeeze against the spinning disc here and it slows down the vehicle. So, these are commonly used in modern automobiles such as motorcycles, cars, etc. In bicycles as well these are used with Disc brakes. This is due to their efficient braking performance and heat dissipation system. So, these are the brakes in bicycle, this is in motorcycle.



Then comes Drum brakes. Drum brakes comprise a rotating drum attached to the wheel with brake shoes inside the drum. When the brake is applied, the shoes press outward against the drums in the surface creating friction to slow the vehicle. Have a wheel cylinder, braking plate is there, brake shoes are there which are attached. Then we have hardware and springs, brake cable is there and these are majorly used in not modern automobiles but old automobiles.

Recent or the modern automobiles use the disc brake, the older automobiles used to use the drum brakes. Trucks still use drum brakes only and some other industrial belt or conveyor systems may also use them. But this is generally used because of its cost effectiveness and it provides a strong braking force. Next is Band brakes. Band brakes consist of a flexible band wrapped around a rotating drum when the brake is applied the band tightens around the drum generating friction.

So, as it is a band brake itself you can see there is a band and this is a drum. There is a friction between band and the drum here. And there is a pivot and there is a lever. When you pull the lever down, this band is tightened. This generates friction and it is tightened around the drum. And this rotating element tries to slow down. These are typically used in hoists, winches and some industrial machines for controlling rotational speed.

Applications of Brakes

1. **Automotive Industry:** Brakes are essential for safely controlling vehicle speed, allowing for stops and reducing speed as needed.
2. **Industrial Machinery:** Used in conveyor belts, cranes, and hoisting equipment to control or halt movements.
3. **Bicycles and Motorcycles:** Brakes ensure safety by providing controlled stopping power for riders.

www.akebono-brake.com/english/corporate/business/images/fig37.jpg
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Then comes Application of Brakes applications are there in automotive industry brakes are essential for safely controlling vehicle speed allowing for stops and reducing speed as needed; industrial machinery where conveyor belts, cranes, hosting equipment are to be controlled for their movement to halt the movement or to slow down the moment brakes are used. Bicycles and motorcycles use brakes brakes ensuring safety by providing control stopping power or for the riders.

Working Principle of Brakes

Energy Conversion

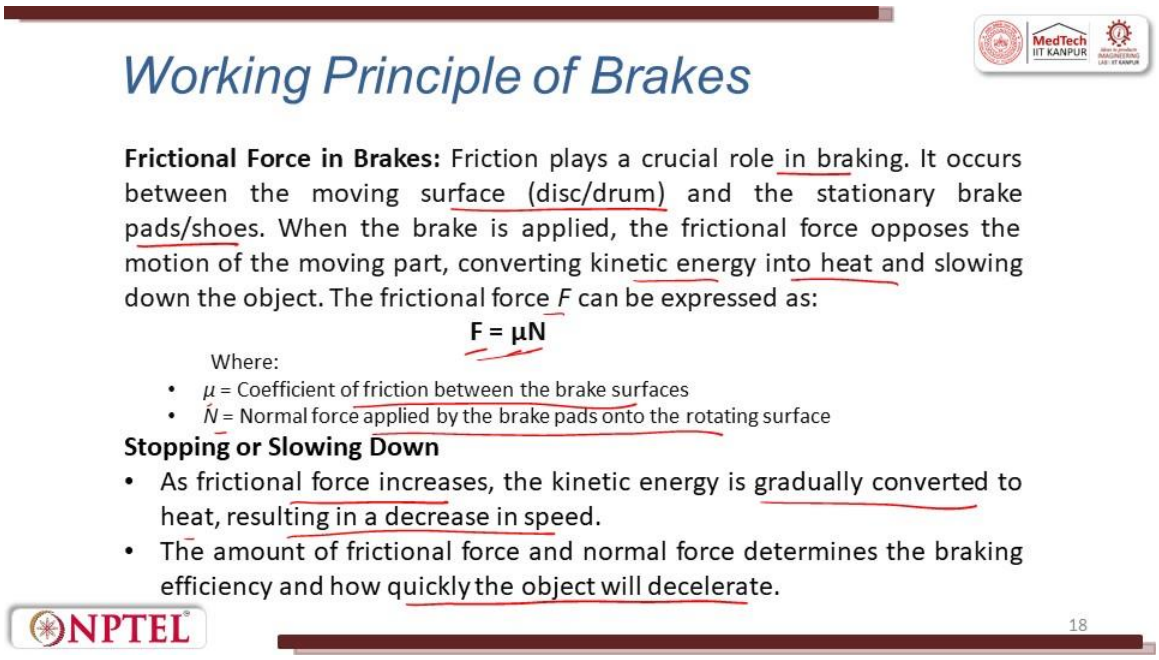
The fundamental principle behind braking is the conversion of kinetic energy into thermal energy. When a brake is applied, the moving object's kinetic energy is absorbed by the brake system and dissipated as heat due to friction. This process slows down or stops the object.

- **Kinetic Energy (E_k)**: The energy possessed by a moving object is given by

$$E_k = \frac{1}{2}mv^2$$

- where m is the mass of the object and v is its velocity.
- During braking, this energy is converted into heat, which is absorbed by the brake pads, disc, or drum.

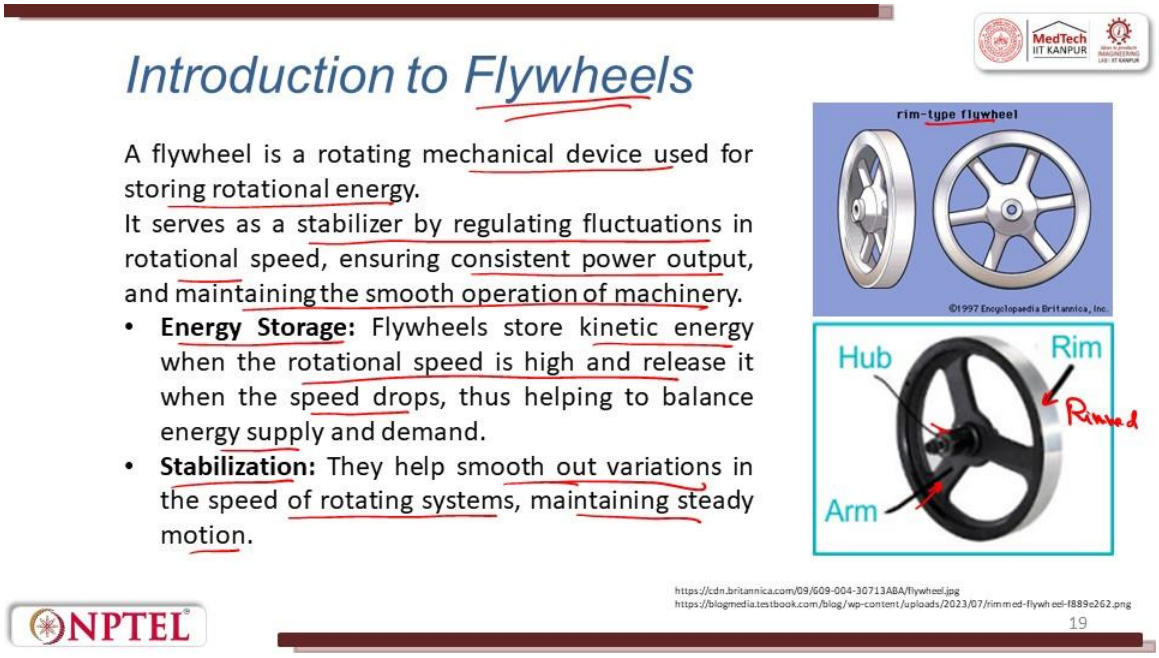
If I try to talk about the energy conversion, the fundamental principle behind the braking is the conversion of kinetic energy into thermal energy. As I have mentioned, kinetic energy converted into heat. When a brake is applied, the moving objects kinetic energy is absorbed by a brake system and dissipated as heat due to friction. This process slows down or stops the object. Kinetic energy, if I put it as a relationship, it is energy possessed by a moving object that is $E_k = \frac{1}{2}mv^2$ at which the object is moving. During braking, this energy is to be converted into heat which is absorbed by brake pad, disc or drum.



To have this energy converted, we need to understand the frictional force in brakes. So, what is frictional force in brakes? Force is equal to mu into N.

Friction plays a crucial role in braking. It occurs between the moving surface that is disc or drum and the stationary brake that is pads or shoes. When the brake is applied, the friction force opposes the motion of the moving part converting the kinetic energy into heat and slowing down the object. The friction force is expressed in this relationship where mu is coefficient of friction between brake surfaces and is normal force applied by the brake pads onto the rotating surface. So, stopping or slowing down.

This decision is to be taken by the brake depending on the pressure that you apply. As friction force increases, the kinetic energy is gradually converted to the heat and resulting in decrease in speed. The amount of friction force and normal force determines the braking efficiency and how quickly the object will decelerate. So, this is the use of the brakes.



I will now give you a brief introduction to the Flywheels. Flywheels. Rim type flywheel. Flywheel has a hub. It has a set of arms. It has a rim.

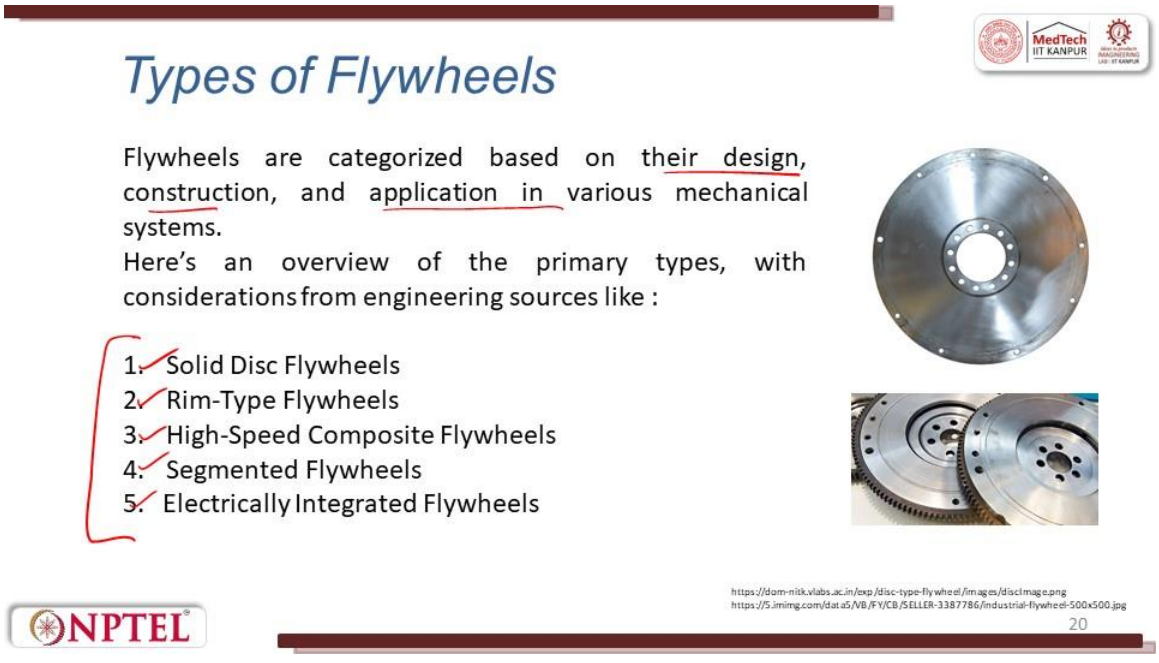
So what is a flywheel? It is a mechanical device that helps to store energy. Because of the weight of the flywheel, the angular momentum is there that helps to store the rotational energy. Then this rotational energy in form of kinetic energy is proportional to the product of its moment of inertia and the scale of its rotational speed. We have discussed in moment of inertia before, but flywheels are there.

You have a smaller shaft that does not have any weight. You attach a flywheel over it, flywheel will give it a weight that helps to transmit heavy power. That is this energy, whatever this rotating shaft is there, if a flywheel is there, flywheel have to rotate the other shaft with a heavier load. So, flywheel is a rotating mechanical device used for storing rotational energy. Flywheel is generally a rimmed flywheel.

This is a rimmed flywheel. There could be flywheel without shaft as well which is known as shaftless flywheel. There are super flywheel nowadays in which solid core or hub is there and multiple thin layers of high strength flexible material such as some steel or carbon fiber etcetera are there which are wound around it. So, different kinds of flywheel are there. This serves as a stabilizer by regulating fluctuations in the rotational speed, ensuring consistent power output and maintaining the smooth operation of machinery.

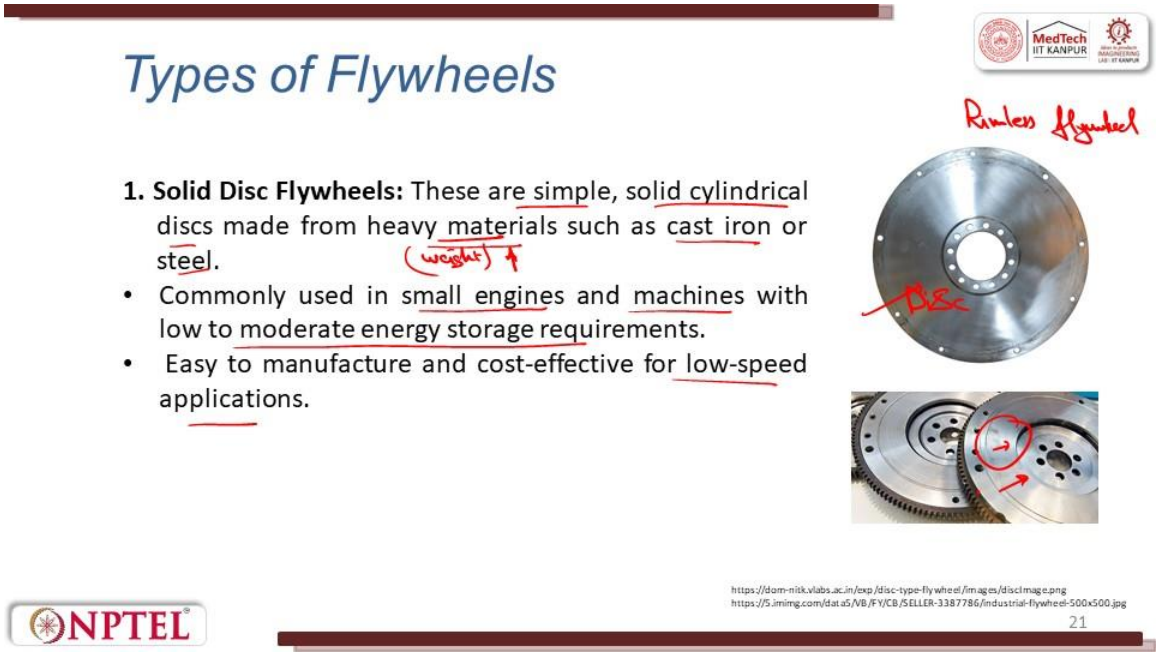
So, the first function of flywheel is Energy Storage. Along with it, it Stabilizes the motion. Energy storage, flywheels store kinetic energy when the rotational speed is high and release it when the rotation speed drops. Thus helping to balance energy supply and demand stabilization. They help smooth out variations.

Variations in rotation when we have a flywheel the rotation would be smooth any variations which are there in the shaft without flywheel could be there, but if load is there the shaft could slow down or maybe move forward, but flywheel will help you have a smooth motion throughout even it is loaded variable load is there is unloaded while flywheel will still have to have a stabilized movement or the stabilized rotational systems it maintains steady motion.



Types of Flywheels; flywheels are for multiple types, Solid Disc flywheels, Rim Type flywheels, High Speed Composite flywheels, Segmental flywheels and Electrically

Integrated flywheels. Flywheels are categorized based on their design, construction, application in various mechanical systems. So, here is an overview of primary type with considerations from engineering sources. These are the flywheel of primary types when we consider from the engineering sources.



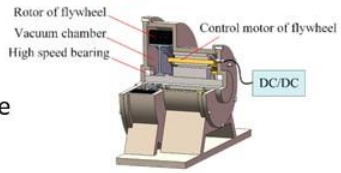
First is Solid Disc Flywheel. These are simple solid cylindrical disc made from heavy materials such as cast iron and steel. You see heavy material is written here that means weight is a concern for a flywheel to be designed. This is simple disc.

These are commonly used in small engines and machines with low to moderate energy storage requirements. So, when rim is not there only disc is there this is known as rimless or disc flywheel or rimless flywheel. This is easy to manufacture and cost effective for low speed applications. For example, you see this gear is there, its hub does not have sprocket. It itself have a solid disc here. So disc works as a disc flywheel here.

Types of Flywheels

2. **Rim-Type Flywheels:** Consist of a heavy rim connected to a central hub via spokes. Most of the mass is concentrated on the outer rim, increasing the moment of inertia.
   - Found in automotive engines, large machinery, and applications requiring higher energy storage.

3. **High-Speed Composite Flywheels:** Made from lightweight composite materials such as carbon fiber, designed to operate at very high speeds.
   - Used in advanced energy storage systems, regenerative braking electric vehicles, and aerospace applications.



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Then comes rim type which are most commonly used. This consists of a heavy rim connected to a central hub via spokes. This is a rim. These are the spokes.

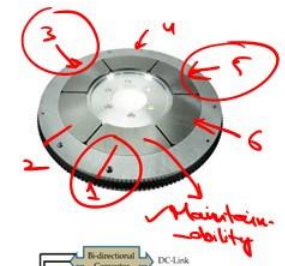
This is a hub. Most of the mass is connected on the outer rim increasing the moment of inertia. To increase the moment of inertia, the major mass is here on the outer surface. These are found in automotive engines, large machinery and applications requiring high energy storage. These are efficient for high rotational speeds.

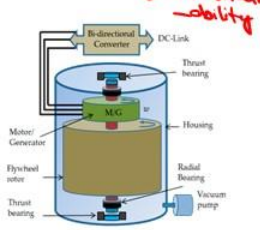
I would say for high rotational speeds and for greater energy storage capacity. Then comes High-Speed Composite flyways. These are made from lightweight composite materials such as carbon fiber designed to operate at very high speeds because if flywheel weight is very heavy, if it is made of a steel, it would be difficult to rotate it at a higher speed. So, when the high speed is required, the weight has to be lower. I will put weight has to be lower here.

In the other type the weight was supposed to be heavy in the solid disc type. So, here in the composite type as the name suggests it is composite the material has to be lightweight. So, speed is supposed to be high here these are used in advanced energy storage systems that is regenerative braking electric vehicles and aerospace applications. So, these have high energy storage efficiency and their weight is less and they have ability to operate at high speeds.

Types of Flywheels

4. **Segmented Flywheels:** These flywheels are assembled from individual segments or parts rather than being a single solid piece.
   - Used in heavy-duty applications such as power generation, where ease of maintenance and handling is essential.
5. **Electrically Integrated Flywheels:** These flywheels are designed to integrate with electrical systems, often used with magnetic bearings or coupled with electric motors / generators.
   - Ideal for applications requiring rapid energy storage and release, such as uninterruptible power supplies (UPS) and hybrid energy systems.





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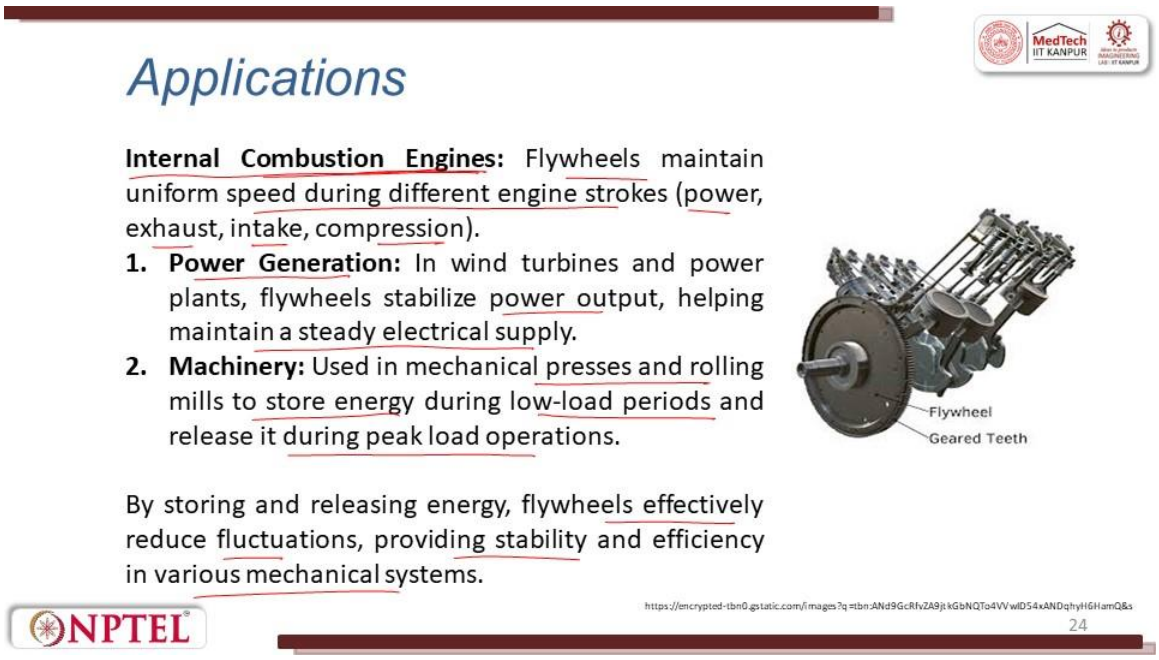
Then comes Segmental flyways. Segmental or segmented flyways are assembled from individual segments or parts rather than being a solid piece. So, these are segments. This is segment 1, segment 2, segment 3, segment 4, segment 5 and segment 6. These 6 are separate segments. These are joined together.

In place of 6 segments, we could have used only segment 1, 3 and 5. In this case, it could have become kind of a spokes for it, these are used in heavy duty applications such as power generation where ease of maintenance and handling is essential segmental is there because we can remove it, we can have a better maintainability maintain ability, these are easy to transport as well because if heavy or big size flywheel is there, it could be 1 meter, 2 meters flywheel. If small segments are there, these can be easily stored in that transport vehicle and could be easily transported.

These are also easy to install because different segments are there and definitely maintainability is there. Then comes Electrically Integrated flywheels. Electrical integrated flying wheels are designed to integrate with electrical systems. These are often used with magnetic bearings or coupled with electric motors and generators. These are ideal for applications requiring rapid energy storage and release such as uninterruptible power supplies that UPS and hybrid energy systems.

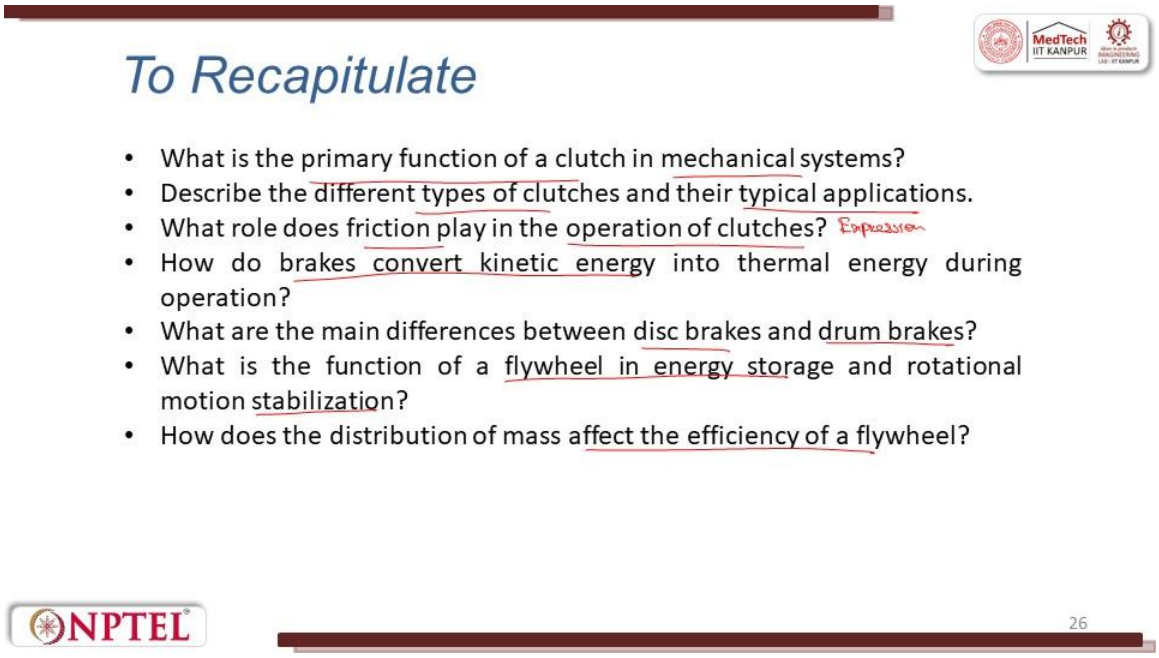
So, these are used for efficient energy transfer and reduce mechanical losses because these are electrical, these reduce mechanical losses.



About the Applications of Flywheels, first is Internal Combustion Engines. I have talked about multiple applications. When I talk about IC engines, flywheels maintain uniform speed during different engine strokes. Just to recall, flywheel helps to store energy.

It helps to stabilize the rotation motion. So to stabilize the rotational motion in power stroke, exhaust stroke, intake stroke, compression stroke in IC engines, flywheels helps us to serve the purpose. Then is Power Generation. In wind turbines and power plants, flywheels stabilize power output, helping to maintain a steady electrical supply. Machinery, these are used in mechanical presses and rolling mills to store energy during low load periods and to release it during the peak load operations.

So, by storing and releasing energy, flywheels effectively reduce fluctuations providing stability and efficiency in various mechanical systems. Using fluctuations, again stabilizing is the purpose.



So, just to recall what we have discussed in this lecture. We talked about the clutches, brakes and flywheels to talk about some questions that intrigues us to understand it better. First is what is the primary function of a clutch in a mechanical system?

Describe different types of clutches and their typical applications. What role does friction play in the operation of clutches? We can also put the expression for friction here. How do brakes convert kinetic energy into thermal energy during operation? What are the main differences between disc brakes and drum brakes?

I talked about the application in the modern vehicles and the old vehicles. You can put some other differences there. What is the function of a flywheel in energy storage and rotational motion stabilization? How does the distribution of mass affect the efficiency of a flywheel? So with this I am closing this lecture and I will keep talking about the mechanical components in the coming lectures and in the end of this course I will take one lecture on statistics.

That is, what is the role of statistics in engineering? When you talk about taking observation, calculating the torque or observing the torque or noting down certain readings during experimentation, role of statistics is also very important. They are what to see, whether mean, median, mode, what do you see? So, that would be also discussed in this course itself and we will meet in the next lecture. Thank you.