Design of Mechanical Transmission Systems

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Week – 12

Lecture - 32

Lecture 32_Clutch: Centrifugal Clutch

Good morning. So we will continue about the clutch design aspect. So these are the topics we have been covered so far. So particularly we are discussing about the torque transmitting capacity aspect for various clutch type for single plate clutch, multi disc clutches, cone clutches and today we are going to learn about centrifugal clutches aspect. Before going to understand about the centrifugal clutch I would like to play a video for you. This is the video.

In this video we are going to learn how a centrifugal type clutch works. The main function of a clutch is to engage and disengage the mechanical link between two rotating machine parts. A clutch can be operated manually or it can be an automatic type. In a typical motorbike clutch unit, clutch is kept engaged with the spring pressure.

Thus power is sent to gearbox from engine. Generally, a centrifugal clutch is designed to work automatically depending on centrifugal force. When an object starts moving in a circular or curved path, a type of force keeps pushing the object outside of that path. This is called centrifugal force. Centrifugal force depends on the velocity of the moving object, radius of curved path and the mass.

That means for a rotating object, if rotational speed increases, then centrifugal force increases too. Centrifugal force can be fun or, ignoring or not knowing this basic physics stuff, can be very dangerous for you in some situations. Or centrifugal force can be used with brilliant engineering technique just like in centrifugal clutch. A centrifugal clutch consists of different parts. Its inner hub is powered by the engine output shaft and the outer drum is connected with the transmission shaft.

In this type of design, a number of mechanical shoes are installed on the inner hub plate. These shoes can rotate from the hinged points. But tension springs keep it away from the drum's inner surface. The inner hub assembly with the shoes starts rotating along with the engine shaft. When rotational speed increases, centrifugal force makes these shoes turn against spring force. These shoes' lining creates frictional grip with the drum's inner surface. So it makes the outer drum rotate along with it. Thus, power is transmitted through the centrifugal clutch. Centrifugal force reduces when the engine shaft speed drops below a certain limit. Spring force pulls back shoes from the drum surface.

And the drum becomes free. So the transmission shaft doesn't get affected by engine braking load. Similarly, during starting the engine, engine stays free from driven load. So the engine can be started in no load condition. When engine RPM reaches a certain limit, the centrifugal clutch automatically engages and starts transmitting power to the driven unit.

Thank you for watching. So that's about the centrifugal clutch. So in fact, I think I have shown this also earlier. You can see in the video you have seen it, right? The video, this is something shoe. It is called shoe. You could see, right? This is one shoe and two and three. All three shoe get together in constrain with the spring. This is the spring. So again the number of shoe will vary. It depends on how much torque you want to transfer.

It can be three, it can be two, it can be four. Probably you could see this is actually two shoes, centrifugal clutch. In fact, I think I have shown you this also earlier, right? This is nothing but your centrifugal clutch. So this is your drum, right? And this is the one which is going to be fixed with your engine. Sorry, this is to the drive shaft where you wanted to, driven shaft where you wanted to transmit the power to the gearbox, right? And this is the one which is going to be fixed in the engine side.

And you can see that there is a two lobes clearly. The two lobes are there and two lobes are connected with your spring. In fact, each lobe will have a friction lining, right? As rotation, right, due to centrifugal force, this is tried to expand against the spring force. So when the centrifugal force is same as the spring force, then it will start floating. If the spring force is greater than the centrifugal force, it will be intact, right? As increasing the speed, the centrifugal force keeps increasing.

At one stage it will be equal. After that it will be greater than your spring force. At that condition, it will try to expand, right? And expand radially, it will expand radially, such a way that make a contact through friction lining, right? Then transmit the power, okay? So what is the advantage? You can operate the system without loading condition, make the transmission very smooth. That is the purpose, having a centrifugal clutch aspect. And you can see here also, this is a typical schematic diagram where you have shoes, right? This is your drum and the entire arrangement is called as a spider.

Shoe with the spring is called as a spider and you will always have a spring, right? Because that is the one which is controlling your centrifugal force aspect, okay? So before going to the centrifugal force, yesterday lecture I have discussed about the cone clutch aspect, right?

I have discussed about the cone clutch aspect. So I said cone clutch is extensively used. One of the application is a synchronous mesh gear. This is nothing but your synchronous mesh gear. This is actually the gear, right? You can see this is the gear and the gear will have a, it is a helical gear.

You can see that this is attached with this cone. If you look at in this direction, you can see that there is a small angle. Tap and you can see the tapered and this is nothing but the cone arrangement. And top of that, this is the blocker ring. If you look at internally, this also is a cone type.

So they will make a nice contact so that there won't be any slip and make the transmission. In fact, maybe I will show. This is the, the synchronous mesh gear aspect and this is the hub and they will make a contact through blocker ring and transmit such a way that the speed of the gear and the speed of shaft will be same. That is why it is called synchronizer, okay. So in the synchronous mechanism, extensively used cone type of clutch arrangement, okay.

So when now, I think I have discussed in the class, whenever you say constant mesh, the constant mesh can be a dog clutch arrangement. The another one is the synchronous mesh arrangement, okay. The synchronous is very smooth, less noise, very compact for a human, you know, for a comfort level aspect, okay. So this is again an example for synchronous mesh with the cone clutch arrangement, okay. Now we understand the centrifugal force which is causing to move the entire spider through shoes, right.

So that means we need to understand how much the mass we need to know. So suppose you want to transfer fixed amount of torque, right, for the engagement. So we should aware of the, how much torque we need. So what would be the mass of the shoe? How many shoes you need? Then what would be the dimension? So those aspects we are going to learn from today's lectures. So, I will draw the schematic diagram, right.

So just before giving, I will introduce the dimensions. So, take the r_d. r_d is the radius of drum. r_g is the radius of centre of gravity, okay, of the shoe engagement. C.G, centre of gravity, okay, of the shoe in engagement, during the engagement.

m is the mass of shoe. I am talking about only single, each single shoe, okay, not the entire one. And P_{cf}, centrifugal force, right. P_s is a spring force and ω_1 okay, speed at which the engagement start. And ω_2 is the running speed.

Yeah, right. You can see this is the, just nomenclature. r_d, r_g, m, P_{cf}, P_s, ω_1, ω_2. So now I will draw the schematic diagram and the forces also. So assuming this is your drum arrangement, right. Yeah. Like this, okay. So there is a shoe at the centre. So it has some mass and this is your CG, right. And this is connected through spring, right. This is what happening, okay. So this connected spring, this is drum, okay.

And this is a certain angle. So the shoe angle you can say θ. At the moment you are not considering. And the dimension between centre to here this is your drum diameter R_d, right. The CG will flexible. So it change, depends on the things, okay. So this is your r_g radius of due to gravity aspect, okay. And if you look at the, just I wanted to show the force balance. This is your, the mass, shoe mass, okay. This is your CG, okay, right. So usually what happen, the spring try to pull inward, right. So you will have your spring force P_s, right. But as you increase in the speed, it will move upward direction. So this is your centrifugal force, the P_{cf}. Okay. So when do you expect engagement, right. When you overcome the P_s, right, that means there is a net force during the engagement. Then we will make a contact through friction. so that should be your P_{cf} – Ps. P_{cf} minus Ps. Then I am not saying P_{cf} at the later stage, okay. And that is your μ okay. So when you talk about, so initially you will have one centrifugal force at the beginning of the speed. At the end of the speed you will have another centrifugal force. So we will say this P_{c2} aspect.

P_{c1} is the initial one. Yeah. So the centrifugal force at the beginning, okay, ω_1 at a speed. So what do you expect?

$$P_{cf1} = m{\omega_1}^2 r_g$$

Again depends on your radius which is the centre of gravity, okay. Similarly, centrifugal force at the running speed where the engagement happened, right. This is before the engagement and this is the thing which is ω_2 speed.

$$P_{cf2} = m{\omega_2}^2 r_g$$

This r_g also will be variable, okay. It is a variable. So the centrifugal force is balanced by in equal and opposite spring force. Similarly P_{cf1}, right, is balanced by an equal and opposite spring force P_s, right, at the beginning of the engagement. So

$$P_{cf1} = P_s = m{\omega_1}^2 r_g$$

So the moment, right, as speed increasing, right, the P_{cf1} will greater than your spring force. That is what happened. So, okay, so that is where, so when in this condition the shoes move, moves radially outward, radially outward and make a contact with the drum through friction lining, right. That is what happening, okay, through friction lining, okay. So then the net force during the engagement, the net force

$$P_n = P_{cf2} - P_s = m{\omega_2}^2 r_g - P_{cf1}$$

This is m ω_2 square. Then this should be r_g. This should be, right. So what do you happen to, yeah. What is the P_s? P_s is nothing but your P_{cf1}, right. After that only it will make engagement.

Before that it would not. So this should be equivalent to P_{cf1}. So when you rewrite

$$P_n = m{\omega_2}^2 r_g - m{\omega_1}^2 r_g = m r_g({\omega_2}^2 - {\omega_1}^2) \quad (1)$$

$$frictional\ force = \mu P_n = \mu m r_g({\omega_2}^2 - {\omega_1}^2)$$

So this is your net force, right. The net force acting on the drum, that is the equation number 1 we can say there. But this is just a force but this is happening through frictional aspect, right. So therefore the frictional force will be µ times your P_n, right, okay. This is fine. Frictional force is fine. Now I need to find as a frictional torque now, T, right. So what is the frictional torque? μP_n, right, into the frictional torque with respect to your drum diameter, right r_d.

$$frictional\ Torque = \mu P_n r_d = \mu m r_g r_d({\omega_2}^2 - {\omega_1}^2)$$

this is what happened, okay. So this is the entire thing, okay. This is for the one shoe, right. For z number of shoe, right, number of shoes then the total frictional torque capacity of the centrifugal clutch, right, is

$$T = \mu m r_g r_d Z({\omega_2}^2 - {\omega_1}^2)$$

So this is the equation we should use it. So this much torque is transmitted through shoe clutch arrangement, okay. The question is, so what is the application? Any idea what are the application? You want to have a smooth engagement, right. Where do you expect? Have you seen how the cranes operating? The cranes and the hoists and all, how do they operate? They had to supply, get the power from the motor, right. How does it happen? That is through this centrifugal clutch. You do not want to, you want to have the transmission very smooth with the low load condition.

In that condition mostly the preferred clutches would be the centrifugal clutch, okay. You can have a cranes, ball mills, all cement mills for heavy duty application and also you can have a land mover, you know land mover where you want to get the grass, right. There also they used the centrifugal clutch. How about gokart? Have you been to gokart? Right.

They are connected with the electrical thing and you keep do. That is one way or else there is a small pit that is also do that. Which they, there use pretty much the centrifugal clutch, okay. Yeah, so that is about the centrifugal clutch.

We will do a couple of problem. Then tomorrow we will start the dynamic and thermal analysis of a clutch system which is very important. Yeah. So can you take down the problem please?

Q4. A centrifugal clutch transmitting 200 kW at 750 rpm consists of 4 shoes. The clutch is to be engaged at 500 rpm. The inner radius of the drum is 165 mm. The radius of center of gravity of the shoes is 140 mm when the clutch is engaged. The coefficient of friction is 0.3 while the permissible pressure on friction lining is 0.1 N/mm^2. The shoe angle is given 70°. Calculate the mass of each shoe and also find the dimension of the friction lining. So they need, they have, we have to find out the, the dimension for the friction lining also. Right. So there is a transmitting power is given.

So transmit power is given 20 kilowatt operating at 750 rpm. The number of shoes are given 4. The initial speed is given 500 rpm and the engagement speed 750 rpm. The inner radius 165 mm, inner radius of the drum r_d is given. The r_g is given 140 mm. That also given. μ is 0.3. Then permissible pressure p_a 0.1 N/mm^2 and theta, the subdued angle of the shoe is 70°.

Okay. We need to find out, solve the problem. It is a very simple problem. It is very straight forward. First we have to find out the mass. Right. So we need to know that the first condition

$$T = \mu m r_g r_d Z({\omega_2}^2 - {\omega_1}^2)$$

I think this is the formula. Right. This is the formula. T is, already we will find out what is the T. You know μ is given. r_d you know. r_g also known. Z is known. ω_2 known. ω_1 also known. So you need to find out the mass. Okay. The power, right. The power is 20 kW. N_2 is 750 rpm. N_1 500 rpm. Z is number of shoes is given 4. Right. Then radius of drum 165 mm. Radius of the center of mass r_g 140 mm. Yeah. μ is given 0.3. The allowable permissible pressure 0.1 N/mm^2. Okay. Just we will find out the ω_2.

$$\omega_2 = \frac{2\pi N_2}{60} = \frac{2\pi * 750}{60} = 78.54\, rad/s$$

$$\omega_2 = \frac{2\pi N_1}{60} = \frac{2\pi * 500}{60} = 52.36\, rad/s$$

So I would, you think you should get 78.54 radian per second. And this would be 52.36 radian per second. It is clearly given. Okay. So when do you expect power transmission? When do you expect the power transmit? Right. Yes. Yeah. Okay. No, no. Which speed? That is the question. Torque into the final speed ω_2 .Right. That is the speed the power is transmitted. Not before that. So we need to find out the torque.

Okay. So $T = \frac{P}{\omega_2} = \frac{20*1000}{78.54} = 254.25\ Nm$

This much torque is transmitted. Yeah. Now we know T

$$T = \mu m r_g r_d Z({\omega_2}^2 - {\omega_1}^2)$$

$$254.65 = 0.3 * m * 0.165 * 0.140 * 4 * (78.54^2 - 52.36^2) \ \ \rightarrow m = 2.68\ kg$$

Substitute and tell me what is the m value. So can you have what is the value you are getting for the shoe mass? Yes 2.68 kg mass. That is the mass of the shoe. Okay that is fine. So the next step would be we need to find out the dimension of the brake lining. Right dimension of the brake lining. Friction lining.

Here is clutch purpose. So we do not want to say brake lining better it will say friction lining. Okay. So actually this is just give you a diagram. Okay.]This is the arrangement right. So this is your θ 70 that is clearly given. And yeah. Right. So this is your drum r_d. Okay. I am just showing you in three dimensional. This is the arrangement. This is your friction lining. I am just showing the things. So this would be your face width and this would be a arc length right.

That will be arc length l you can say that. Yeah. So what happen l equal to?

$$l = r_d\theta = 0.165 * \frac{70\pi}{180} = 0.2\ m$$

So that will give you information. So what is the value you are getting? l equal to what? l equal to we should get 0.2 meter. So that is the value you are getting. The length of the arc length of the friction lining.

So that we know that so but we do not know about the face width. Right. But you got the pressure. The friction lining pressure is given. Right. So the net force acting on the friction lining right. On the drum and the lining also together should be equivalent to your, equivalent to your allowable pressure into friction lining area.

$$\text{the net force acting on the drum lining } P_N = p_a \times l \times b$$

This is your arc length l and this is your projected length, projected area b. So that is clearly given. Right. This is your net acting force. So p_a is given right. p_a you know that. p_a is given 0.1 N/mm^2. That is clearly given. Okay. Tell me what is that value you are getting? How do you find that net acting force p? Find out the net acting force from there you do that.

It is much easier. So net acting force maybe I can rewrite. Okay.

$$P_n = mr_g(\omega_2{}^2 - \omega_1{}^2) = p_a \times l \times b$$

$$2.68 * 0.14 * (78.54^2 - 52.36^2) = 0.1 * 10^6 \times 0.2 \times b$$

$$b = 65\ mm$$

So what is the friction lining width you are getting? 65 mm? Yeah. In mm? 65 right? Yeah. Okay. So you get 0.065 m or else the friction lining 65 mm. So now we know l also 200 mm. So these two are friction lining dimension okay. Friction lining dimension for each issue right for each shoe. The same thing we need to do for other things also. Okay. I think another small problem just I will just discuss with you.

Then maybe you can do it later stage. A center pull cut consists of 4 shoes each having a mass of 1.5 kg. In engaged position the radius of the center of the gravity of each shoe is given 110 mm, while inner radius of the drum is given 140 mm. The coefficient of friction is 0.3. The preload in the spring adjusted in such a way that the spring force at the beginning of the engagement is 700 N. The running speed is 1440 rpm. Calculate speed at which the engagement begins which is ω_1 and also what would be the power transmitted by the clutch at 1440 rpm which is they are asking about the P power which is torque into ω_2. This is very simple problem that you can do it as a homework. Okay. And tomorrow I will stop now.