Design of Mechanical Transmission Systems

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Week – 11

Lecture - 31

Lecture 31_Clutch: Multiple Discs and Cone Clutches, Problem Solving

Good morning. So, we will continue about the design of clutch system. I think so far we have discussed the clutch types, clutching, working method. Particularly we discussed about the torque transmitting capacity with respect to for single plate clutch. Within that we have discussed about uniform pressure theory aspect as well as uniform wear theory. Now we will move on to the other type of disk for a torque transmitting capacity aspect.

So, we are going to learn about multidisc clutches aspect and also cone clutches and we will do a couple of problems from today's lecture. The question is we have discussed about the single plate clutch system and we have seen the model also very big size right. But the problem is the size is big and also the when considering the surface area, actual surface area do you think this is enough to transmit the higher torque that is the question right. So, if we want to transfer the more torque we need to have the more surfaces that is one aspect.

So, not only that you need to transfer the more torque, but may be if you reduce the space limit if there is a space limit then we need to have a again a different aspects. So, what I want to say that when you want to have a large torque capacity transfer that is one thing large torque capacity aspect and also you have to have more surfaces to have a high heat capacity. In that case you cannot use a single disc clutch not only that the wear remember I asked one question there are two disc rotating their contact each other through spring mechanism a diaphragm from then the power is transferred from the drive to driven this is what I said through friction lining this is what I said. But I asked you one question the clutches are operated in oil condition also right remember this is the question I asked you why right. So, if we have a dry clutch the wear will be very high the moment you have lubricated the where it will be reduced.

So, what I want to say that when you want to have a multi disc clutch system you have to look at different aspect in terms of higher torque capacity, high heat transfer, low wear more importantly high power weight ratio. So, that a smaller size you can transfer the

higher power and especially the space restriction right. So, the clutch size is probably may be one feet or 12 inches that is a diameter right. So, single plate whereas, for scooters and motor cycles or motor bikes do you think that is good enough it is too big right. Of course, we are doing a projects for a two different aspect one is jeep, other one is sports vehicle right.

So, when you have sports vehicle the space is even more limited. So, what is the solution then. So, in that case when you have a high torque high heat capacity and you need to have a low where at the same time as small as possible then the only solution would be multi disc clutches multi disc clutches. So, this is the arrangement you can see that very interestingly this is the complete assembly you can see this is the complete assembly and this is the if you do the cross section only half of the cross section you can see that. So, when you cut through here and zoom in right.

So, you would see in this arrangement look at this, you have two things one is at the backup plate I will explain what is that mean this is your backup plate then you have a separate plate in between friction discs also there, the separate plate is called as a rotor, the friction disc is called as a stator hope you do remember what you mean by rotor and stator one is rotating other one is fixed and if you look at the arrangement what is this is nothing, but your friction thing right. So, this one and here this one they are arranged to one link they are arranged to one link whereas, this one you can look at again very carefully the rotors are arranged in the another link. So, what happen through the spring when you do the operation they will press against each other you can see that. So, normally the rotor will be more than the your stators or friction plates ok. Let me ask one more question have you ever seen aircraft brake system, aircraft carrying very heavy energy right ok.

So, during the landing they had to not only apply the thrust where flaps will be open ok flaps will be open that will reduce the things that would not be enough that would not be enough and you need to have a brakes also. So, what type of brakes do you expect I am sure in the thermal analysis we would have seen that right. So, what type of I mean I just wanted to say that what type of disc brakes are available how many disc brakes are available in the aircraft not the clutch have you seen, did I show any pictures of that it is a multi disc it is a multi disc ok. In fact, the temperature will be more than 200°C usually they go for a carbon-carbon composite brake aspect. Same concept same thing is applicable for a multi disc clutch system the operation is similar right that is the thing.

So, you could see that. So, you have a stator and the rotor then arranged in a staggered manner based on the capacity how much torque you want to transfer and do the performance ok. So, otherwise this is same as a single plate clutch system only difference is you will have more number of surfaces yeah. So, this is taken from Liang Yu from tribology transactions and advantages the increase the amount of torque able to transmitted

the decrease in the pedal operate to clutch and obviously you are reducing the size also right. So, even though you creating the number of plates or number of this more, but the overall weight you are reducing the moment you reducing overall right what happen your specific fuel consumption will be improved ok. And one more thing is the inertia effect also can be reduced. Obviously, larger diameter the inertial effect will be larger right. So, the moment you reduce the diameter the inertial effect also can be reduced. So, that is one of the advantage having a multi disc clutch system. So, this multi disc clutch system is used in all two wheelers.

So, this is the advantage be it a scooter or bike motor bike right or even heavy sports vehicles they use this type of multi disc clutches. So, the same equation only difference is you have to multiply number of surfaces that is what is given z is given from uniform pressure theory for uniform wear theory you could see that there is a equation should come yeah the same equation

$$For\ uniform\ pressure\ theory\ \ T = \frac{\mu P z}{3}\frac{(D^3 - d^3)}{(D^2 - d^2)}$$

$$For\ uniform\ wear\ theory\ \ T = \frac{\mu P}{4}(D + d)$$

Where, z = the number of pairs of contacting surfaces

Number of discs = z+1

z_1= number of discs on driving shaft

z_2 = number of discs on driven shaft

µPz right. So, this is your R_f similarly, µPz and this is your R_f for the uniform wear theory z is the number of pair of contacting surfaces ok. So, number of pair of contact surfaces within that. So, suppose if I want to have a three friction plates.So, how many I need to have a rotors assuming I have three stators. So, rotor, stator, rotor, stator and should end with the rotor not the stator. So, obviously, the number of surfaces would be right z plus1 number of disc is ok. So, number disc will be z plus 1. So, the z_1 is the number of disc is on the driving shaft which nothing, but your rotor and z_2 is the number of disc on the driven shaft which is nothing, but your stator ok.

Let me ask one more question have you ever observed how aircraft is landing on the ship I am talking about the ship carrier have you ever seen it ship carrier, war ship may be right what would be the number of ships landing on the ship carrier. So, what is the typical what is the typical runway the runway is restricted to 800 to 1000 m whereas, in the on the airport the regular surface airport you will have large running runway. So, but the fighter aircraft will come very high speed not the regular speed of your passenger or flights or cargo

flights. So, what happen how do they achieve you have thread is there that is one thing is called arrested barrier ok arrested barrier, but you will see only thread, but underneath the deck there is a brake system which is arrested barrier brake system which exactly will have a the rotor and stator very huge ok. That is also there and this is that you can see that the same equation if you I mean compare to your single plate I will be re modify it is a μwhich is a μP right and R_f is the friction radius right only thing is you have to multiply the number of contact surfaces similar way it is a same equation μP and R_f z will be need to do that.

So, this is multidisc clutches normally the moment you go for multidisc by default they are lubricated that is a difference understand that ok. This is why I asked you in the previous lecture why you need to have a lubricated because the surfaces are more when the surfaces are more the heat generation more when the heat generation more right the wear will be more. So, to avoid that they will enter the clutch system multi disc system will be immersed into lubrication in the things. This is the reason precisely I asked you a contradicting question our purpose of clutch is to have a friction then what is the need of lubrication right that was the question I asked you now you know the answer. So, the reason is you need to have a friction at the same time you have to look at the other performance also right.

We look at right based on that the lubricant need to be provided for the multidisc clutch systems. Now, you can see the difference between the dry and wet clutches for single plate clutch as a higher coefficient of friction usually very high greater than 0.3 you can see that. However, if you look at a multi clutch right they have a less than 0.1 because they are lubricated that is a difference. The torque capacity of dry clutch is high compared with the wet clutch of the same given dimensions right. Obviously, the lubricant will reduce the friction aspect the heat dissipation is difficult to dry clutches in wet clutches the lubricant oil carries away the friction heat. The purpose of lubricant is develop a film between the two surfaces and remove the heat as a coolant. So, that is another reason the wear rate is far less in wet clutches compared with the dry clutch. Obviously, it has a lubrication right.

The engagement in wet clutch is smoother compared to dry clutch holding them difficult right. Whereas, we have very good compartment having a place rotor stator rotor stator and backup rotor also they are all linked. So, well synchronized mechanism is available for multidisc clutch system that is the thing ok. Now, we will move on to the cone clutch ok. The cone clutch there is a one more type called as a cone clutch.

Have you ever seen cone clutch first of all? If I had come to my office I would have shown some synchronous gears I would have shown that right. May be I forgot to bring it here, but I will show it may be tomorrow lecture. So, they extensively used for transmission aspect ok that is one specific application of cone clutch. Any application do you aware of

for cone clutch aspect? How about moped? In moped they have a cone clutch arrangement ok. So, what is the difference what is the need of cone clutch right.

Because this is the typical arrangement of cone clutch right. This is the arrangement. So, let me finish this things. So, you have a female cone this type is a drive this is from coming from the engine this is the drive and this is your driven thing ok. This is the driven side and this is the female cone and this is the male cone or part or counterpart like this.

And this is the where you have a friction lining. So, you can see that this is your friction lining this entire portion is your friction lining. And of course, we have a spline also where this is actually fixed with the fly wheel, this part is fixed with the fly wheel right. And this part is extended to the gear box yeah that is arrangement. And you have a spring actuator to make a proper clamping right clamping aspect.

So, what is your observation how does this different from regular plate clutch that is a question. Look at this they have a nice cone arrangement will give you more real contact surface more real contact surface right. Real contact frictional surface. So, that is the advantage ok. Let me ask one more question the basic question you have rotating disk this one and this one ok.

This when they will when the press due to clamping force and try to attain the same speed right. There is a possibility of slip, but if you have cone arrangement then another counterpart right like a that is what I said. So, when they move together right do you expect any possibility of slip very less or limited ok that is advantage. Now, only at first they will make contact then they will attain the speed that is how they do that. So, that means, making a proper contact through the wedge action this is nothing, but wedge.

If you look at probably you see the better aspect here yeah. You can see this is in fact, so the arrangement will happen between these two. So, this is nothing, but wedge shape. So, this is the arrangement between this is wedge shape. So, then the end this is α is nothing, but your cone angle may be I will say that α is nothing but semi cone angle.

So, you have to the same concept similar to single plate clutch only difference is you will have a wedge shape right. So, that means, the normal force will act along this the friction lining. Usually we take it as this is the face width b, b is the face width similar to your gear face width, b is the face friction phase width yeah of friction lining. So, if you rearrange right may be I can show you better way the forces yeah the only difference is yeah straight away I am giving the thing.

$$For\ uniform\ pressure\ theory\ \ T = \frac{\mu P z}{3 sin \propto} \frac{(D^3 - d^3)}{(D^2 - d^2)}$$

$$For\ uniform\ wear\ theory\quad T = \frac{\mu P}{4sin \propto}(D + d)$$

Where,

Sinα = semi cone angle, usually recommended αvalue is 12.5°

So, this is the force yes from the strip right. So, if you see the strip I am taking only the half of the thing. So, this is your r and this would be your D may be I will say a d by 2 like this yeah this is D by 2 and this is your α pressure angle. So, this will act in this direction normal way. So, then you will have a two components vertical component and the horizontal component this is your activation force P right with the smallest strip period Pδ and this should be a cosα and this should be a sinα. So, if you do that the sinα will come into denominator that is the difference is coming.

So, rest of the thing same right only this is the thing. So, normally the semi cone angle is recommended 12.5° right. So, let me explain one more concept the cone should be lesser than the certain angle assuming this is a slope you have a slope right I have a block right when we expect the block will slide assuming this is the load is W when we expect the block will slide at what angle. So, this is the tan sorry yes or μ equal to tan theta right mu equal to tanθ that means, so the moment you increase that the θ should be right that is your angle of repose it is called angle of repose.

This θ what are you do right. So, we have to maintain α always lesser than the θ and one more thing is the friction should be lesser than static coefficient of friction. Obviously, this is the condition this is the reason, two condition to avoid the slip right. So, question is what happen if you have if you keep the angle equivalent to your semi cone angle what do you expect do you expect there is a contact do you expect there is a frictional contact such a way that transfer the power from female cone to male cone no. So, they will have kind of self locking you expect self locking because it will slide you cannot make it. So, this is the particular reason you have to keep your semi cone angle as low as possible perhaps when I show the the gear I will show what is the angle I can you can see that very small probably 3° or 4° as low as possible.

So, this is the torque transmitting capacity for a clone clutch aspect and we will do a problem please we will do two problems now can you take down the problem number two please a small problem. So, problem number two question number two.

An oil immersed multidisc clutch with the molded asbestos and one side and steel disc on the other side is used an application the torque transmitted by the clutch is 75 Nm the coefficient of friction between the asbestos lining and the steel plate in the wet condition is 0.1 the permissible intensity of pressure on the asbestos lining is given as a 500 kPa. The outer diameter of the friction lining is kept as 100 mm due to space limitation assuming

uniform wear theory calculate inside diameter of the disc the required number of discs and the clamping force P, you need to find the required number of you need to find out inside diameter of the disc the required number of discs as well as the clamping force this is the problem very simple problem. So, if you look at this is your torque T_m or T this is your μ right and this is a maximum allowable pressure 500 kPa right D is given 100 mm yeah clearly

Given data T = 75 Nm, μ= 0.1, p_a= 500*10^3 kPa or 0.5 N/mm^2

D = 100 mm

this is clearly given. It ask you to use the uniform wear theory right

$$For\ uniform\ wear\ theory\quad T = \frac{\mu P z}{4}(D + d)$$

and you need to multiply z. So, torque is given yeah torque is given what else we know μ is known to us P we do not know and we know only D and this is not known and this also unknown there are so many unknowns are there how are you going to solve the problem. When do you expect the maximum torque will be transferred during when you have a clutch system when there is maximum torque remember I said one information better to keep $\frac{D}{d}$ ratio 1.5 to 2 right in this condition. In fact, I gave clearly a 1.7, I think 1.7 is the at maximum torque will be given ok. So, that is the formula that is condition we will use it.

So, in fact, if you rewrite $\frac{d}{D}$ will be exactly 0.577 for maximum torque condition T_{max} condition. So, this is the relationship we are going to use it ok. So, can you find out what would be the yeah when you have $\frac{d}{D}$ right 0.577 we can find out straight away

$$\frac{d}{D} = 0.577 \rightarrow d = 0.577 \times 100 = 57.7 \approx 58\ mm$$

d is 57. 7 mm may be you can make it approximately 58 mm is clearly given ok. So, now, we have to find out the clamping force first then we have been able to find out the number of nothing. So, now, we got one aspect is the inner diameter of clutch is equal to 58 mm this is fine ok. Yeah clamping force

$$P = \frac{\pi p_a d(D - d)}{2} = \frac{\pi \times 0.5 \times 58 \times (100 - 58)}{2} = 1913.23\ N$$

P equal to this is the equation right hope you remember just substitute Π 0.5 into this should be yeah suffix into 58 100 minus 58 or in mm ok we are not going to change anything obviously. So, what is the clamping force are you getting are you getting 1913.23 N this is the value you should expect ok this is your clamping force. Yeah. So, now, ultimately

we have to find out the number of surfaces that number of pairs for transmitting 75 Nm torque. So,

$$For\ uniform\ wear\ theory\quad T = \frac{\mu P z}{4}(D + d)$$

$$75 = \frac{0.1 * 1913.23 * z}{4}(100 * 10^{-3} + 58 * 10^{-3})$$

$$then, z = 9.9 \approx 10$$

$$z + 1 = 10 + 1 = 11\ discs$$

$$rotor\ discs = 6$$

$$stator\ discs = 5$$

can you tell me how many number of surface you are expecting here. So, just substitute all the values here and find out what is the z value ok.

How much yeah that is round actual 9.9 yeah 9.9 just I wanted to explain. So, obviously number of surfaces cannot be as a decimals it has to be it has to be whole number. So, the total surfaces right number 10 right the total wear surfaces. So, in fact, if you want to understand number of disc right z plus 1 that is what we said. So, will be 11 disc you have. So, how many rotor discs how many stator or frictional disc that is the questions. How many do you expect here how many 6 plus 5 that is it always rotor, rotor right they have to be a outsider then you will have a things ok yeah that is the thing. I think this is for the multi disc aspect. Now, I will go for the another problem question number 3 for cone clutch aspect ok.

A cone clutch is used to connect an electric motor running at 1440 rpm with the machine which is stationary. The machine is used to connect a rotor of 150 kg mass and radius of gyration as 250 mm. The machine has to be brought to the full speed of 1440 rpm from stationary condition to condition in 40 second duration. The semi cone angle is given 12.5°. The mean radius of the clutch is twice of the face width. The Cof is 0.2 and the normal intensity of pressure between the contact surfaces should not exceed 0.1 N/mm^2. Assuming uniform wear criterion (a) calculate inner and outer diameters of cone clutch. (b) Find out the face width of the friction lining. (c) the force required to engage the clutch which is clamping force and 4 or (d) the amount of heat generated during the heat engagement of the clutch. We have to find out ok yeah. So, the in fact the data wise if you look at there is a speed is given, cone angle is given, coefficient of friction is given, maximum allowable pressure is given, but no information about the inner and outer diameter of cone clutch, but there is a relationship is given face width.

The face width is given I mean R_m it should be twice of the face width that is the only thing is given ok yeah. So, what is the way to we are going to solve this problem anything? Any idea would like to share? Yeah you need to find out the torque the torque is not given. So, we need to know what would be the torque ok. So, once you know the torque then you can use the standard find out torque then use the standard cone clutch torque equation from there find out the inner and outer diameter then face width and the clamping force. So, we are doing in the reverse manner right.

The data is given your speed data given data 1440 so much rpm yeah that is correct, μ is given 0.2, your mean radius is 2 times of face width then your allowable pressure is equal to 0.1 N/mm^2, α given 12.5° this is clearly given ok. Then something they talking about the mass 150 kg right then the radius of gyration k is how much is given 250 mm or else 0.25 m and time is given t is given 40 second yeah that is clearly right. What will be the initial speed? it is a stationary initial speed is ω_1 equal to 0 then final speed ω_2 equal to 2ΠN by 60 so this is the where you have to substitute

$$\omega = \frac{2\pi N}{60} = \frac{2 * \pi * 1440}{60} = 150.8\, rad/s$$

So, I know ω_1 equal 0, I know ω_2 do you know angular acceleration because these are rotating masses these are rotating right. So, you need to know that angular acceleration α nothing but

$$\alpha = \frac{\omega_2 - \omega_1}{t} = \frac{150.8}{40} = 3.77\, rad/s^2$$

So, what is the angular acceleration 3.77 so much rad/s^2 alpha is given that is we got it yeah can I move to next slide it is ok yeah. So, my torque

$$T = I\alpha = m * k^2 * \alpha = 150 * 0.25^2 * 3.77 = 35.34\, Nm$$

So, we got set away the torque from the things ok. So, now, the condition is we need to find out what would be the dimensions right and also we need to find out the clamping force all those information is there.

So, you have to use the uniform wear theory right yeah before going to use the uniform wear theory the relationship given right. So, let me draw the things I am just showing the only the half of the clutch aspect yeah right. So, this is your face width assuming that this is the face width yes. So, this is would be my inner diameter right the cone thing this will be d by 2 and this would be D by 2 that is the information and this is your α is given right. So, we know R_m is given as a 2 times face width is given that is one relationship is given ok.

Can you find out what will be the b in this diagram right what is your thing I want to find out may be can you tell me what is the sinα here can you say difference of these two right

$$sin \propto = \frac{D-d}{2b} \quad (a)$$

that is a relationship already we know R_m equal to 2 b,

$$R_m = \frac{D+d}{4} = 2b \ \ (b)$$

R_m is nothing but D plus d by 4 equal to 2b. So, now can you tell me what is the sinα here. So, now can you tell me what is that. So, now we know that ok. So, we can make it as this is a and this is equation b using equations a and b right. So, we would expect

$$\frac{D}{d} = \frac{4+sin\alpha}{4-sin\alpha}$$

D by d is equal to 4 plus sinα and 4 minus sinα

α is given 12.5 right. So, if you substitute you will get the ratio

$$\frac{D}{d} = 1.1144$$

1.1144 ok. So, fine. So, can you find out what is the diameter inner and outer. So, your D will be 177.29 mm ok, d equal to 159.09 may be we approximate 160 mm and this should be 178 mm also it is ok yeah. So, what is the b actually what will be the b, b would be

$$b = \frac{D+d}{8} = \frac{178+160}{8} = 42\ mm$$

that is the value face width is given ok. Now, I have to find out what would be the clamping force sorry sinα just I want to do μ substitute please yeah 4 into torque already we know that.

$$The\ clamping\ force, P = \frac{4Tsin\alpha}{\mu(D+d)} = \frac{4 * 35.34 * \sin 12.5}{0.1 * (178+160) * 10^{-3}} = 455\ N$$

So, that gives me clamping force 455 N. So, that gives me yeah this should be the clamping force 455 N. So, ultimately what they are asking how much heat generated right heat generated similar to your brake similar to heat generated means. So, initially 0 speed then

you make a contact you will achieve the another speed all right. So, within that what is the power generation that is the question ok. The heat generation

$$H_g = T.\theta$$

So, T into θ that is it right T already known to you you have to find out the θ right. So, you know ω_1 equal to 0 ω_2 equal to already we know 150.8 rad/s yeah. So, we need to know the average because during the entire operation you have to take the average velocity yes.

$$\omega_a = \frac{\omega_1 + \omega_2}{2} = \frac{150.8}{2} = 75.4\, rad/s$$

$$\theta = \omega_a t = 75.4 * 40 = 3116\, rad$$

So that is ω_1 plus ω_2 by 2 similar to brake aspect that should give you 75.4 rad/s right θ nothing but what is the θ is equal to ω into t yeah 75.4 into 40. So, thus gives you θ is 3,116 so much radians.

$$H_g = T.\theta = 35.34 * 3116 = 106.59\, kJ$$

the heat generation this must heat generated while clutch is engaged. So, even though the second taken 40 seconds right, but you can see the how much heat is generated during the clutch operation I think.

So, I will stop now tomorrow I will continue with the centrifugal clutch then will go for the dynamic analysis before going to dynamic analysis I will cover about the theory aspect. Thank you.