Design of Mechanical Transmission Systems

Prof. Ramkumar

Department of Mechanical Engineering

Indian Institute of Technology Madras

Week – 05

Lecture – 13

Lecture 13_Automobile Gearbox: Module Calculation Concept - Part II

Good morning. So, we will continue where we stopped in the last lecture about module calculation. So these are the topics in red color we covered. We will continue with the module calculation aspects and this is the problem. We have done various aspects for given the ratio, gear ratio and the torque aspect. We have done the ray diagram, select the gear type, done the ray diagram, kinematic diagram, also done the suitable materials.

Now finally, we are in module calculation aspect and this is the equation we have used based on the bending aspect, module equation and also based on pitting aspect. In fact, as I said since a pitting stress is very high, higher than the bending stress would be preferred to use pitting stress based calculation for your module aspect. Of course, there I talked about the ψ factor which is a frame factor ratio or else we can say a structural support. We have choose the ψ value as a 30.We have taken the lowest value. And we got our module calculation. The module what we got is we have taken the model m = 2.412. This is what we got it.

This is when you have a ψ equal to 30 and your factor of safety S^2 equal to 1.5. Just wanted to show the relationship between your factor of safety as well as the structural support or frame factor ratio. So, this is your factor of safety for its various value your structural support ψ right just extended assuming your factor of safety 1.5, 2, 2.5 and 3. The structural support 30. I will take the lower limits 40 or may be 35 and 40. So, this should be as you we got 2.41, 2.65, 2.86, 3.303, 2.29, 2.52, 2.72, 2.89, 2.19, 2.20, 2. 2.41, 2.60 and 2.76. So, what is your observation assuming that your fixed factor of safety 1.5 right if you choose and if you vary your structural factor as increasing the higher value, structural support value your module is reduced. You can see the trend is the module is reduced. Otherwise you fix structural support 30 and you change your factor of safety right when you change the factor of safety 1.5, 2, 2.5 you could see there is increasing trend in the module calculation. So from this your observation you have to do optimization. The purpose is you do not want to have the failure aspect that is one thing. At the same time we have to look after the materials the weight, volume that is also very important. Higher the module what happen to you gear size will be increased right. So we have to be very, what you say that you should be you cannot have too much factor of safety same time you cannot have a very high structural support also. We have to do some a kind of optimization and get the best out of it like.

So, out of subject just wanted to inform you. Lot of my research work I do optimization. So I have done lot of gear box optimization to meet the tribology constraint including pitting stress, bending stress and reduce the volume. Like that I have done the extensive work and publish in mechanical machine theory one of the top impact journal paper. You can refer my website to understand more about the optimization aspect. So what was the teeth we choose the profile aspect right this is the one then what we have done even though we got 2.412 we have to choose the standard one. So what we have done we have taken the m = 2.5 mm based on the standard aspect ok. So this is the model we have chosen.

In fact if you move further above the things remember we have chosen the full depth right pressure angle 20 degree spooled gear a full depth. So this is what you see that. So this is your other parameters of the gear profile this is for addendum, dedendum, clearance, working depth and the whole depth and tooth thickness all those information you have to follow based on what profile you have chosen. We have chosen 20^{0} pressure angle with the full depth system aspect. So in fact further if you find out what is the value the based on the thing m = 2.5 mm that is the module value fine. Your addendum 3.125 after multiplying, ok I am just giving the right away values and dedendum 0.625 mm and working depth working depth means from the top space to base circle right to the base circle or pitch circle the working depth ok. The working depth 5 mm the whole depth is 0.625 mm and this are the standard nomenclature for gear 5.625 mm and tooth thickness (t) = 3.927 ok this is the millimeter. So one parameter missing which parameter is missing is a face width right that face width parameter is missing yeah we need to find out what is the face width. Now we will move on so this is what we have chosen right remember for the first gear, we have chosen the first gear we have chosen this ψ ratio in terms of ψ ratio $\frac{b}{m}$ right we have chosen the $\frac{b}{m}$ as a 30 right. 30 we have chosen so if you substitute model we know 2.5 then what happen the face width for the first shift gear that should be 75 mm right that should be75 mm ok that is 75 mm. So 75 mm which gear? Gear number 12 remember please check your kinematic diagram first gear is meshing gear 11, right, gear 12 mesh with the gear 11 that is your first gear shift, first gear shift maybe I can write gear 12 mesh with the gear 11 ok. So this is the face width of 12 equal to 75 mm ok right look at this graph ok this is taken from automotive transmission system and as you aware of that higher the speed, the torque lower, ok but the lay shaft as a constant torque ok but the stresses will be different.

So in order to accommodate stresses we have to play around the changing the different face width for each gear. So the first gear we have done using the structural formula second gear we can choose 0.4 for second gear this is a $\frac{b}{d}$ ratio not $\frac{b}{m}$ this is $\frac{b}{d}$ ratio as a 0.4 ok. The remaining they are almost same right this third, fourth, and fifth they are almost in the range of 0.3. So what I could do for third, fourth, and fifth gears right gear shifts this is gear not gear gear shift I will choose $\frac{b}{d}$ ratio as a 0.3 b is the face width d is the your pitch diameter ok d is your pitch diameter. So we have done b for the first gear shifting now we need to do for other gear shifts. Before proceeding, we should know the number of teeth for the each gear aspect right as you aware of that we have done the gear teeth calculation and found some gears are less than 17. So what we have proposed without altering changing other parameters we double the gears number of teeth gears ok.

In fact the number of teeth in all gears, right, all gears of this gear box ok the $Z_1 = 34$, $Z_2 = 68$, $Z_3 = 28$, $Z_4 = 74$, $Z_5 = 32$ this is the where we had a16 Z_5 was 16 earlier calculation. So once you multiplied, we got 32, $Z_6 = 70$, $Z_7 = 38$, $Z_8 = 64$, $Z_9 = 52$, $Z_{10} = 50$, $Z_{11} = 66$ $Z_{12} = 36$ ok. And if you do summation of each Z1 + Z2 that should give how much 1 or 2. So all the 34 + 68, 28 + 74, 32 + 70, 38 + 64, 52 + 50 all teeth are matching ok all teeth are matching. Now we will do the calculation for the second gear shift please refer your kinematic diagram where gear 10 mesh with gear 9 yeah.

So m we know that m = 2.5 mm that is already known to us. So now $m = d_{10}/Z_{10}$, I am giving the number based on the things and Z_{10} equal to right from here we want to find that what will be the pitch diameter 2.5 * Z_{10} will be 50 ok and that should give me 125 mm this is for second gear yeah. So then the $\frac{b}{d}$ ratio we have chosen what b by d ratio we have chosen as a 0.4 in that case by b_{10} should be I am taking a gear 10 125 already we know that that is gives me 50 mm.

Look at the difference earlier, we had 75 for gear number 12 the face width now gear number 10 the face width reduced to 50 mm ok. You may ask question why I choose a gear10 why cannot be gear 9? Gear 10 is the drive gear right that is the one which is transferring the force from gear 10 to gear 9 that we always should focus about the drive gears rather driven gear aspect. Now for third gear shift right here is gear 8 mesh with gear 7 ok and we have chosen the $\frac{b}{d}$ ratio equal to 0.3 and as usual m equal to d_8 * Z_8 ok and we want to know what is that $d_8 = 2.5*64$, Z_4 equal to 64 that should give me 160 mm. So then 160 mm then the corresponding $b_8 = 0.3 *160$, I would expect 48 mm is the face width this for third gear. Similarly we will go do for fourth gear also fourth gear shift your G_6 mesh with G_5 as usual we have taken the b by d ratio 0.3 sorry 0.3 just the ratio factor m equal to d_6*Z_6 right then, d_6 equal to 2.5*70 number of Teeth for gear 6 175 mm then $\frac{b_6}{d_6}$ is 0.3 by doing that your b_6 must be 0.3*175 is gives me 52.5. So we will make this approximately

53 mm ok. For fifth gear shift, where your gear G_4 mesh with G_3, m equal to as usual $\frac{d_4}{Z_4}$. So from here if you calculate $d_4 = 2.5*74 = 185$ mm, then b_4 by d_4 we have chosen as a 0.3 from here your b_4 would be 0.3 * 185 is gives me 55 mm ok. Now we got the face width for each gear shifting right gear shift 1, 2, 3, 4, 5. In fact if we do a gear shift we can do the table, gear shift on the face width right, face width is in millimeter if we tablet them. So this is the phase width for each gear shift right. This is 1 is giving 75 mm, 2 - 50 mm 3 - 48, 4 - 53 then 5 is 55.

So can you see that what is happening as your gear changes right. Now gear changes happening your phase width reduced of course you may ask question the first 2 gears first gear I understood and second is and third are reducing but what happen when the moment it goes to fourth and fifth gears, it is again increasing. Now you know when you refer that $\frac{b}{d}$ ratio it is slightly above 0.4 now you know that ok because the sizes changes to accommodate the face width will increase slightly for the higher shift gears right.

Interestingly this is as explained earlier taken from our building machine design section in the foyer where you would see this is the manual transmission sliding gear box of course, we are doing the problem for manual transmission constant mesh not the sliding mesh but does not matter. So can you tell me what the gears are here. So this is your input shaft right this is coming from the input shaft straight away you could see your reduction here you can see the reduction, then you have this is your first gear right the first gear when slide, this is your first gear right and this will move to slide make a contact then this is your second gear straight away as a thing and this is your third gear ok this is your third gear. The fourth gear I guess this straight away connect your input shaft right that is why you could see there is no space also, there is no space also right it is straight away connect things. Could you please observe what is that happening the first gear look at this the face width how big the face width right, second gear you can also this is slightly reducing right you can see the face width is reduced and even for a third gear also reduced here, then this is your first gear reduction where coming from the things.

So by choosing the face width also another advantage is you are reducing the shaft length. So you can see this multiple benefits. You can see this multiple benefits. If you have if you had been fixed face width as constant for all the gears you are having a more mass right, not only that and also you are adding the length of the shaft which is against optimized compact gear box aspect that should be avoided. So by this is the way you need to do let me put one more question, sometime ok do you think face width for the meshing gears are equal or can be variable? It can be variable, it can be variable lean or be face width are equal ok.

So wherever the power transmission occur right where is going to be more stress here the receiving side the gear also can have a higher phase width that also possible. So design is the multiple solution, it is not single solution it is a multiple solution problem depends on what is the requirement. Based on your requirement, you can keep use different solutions ok. So this is the sliding mesh and since I talked about shaft I just wanted to give you another information ok. The center distance, you can see this is standard center distance we have chosen, there is no concern in the problem about center distance.

So we are free to choose the module calculation without worrying about the center distance aspect ok. Let me ask you question what is the center distance now? Can you tell me what is the center distance? We know the model right we know the model. So we have gear number 12 and gear number 11. So tell me what is that center distance we have to choose? We are going to have right and the module is given m = 2.5 mm right m equal to 2.5 mm that is there. How do you call the center distance? Center distance equal to

$$a = m * \left(\frac{Z_{11} + Z_{12}}{2}\right)$$

$$a = 2.5 * \left(\frac{66 + 36}{2}\right)$$

$$a = 127.5$$

So what is the answer you are getting? 100? 127.5 mm ok. So ok now we know that 127.5 mm we got the center distance. So do you think that is standard center distance? We have 125 you can see that preferred is 125 you given. So the next preferred is 160 or else that is too big right that is too big.

Maybe you can choose 140 also ok. But in this problem there is no constraint for center distance aspect. In assignments in the exam if you get center distance constraints you have to follow the standard aspect ok. This is taken from Vauxhall 6 + 1 gear box. Look at this configuration. It is nicely arranged right. As I said one of the lecture I have mentioned multistage where you have one input will have two output shafts right.

You can see this is taken from the brochure of Vauxhall and there are you can see that there are three shafts are arranged. So where are you have a length constraint right in the in the constraint, you can go for two output shaft aspects. You can see here, this is arrangement. The same thing with the kinematic arrangement. So you have to be very careful the gear common gear should be will have a required gear ratio one gear for both output shafts. That is the way that we have to design. I think I will stop now. Thank you.