# Kinematics of Mechanisms and Machines
**Prof. Anirvan Dasgupta**
**Department of Mechanical Engineering**
**Indian Institute of Technology, Kharagpur**

## Lecture – 40
## Gear Trains – III

Based on our discussions on Gear Trains in this lecture I am going to discuss about gear boxes, which will essentially be application of gear trains the in gearboxes.

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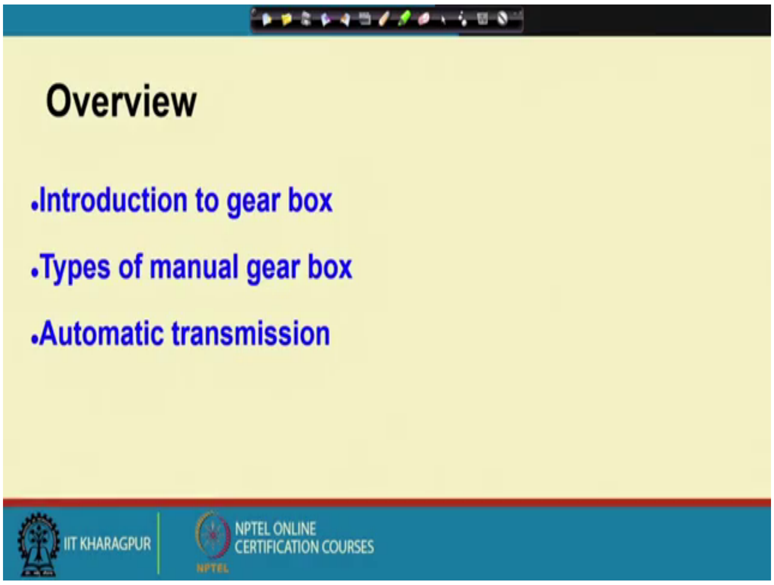


I will introduce what is a gearbox is will look at two kinds of gearboxes manual and automatic. A gear box is a combination of gear trains with possible variable transmission, when we require variable transmission ratios, because of various reasons we will discuss that we require a gearbox with certain gradations of gearing ratios.

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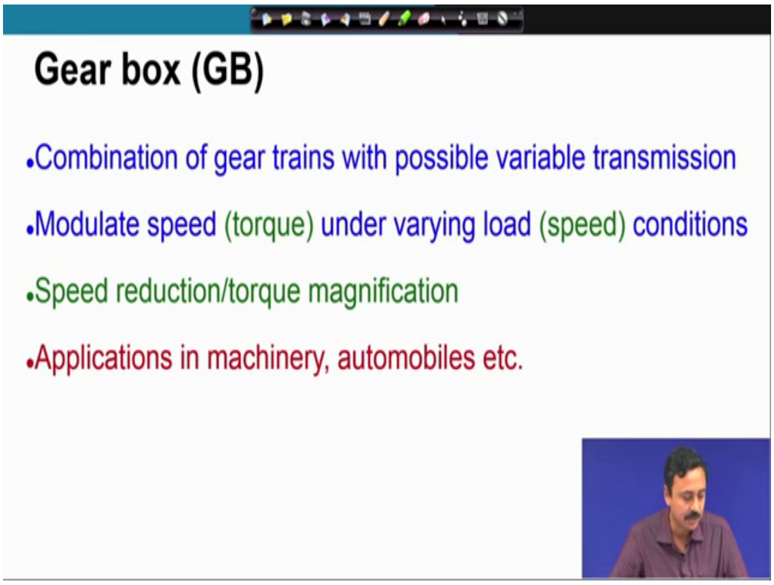


These are used to modulate speed for varying load conditions or the modulate torque under varying speed conditions. For example, when we start an automobile or a vehicle we start with the lowest gear the first gear which has a transmission ratio which is very low, but it can transmit a very high torque. The reason being when we start, when we start off from 0 speed our acceleration required is very high.

But, we need not have a very high speed to begin with our speeds are low, but our torque requirement is very high. And, when we go to cruise speed then our torque requirement is low, but we require a very high transmission motion transmission. So, this gearbox allows us to make this variation, when we have speed reduction we have a torque magnification. These are applied in machinery automobile etcetera as you know.

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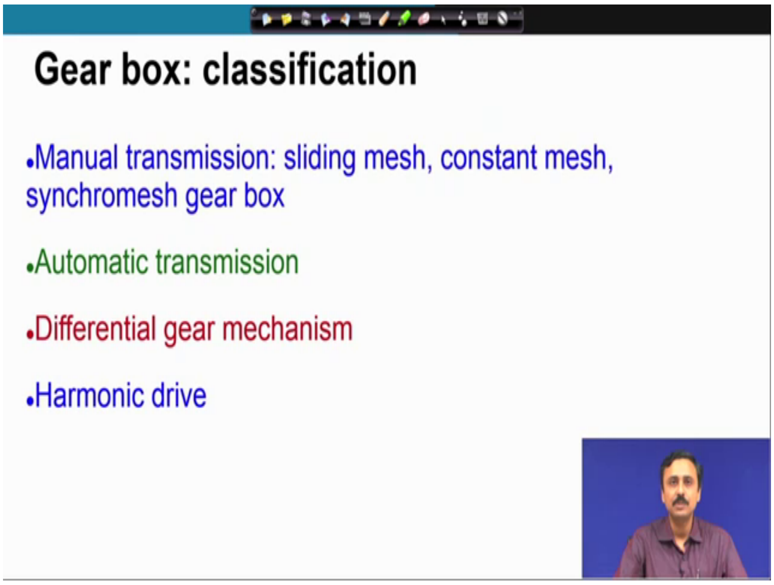


Now, gearboxes are classified as manual transmission, under manual transmission, we can have sliding mesh, constant mesh, and synchromesh gearbox. Under automatic transmission we use epicyclic gear trains. We also have differential gear mechanism this you know we in 4 wheelers for example, in cars, trucks, buses when we take a turn the inner wheel has to rotate at a lower speed than the outer wheel, but at the same time the torque has to be transmitted to both the wheels.

For this we use a differential gear mechanism or a differential gearbox. Other than that we also have harmonic drives which is a very special application of gears in which actually we use flexible gears, but this harmonic drives are used for very high reduction in speeds. So therefore, it can magnify torques to a huge extent, but we are not going to discuss differential gear mechanism or the harmonic drive in this lecture. We are going to restrict ourselves to manual transmission and automatic transmission.

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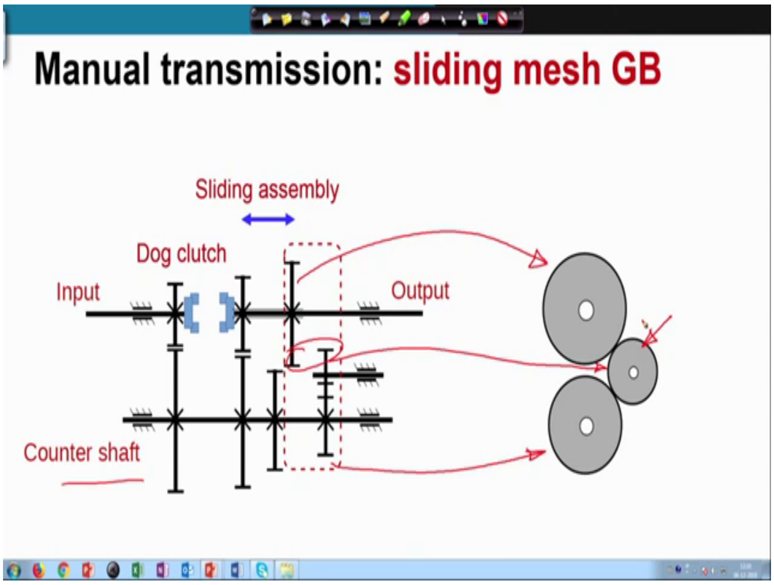


We will start with the manual transmission when using the sliding mesh gearbox. Here is a schematic of the sliding mesh gearbox. In this there is a part of this gearbox which is sliding; here I have marked out for this part. As you can see these two gears they cannot rotate with respect to the shaft, but they can slide this whole assembly can slide. Therefore, you can have meshing here or if you slide it this way, you can have meshing between these two gears or if you slide it further then these two components they come in contact.

These are called the dog clutch. These two components are the dog clutch they come in contact and lock the input gear to the input shaft to the output shaft. There is another part of this gearbox which is the reverse gear. Now, if you slide the sliding assembly to the right, then this gear will come and mesh with this gear, now here there is a clutcher. So, I have shown it separately, this gear which will come and mesh is this; it will mesh with this gear which is this intermediate gear, and this gear is on the counter shaft this fixed on the counter shaft.

So, when you slide the whole sliding assembly and bring this gear in mesh with this and this is the configuration. Therefore, now between the counter shaft and the output shaft there is this intermediate, we are setting which will reverse the direction. So, this is for reverse gear which we will now discuss.

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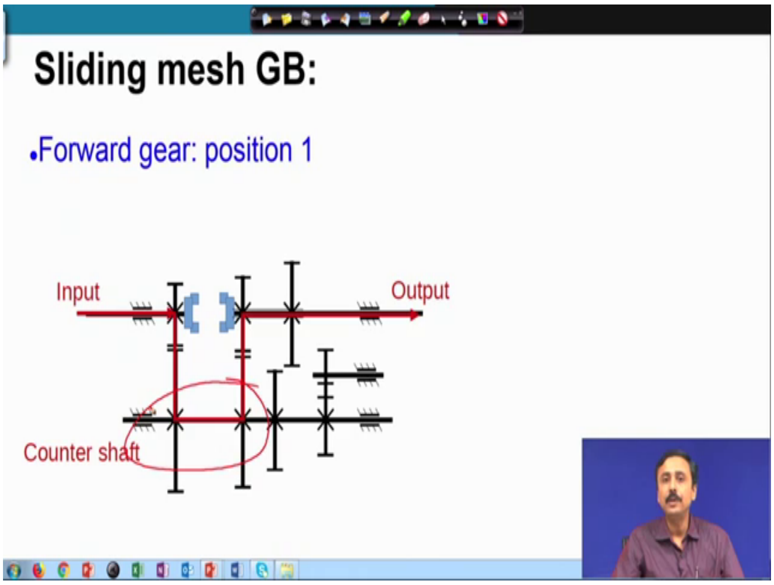


This is the configuration when you are in forward gear position; position 1. So, the input motion goes from here to the counter shaft; counter shaft the name as the name suggests it is opposite rotating, it is transmitted here to the output shaft. You can very easily recognize that, this gear train now in this configuration is a compound gear train.

There is this shaft which carries 2 gears. So therefore, this is a compound gear train and you can calculate the gearing ratio.

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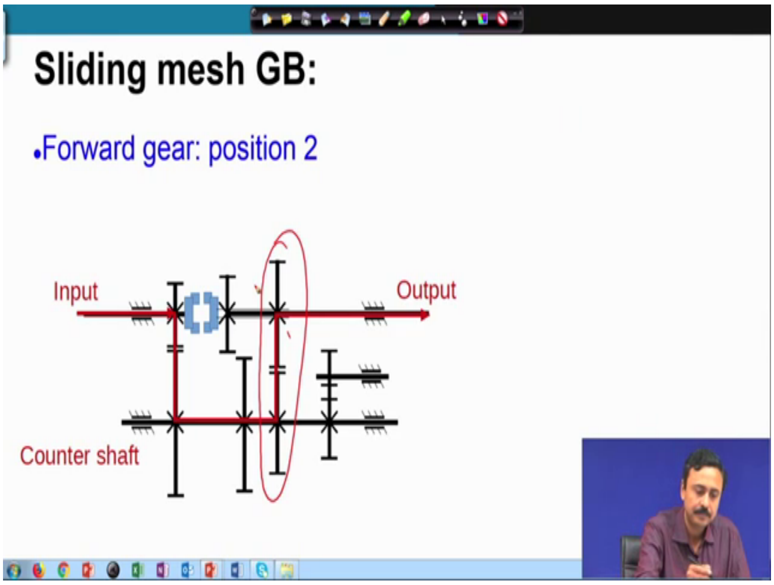

In position 2 so, we have these two gears in mesh therefore, our transmission path is like this because the number of teeth are different now in this pair therefore, we have a different transmission ratio.

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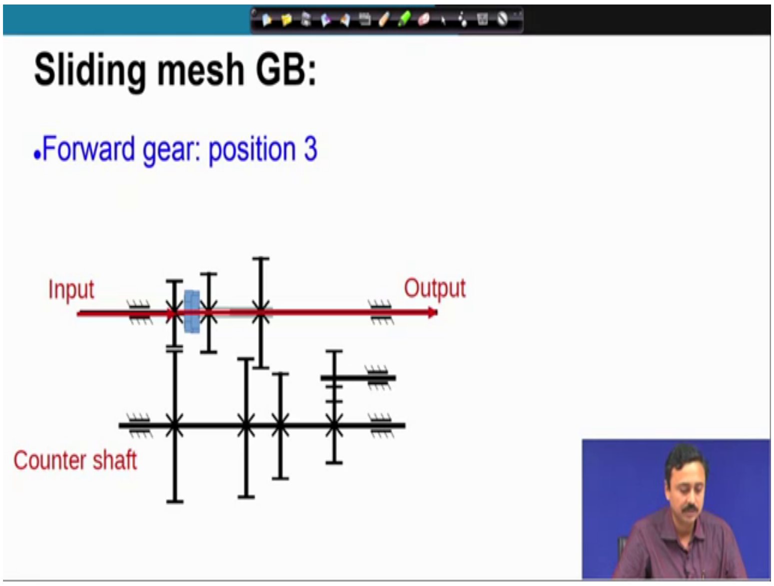


In the third configuration the sliding arrangement is pushed further left. So, that the dog clutch is now in contact. So, it will lock the input shaft to output shaft. Therefore the transmission ratio in this case is 1. So, this is a through transmission.

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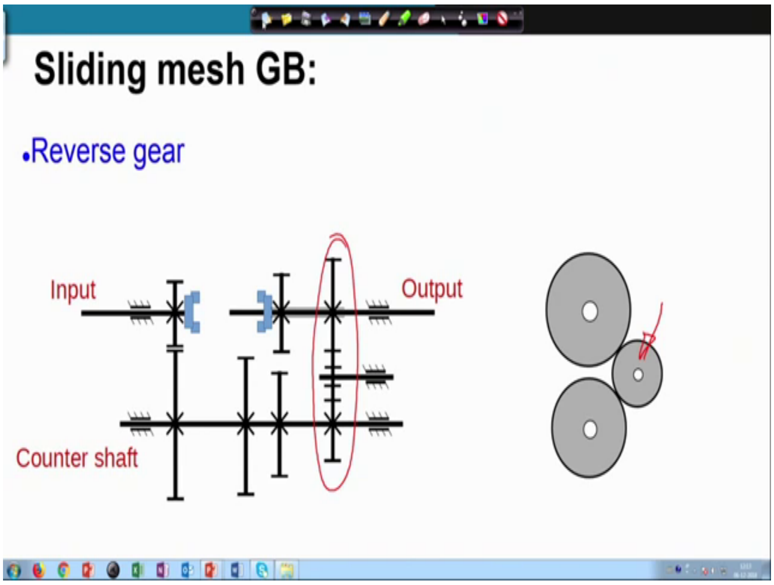

Now, when you push the sliding arrangement to the extreme right then you have these 3 gears in mesh with this as the intermediate gear, because of this intermediate gear the direction of rotation is changed at the output. Because of the intermediate gear the direction of rotation is changed at the output and this is the reverse gear. So, this is the sliding mesh gear box.

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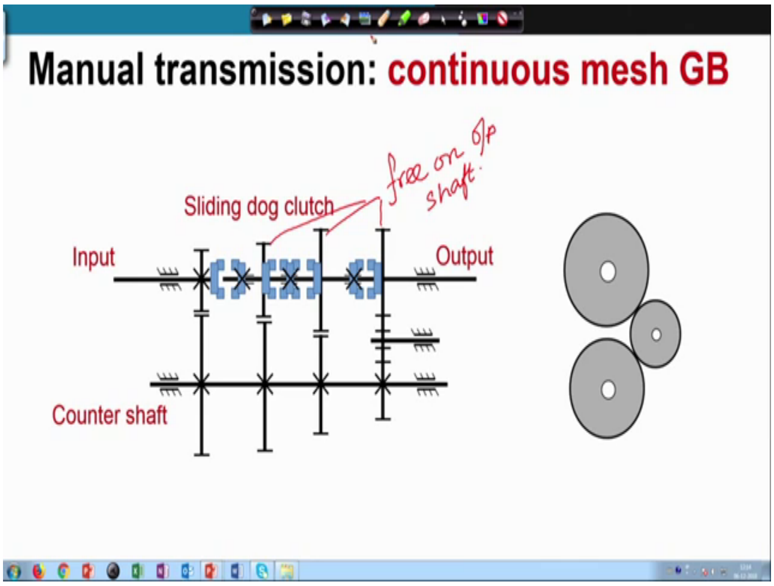


Let us now look at the continuous mesh gearbox this is a schematic. In this gearbox the gears are always in mesh as has been shown. So, this is the input shaft, this is the counter shaft; here there is a pair of mashing gears here there is another, here there is another. So, there are 3 continuously meshing gears. So, as you can realise that therefore, the gears on the output shaft cannot be fixed. So, they must be freely rolling, freely rotating on the output shaft. So, these gears are freely rotating. So, these 3 gears are free on the output shaft they can rotate it freely on the output shaft. Now, what connects this gear the, these gears to the output shaft is the dog clutch.

Therefore for example, this dog clutch if you engage it on the left then you have transmission like this if you engage it on the right, if you engage it on the right then the transmission is like this. So, you can change the transmission by changing or sliding the dog clutches now, instead of the gears, instead of sliding the gears now you have sliding dog clutches, which engage the individual gears on the output shaft. So, these dog clutches are on the spline shaft which means they cannot rotate with respect to the output shaft, but they can slide on the output shaft.

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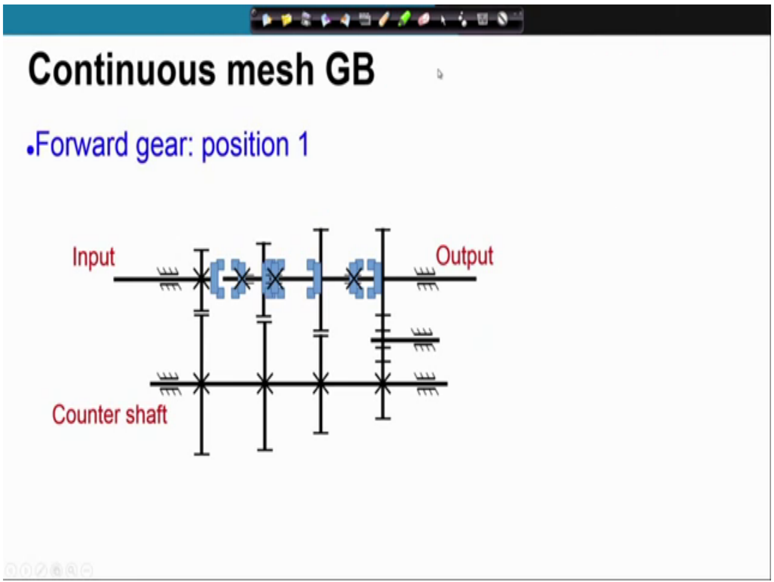


Then let us look at the forward gear position 1. As you can see here is this engagement of the dog clutch. Therefore, our transmission is this is our path therefore; the transmission ratio of this gear pair decides the net transmission ratio.

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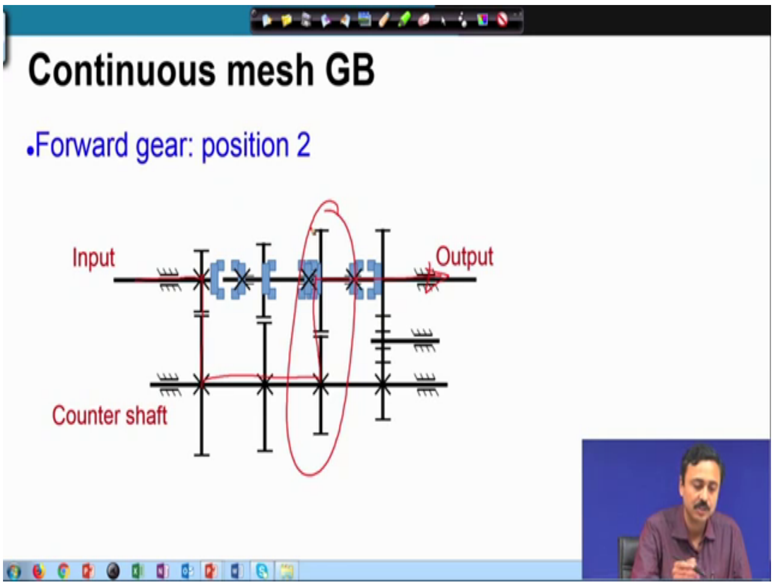


When you put the dog clutch in position 2 you slide it to the right and engage this gear pair which means now this gear is connected to the shaft our transmission path becomes this. Therefore, the gearing ratio of this pair of meshing gears decides the net transmission ratio of the gear box.

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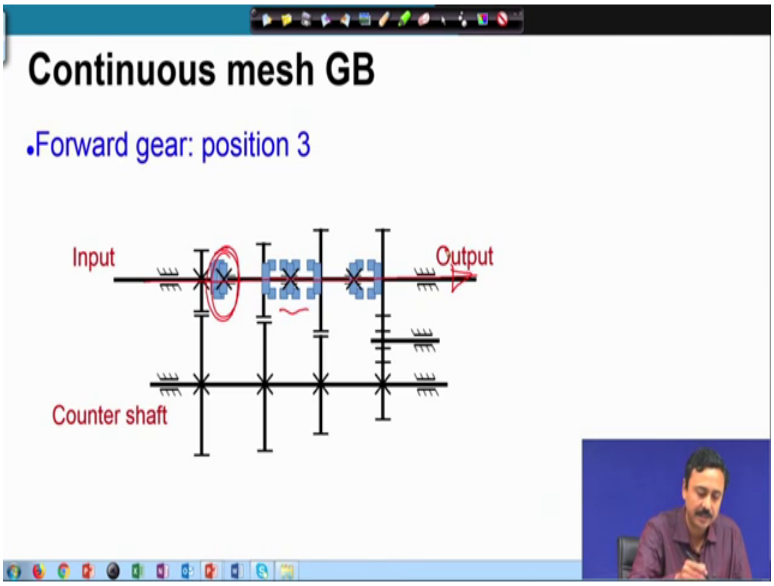


Similarly, if you put this dog clutch engage this dog clutch and free this dog clutch this is in the unconnected position, and this is in the connected position then the input shaft is directly connected to the output shaft. So, that is a direct transmission.

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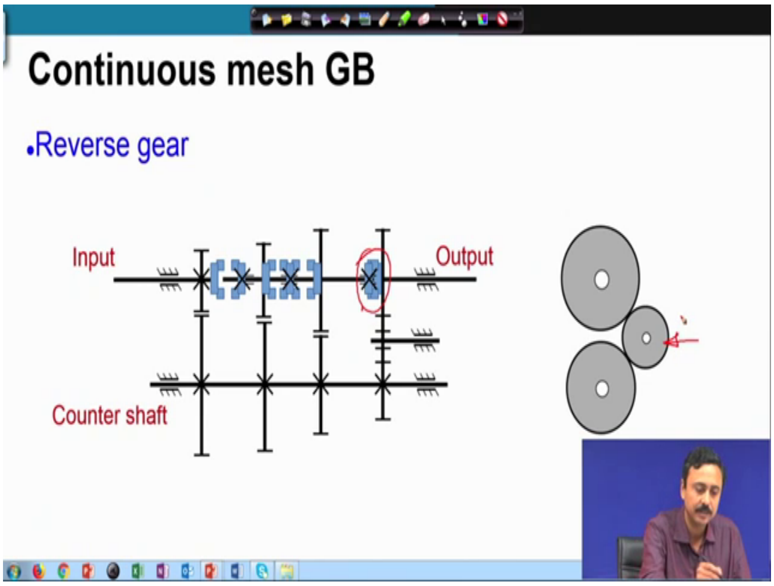


And, if you engage this clutch then you have the reverse gear transmission, because of this intermediate gear, this is the continuous mesh gearbox. The advantage of a continuous mesh gearbox is you do not have the gears coming in and out of mesh that causes lot of wear and damage to the gears. So, here it is the dog clutch which takes that load otherwise the gears are on in mesh throughout therein continuous mesh. So, the sound and vibration and noise these are much reduced.

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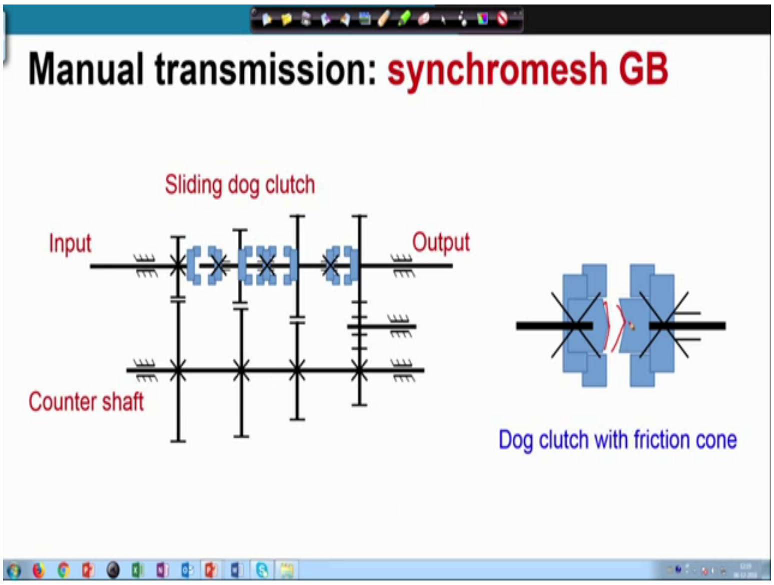


Next we are going to look at the synchromesh gearbox. Here the idea is very similar to the continuous mesh gearbox except that this dog clutch is slightly more sophisticated, which I show here now this dog clutch also has a friction cone a friction clutch.

These are the friction cone engagement. So, this is clutch the idea is to bring the speeds of the output shaft and the input shaft at the same level before engaging the dog clutch, because whenever the dog clutch is engaged suddenly there will be jerks there will be vibrations. To prevent that there is this friction cone which is the clutch which reduces the speed difference between the 2 shafts or of the 2 dog clutches. So, therefore, what you have is this.

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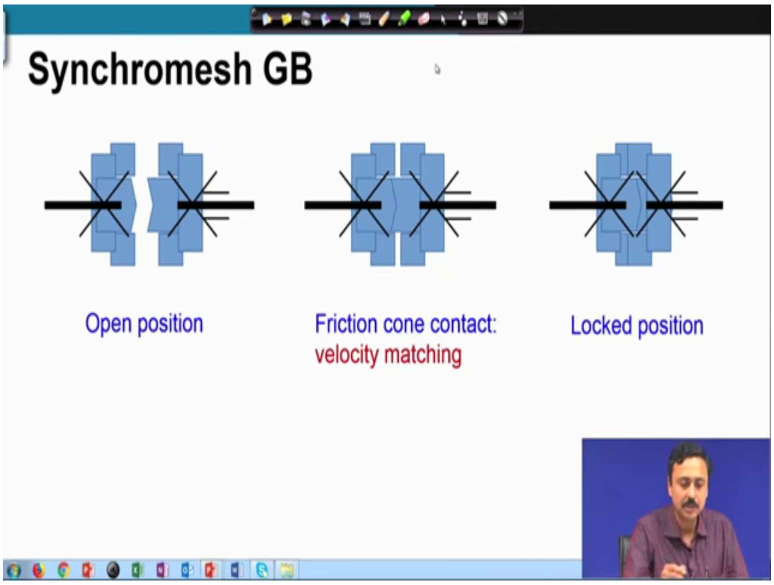


So, this is the open position when it is not engaged, when you start pushing the dock clutch, when you start sliding the dock clutch. The friction cones first come in contact and this leads to velocity matching. Before the dock clutch comes to the lock position. The once the dock clutch is lot then the 2 shafts are in complete synchronisation they are connected. Now this is applied now, to the gearbox. So, let us look at this operation once again.

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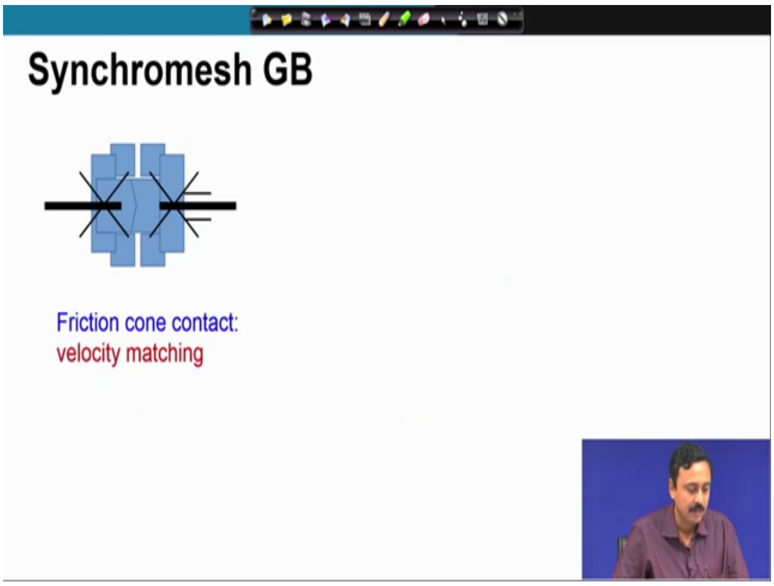

So, this is the open position, this is the friction cone contact and there is a further motion of the dock clutch which locks it.

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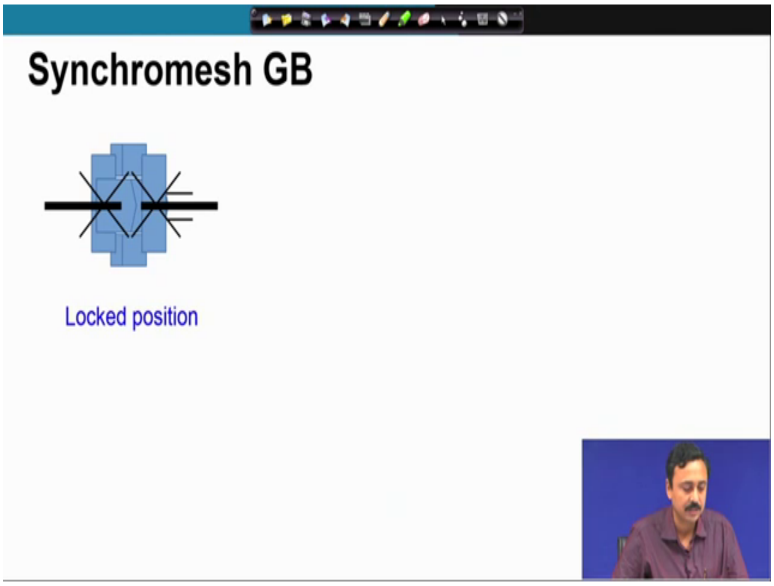


So, the friction cone or the friction clutch is given to match the velocity, the velocity matching and then finally, it is the locking.

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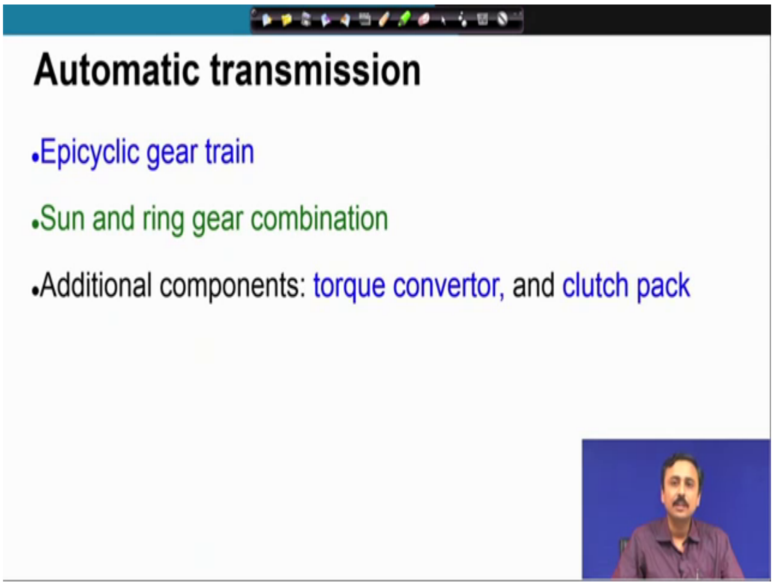


Now, based on this we have the synchromesh gearbox. And synchromesh gearbox is they have very smooth operation that is a advantage. Next we are going to discuss the automatic transmission, automatic gearbox. An automatic gearbox uses epicyclic gear train. This has both sun and ring gear combination, which we have discuss before there are additional components the torque converter and the clutch pack we are not going to discuss them in detail, but we are going to refer to this clutch pack.

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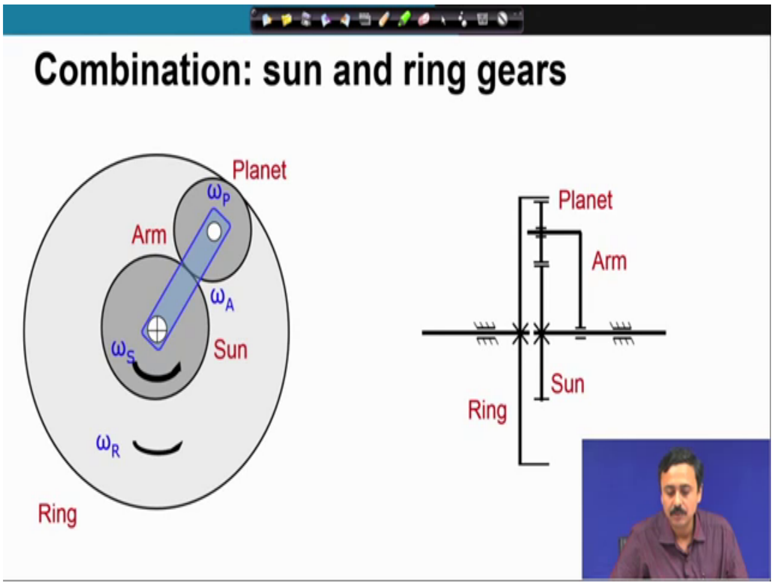


Let us recapitulate what were discussed in the kinematics of epicyclic gear trains with sun and ring gears, this is our schematic.

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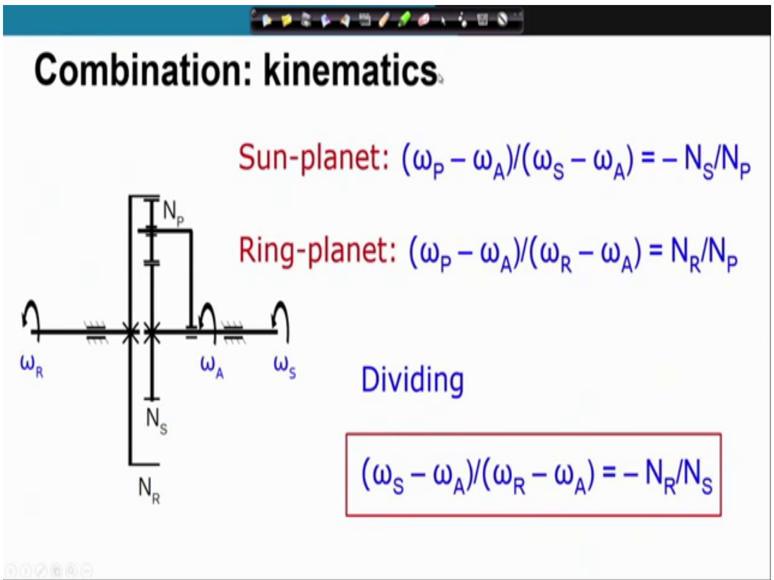


So, this is the relation for the sun planet system, this is the combination that the ring planet combination. And, if you divide one by the other then you had this relation between the omega sun, omega of the R, omega of the ring, in terms of the number of teeth on the ring and the sun.

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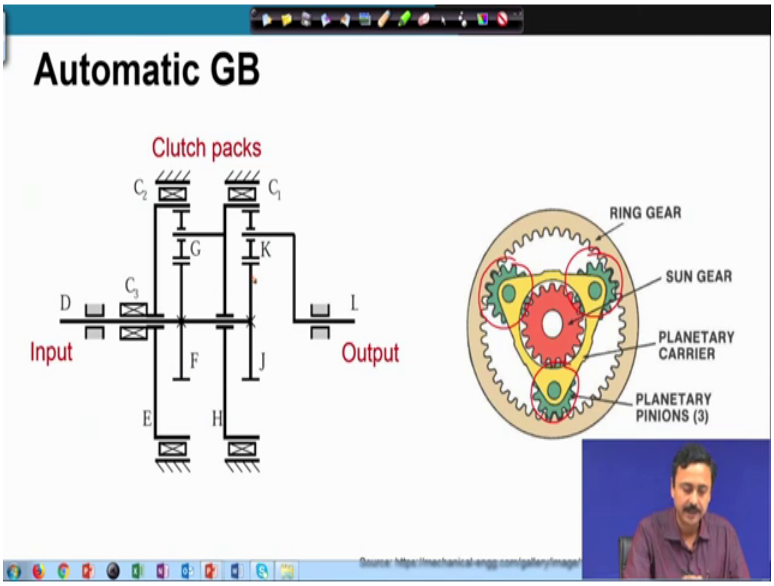


So, with this let us now look at an automatic gearbox a schematic of an automatic gearbox. So, here I have shown very simple gear box. This is the input this is output here we have what are known as clutch packs. These clutch packs will connect these ring gears to the ground, which means if I engage C 1, then the ring gear h gets connected to the ground which means the ring gear H cannot rotate. Similarly, clutch pack 2 if I disengage C 1 and engage C 2, then the ring gear E gets connected to the ground which means it cannot rotate. Similarly, here we have clutch pack free which if you engage then the ring gear E gets connected to the input shaft E.

In other words the omega of e is same as omega of T. Now in an automatic gearbox in reality you do not have just one planet gear as I have shown here, but you have multiple planets this is for balancing and for robustness of transmission. You have for example, here it shows 3 planet gears, planet pinions, which is carried on this planet carrier and this is the sun gear and the outer one is the ring gear. But to avoid clutter in the diagrams I have shown only one planetary pinion.

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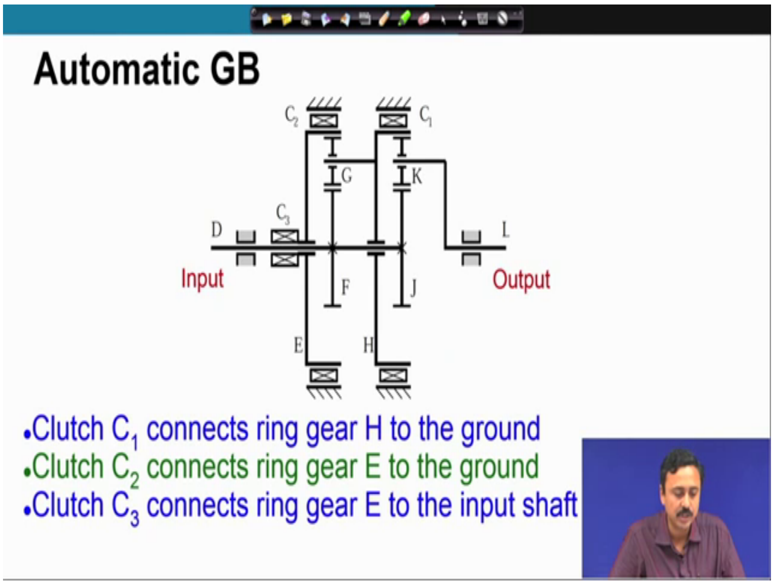


Now, as I have mentioned clutch C 1 connects ring gear H to the ground which means it is immobilized, clutch 2 immobilizes the internal the ring gear E and clutch C 3 connects the ring gear E to the input shaft D.

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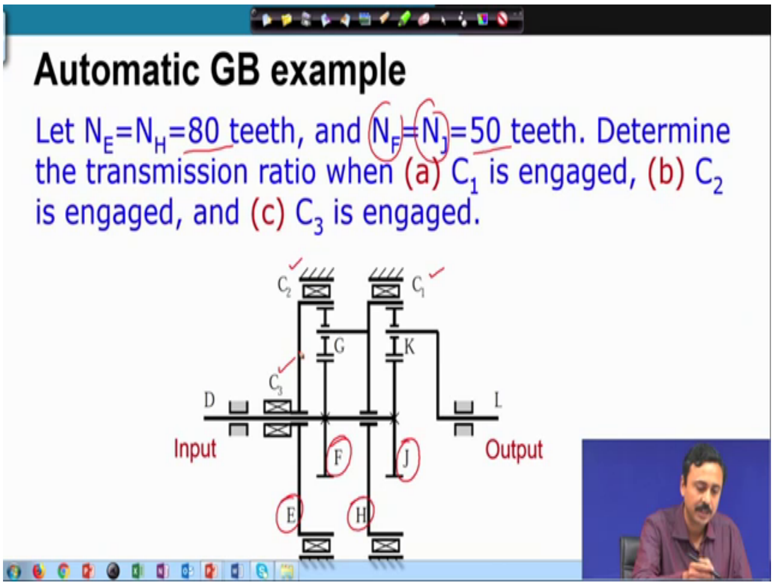


Let us consider an example and calculate the gear ring ratios for this gear box. So, I have considered some values N E is equal to N H. So, number of teeth on E and H they are equal and equal to 80. N F and N J these are the 2 sun gears they have 50 teeth each. The question is to determine the transmission ratio when C 1 is engaged, b C 2 is engaged and c C 3 is engaged. So, when these clutch packs are engaged 1 by 1 what are the transmission ratios let us try to calculate these transmission ratios.

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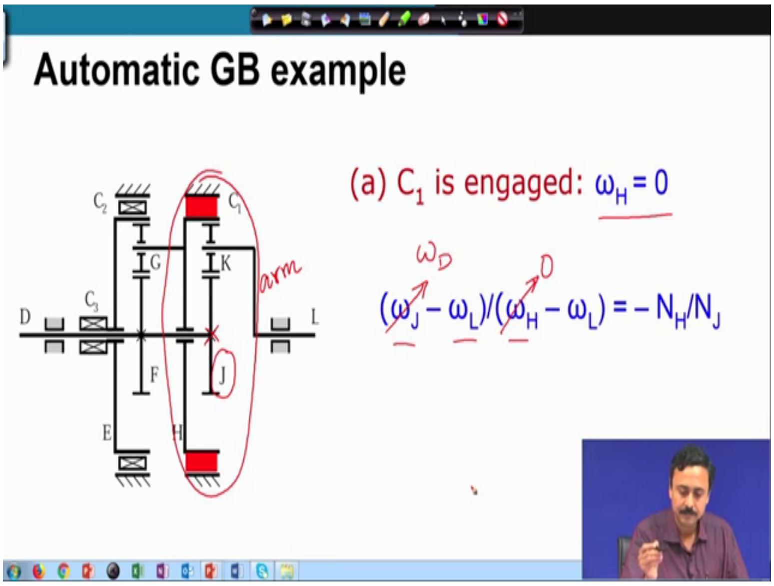


When the clutch pack C 1 is engaged as I have shown you the ring gear H is immobilize which means that omega H is 0. In that case, if I write out the kinematic relation involving omega J, omega L which is the arm. So, this is arm L is the arm and omega H. So, I am considering this part of the gearbox, then I can write out this relation. Now, here because clutch C 1 is engaged omega H is already 0 and if you notice omega J this gear J is connected on to the input shaft D. So therefore, this is nothing, but the input motion omega D.

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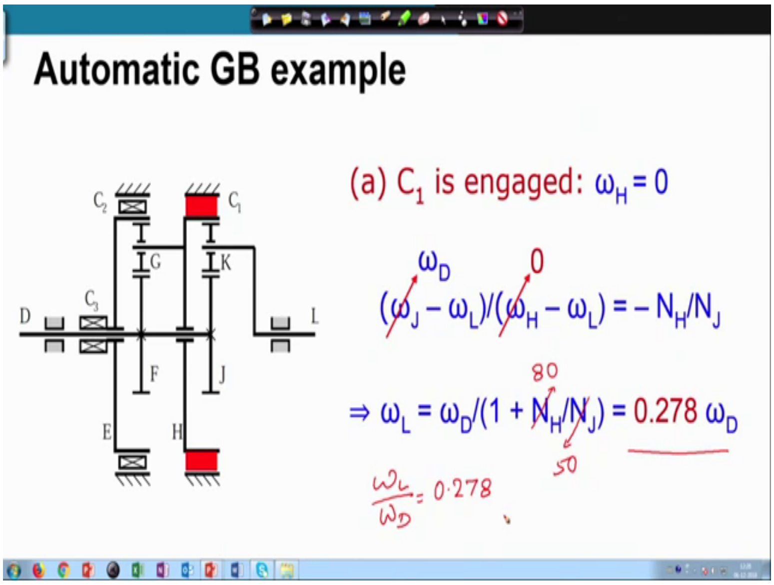


Therefore, once I have all theses in place. So, omega H is 0 omega J is omega D. So, I have a relation between omega D and omega L. Now, omega L is also the output this is the output angular speed. Therefore, I have relation between omega D and omega L, which I can solve very easily from here which I have done and it turns out that for the given data this was 80, N H was 80, and N J was 50. So, for this data you have omega L omega D as 0.278. So, this is the transmission ratio when the clutch C 1 is engaged.

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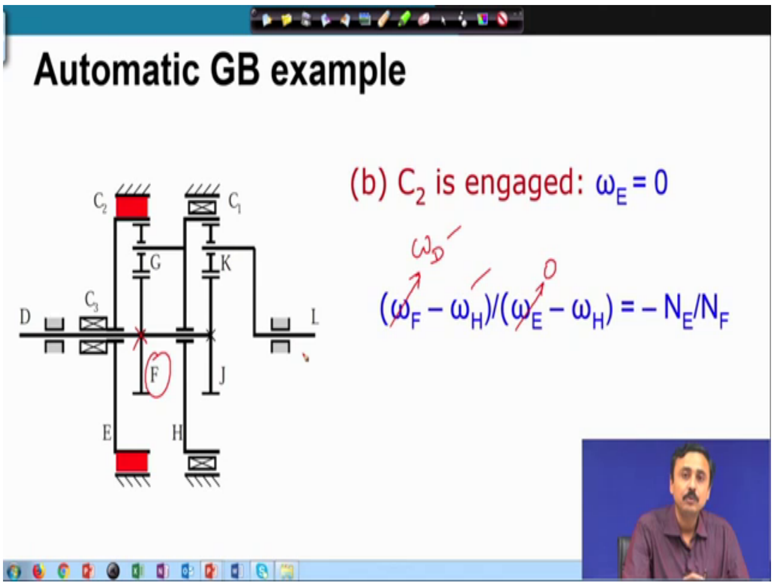

Next, let us look at case b where C 2 is engaged once C 2 is engaged omega E goes to 0. Therefore, in this relation this is 0 and you will also noticed that this sun gear F is connected to the input shaft. So, this is same as a mega D. And therefore, we have a relation between omega D and omega H. So, omega D and omega H so, this ring gear H. So, we are yet to reach the output shaft angular speed we have to go one more step.

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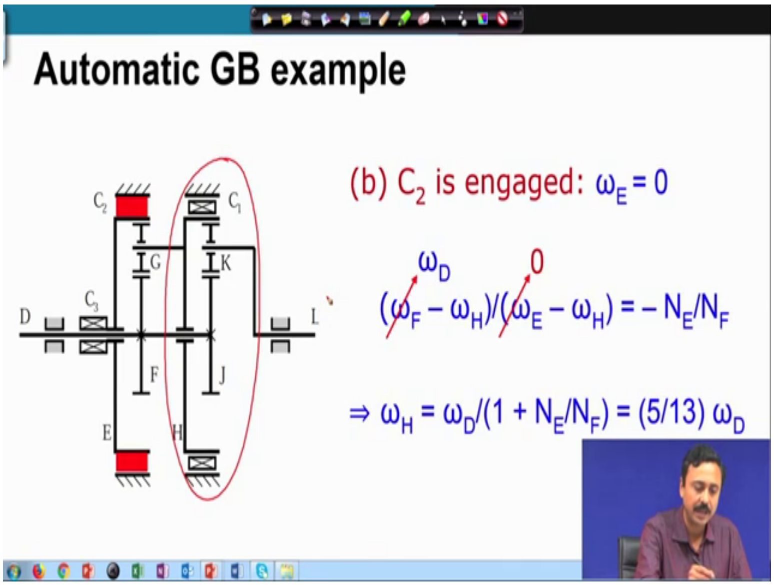


So, let us proceed first with this calculation. So, omega E is 0 omega F is omega D therefore, I can relate omega H in terms of the input angular speed which is omega D. Once this is accomplished we now look at this part of the gearbox, we have omega H and we also have omega J we have to find out omega L.

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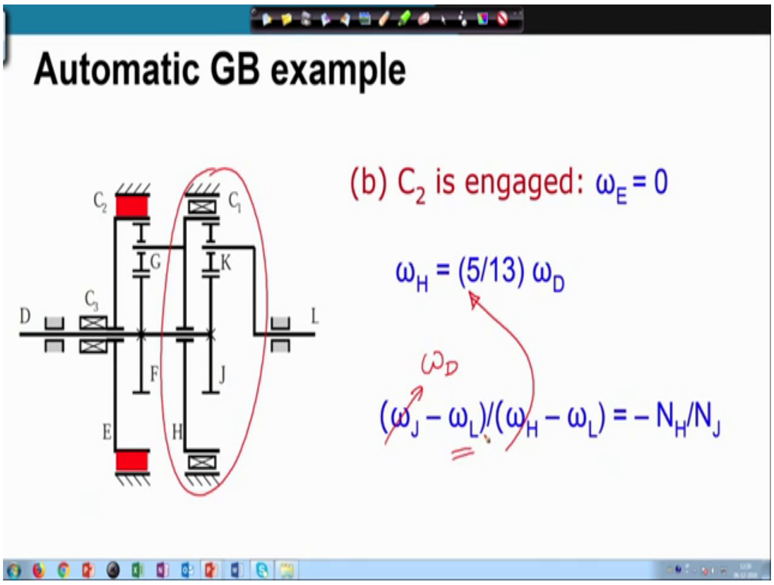


So, let us look at that therefore, with C 2 engaged we have already determined this relation omega H is equal to 5 by 13 omega D. Now, we look at the second part of the gearbox and write out this relation here omega J is omega D, and omega H is known to us in terms of a omega D. Therefore, we have a relation between omega L and omega D.

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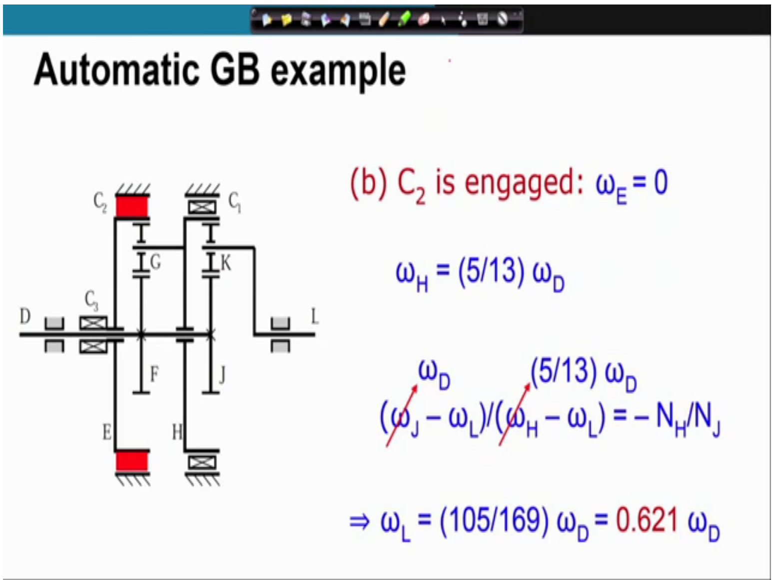


Let us calculate that so, this is calculated and this omega J is equal to omega D if you do that calculation finally, you will have omega L by omega D as 0.621. So, this is the transmission ratio between omega D and omega L when clutch C 2 is engaged.

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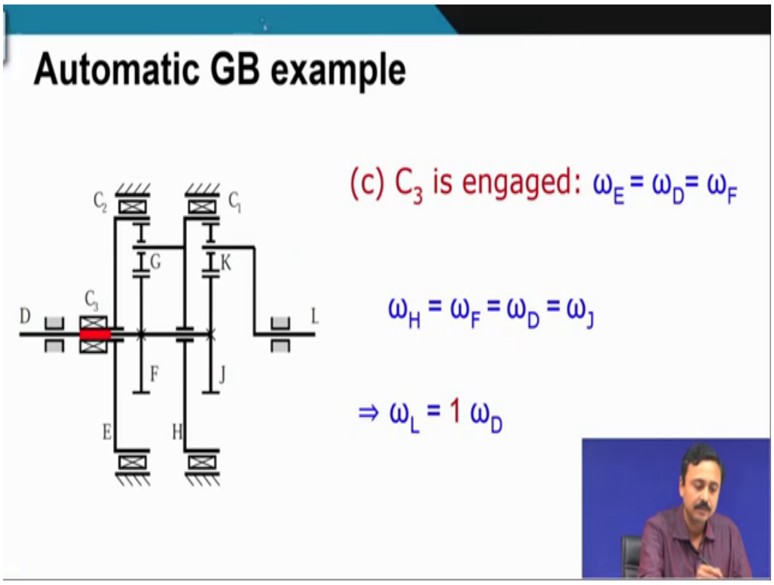


Now, let us consider the third case in which clutch C 3 is engaged what clutch C 3 does is it connects the input shaft to the ring gear E, which means omega D is equal to omega E. And, we also have already have omega F is equal to omega D, because it is fixed to the input shaft D. Now, if you use the relation for this part where omega E, omega F is equal to both are equal to omega D, then you will realise that omega H is also equal to omega D. Because, these two gears are now rotate rotating in (Refer Time: 27:26). So, they have the same angular speed. Therefore, the planetary pinion actually moves it moves like a fixed gear along with this.

So, all the gears have the same angular speed it, there is no relative rotation of the planetary pinion. Therefore, omega H is same as omega D. So, you have omega H is equal to omega E is equal to omega D and that is also equal to omega J omega D is also equal to omega J. Therefore, this also gets fixed therefore; this output which is the arm the output shaft which is connected to the arm has the same angular speed as the input. So, the output shaft has the same angular speed as the input.

This is because the ring gear and the sun gear both have the same angular speed in such a case your planet gear the planetary pinion has also the same angular speed. And, the arm also has the same angular speed this you can very easily derived from general kinematics relations before the transmission ratio in this case is 1.

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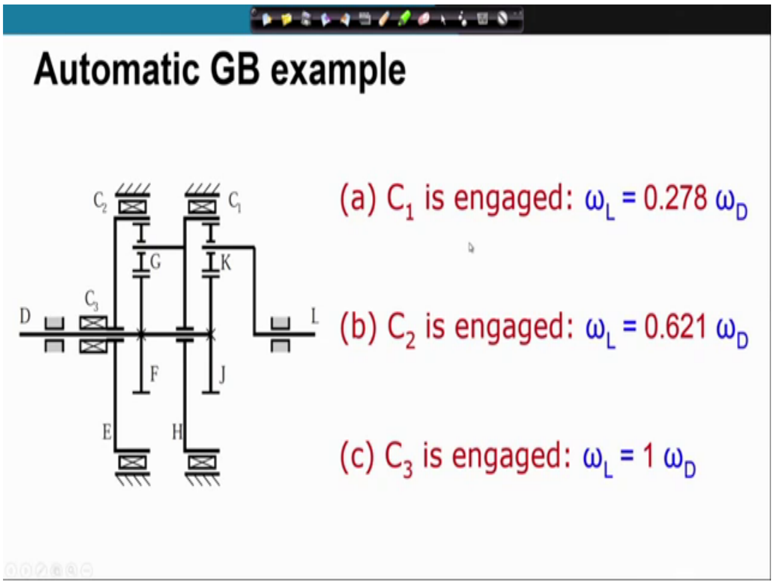


So, let us recapitulate our calculations in case a when C 1 is engaged the transmission ratio is 0.278, in case b when C 2 is engaged the transmission ratio is 0.621, and when C 3 is engaged the transmission ratio is 1. So, that concludes our discussions on the automatic gearbox example.

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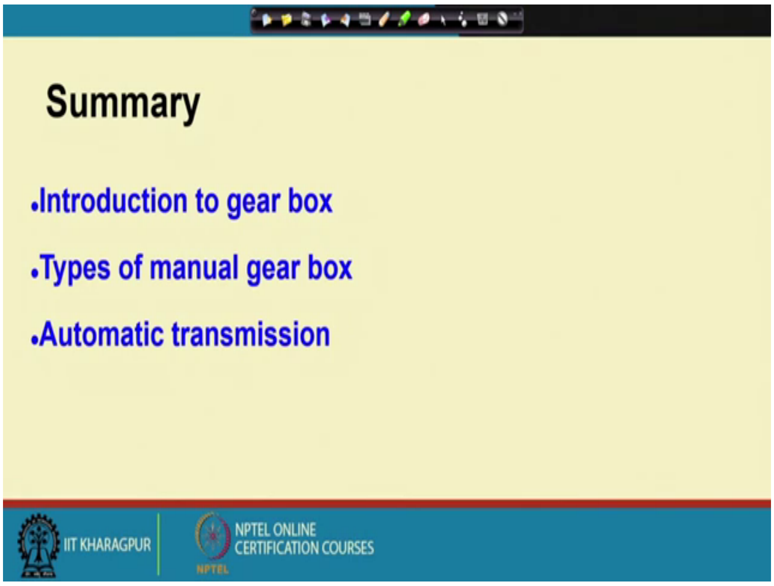


So, let me recapitulate what we have discussed we have introduced gearboxes based on our discussions on gear trains. I have discussed manual gear boxes and automatic gearbox and under manual gearbox we have discussed sliding mesh, continuous mesh, and synchromesh gearboxes. And, under automatic transmission we have looked at an example, we have calculated the transmission ratios using our general kinematic formula which we have derived for epicyclic gear trains.

So, with that I will conclude this lecture.