Gear and Gear Unit Design: Theory and Practice
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Lecture – 40
Harmonic Drive Gear

This is module 8, we are continuing with internal epicyclic and other special gearing. This is lecture 2 where I shall discuss about is very special gearing, which is called harmonic drive gear.

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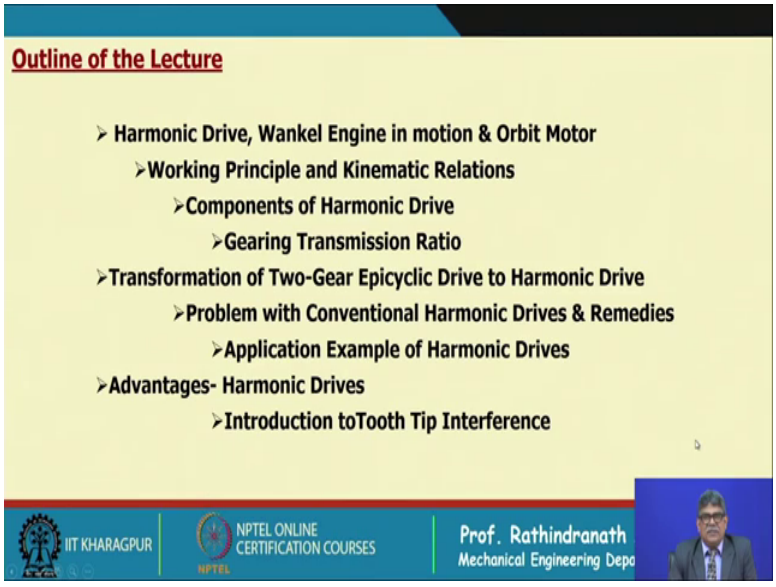

Now, in this lecture first of all I will show you that Harmonic Drive, Wankel engine in motion and orbit motor, they are all having same kinematic relation. Working principle and kinematic relations will come next, then components of harmonic drive, then gearing and transmission ratio.

Transformation of 2 gear epicyclic drive, which I have discussed in the earlier lecture, 2 harmonic drive how we can from 2 gear epicyclic drive, we can arrived into harmonic drive. Next problem with conventional harmonic drives and remedies application example of harmonic drives, then advantage harmonic drives what are the advantages of harmonic drives. And finally, we will discuss about a problem which is called deep interference which occur in case of harmonic drive with very less teeth difference

between the in pinion and gear internal gear ring gear and mating pinion, that I shall discuss.

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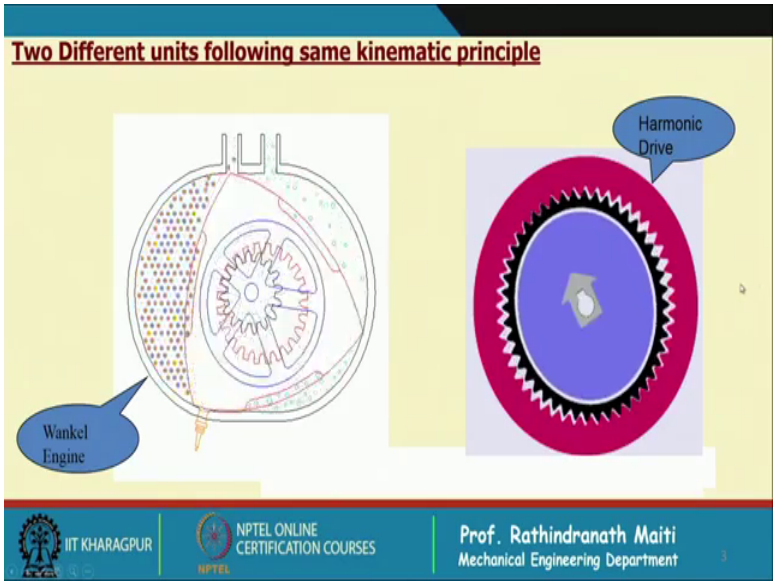

Now, this is the harmonic drive which already I have discussed say as we find that if we keep the outer race fixed then this gear is a flexible gear ; that means, gear are on flexible rim and inside the blue one is the arm.

If we observe this arm when it rotates by one then this flex gear, which is in black in color just rotate one or t teeth depending on, how much difference is there? If there is one to the difference it will rotate by 2 teeth and it will rotate in the opposite directions, and the blue one is taken as input this is the cam and the flex gear is taken as the output and the ratio in the order of this teeth number teeth number of the black one the flex gear divided by the difference in this tooth.

Now, in case of harmonic drive this difference is normally 2. Now here if this is also almost the same motion, which I have shown the see that is the Wankel engine in case of Wankel engine, if you compare with the harmonic drives harmonic drive is having the teeth and looking there are teeth, but in case of Wankel engine do you find the teeth except the inner one; inner one is further transmitting the motion of the triangular load component, but actual gearing there is the outer casing and the inner triangular member.

If you observe the outer casing this is somewhat oval shaped, somewhat elliptical shaped, and distinctly we can find there are 2 lobes right hand one lobes left hand 2 lobes. This means that in this case the inner one is having 3 lobes outer one is having 2 lobes, we can compare is a 3 tooth and 2 teeth that is also giving the same motion as in case of harmonic drives, but it is in the opposite way the in case of harmonic drives the ring gear is having 2 teeth mode, than the flex gear and in case of Wankel engine what we find the inner one is having 3 teeth outer one is having 2 teeth.

This can be designed so, but there is not much scope of discussing the Wankel engine only thing I can mention here that as you see that the yellow one is coming the dotted one, that is the intake the fuel intake and exhaust and combustion it is in the fuel intake and objection.

So, in this case in case of Wankle engine what is there that well is injected inside and that is born to give the power and motion. So, inner one and the motion of that inner member is taken out from this a special gear that is again an epicyclic gear anyway these are in the same kinematic motion.

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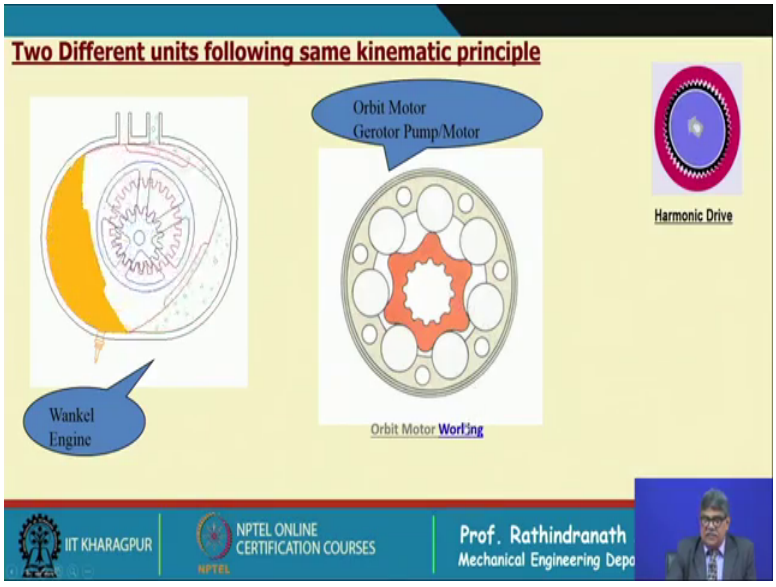

Now, along with that we can also relate the another machine, which is called orbit mate motor, in orbit motor what we find if we look into this that this is a having a outer gear, which is nothing, but a ring and the lobes are in form of cylindrical roller and inside there is a cam sort of things which is having lobes.

If we count the outer one is having 7 inner one is having 6 inner one profile is called modified epitrochoid outer one is nothing, but the envelop of this one and they are conjugate to each other. And these points although it is moving on these lobes, but this point will be, be always in contact therefore, this spaces can be used as a chamber which will act in compression and expression expansion and in that way this also can be used as a motor and as well as pump and this as for the geometric feature is concerned as such the teeth are concerned lobes are concerned these are having the relations both are cycloidal class of teeth.

In this case the; it is just opposite outer one is having 2 inner one is having 3 in this case inner one is having 6, outer one is having 7 and the transmission ratio here is the lobe number of the inner one because we are taking the output from the inner 1, divided by the difference is 1. So, transmission ratio as such the gearing is concerns it is 6 let us have a look into this; what is the motion.

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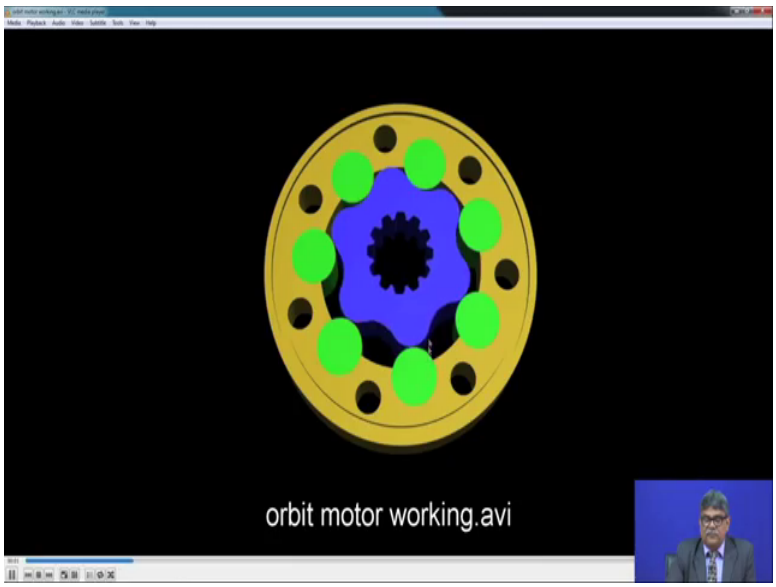

As you see that when the inner one which is called star is rotating is revolving around the central axis by one revolution we are getting only the motion one sixth of this one.

Let us consider this one this is coming over here whereas, it is coming inside. So, this by that time it has rotated one revelation ok. So, this gearing this is also used as the cycloid speed reducer, which I have shown in the earlier lecture in that case these are directly used for gearing in this case this is used for low speed height of motor, but that is a

separate issue we do not have much scope here to learn about this. If we consider this harmonic drive that again I am showing with which we have generated here as you see say this is this functions in that way; this means that there is a ring gear, and there is a flex gear and the flex gear is rotating by a cam and if we observe it is only 2 teeth progress per regulation.

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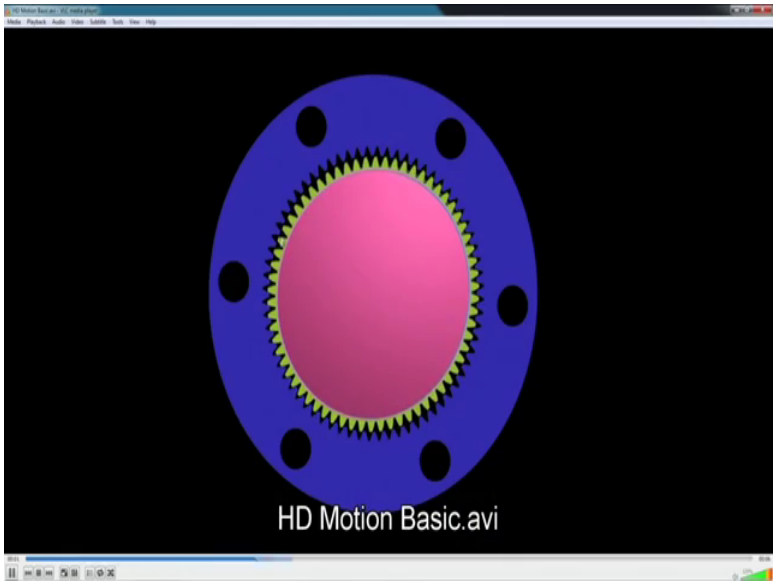

That means it is while say if the teeth difference is 2 and the pinion the flex gear is having 100 teeth the transmission ratio we are getting directly 50.

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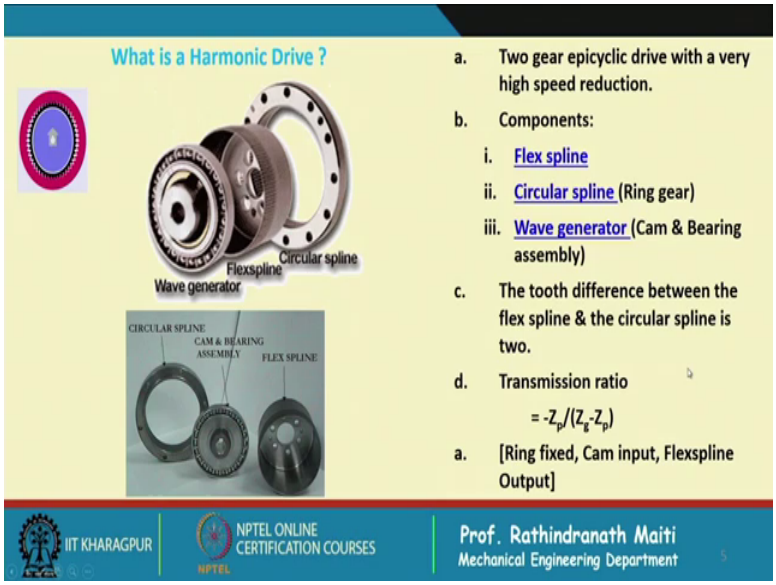

Now, harmonic drive we can say the 2 gear epicyclic drive with a very high speed reduction, because the transmission ratio kinematically we are getting the same. However, if we consider the 2 gear drive and harmonic drive we find the difference in this case there is a flex gear.

So, in after this a little progress I will show you how we can arrived into the harmonic drive from the 2 gear epicyclic drive? So, first of all we shall study what are the components the component is one is flex spline, this flex spline or you can call it flex gear which is the pinion inside the ring gear, circular gear ok.

So, these are the 3 basic components. First one the flex spline, second one is this ring gear, and third one is the wave generator cam. And this is of course, not a single component, this is as we have look into here, this is the oval shaped cam, but to give the frictionless motion or the less friction we have used a flexible rest bearing inside there is the cam, which is of this shape.

This means that a cam solid cam is inside of same shape; that means, you can consider the cam inside will be equidistance from this profile of this cam, it will be inside and within this space there will be a bearing which is originally circular, but it can be made flexible rest. Now I will show you these 3 components and how they are assembled. So, first of all we shall take this is the flex gear.

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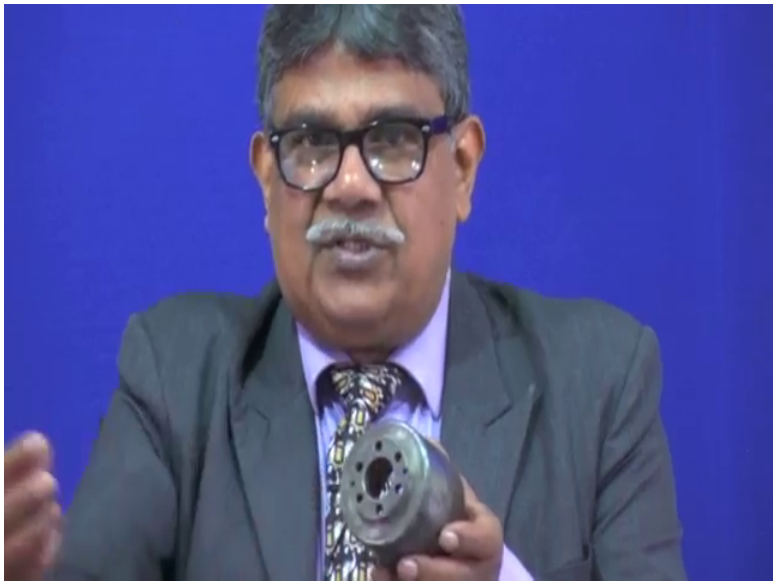

This is the flex gear, if you look into this; this is a very thin wall and these are the teeth and as you find; there are the holes here we can fix a body through, which we can take out the output ok.

Usually this is the output, but it also as well we can keep it fixed whereas, we can take the output from the ring gear and this is the ring gear.

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These teeth are very small teeth we had to take very small, because to make this flex gear that is on the flexible rim. So, teeth are very small in the order of 0.5 or even less module and this is the cam.

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Inside this is the oval shaped cam there is a major axis and minor axis , but difference is very small in open I we will think it is just circular one.

But, if you rotate this one there may have a slight failing about this. Now assembly is not difficult, before going into that I will say this is the cam and this is the flexible wrist bearing inner race and outer race is flexible and this is coupled by a special coupling ok.

Now, assembly is not difficult we can simply take this one and inside we can slightly place and with the pressure we can put inside. So, it has go inside. So, this as this is a flexible this has gone inside and then we can rotate here, this we can rotate inside.

Now, if we put this gear they see this can be assembled a little difficult, because of the reason that teeth number difference as are very small, but still; we it can be put inside and then we can rotate and we find the epicyclic gear motions, the harmonic drive motions.

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If we take a model say this is a model plastic model this is made by harmonic drive gmbh of Germany; they are most famous.

Now, in this case if we consider there is if the outer member there is a red point and if you rotate this one by one revolution and then we will find this point, we have taken this point here and another point on the inner member and as well as on the cam.

So, this is after on revolution we can distinctly find that it has probable rest in the opposite directions of rotation by 2 teeth. So, this I have given you some idea about how it operates and their components and the tooth difference between the flex spline and the circular spline is usually 2; we can make why 2 it is meshing at 2 points along the major axis.

So, difference can be made to; however, it is also possible we can make the difference 4 we can make the difference 8 and still it will work, but the transmission ratio we will gradually decrease for the same number of spline, if there you make the difference say the flex spline is having 100. So, we can make the outer 102 ring gear, we can make 104, we can make 108 like that still it will work , but the transmission ratio will decrease.

So, practical case you will find that always difference is 2, another transmission ratio is in case of the model where usually the ring gear is fixed and the motion is taken out through the calf or the flex spline the transmission ratio is minus teeth number of this flex spline divided by the difference.

Difference is 2. So, whatever the teeth number in the flex spline divided by 2 will be the transmission ratio and minus sign is coming that the motion will be output motion will be opposite to the motion of the cam. Now in this case we have considered ring fixed cam is the input flex spline is the output.

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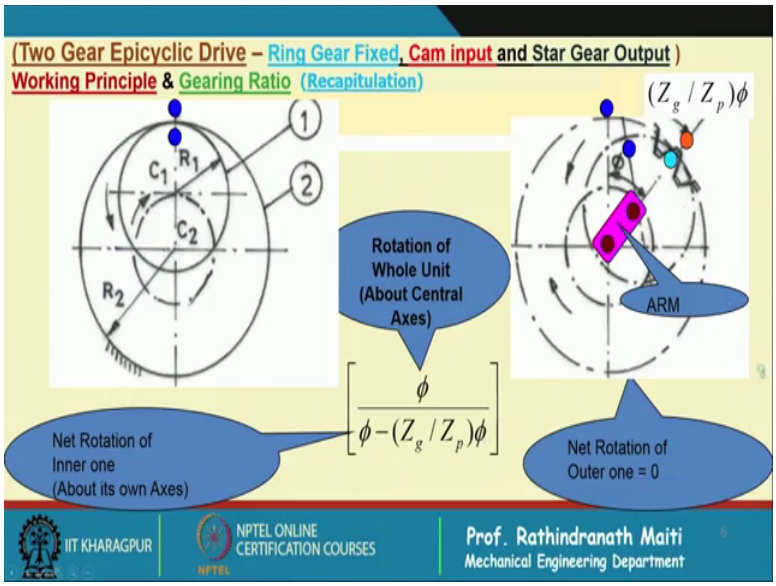

It also can be made other way. So, this is the I have shown here in this case as already described that if you consider this 2 point and rotate the whole unit first phi and then rotate this inner member in the opposite directions. So, that the outer member becomes it is original position; that means, ring gear is fixed and we find this term input is phi the cam is rotating cam has rotated by phi angle output has rotated by first phi and next Z g minus Z p into phi in the opposite directions and we get this type 2 motion.

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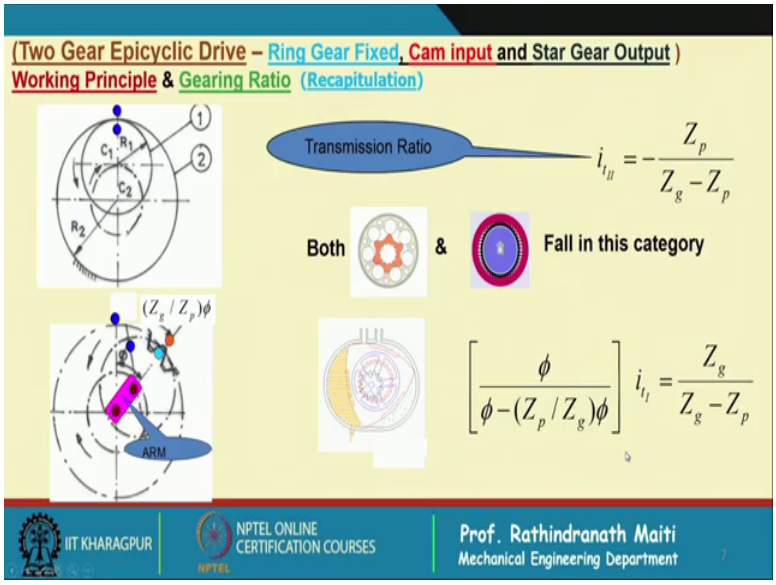

We get the type 2 motion means minus Z p by the difference of the teeth, which is in case of harmonic drives if we keep outer member fixed. In case of orbit motor also it is the same in case of Wankel engine; however, it is in the other way because the this in that case the 2 teeth member is fixed and the rotation is from the 3 teeth member and we get this sort of output.

You will find that while this is rotating in this clockwise directions this will also rotate in the output also rotate in the clockwise directions. Now I shall discuss about the transformation of 2 gears epicyclic drive to the harmonic drives.

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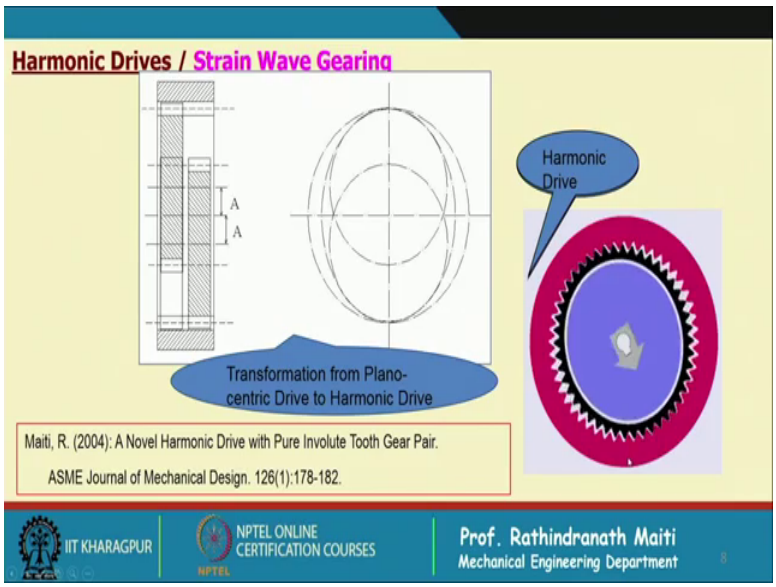

Now, let us consider this 2 gear epicyclic drive in which we can see that this one, we can that this is the ring gear and we have 2 planet at 180 degree and the cam is put inside there you can we can consider that there are 2 camps in opposite directions on the same shaft; that means, one is the extent if it is eccentric in at 0 degree other is a eccentric at 180 degree; if this cam is put inside then this will give the 2 way gear epicyclic drive motion and the reason of taking 2 or 3 planets to maintain the dynamic balancing of the 2 gear epicyclic drive.

But, these gears are solid gears; that means they are not deformed. Now imagine this we have to imagine that we are clubbing these 2 gears inside this pinion, these 2 opinions into same plane physically it is not possible, but what we can do remove one and keep one and make that is very thin rimmed.

Then put a cam inside elliptical. So, that it touches here; that means, one we have removed another one we have stretched to meet at this point with the help of a cam and cam is rotating inside, this will give exactly the same motion what is available from the 2 gear epicyclic drive.

So, this means that from true gear epicyclic drive; we can arrived into harmonic drive making this inner member on flexible rest cuff and putting a cam inside. Now already I have shown how the output is taken from the cam sorry taken from the flex gear and cam is the input one.

Now, this more details can be available here if you interested then you can read this paper. So, what we would say that the 2 gear epicyclic drive with the involute liked tooth can be can give the form of an harmonic drives , but one problem is there obvious that as we are flexing the inner one definitely tooth are also being flexed and conjugacy of the teeth in mesh is being lost.

So, definitely there are some problems in harmonic drive although it gives very high ratio. So, the in details these problems are as follows the cam is elliptical or oval shaped not exactly ellipse; it looks elliptical.

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Conjugacy at teeth contacts are affected involute standard or standard and most popular profiles cannot be used although for very slow motion involute teeth are used, to maintain conjugacy tooth profile is synthesized and gear pair become match part performance is sensitive to center distance and accuracy.

Now, interestingly we have studied a gear having this is a standard product, commercial product, for which the teeth number of flex gear is 156 flex gear or you can call pinion and the ring is having 158 difference is 2 and module is 48 DP which is close to 0.5 to 9 millimeter and it was 30 degree pressure angle, of course there is a correction.

So, this gear is available and they transmit torque just to examine the; what is the gearing action there, we consider at the contact point let us consider there as if it is a circle circular gear. So, we found out the transmission ratio with the teeth proportion teeth proposition, we are measured and we will found out the transmission ratio, but surprisingly it was only 0.78. So, if contact ratio is 0.78 then it definitely the gearing action is not available we have the idea that if the contact ratio should be at least one.

In practice it should be more than 1. So, that there is no failure, but 0.78 definitely it would not work. So, with the 30 degree involute teeth definitely there is multiple contact, there is a contact beyond the normal contact at the teeth normal contact at the teeth. So, therefore, this is quite interesting and this is a matter of investigation.

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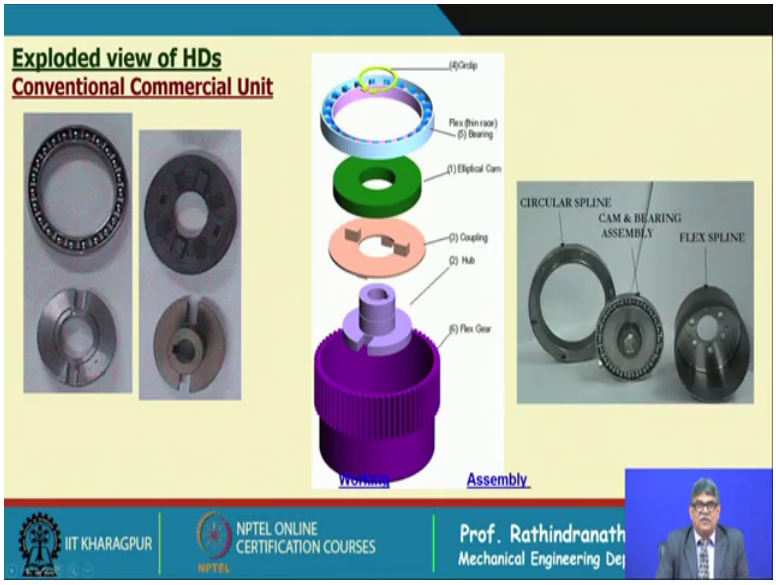

But, and this only we shall learn what is the kinematics and what is the transmission ratio and if we look this components a in details, that this is the coupler this is a half this coupler comes this there is 2 range point, this raised point, this raised portion come inside here.

So, bottom one and the top one goes inside the cam which is oval shaped on which this bearing is put this is on flexible rest and whole become gives the cam and these are assembled one inside which I have shown. So, these are the components.

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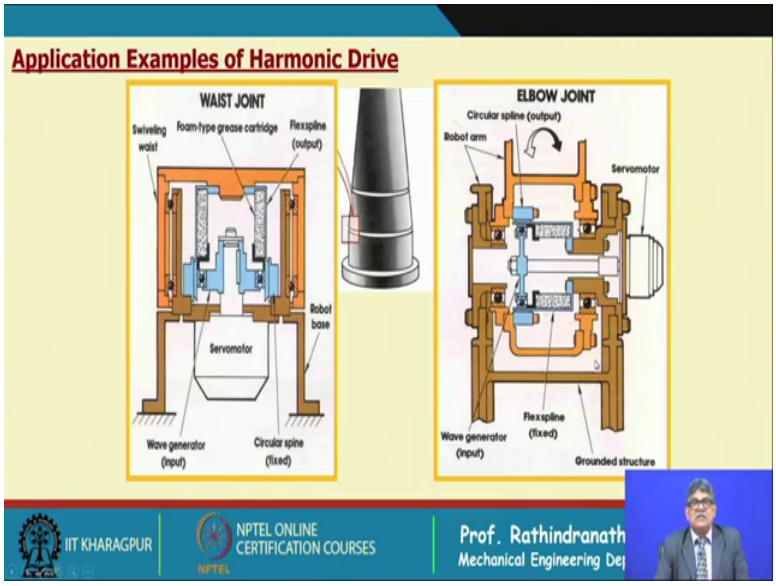

Now, the application if we look into the application of such harmonic drive, this is can be used in the robotics joint here the huge the comma industrial robot is shown, it can be used for rotating the whole body, it can be used for rotating the arm also.

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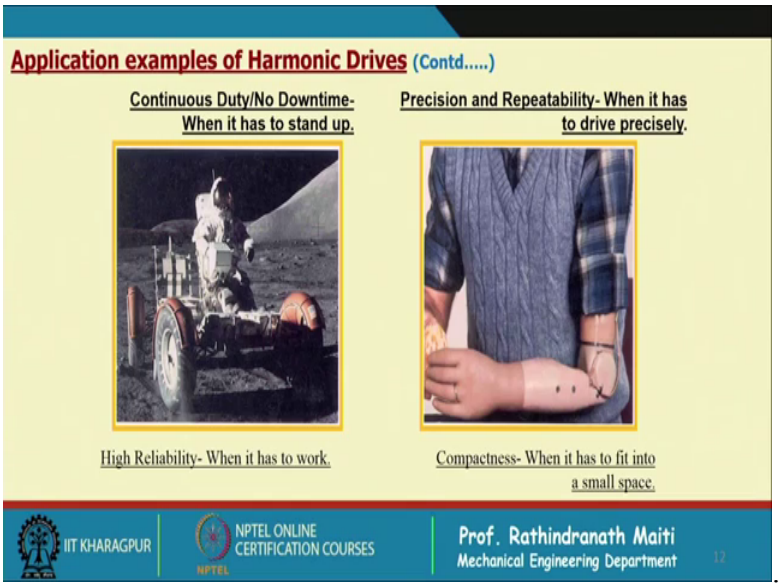

And, here as you see this is an artificial limb and in that artificial limb there is a harmonic drive here and which gives the motion of course, this drive is given by a battery operated motor and that depends on the how this is being operated that might be from the other hand or by just flexing the muscles.

But still this application is there and this is a this it is a space craft it is moving on the moon for here the rudder control and other the harmonic drives is used.

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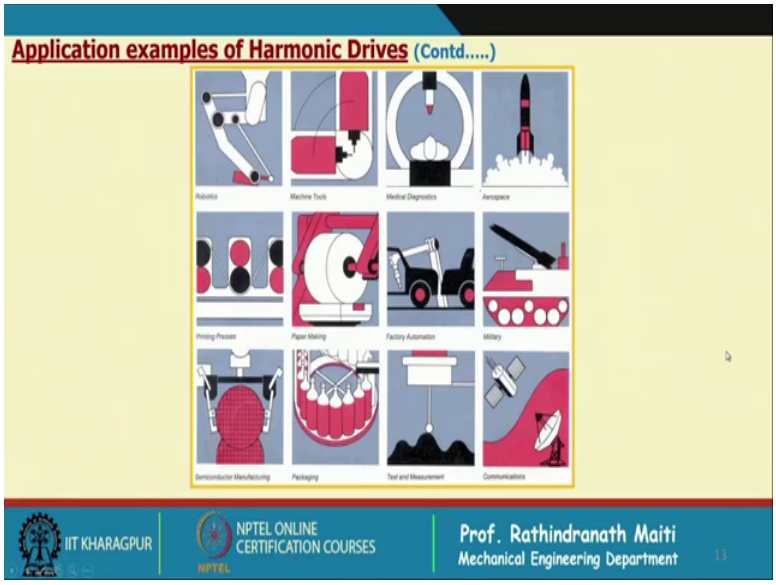

And as you see here the starting from the if we consider the first row the topmost one is the left side topmost one is the anti arm robotic and then comes the machine tools, then the medical diagnostic machine say it is it might be MRI machines or scanning machine and then it is on the aerospace it is used for the radar position control. And then there is the in the printing press this is middle row left one printing press the rollers are being rotated, and also paper making machines, then it is a factory automation it is used, then military purpose also used for the radar control and other operations.

Then semiconductor manufacturing for very small rotation it is used packing in the state is used test and measurements also this is used and communication also it is used and there are many other applications of such harmonic drive, but we should keep in mind as the teeth are very small it cannot be used for very high torque transmission it is. So, for medium torque transmission, but it gives a very good operational feature at slow speeds.

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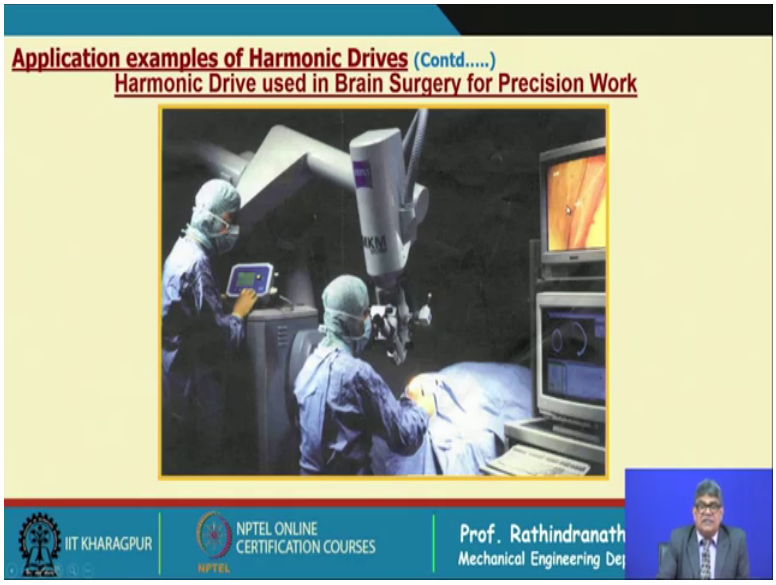

Now, this is another view which shown these are from lea plates and from websites, then this is this machine it is a medical robot which is being used for the operation of the eye they here this motion is very small the doctor is moving a stylus or a stick sort of things.

In that case it might be some indicator through, which the motion of this machine is being given through harmonic drives.

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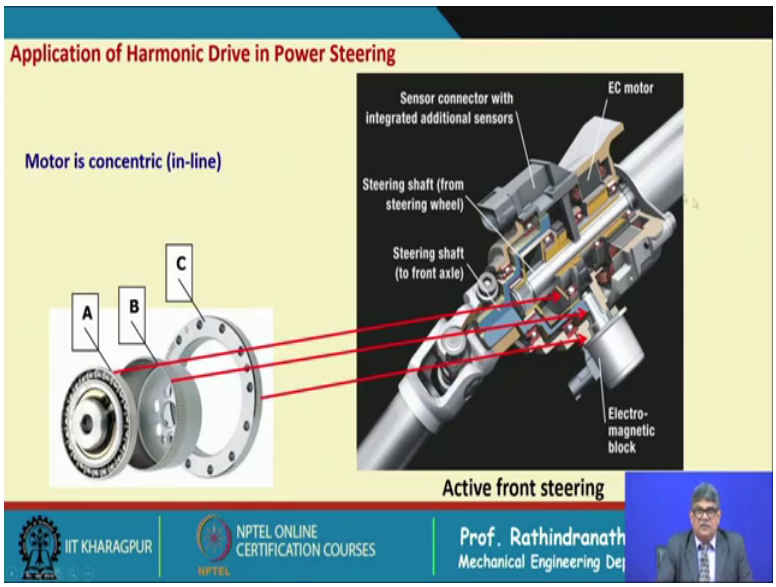

Now this is another example in which case this is the steering unit and for that steering unit here is the harmonic drive and we can see these are the components, they are put this

outer one is the ring gear and there is the flex spline inside and the innermost one is the cam, which is rotating by the steering.

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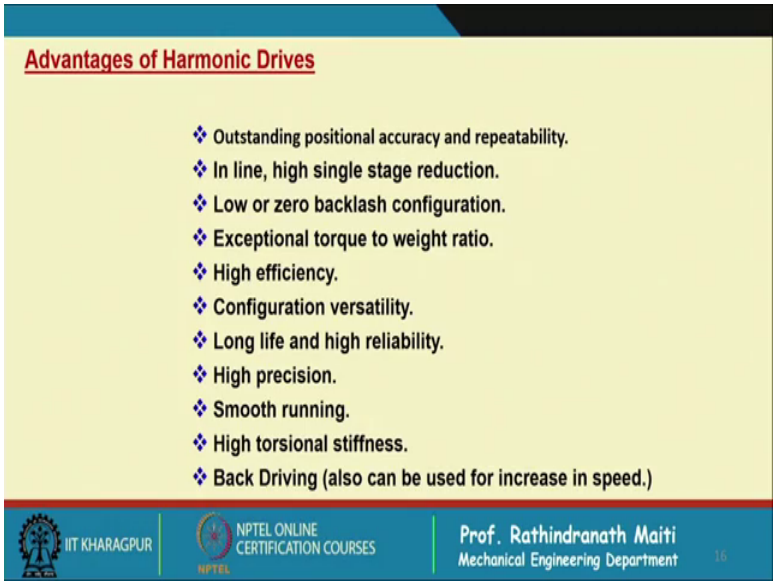

Now, obvious advantage of the harmonic drive outstanding positional accuracy and repeatability, you if we consider the motion the motion may not be very smooth the reason is that the tooth are meshing at multiple contacts, but conjugacy is lost, but it says the accuracy and position is concerned there is no slip.

So, this is possible that we can use for a crucial accurate positioning. Then in line high single stage reduction, low or 0 backlash configurations usually for a very precision application these devices are made backless free and these are operated under a maintained temperature. Exceptional torque to weight ratio very lightweight you can see this is 3 components, which I have shown this can transmit around 200 Newton meter output torque, but it is not much it is only few grams 102 100 grams, high efficiency this is also possible the efficiency is high of course, at slow speed gearing of efficiency may be low overall efficiency is very high, configuration versatility that is possible that we can have the outer ring fixed output from the flex spline or it is vice versa .

Long life and high reliability this it has been seen that access the gearing is concerned this is normally do not fail easily; however, there is a problem of lubrications. So, if there is temperature is not maintained properly then there is a chance of failure of the lubrications. As well as instead of filling the gear teeth the bearing fails usually high

precision this is for also appreciation operations smooth running, it is possible that we can run at a smooth speed of course, at slow speed high torsional stiffness is also available in such unit. Normally we may feel that there is not must torsional stiffness, but it is available and back driving also can be used for increasing in speed.

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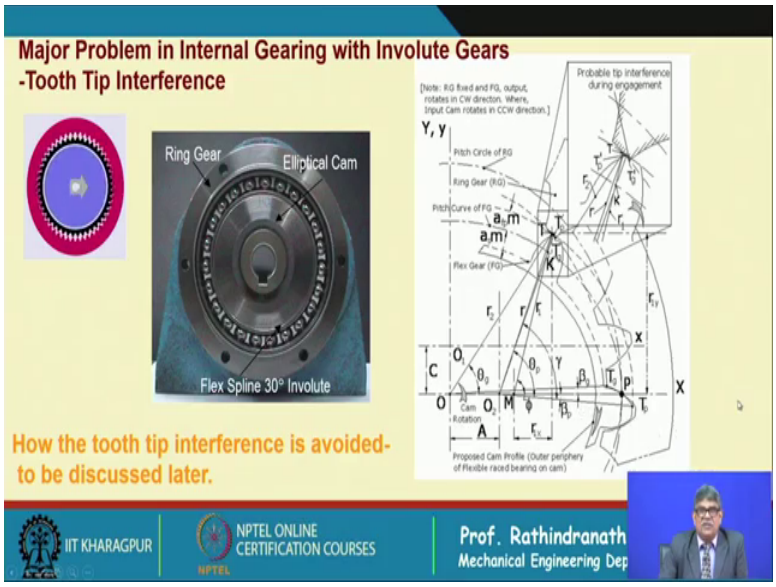

Now, this in designing this gear unit there is many many problems first of all there as the tooth are not involute cannot be used to directly. So, we should find some other teeth which is involute like. So, usually it is possible that we can find out a pair of conjugate teeth profile having this motion, it is not possible that a conjugacy can be maintained 100 percent, but still it is it will be better than the involute teeth. So, finding such teeth profile is a major work in designing such gear unit and next problem is that teeth interference usually for involute teeth for an example which will come this too next.

If we take 20 degree involute teeth stub teeth stub teeth means addendum is 0.8 then difference should be at least 7 in case of 35 degree sorry 30 degree involute this difference can be reduced to 3. With correction it is possible of course, we can go for 2, but in in the in this gear 35 with 2 teeth difference with corrective teeth, it may not give very high torque which is possible with the fixed gearing or you can say solid gearing not flexible gearing.

Now, this stiff interference finding out the teeth; teeth interference is another exercise, which I shall show you in later stage, I shall discuss about this; it is not possible that we

can go for such detail design of such, but this is at least one problem I shall share with you.

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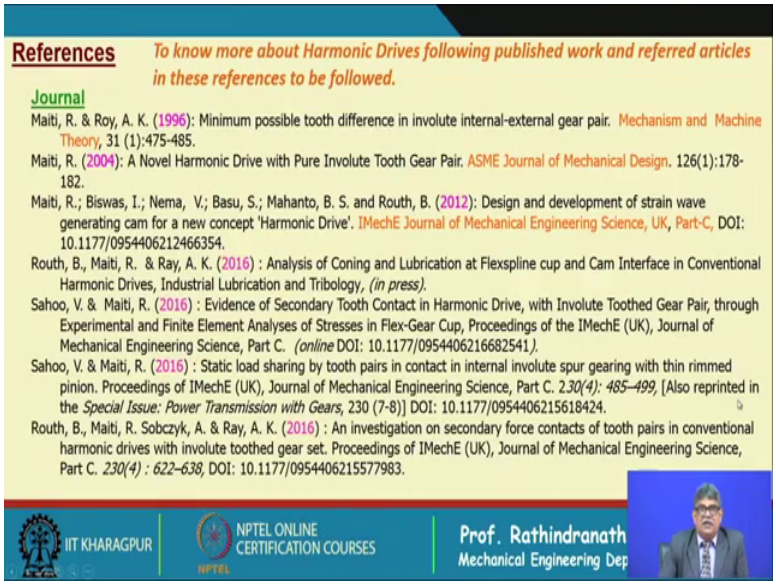

And if you would like to have much more idea about this gearing, then definitely there are available literatures, but these are the literatures which of our own research work and if you are interested you can go through these.

Thank you.