Tribology

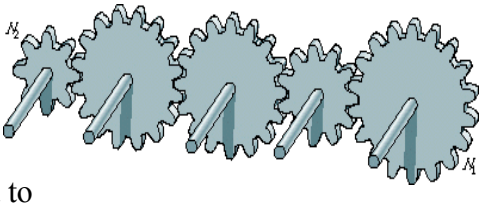
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Lecture No. # 35
Tribology of Gears

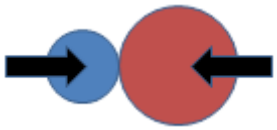
Topic of the present lecture is Tribology of gears. In other words, it can be said gear Tribology. We know, what is the Tribology? It is a science; it is a study of friction and lubrication. So, what is the new topic in this? What is the new word in this the gears. It is a most commonly used machine element.

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GEARS



- Elements required to transmit power between rotating shafts. ~ Different rotational speeds.
- Rotates about axis.
- Consists of gearwheel and teeth.



Often gears are treated as pitch cylinder which roll together without slip.

Positive drive by meshing teeth.

And if you try to define it, we say it is a tooth field, and see there are number of gears. We say the gear 10; gear number 1 is here, gear number 2, 3, 4, 5; 5 gears are in this. And what is the purpose of this is to transmit power from one shaft to other shaft. Basically use to transmit the power. We can use a number of other machine elements to transmit the power, but advantage of the gears is efficiency loss of energy is lesser than other machine elements, and that is the main advantage of the gears. Generally, when we talk about the gears, we talk about the different rotational speeds; we say that this is the shaft 1, will have a different rotational speed compared to this shaft.

Generally, for same rotating shaft, we should not use the gears, will not be having any advantage on that case; except the center distance difference from one location to other location, but not major advantage. So, generally they are used for different rotational speeds.

In other word, if the one shaft is rotating the 1000 RPM, and we want to reduce this RPM to 200, what we will do? We will choose a gear ratio 1 to 5, 1000 is an input speed and output speed we require only 200 RPM. That is a gear pair can work 1 to 5 ratios in this case.

Speed reduction can happen other ways also. You can use electronic device much faster response, but major advantage of the gears is amplification of torque. Amplification is important work it goes with a high load carrying capacity, this is applied high torque reduction of the speed, but that tends to the high torque. And that is why we say that we get amplification something omega by omega n and omega in or the input is a five times more than output will be getting more than five times almost five times a torque. Now, in this case what has been mentioned here this shaft is generally located and located in the sense it is not going to change the axis position, axis will remain fixed and this wheel this tooth wheeled will be rotating about this axis or axis of the shaft.

We can see some funny shapes on the wheel is what we say that tooth shape tooth profile and the whole gear can be named as gear wheel with teeth. What is the importance of this gear teeth can be demonstrated can be elaborated using this two disk. Say there is a blue color disk the smaller diameter; red color disk larger diameter. Now if you want to transmit power from blue color disk to red color disk. They need to be in contact they need to be in mechanical contact and through friction they can transmit a power of blue to the red color disk.

What are the disadvantages? See friction is slightly uncertain, coefficient of friction will vary. It heavily depends on the surface softness. If surface softness is increasing there will be some sort of fluctuation in its speed, whatever the speed in this case 1000 RPM is given to we are going to transmit to other shaft at the lesser speed then 200 of what we mentioned earlier or discussed the 200 RPM if I want on the shaft. There will fluctuation 200 plus delta on higher side delta minus sign may be say 195 to 205 will not be able to get consistent performance; will not be able to get steady RPM which is undesirable.

Another thing is a possibility they may not be in any contact if I say the surface softness is going to give some sort of a variation in a speed, but there is a possibility that these disk will not be in contact and what will happen sometimes we are getting from 1000 RPM to 200 RPM, sometimes we are getting from 1000 to 0 RPM. No transmission, which is highly undesirable almost 0 percent efficiency from input whatever output we are not getting anything. To avoid it, what we do we try to preload these two disks. So, they remain in contact irrespective of our outside condition and involvement conditions.

So, we need to pre load that means, we require additional force, additional deformation or which is again undesirable we know very well is there is a coefficient of friction if we assume the coefficient of friction is fixed. Then because of this compression force if we multiply this normal force with the coefficient of friction there will be friction force, there will be more and more friction losses, or heat generation will be there and there will be some sort of deformation of the disk and there will be wear. To avoid all these complexities tooth wheel is a better option.

Now, in this case this is what we call as the positive engagement. Tooth itself is deflecting other surface that is important for us and that is a main advantage. The question comes how do we decide, what kind of profile is important, what kind of diameter is important, do we design it with we think about lubrication of this contact surfaces, it is necessary for us. We say we decide dimensions based on the torque ratio, based on what kind of amplitude or what kind of magnification we require. In this case we can say that if omega p is a speed of pinion and omega g is a speed of the gear.

Unfortunately, am talking about the gear topic and again we are using the word pinion in this. That is slightly improper because we generally talk about the gear as a pair single gear will not work. It does not have any use. What is the meaning we say that gear always works in a pinion and to differentiate we call smaller size smaller diameter as a pinion, larger size as a gear and they always work in pair. Without paring single gear is useless it is not going to do any job unless it comes in contact with other gear. Now, as I mentioned the dimensions will be decided based on the magnification, which we require if we require five times magnification of torque.

We should go ahead with five times of diameter six times or six times up dimensions always there will be limit. We can cannot go thousand times, five thousand times, ten thousand times. So, there will be some limit but before coming to that, what are the variation in gears, we say gears there is a possibility the external profile and there is a possibility of inner profile or we say these gear teeth can be our inner surface of the disk or outer surface of the disk. Question comes what are the advantages or what are the advantages of inner gear or we say the internal gear or external gears, should I go ahead with the internal gears or should I go ahead with the external gears answer it self comes.

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Torque Ratio

- Generally gear pair acts as a speed reducer aiming torque amplification at output shaft.

$$\text{Torque ratio}, m_A = \frac{\omega_p}{\omega_g}$$

Gear Pair:
Smaller – PINION
Larger -- Gear

Internal & External gearing



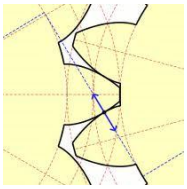
So, when we talk about the gear pair internal gear cannot be matched with the internal gears. So, we require always external gear, but external gears can be paired with external gears. So, advantage of external gear is that it has both utility with external gears as well as the internal gear. Another thing is that whenever we go for the hollow dimension or we say the hollow cylinders machining on the hollow surface is slightly difficult compared to the solid surface or we say outer diameter of the solid surface. So, manufacturing from manufacturing point of view, you can say internal gears will be slightly more complex or we say there will be complexity in developing this kind of gear pair.

Now, there should be some advantages that are why the internal gears are surviving. There are many advantages we can think when we pair gear external gear with internal gear a factor distance is decreasing, center distance is lesser. So, we want to make some sort of compact unit we should prefer internal gears. Because the center distance between the one shaft and other shaft may be not much depend on the dimensions we say it may not be 0, it may be greater than that but it will be always advantageous from the center distance point of view, if I compare external verses external gears and the external gears verses internal gears. So, that is a major advantage of this kind of a gear.

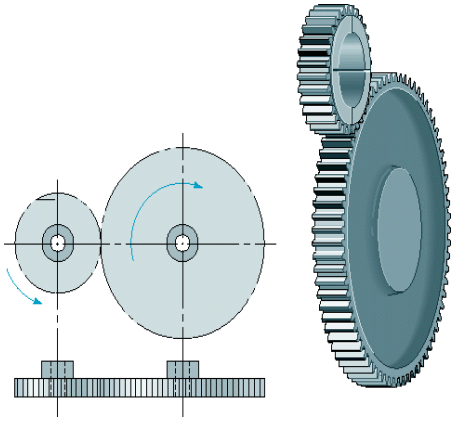
Another thing is that in this case particularly the efficiency slightly on a higher side compared to external to external gears. So, depends on the situation we should prefer, about the center distance, we want to talk about compact design. We will prefer pair of external gears with internal gear. Again internal gears will not be able to get matched with internal gears, but external gears can be matched with external gears.

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Tooth Profile



$$m_A = \frac{\omega_p}{\omega_g}$$



Involute tooth form:
Locus of a point on a line rolling on its base circle.

Velocity ratio does not change due to inaccuracies in center distance.

Now, we will talk about the tooth profile we say that gear has advantage because of the gear surface has teeth. It can match it can provide positive drive, but there will be always a portion of what kind of profile we need on the gear pair. And this is shown over here you can see this gear wheel has some length and whatever the profile or the first surface or we say initial cutting plain that has same profile on a whole axis or we say that complete length wheel has same profile. And this profile what we recommend is generally involute profile that is advantageous. We can think in much simpler manner; involute profile is more like a string which is getting unwrapped from the cylinder to think in a better manner.

We can show over here this is involute profile, it is more like convection when comes in a contact with other gear or we say pinion verses gear, they have a contact surface or many times this is the line contact or point contact depends on the geometry. Most often it will be line contact, because of the line contact load carrying capacity will be on a higher side. Now, we can see there are three dotted circles, one circle two circles and three circle third circle for the one surface or one gear. Similarly for other with one circle second circle and third circle, what is this circle indicating; it is a pitch circle diameter or this circle is indicating base circle and outer circle? So, there are three circle you say that base circle, pitch circle and outer circle.

Now, at the pitch circle when gear and pinion coming in contact they come in contact as a pitch circle diameters or we say that pitch circle are in contact. When we tried to compare with disk friction, disk you say they have a factor diameter equivalent to pitch circle diameter, but in reality, contact is happening below pitch circle as well as above pitch circle.

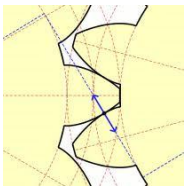
So, what we say this above pitch circle whatever the surface comes that is addendum and surface which is coming below the pitch circle, but above the base circle that is the duodenum.

So, there is some sort of the geometry which is been utilized and as I earlier mentioned to magnify, to amplify top, we require a good pair gear pair. Generally the torque ratio is one we should not use gears it will be useless combination or a bad choice. Now, this we talk about the involute profile and say the involute profile is generally a locus upper point on a line rolling to its base. You can see over here this is a line and this is a base and this line is a tangent to the base. So, we say that is a locus point on the line which is rolling on the base. If shaft rotation changes, this will remain in tangent.

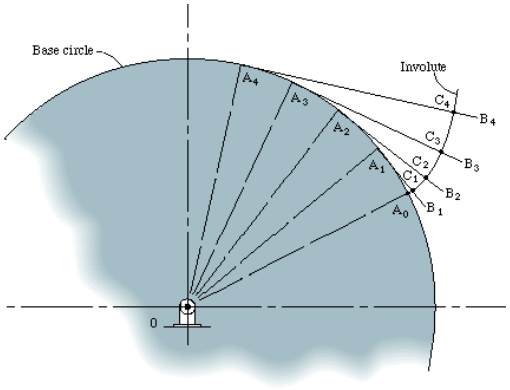
So, this is a continuous process and is a rolling on this surface or we say that to promote the rolling motion. We know the rolling motion has a lesser coefficient of friction compared to the sliding friction. So, we give more emphasis and second thing is that they need to have a positive engagement and above all they need to have a constant speed ratio and that is a major advantage of gear profile, they maintain constant speed ratio. That is slightly complex subject, but we will try to elaborate try to describe in few slides in this present lecture.

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Tooth Profile



$$m_A = \frac{\omega_p}{\omega_g}$$



Involute tooth form:
Locus of a point on a line rolling on its base circle.

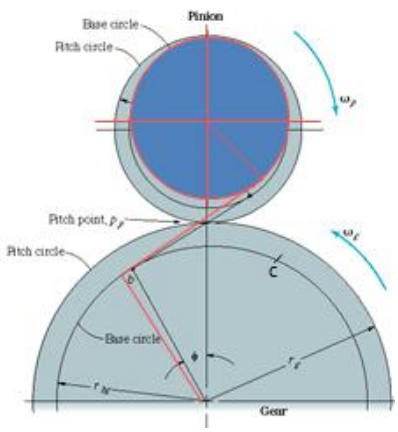
Velocity ratio does not change due to inaccuracies in center distance.

Now, this is how to generate a involute profile, you can see this is profile and same profile is a shown over here and this is giving a mechanism how this profile comes out. This is a base circle given to us. Now, we assume this is an initial point of a strain on a base circle and we want to unwind this strain keeping a tendency between a strain and the base circle like this is 0. This is already a point on a surface now this when comes to the B_1 there is a point

unwound and that tangent comes over here A_1. So, this A_1, C, B_1 is a tangent to the base circle.

Similarly, and this is the point or which is the next one from initial position is A_0 next position is C_1 naturally. Next when we unwind it we assume that this is a separate portion may be slightly more than this. So that we can handle it easily this strain. Now, as we are unwinding it there is another point the C_2 we say the A_2 and C_2 is a tangent to base circle, A_3 C_3 is tangent to the base circle, A_4 and C_4 is tangent to the base circle. Now, if we connect this points A_0, C_1, C_2, C_3, C_4 that is going to give us a tooth profile that is going to give us involute profile and this is important to keep velocity ratio constant. So, wherever gear pair is in contact they maintain constant velocity ratio and that is important from drive point of view from mechanism point of view.

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Tooth curves of the mating Teeth need to be tangent to each other.
Line of action is tangent to Both pinion & gear base Circles.
On changing center distance
Line of action still remains Tangent to both base circles
But slope changes.

Pressure angle ??

$$m_A = \frac{\omega_p}{\omega_g}$$

Pressure angle at base circle is zero.

To elaborate this, what we mentioned in previous slide is a base circle, this is a slight description of the base circle, and you say this base circle and this pitch circle. Pitch circle is generally used to calculate all other dimension. That effects to circle diameter, where the tooth disk are coming into contact, but pitch base circle is a point or is a circle from where the involute profile starts. That is why we say that, this is a starting point of involute. We try a tangent it will meet the base circle of other gear or we say other if am thinking of this is a pinion; it will meet the base circle at a point.

It will be tangent to other gear wheel or gear and this A B is a tangent to both. You can see that this is a intersecting line of centers well a center line, which is connecting two centers at a pitch point and this pitch point generally we call this is a rolling motion or there will be hundred percent rolling on the pitch point. Any other portion rolling will not be completely rolling, but along with some sort of sliding and the whenever we know very well wherever the sliding comes friction force will come and we need to avoid that friction as low as possible.

That is why we provide some lubrication for the gears. So, what is retail over here? So, the tooth curves of the mating teeth need to be tangent to each other. So, when the tooth profile of the one gear or we say the tooth profile pinion is should be tangent to tooth profile of a gear. They need to be at tangent they cannot penetrate each other that are the important. However, there will be excess of wear; there will be excess of damage there will be fracture; there will be winding we want to avoid that. So, tooth curves of the mating teeth need to be tangent to each other. Second thing is that this is line affection; A B is line affection is more like a gear unwinding string from the base circle and putting on the other they are just getting joined over here. So, line affection is a tangent to both pinion and gear based circle. Now, what is the advantage of keeping all these we say if there is a change in the center distance, we know that will happen during assembling we cannot be very precise on assembling.

We cannot be talking about the nanometer scale, when the gear itself is in centimeter or meters dimension we will not be able to talk about the very fine level. So, there is a possibility of some sort of a change in a center distance, you say this center and this center we cannot keep center distance fixed during assembling, may be in one part we are able to keep this is the 50 mm, in other part there is possibility of 50.1 mm, other possibility is a 49.9 mm or 49.95 mm. There is some sort of variations some few micron variation. So, there are lesser than 1 mm distance variation possible.

So, if that is a situation involute profile will give flexibility it will still keep velocity ratio constant. Just to elaborate, that we can say let base circle is been pushed away from its initial position due to the some sort of assembling for it. Now, again there is a base circle if you draw a tangent it is going to make a tangent on other base circle that is involute profile. That is a beauty of involute profile. Tangent velocity ratio will remain constant; even I know we can say there pitch circle diameter will change slightly. But not to greater extent and that is a

good point we can what is the drawback of this disassembling or we say this misalignment or we say there is a change in a center distance is that only the attitude angle will increase.

If we are increasing the center distance, question comes, what is the altitude angle? Is it harmful factor or a useful factor? Generally, altitude angle is been designed as per the requirement we say that, we cannot make infinity number of teeth on gear. So, we require some thickness some width with a gear teeth has some thickness and there is some misplacing of a level. We cannot get at the infinity and that is why to maintain some contact ratio and some spacing between the teeth we required some sort of pressure angle or we say that to reduce interference, we require a gradual engagement, gradual disengagement.

We require some sort of pressure angle the lesser or larger value will have its own advantages and disadvantages. Extended the size, which some time back was around 40 and half degree pressure angle. So, that this five few years back it was around 14.5 degree, but we find slightly more interference and we have limit on number of teeth, which can be kept for this kind of pressure angle that is why we relaxed it. Now, these extended pressure angle is known to be as common as 20 degree. Sometimes it can be kept at 25 degree also, but this is what we call as a pressure at a manufacturing time, when we assemble it we are able to see the pressure angle is going to change.

Here, the 5 is a pressure angle and this pressure angle depends on operating condition, when we manufactured. So, that 14 and half degree, 20 degree, 25 degree and when we assemble it there is a possibility of change in pressure angle and if there is an increase in a center distance or this to gear wheel then this pressure angle is going to change. How to determine; how to assemble this pressure angle, we have some formula for that we say that, it is a function of $\cos\phi$ at any point is say they may be I may be here I may be here I may be here.

So, ϕ at the I can be given as a cos inverse we say that a cos of this as a ratio of R_b by R_i. R_b is a radius of the base circle and R_i is some hypothetical circle with radius of that hypothetical circle may be say this line if the point is here if I connect this to the center and draw a circle over here, that will be the radius of that circle. So, this is a hypothetical circle or we say measuring circle which we construct or make it so that we can get results. So, pressure angle will be continuously changing first the assembling time and as well as it will be changing during operation and what we discussed what we do the calculation most often, we will do the calculation related to the pressure angle.

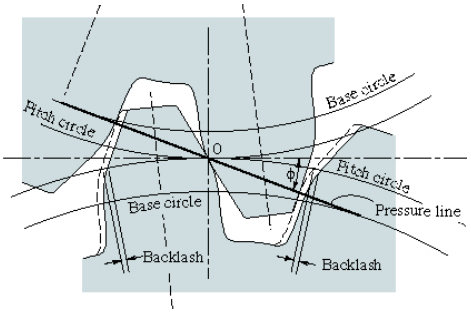
Pressure angle related to the pitch point or we say what we have mentioned about 14 and half 20 degree 25 degree, that is a pressure angle at the pitch point. As this value is this R_i is continuously increasing there will be that value or if R i is equal to R_b, we know that is equal to 1, the pressure angle will be 0. So, generally we do not use a contact up to the base point we keep some clearance. So, there should not be any digging action should not be much problem if we keep slightly away from that.

So, there will be always same finite value greater than 0 and maximum value we can say least to the base on whatever we have been designing and after assembling what has been achieved. So, we after assembling if initially we design value are 20 degree and after some lead its 22 degree or 23 degree that will be max value in this case.

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Backlash: Difference between tooth space and tooth thickness.

- Prevents jamming of teeth.
- Compensates for thermal expansion of teeth.



Any limit on Torque ratio ?????

Now, what we talk about gear profile, and we say that this is the positive drive, and it needs to go in some misplacing; that is why the positive drive will happen, otherwise there will not be any positive drive. So, what should be the spacing? So, spacing should be slightly more than the thickness of gear or we say that this complete width of the gear teeth. If it is slightly more than that, what will be happening, we can avoid the jamming. If this protruded surface is going in some slot naturally, if available distance is lesser than the width of this protruded surface, naturally there will be jamming action, and then there will not be smooth drive.

Second thing is there is a possibility of change in the temperature, there is a possibility of increase in temperature, and we know how material generally gets expanded on application of temperature. So, there is a possibility of this profile getting expanded. So, we need to keep some sort of a room for that, so that we can think about the compensation for thermal expansion of the teeth. These are the positive points of the backlash, but there are certain negative points of the backlash.

What are those negative points? First thing is that there is a backlash, and there is a discontinue motion. You say that gear wheel is rotating 10 degree in an anti-clock wise and after that is rotating back in a clock wise by 10 degree. So, there is isolation and that is going to create more problem, if there is a clearance that power transmitted for the few degree will be lost, it will be changed back. Another thing is that there is a clearance available, it has a room to vibrate and the vibrating condition will start vibrating and it will start knocking, hammering at the surface then it will cause more wear that is a problem.

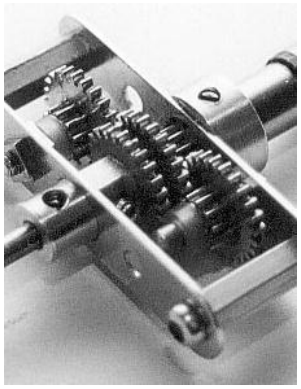
So, we need to have some sort of trade between spacing and no spacing. We require a spacing to avoid the jamming, to avoid problem related to thermal expansion we say to compensate for the thermal expansion. Similarly, we do not want a spacing from the vibration point of view; we do not want the spacing. So, that it should not create a vibration, it should not make a noise in that case and then from the power lost point of view also. So, we need to have some trader now, but we discussed initially about gear have advantage of a torque ratio. Magnification of the torque may be say from 20 Newton to 40 Newton meter, 40 Newton meter to 60 Newton meter, 100 Newton to 200 Newton meter. But there is always some limit we cannot keep on going the 100 times, 1000 times like that there will be some limit on that.

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Velocity ratio

- Normally speed reduction for a single pair of spur gear < 7:1.
  - Size of gear wheel increases → Gear box size.
- For high speed reduction. Two stage or three stage construction are preferred.

Compound Gear Train: At least one shaft carries two gears.



Helical 10:1
Internal 4-8
Bevel 1-8
Cylindrical worm 3-80

Now, their limit comes from number of points and what we say the torque ratio and velocity ratio we can quantify in similar manner. So, generally the gear is a spur gear. Interesting, what is a spur gear? We talk about the gears. Now, we are talking about the new one, new

thinking a word comes as a spur gear. So, wherever gear teeth they are parallel the length of the gear teeth is parallel to the axis that will turn out to be a spur gear and we are fixing some limit or you say the velocity ratio as a 7 to 1 or 1 to 7 for a spur gears.

Possibility is that if we go for a larger one what will happen. Diameter is continuously going to increase and there may not be availability of that much space. So, say from the size of the gear wheel or gear box size, gear wheel size need to be limited. Otherwise, if the gear size continuously increases we need to have a box, which contains the lubricant, the size will continuously increase and you do not want that kind of thing. So, to keep that shape we require some limit on size if you want 10 to 1 ratio we want 40 to 1 ratio. What should we do in that situation?

There is another way we say that for higher speed reduction we can go for the multi staging may be slightly we say that more number of shaft can be utilized and we can think about the multi staging may be say in one stage we are thinking about the 1 to 7 or 1 to 6 or 1 to 5 and second stage again 1 to 5 1 to 5. So, in this case 5 into will turn out to 24 and can go with third stage 1 to 5, it will turn out to be 1 to 5. So, that is going to give us a compact design. We do not require that much larger diameter, because larger diameter, again manufacturing will be a problem it cannot be so easily stimulus. So, that is why we prefer multi staging.

And this is an example A_1 gear box is shown in the photograph, the gear box is shown here. You can see the shaft has A_2 gear wheel, one gear wheel, other gear wheel one is a larger, other is a smaller. So, this larger this smaller this larger to be slightly smaller than there is a larger and smaller and we can combine this is a typical example of gear box used in auto mobile, which has 4 to 5 ratios and we know the gear 1, gear 2, gear 3, gear ratio 4 and we keep on changing gear ratio, first gear will give maximum torque and final gear will give same rotational speed or the engine speed or we can say slightly more than that also is possible.

But we need to account a lubrication properly. We need to design properly. So, there is a possibility of multi staging and what we said is also can be named as compounded gear trains. Simple gear trains only one shaft one shaft one gear; compounded gear train one shaft having more than two more than one gear pair on that or we say gear wheel on that. So, compounded gear train we require is useful to save the space which is a current demand. We do not have that much space if we are talking about a mobility point of view. Naturally, we

require a compact size and wherever compact size comes; we can think about the multi stage gear or compounded gear trains.

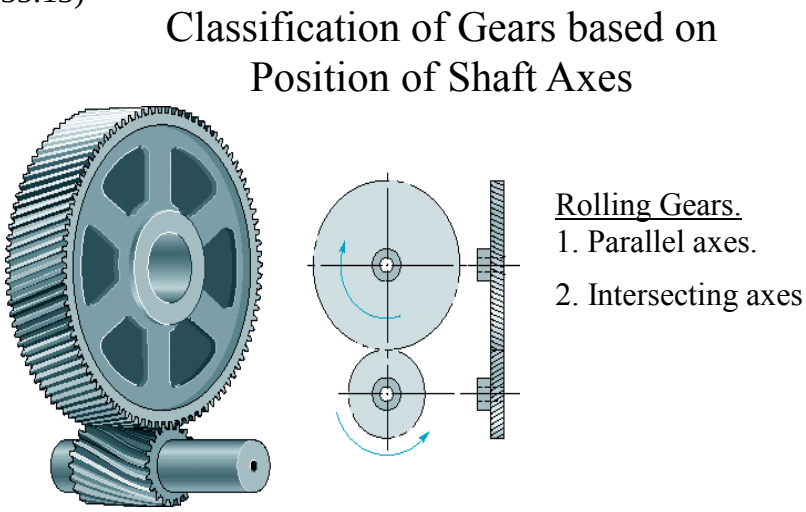
Now, in this slide particularly I mentioned about the spur gear and we say the 1 to 7 ratio and this is a typical example of the spur gear. You can see that this tooth length is straight and axis also moving in the same direction. We say whatever the direction of the axis it is clear profile in same direction. So, the straight or in parallel and they do not have any angle. So, that is a spur gear, but there is a possibility of some sort of helices. We want to increase a factor area of contact, when if you increase a factor area of contact what will happen there is a possibility of gradual engagement, gradual disengagement.

So, when we talk about the high speed operation and do not know the excess of vibration. So, there should be gradual engagement, gradual disengagement and we prefer helical in those situations. That is why, we can think about the gear helical gear ratio and that is slightly more than a spur gear ratio that is a 10 to 1. There is another possibility we can think about the internal gear or internal helical gears, internal spur gears. The gear ratio in this case can be kept in the 4 to 8, we are not talking about the 1 to 1, and we are not talking the 1 to 2.

Because, the gear generally having internal teeth have a larger dimension. So, most preferable range will be in this case is a gear ratio 4 to 8. Talking about the bevel gear is another term. We talk about the spur gear; we talk about the helical gear and talk about the bevel gear. Slightly, difficult to think over, if we have already learned the machine design course then there is no problem. But there is a bevel gear which works with a cone geometry. So, that these are the cylindrical geometry and they are rolling gear. One geometry is rolling always one cylinder rotating other will rotate about that, if the axis is the fixed.

So, there is a possibility of cone. So, there is a cone shape over here and there will be another cone shape by the axis is at the 90 degree. They are going to intersect that is going to give us a bevel gear or we say the truncated or we say that custom of the cone can be used as a bevel gear and similarly we have a cylindrical worm gear is too much too many terms have been utilized without giving photographs, that is why we are going to show some photographs in next slide.

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See this is a helical gear. You can see there is some sort of helices may be if there is a shaft exist and there will be some angle between this and the shaft axis. This is a helical gear, but as a length is taper, I can compare this street length with a taper length. We know the taper length and length will be more for the same fixes and if the length is more naturally engagement will be more. If there is more engagement there will be lesser noise, more surface contact happening and there is a gradual engagement disengagement is possible.

And generally this kind of classification is coming based on the shaft axis and relation of the tooth profile or tooth axis or we say the tooth length axis. In this case some sort of helices angle is provided and there are other combination also we can use a different terminology for that say we want gear having a parallel axis. In helical axis, helical gear as well as spur gear, shaft of the axis shaft will be parallel.

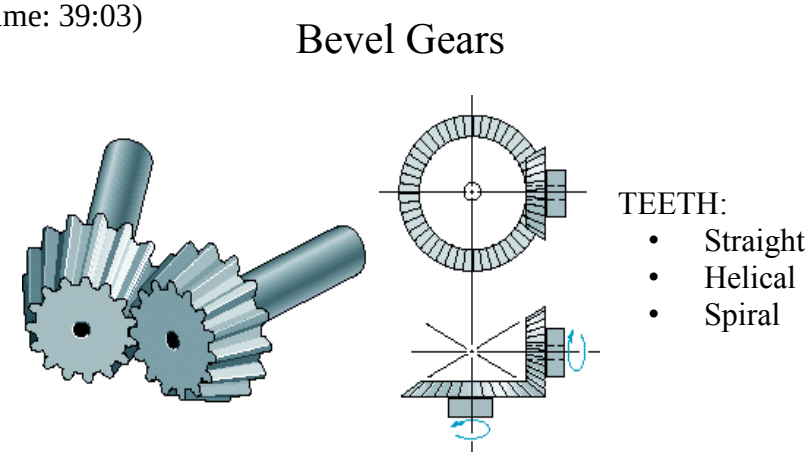
And based on that we can say they are spur gear and helical gears and they can be named as rolling gears. Reason being in rolling gears sliding is lesser there will be more rolling action. In a similar category we can keep bevel gear also they have intersecting axis, but classification is based on the shaft axis. Shaft axis parallel than is a spur gear or helical gear shaft axis are intersecting not necessarily at 90 degree, it can be 60 degree, it can be 70 degree, it can be 80 degree depend on what kind of a shaft we are using, what kind of assembling we require and what is the final result what is the final requirement from that assembling.

So, there is a possibility of intersecting axis as a bevel gear and they are we say that particular in this case, we are using helical we are showing helical gears. They have noise free operation they are quieter; only the disadvantages are you can see over here, because of the axis or we say axis and this gear length tooth length they are not parallel. There will be some component along the axis also. Otherwise gear should bear tangential load or some sort of a radial load, but in this case additional compound is coming that is going to create more problem, we require some extra bearing.

Sometimes, we use a gear profile in this side and just opposite we say same angle as opposite side we use other profile that is known as a double helical gear or herringbone gears. We say that one helical gear is like this and we use other gear having axis like this and just gear length perpendicular to not perpendicular having some inclination with this. So, whatever the component this gear is going to generate an axial direction same component should be generated by other gear in opposite direction.

So that axial force is cancelled out there itself, it is not going to get propagated, it is not going to both the bearings side that is a hang on having gears and that is important to cancel the axial force, but disadvantage is that manufacturing of those kind of gears is difficult. So, we generally avoid as far as possible from complexity point of view, from cost point of view and if we do not have a choice we can go ahead also.

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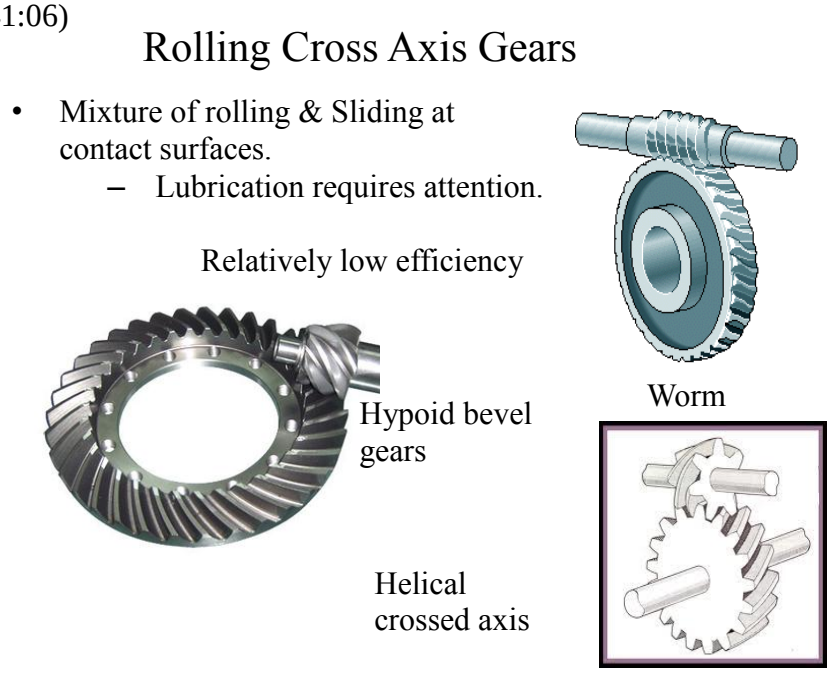
This is a bevel gear, what I mentioned and we say this is compact geometry. You can see here bevel gear also has spur gears. Spur is more like an m axis is a parallel not to some extent is inclined, but if length wise we say that yeah they are taper, but parallel to the axis. So, these

are the spur they are not have the helical, there is a possibility these length can be in helices angle also. There is a possibility of a spiral so, that is why we say bevel can be divided in a straight length helical length and a spiral length. Naturally as straightness is reducing, engagement will increase and noise generation will reduce.

So, straight teeth will be least preferred compared to helical from noise point of view compared to the spiral, helical will be less preferred. But the complexity manufacturing cause is going to increase with this kind of profiles and we mentioned that bevel gear, helical gear and spur gear. Here the axis is either parallel or shaft axis is parallel or intersecting, but they are in same plane they are coplanar. We can name those gears as a rolling gears reason being a motion at the contact surface is happening primarily because of the rolling motion.

They have relatively small sliding and interesting thing they will not be having any sliding at the pitch point. So, they give the good positive engagement relatively lesser sliding and that is why these gears have a higher efficiency. We talk about the efficiency 90 percent 95 percent that is a very high side, but other gears where they are not in plane they are in different planes, the shaft axis are in different planes than there is a possibility of higher sliding and that is going to lose efficiency.

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That is why we say that they these gears can be named as rolling cross axis gears. Rolling can be removed you say they are cross axis gears. You can see axis of the wheel and axis of this they are not going to intersect at anywhere they are not parallel. So, not parallel not

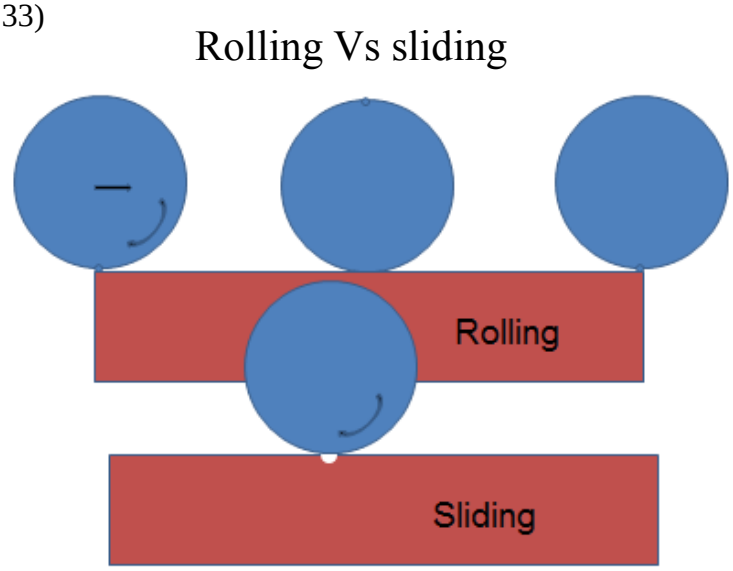
intersecting and they can be treated in total different plane, a single plane cannot contain these two axes that is why they are kept in a separate category. So that in this kind of gears what is going to happen we get a mixture of rolling and sliding at the contact surface and wherever there is a sliding we require lubrication.

The Tribology is going to play major role and wherever there is a rolling there will be contact fatigue. We have an estimated bearing lives which was happening because of contact fatigue. So, that will be a major I mean feature in those cases. So, we require lubrication or special attention need to be paid whenever this kind of gears we are using. So, this is what we are showing a worm here, this can you see the dimension this is a larger dimension compared to this dimension. That is why worm gear they have very high speed production or torque amplification can reach to the forty also. So that whatever the torque is been transmitted to the shaft forty times can reach to the shaft.

So, that is a high torque transition capability of a worm gear, but there will be high sliding and that is going to reduce their efficiency. They are not very efficient, but when the load carrying capacity is required they are the best. There are other possible combinations also we can say helical gears, but having cross axis. So, you can see in this helical gear and they are cross axis because of the geometry they do not make a line contact. They make only point contact and whenever there is a point contact naturally stresses will be very high, load carrying capacity will be lesser that is why this kind of gear pair is used for the relatively lesser torque and this gear pair is been used for the larger torque while helical cross axis gear is used for the lower torque transmission, we say that there are gear ratio or torque ratio will not be that high. In addition, we have some variation in the bevel gear what is happening in this case axis of the shaft and axis of this shaft, they are not going to intersect.

They will remain at the some distance or we say the half set there will be some sort of a gap between the axis and then there will be continuous rotation and other things will happen, but because of this gap this is because of the half set between the axis sliding will be on a higher side and this gears will be there are known as a hypoid gears again very much used and useful gears. They are commonly used in automobiles. We say that these gears are slightly lesser profile because of the low efficiency. But from torque point of view, amplification point of view this case can be utilized, particularly worm gear can be utilized, mostly is used for the hosting purposes.

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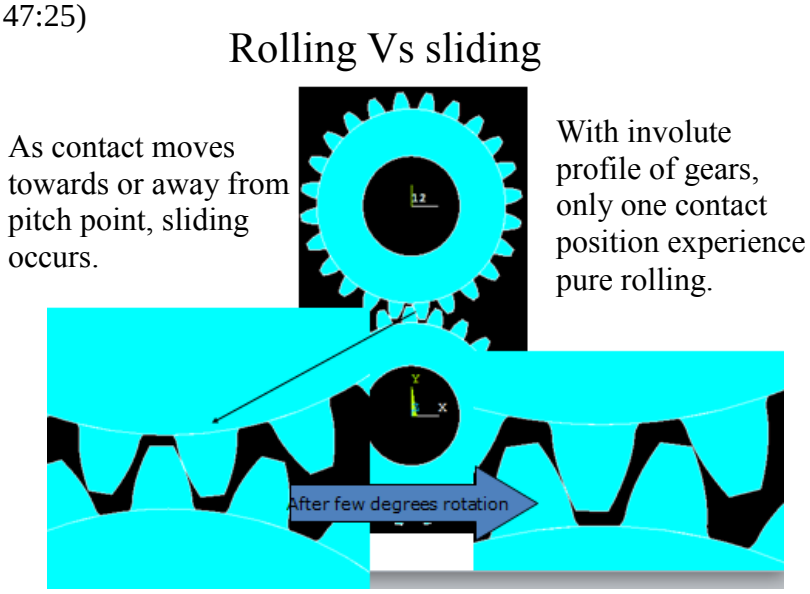
We talked so much about the sliding and rolling and we say that spur gear has a lesser rolling, but spur is itself a parallel shaft gear has a lesser sliding, more rolling. When we talk about worm gear we say it is a high sliding and lesser rolling. So, the efficiency will be lost. So, let us have a slight description or detailing of what is a rolling? What is a sliding? We know by just completion, am going to describe something in this slide. Let us say this is one V and is going to roll on a straight surface or we say curved surface which has a much larger radius.

So, this is a rotation showing that is the clock wise rotation and there is no fixation of what will happen because of this rotation. It will try to translate also move this axis, along this edge may be after 180 degree. You say half rotation this point of contact will be changed to this point of contact not this point of contact, whatever the point contact P over here. This point is reaching here or we say that other new point is going to come in contact may be say whatever the point here is A here and B here, A is getting shifted over here and B coming over here. So, initially B was not in contact now B is coming in a contact.

And this distance is equal to pie r, whatever the half width whatever this axial translation we say that translation motion is equal to pie r. After completion of rotation whatever the initial position in the same position is regained over here. So, whole this length is a pie d. Now circumference has been developed and we are getting pure rolling motion point of contact, they are continuously changing they are not on the same point. So, there is a pure rolling hundred percent rolling there is no change in this. Now, if we talk about some pitch in over here, you can see this is some sort of a penetration over.

Here, now if this disk is going to rotate over here. What is going to happen? As there is no continuous motion this disk will not be able to transmit. It will keep rotating, but there is no translation and that is going to create a more sliding in this situation and we say that this sliding is dominating in this case understood. The first case is a rolling; second case it is a sliding.

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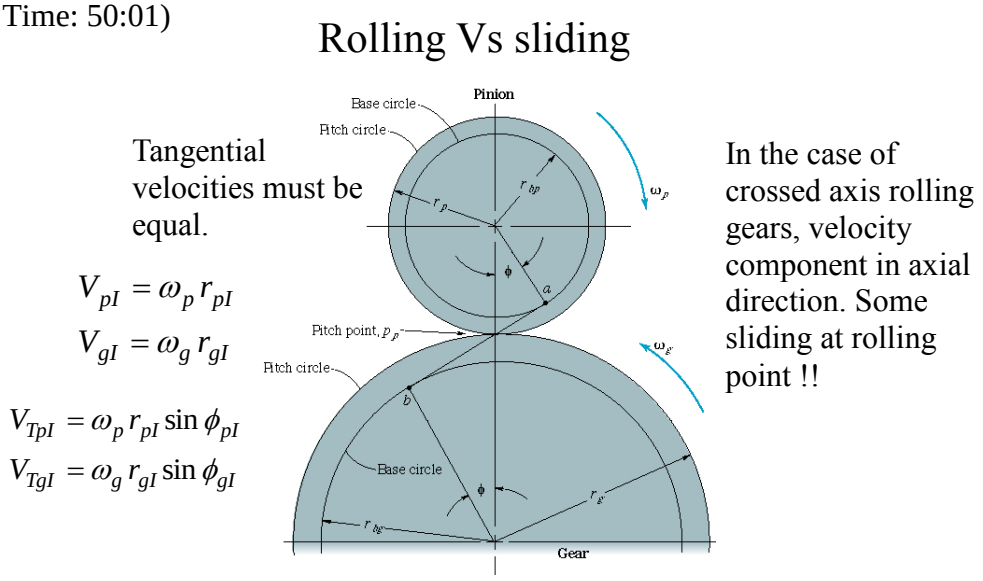
So, there is some difference in rolling and sliding. Now we can elaborate little more on this rolling and sliding, where really showing tooth profile and having a contact. You can say this having A 1 gear 1 gear 2 and we say pinion gear and there is some contact. I cannot see anything over here. So, let me magnify it say this is a magnification there is a point contact or line contact over here. Now, as a shaft is rotating naturally this point of contact will change and this is after a few may be few degree or maybe say some milli seconds. This point of contact is going to change, point of contact is changed. This point of contact is changing after rotation. So, same portion is not there that means, same point is not in contact, but there is a change in point and that is why there is a rolling action.

But, there is another problem we think about the pitch circle diameter and above pitch circle diameter below pitch circle diameter. So, initially this position is below pitch circle diameter and after that this is above pitch circle diameter and we know rolling option, rolling happens at the pitch circle. That is why this point will have some sliding; this point will have some sliding they are not on a pitch circle. So, there will be may be sliding in this case will be in reverse direction, opposite direction, but sliding will be there and that is going to generate

some sort of friction and that is going to cause friction that is why we require lubrication in this situations.

What we can say in this slide, we say with involute profile of the gears only one contact position experience pure rolling that is on a pitch point. Other than pitch point it is going to get a combination of rolling and sliding. And say that a contact moves away or towards if there is a pitch point over here the contact moving towards the pitch point and the pitch point is fine moving towards the pitch point there will be sliding. At pitch points sliding will turn out to be zero away from the pitch point again the sliding will start and will be maximum sliding contact remains after that again there will be disengagement. So, there will not be any motion transmitted from that gear tooth, but other gear tooth will come the process will continue in this situation.

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Now, this can be further elaborated mathematically and quantify, on that using this slide. We have shown this same figure earlier, we say that this is the pinion, this is the gear smaller diameter, larger diameter; the gear profile will start from the base circle. And this is point here, and this is another base circle of the gear. So, point B here, connect this, this will be the line of action. Now, if we think from a tangent from a gear ratio point of view, what we need to say tangential velocity must be equal. We know for the diameter to the tangential velocity of the pinion and tangential velocity of this gear need to be same.

That is basics or this is the basic, fundamental of the gear. If we cannot equate we say the r n 2 omega need to be constant, and

based on the radius ratio, we find what will be the reduction in speed and because of that there will be amplification of the top. Now, if I try to tick any point on this line of action may be say this point is high. This point is high I can connect this i with this center; So, there will be base radius and will be more than that. Similarly, if I connect this with this it will base radius compared to base radius this radius will be slightly more.

Now if I try to point out, what will be the velocity perpendicular to the radius? In first case I can find out pinion omega p is known to us and r p i or the r radius of pinion and i is a point. So, this is a r p i similarly in the gear case the velocity is perpendicular to the radius that is omega g as a angular velocity into r g i, g you say the r g radius of the gear at the point an you can connect this point r g i. Now, this is shown this line is been connecting and the velocity perpendicular to this. That is a velocity which is shown here V p i. Same thing in the gear this is connected with the point and this velocity is perpendicular now this velocity is not moving perpendicular to the line up center.

We are having some inclination with that. So, need to be resolved in two components one will be perpendicular other will be like this. So, one component is going to separate may be say impose some load in a bearing, if we say it is shaft this gear is mounting to the bearing, this gear is a mounting this bearing gear is mounted on pinion bearing. So, bearing is going to experience some radial load and other component will be tangential direction tangential to the lineups, which is more desirable. Velocity which is perpendicular to this or we say when they are coming on contact the gear contact velocity, which is a tangential to the gear profile that is more important.

Those need to be equal if they are equal then there will not be penetration of the gear teeth, otherwise there will be penetration of the gear teeth. So, we require tangential and that is a t p i the tangential velocity that can be given as same velocity V p i into sin p i that is a pressure angle at the point. What is the pressure angle point? That is going to give us component of this solution. Same thing in this case velocity tangential velocity of the gear at the point i is given omega g r g i that is the radius into sin of the pressure angle at that point i.

So, this is when we try to see the pitch circle. This will be r in this particularly it will turn out to be r this will be turn out to be r p and pressure angle will be common in both the cases. The pressure will move out omega p into r p minus omega g into r j and that will be equal to 0. Tangential velocity will be equal and that is the pitch point there will not be any change in velocities of the pinion gear. They will be equivalent that is why there will be perfect rolling,

otherwise there will be difference and if there is any difference in any point there will be sliding and that is harmful, that is a disadvantageous.

We should try to keep this minimum, otherwise if you are not able to keep minimum and there is some sort of hindrance or there is some sort of geometric constraint and we say that from design point of view. We cannot achieve that then we require a lubrication. We need to provide proper lubrication.

Now, this is what we are talking about the simple spur gear, where parallel teeth are there, but there is a possibility of a helical gear there will be some extra angle along the axis. And in the case of the cross axis rolling gears, because their profile is different manner axis are different, sliding will be more.

If there is more sliding, naturally there will be more efficiency loss. And if there is efficiency loss, naturally more heat generation will be there; that is why we say in the case of the cross axis rolling gears, velocity component is in axial direction. And this is going to be because there is some sliding at the rolling points, otherwise in this case there will not be any sliding at the pitch point, but here there will be sliding even at the pitch point, which is harmful or we need to account that. So, that is why we said we require friction calculation. And there once we know, what the friction calculation is, we think about it because of friction, there will be friction requirement. So, we will be discussing those things in our next lecture based on friction and lubrication. Thank you.