Metrology
Prof. Dr Kanakuppi Sadashivappa
Bapuji Institute of Engineering and Technology Davangere

Lecture – 25
Introduction of Gears

I welcome you for the series of lecture on gear measurement and at module 7, the following topics are covered in this module. Introduction to gear covering the various types of gears and then how gears are manufactured and some details about the tooth profile those things. We will be studying and then we will study about the various terms used in association with gear and then we will move on to a measurement of flow for gear.

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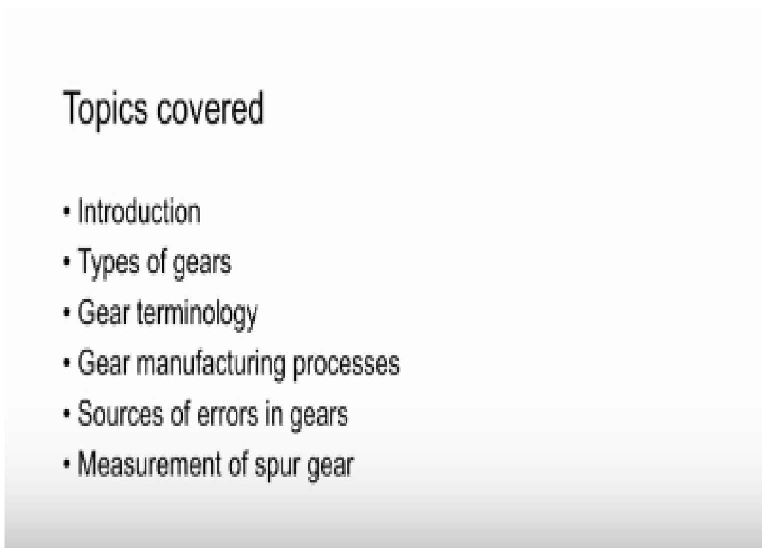

Now we will start elected one in module seven so in this lecture the following topics are covered Introduction to gear, the various types of gear, gear terminology and gear manufacturing processes. What are the sources of errors in gears and measurement of spur gear.

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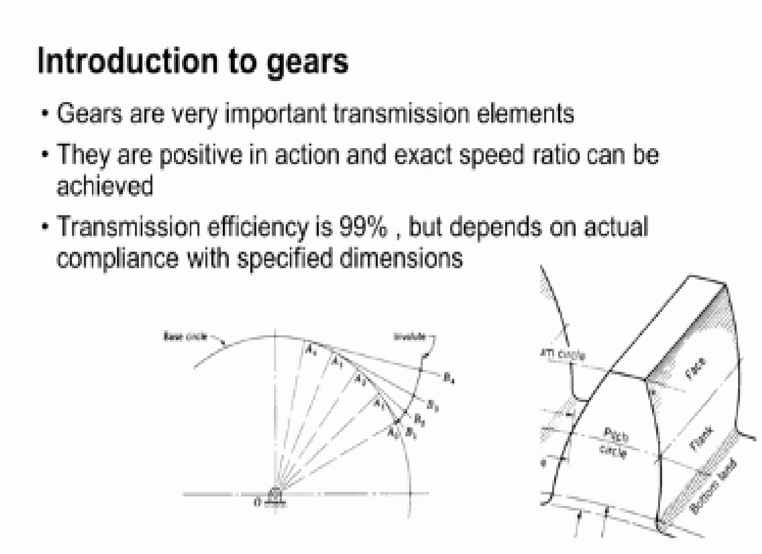

Now let us start the first topic that is introduction to gear so these are the very important transmission elements to transmit the power. They are positive in action that means there is no slippage in the case there is a chance, there is a chance of slippage whereas in the gear drive it is the positive transmission and exact speed ratio can be achieved by using the gear.

Transmission efficiency in the case of gear is the almost 99% but it depends on the actual compliance with specified the dimensions of the gear so here we can see a tooth of a spur gear and some of the terms also. We can see this is the face and the flank of tooth and the bottom land of tooth. Now what we can observe here is a particular profile of the tooth different profiles are used normally cycloidal profile and even involute profiles are used.

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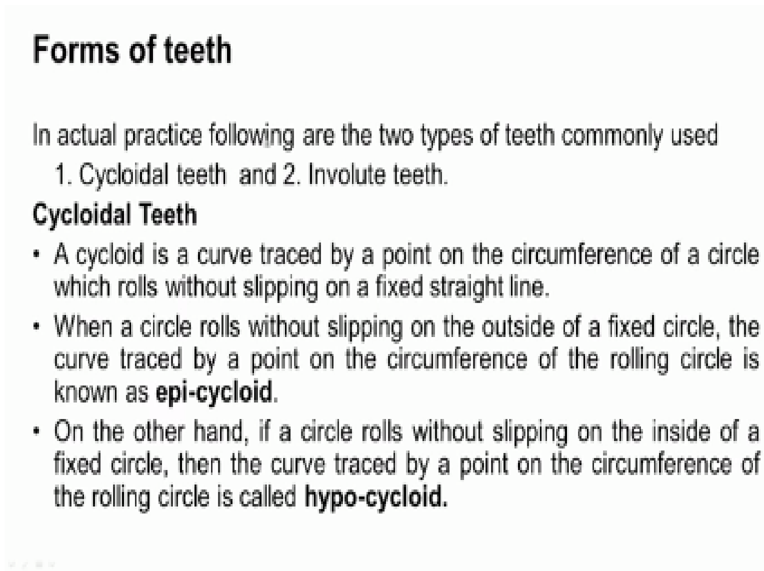

Here you can see an involute profile so we will discuss about these profiles in detail the different forms of profiles of teeth normally used or cycloidal teeth and involute teeth. So cycloidal profile it is a curve traced by a point on the circumference of a circle which rolls without slipping on a fixed straight line, the example that we have a fixed straight right line and then we have a wheel which will rotate which will roll on this fixed head line without any slippage.

Now we consider a point on the circumference so when we roll this wheel how what is the path followed by this particular point so this profile is called cycloid. When a circle or a roller rolls over rolls without slipping on the outside of a succeed circle the curve graced by a point on the circumference of a rolling circle is known as hypo cycloid.

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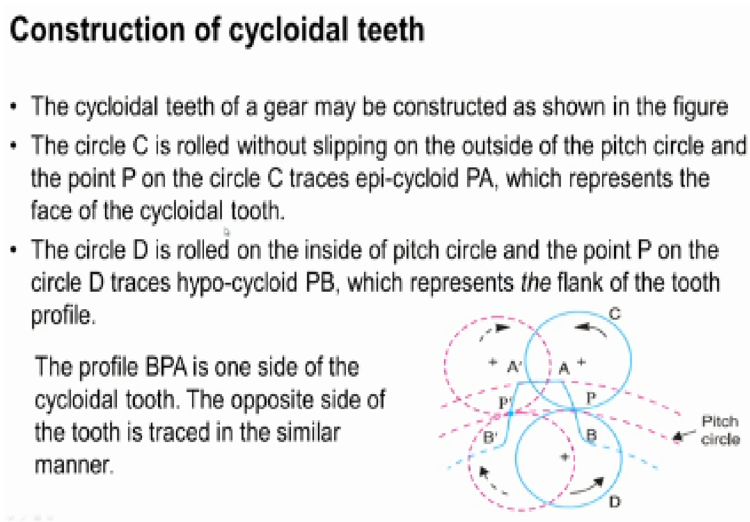

On the other hand if a circle rolls without slipping on the inside of a fixed circle then the curve traced by a point on the circumference of a rolling circle is called hypo cycloid. Now you can see let us learn how to construct a cycloidal path. I can see here we have a fixed circles known as the pitch circle and then we have a rolling circle C, which is which rolls on the outside of the pitch circle and they have another circle D which rolls inside the pitch circle.

Now the cyclodial teeth of a gear may be constructed as shown in the figure the circle C is a this circle is rolled without the slipping on the outside of the pitch circle and the point P. So we have a point P here on the circumference of circle C the point P on the circle C traces hypo cycloid PA. I can see here when it rolls like this in this direction it traces a path PA, so this PA represents the face of the cycloidal tooth and then the circle D the second circle which rolls inside they fix a circle the circle D is rolled on the inside of a pitch circle and a point P.

Again we consider the same point the point P on the circle D traces hypo cycloid PB. So when it rolls in this direction it the point P trace of this path PB which represents the flank of the tooth profile and this diagram you can understand what is the face of the tooth and what is the flank of the tooth. The profile BPA the profile BPA is one side of the cycloidal tooth the opposite side that is the B dash, P dash, A dash the opposite side of the tooth is traced in a similar manner.

Now when we combine the 2 profiles B dash, P dash, A dash and the BPA and when we join A and A dash with a curve then this becomes one 2th here.

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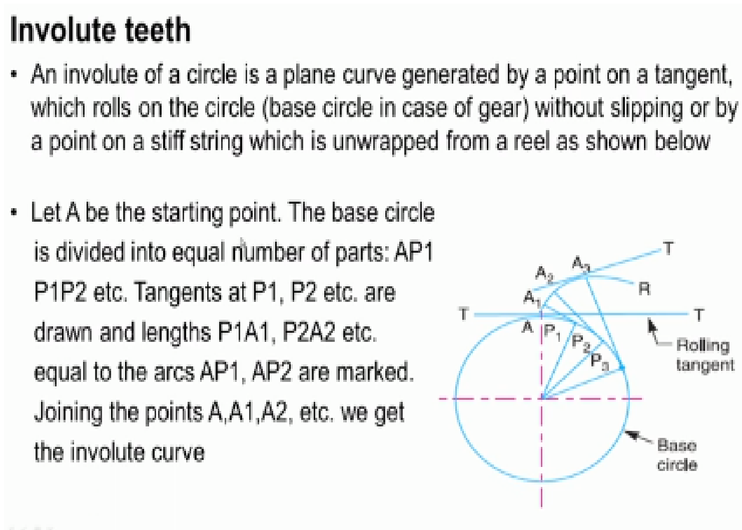

Now the how do we construct an involute tooth this is about the construction of a cycloidal profile, now we will try to understand how what is involute profile and how to constructor involute profile. We can see we have a base circle and then we have a tangent TT so in this involute profile the tangent is rolled over the base circle without any slippage.

We consider a point A on the TT when the tangent TT rolls over the base circle what is the path traced by the fixed point A. So that becomes the involute profile and involute of a circle is the plane curve generated by a point on a tangent which rolls on the circle base circle in the case of beer, so in the case of gear without slipping or it is a point generated by a it is a curve generated by a point on a stiff string which is unwrapped from a reel as shown in this picture.

So now let us study how to construct the involute profile so let A be the starting the point we have the starting point A, here the base circle is divided into equal number of parts AP1 P1,P2,P2,P3 like this. So the base circle is divided into equal number of parts, then the tangents at the P1P2 etc are drawn you can be here at Point A we have a tangent TT and at P1 point P1 again we have another tangent A1P1 at the point P2.

We have another tangent A2P2 that is tangents at P1P2 etc are drawn and length P1A1, P2A2 etc equal to the arcs AP1,AP2 etc are marked then by joining the point A, A1, A2, A3, etc. we get the involute curve. so this is the involute curve.

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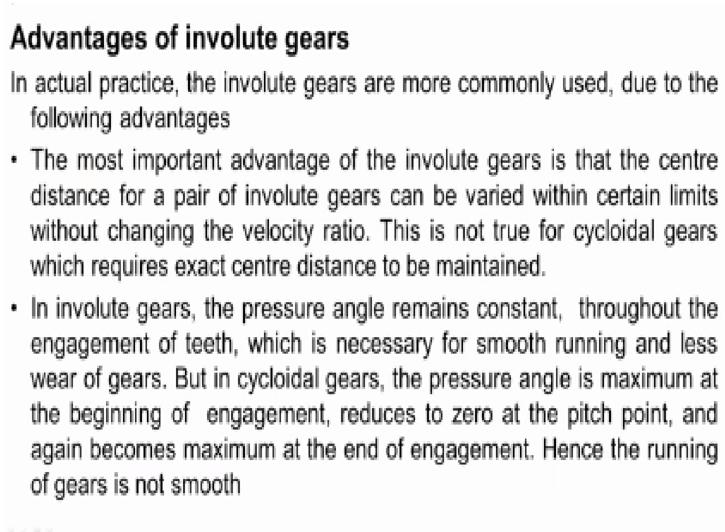

Now what are the advantages of involute profiles are gears this involute profiles in actual practice involute gears are more commonly used. Due to the following the advantages the most important advantage of the involute profile gear is that the central distance for a pair of involute gears can be varied within certain limits without changing the velocity ratio this is not true with a cycloidal gear which requires exact centre distance to be maintained.

In the involute gear the pressure angle remains constant throughout the engagement of the teeth. That means from the beginning of engagement till the end of engagement the pressure angle remains constant, we will discuss about the pressure angle later the pressure angle remains constant throughout the engagement of the teeth.

Which is necessary for smooth running and less wear of gear but in the case of cycloidal gear the pressure angle is maximum at the beginning of the engagement and it reduces to 0, the pitch point and again it becomes maximum at the end of the engagement, hence the running of gear with cycloidal profile is not smooth.

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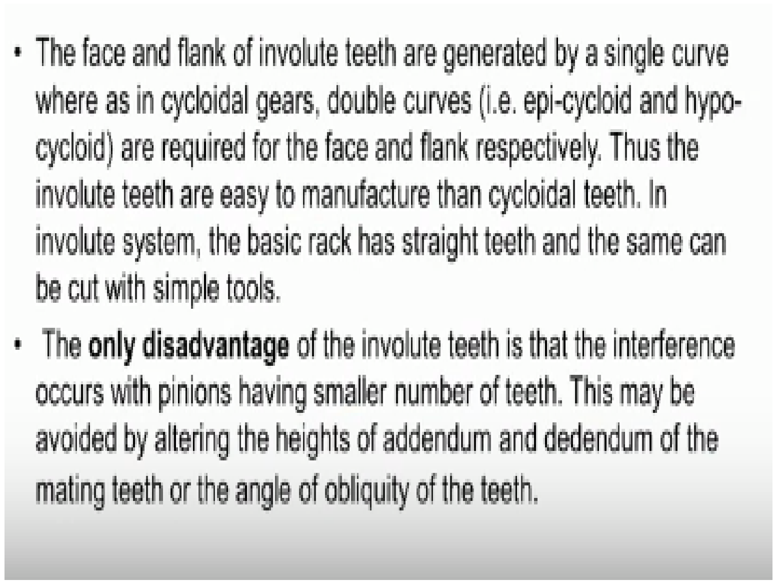

Then the face and flank of involute teeth are generated by a single curve, whereas in the case of for cycloidal gear double curve that is epi cycloid and hypo cycloid are required for the face and flank respectively. Thus the involute teeth are easy to manufacture than the cycloidal teeth in the involute system, the basic rack has a striped teeth and the same can be cut with simple tools.

The only disadvantage of the involute teeth is that the interference occurs when interference occurs with pinion having smaller number of teeth. This may be avoided by altering the heights of addendum and dedendum of the mating teeth or the angle of obliquity of the teeth.

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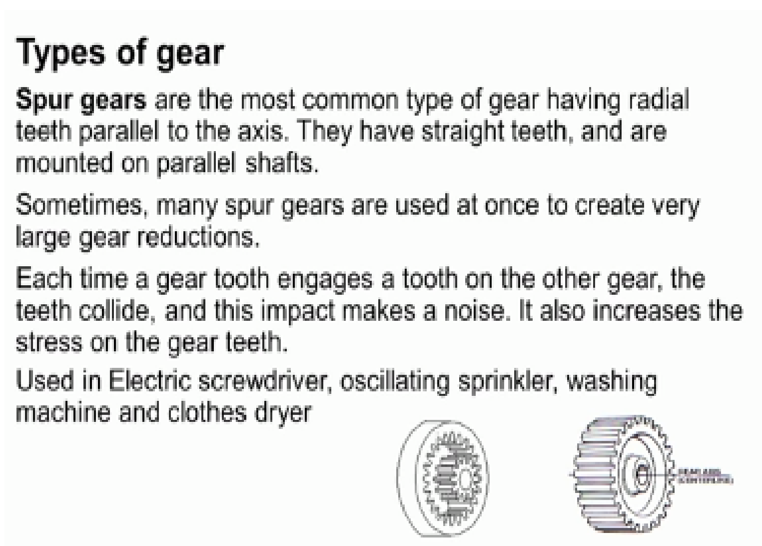

Now let us move to the various types of gear different gears are available so first one is the spur gear very commonly used type of gear is the spur gear. It is having the radial teeth parallel to the axis so we have the axis gear axis and the teeth are parallel to the gear axis and the teeth are straight and are mounted on the parallel shafts.

So if you want to transmit the power we have a shaft here over which the gear is mounted and then they have another shaft with another meeting gear. It means the gears are mounted on the parallel shafts, if the axis maybe the shafts are at some inclination. Then spur gear cannot be used sometimes many spur gears are used at once to create a very large gear reductions.

Each time a gear tooth engages a tooth on the other gear that means that the gears are rotating so we have the T of one gear and then we have the T of another gear. So when it rotates like this this tooth will impact on this tooth meeting tooth that is there is collision between the teeth meeting teeth so this impact makes a noise it also increases the stress on the gear teeth.

So they are normally used in electric screwdrivers, oscillating sprinkler, washing machine and clothes driver ah clothes dryer.

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The other type of gear is helical gear the teeth on helical gear are cut at an angle to the face of the gear I can see here the teeth they are at some inclination some angle is provided. When the 2 teeth on helical gear system engage the contact starts at one end of the tooth and gradually spread as the gears rotate until the 2 teeth are in the full engagement so this gradual engagement makes helical gear operate much more smoothly and quietly than the spur gear.

In the case of spur gear there will be impact from one to the other whereas in the case of helical gears in the since we engagement is the gradual there is no impact and noise is very very less for this reason helical gears are used almost they are used in the car transmissions you can see here this is a single helical gear.

The bigger one is called gear and the smaller one is called pinion and here we have parallel configuration that means the 2 axis they are parallel to each other and here. Cross configuration, we can see we have the axis one that is here and the other one axis here and here. We see double helical gear can see the angles in this fashion as well as in the other direction so this is a double helical gear.

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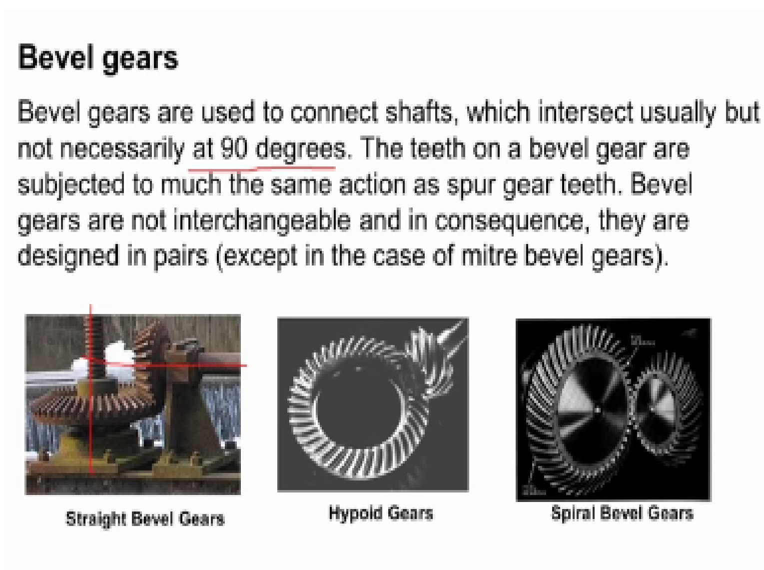

Now we have another kind called bevel gear bevel gears are used to connect shaft, which intersects usually but not necessarily at 90 degree. So we have one axis here and another axis here so the angle is the 90 degree, so when the shafts are like this then we can go for the bevel gear it is not necessary that it should be 90 can be a lesser than that also the teeth on a bevel gear are subjected to much the same action as spur gear teeth.

Bevel gears are not interchangeable and in consequence, they are always designed in the pairs I can see here we have straight bevel gear the teeth are straight whereas here spirals bevel gear there is curved the teeth are curved again these this type is called hypoid gears.

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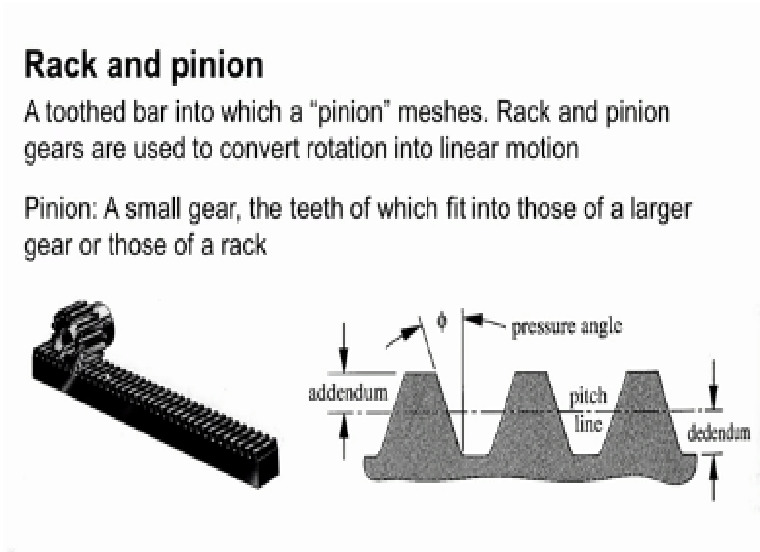

We have a rack and pinion type I can see the picture here the straight tooth bar is called the rack and a smaller wheel is called pinion. Rack and pinion gears are used to convert rotation into linear motion so in the pinion rotate then the rack move linearly. So pinion is the small gear the teeth of which fit into those of larger gear or those of rack. Then we have a schematic diagram of rack here.

So we have the pitch line and then the addendum dedendum and pressure angle etc they terminology we will see after some time.

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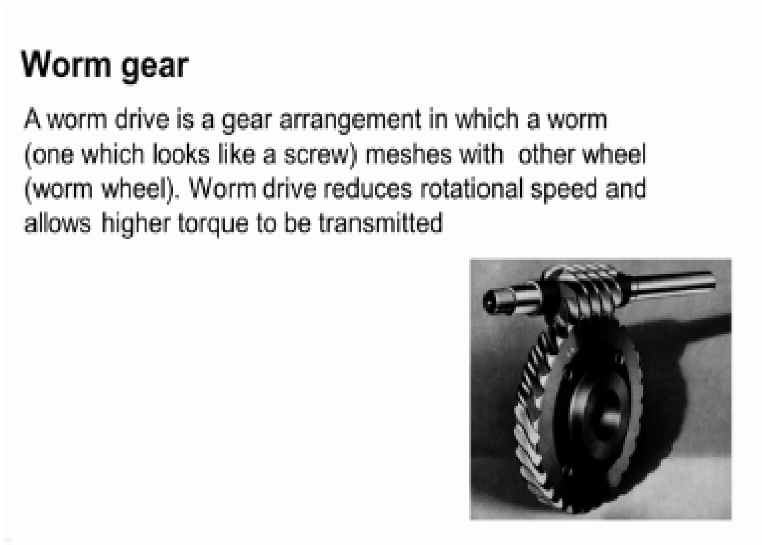

We have another type called worm gear the picture shows the worm gear. A worm drive is a gearing arrangement in which a worm it looks like a screw, so this is called a worm. The worm measures with other wheel called worm wheel. So this bigger one is called worm wheel worm drive reduces rotational speed and it allows a higher torque to be transmitted.

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Now we will move to anti backlash gear you can see the photograph here we have split gears. so we have this one part here and another part here. These are designed for precision applications for example radio tuning dial these springs are used for tensioning the gears and then to eliminate the backlash, plastic, brass, stainless

Steel and aluminum are the most normally used materials for manufacturing anti backlash gear they are available in the spur, bevel and worm gears so these anti backlash here they have very minimal backlash so wherever a very precision transmission is needed for example the CNC machine tools etc this anti backlash gears are used.

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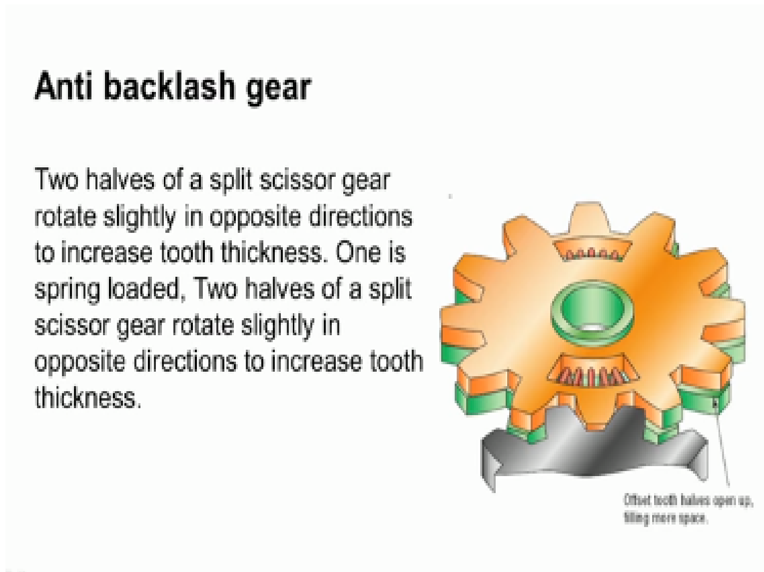

This schematic diagram of anti backlash gear, we have 2 parts of the gear 2 halves of a split scissor gear. They rotate slightly in opposite direction to increase the tooth thickness one is the spring-loaded 2 halves of a split scissor gear rotated rotates slightly in opposite direction to increase the tooth thickness.

I can see the diagram here it is the split so there is slight relative motion between one part and the other part, so thereby increasing the tooth thickness. So this is the tooth thickness so when the tooth thickness increases it reduces the backlash.

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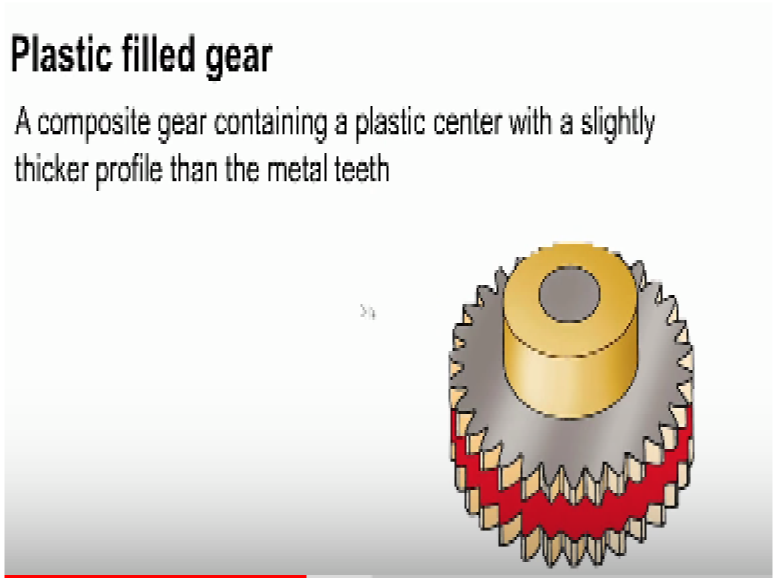

So we have composite gear a composite gear containing a plastic Center at the center. We have a plastic material and on either side we have metallic material a plastic Center which is slightly thicker profile than the metal teeth. So the thickness of plastic teeth is slightly more and compared to the tooth thickness of metal part, so this also will help in the backlash.

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So here we can see different kinds of gears the combination of gears compound gear and then gears with the key ways, so different types are used for depending upon the application.

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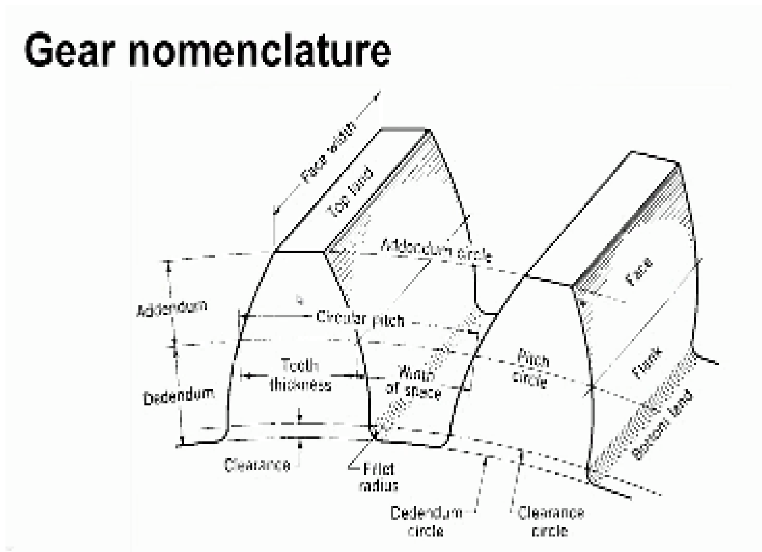

Now we will move to the gear nomenclature what are the various terms used to discuss the gear. You can see we have 2 teeth here and it is the profile of the tooth, either involute profile or cycloidal profile is used to make the gear. so this portion this is the face width so this is called the face of tooth and this is called flank and it is the bottom land so this the distance from here to here is called face width.

So this is the top the last is called top land and then we have a curve passing through the top land here so this is called the addendum circle the circle is addendum circle and then we have another imaginary circle called pitch circle okay so pitch circle is it will on the pitch circle see if we observe here we have a tooth thickness that means this is the material thickness is equal to the width of space.

So such a way we have to write the pitch circle and the distance from this point to the corresponding point or next tooth is called a circular pitch and the radial distance from the pitch circle to the addendum circle is called the addendum and we have a dedendum circle which will pass through the root so this is the addendum circle and the radial distance between the dedendum circle and the pitch circle is known as dedendum.

Then we have a clearance circle here and then a small fillet radius and this is the clearance so here is a gap between Clearance circle and dedendum circle.

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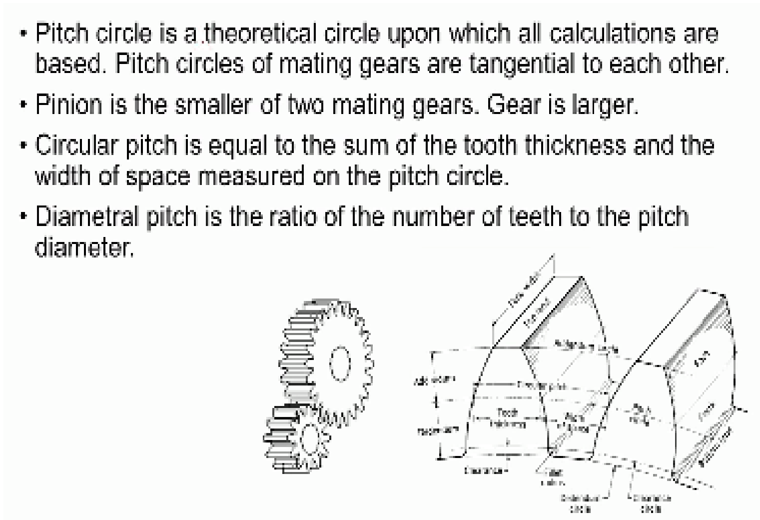

Now pitch circles is a theoretical circle upon which all calculations are based. Pitch circles of mating gears or tangential to each other and then pinion is a smaller of the 2 meeting the gear here you can see a meeting here the bigger one is called gear and the smaller one is called pinion. The circular pitch is equal to the sum of or 2 thickness.

This is the circular pitch is equal to sum of 2 thickness and width of space, measured along the pitch circle diameter pitch is the ratio of number of teeth to the pitch diameter also known as pitch circle diameter.

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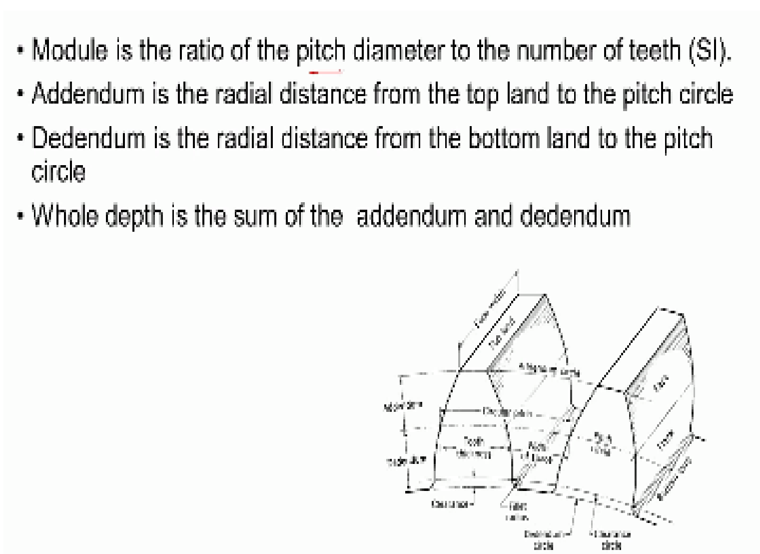

A module is the very common term used with the gear the module is the ratio of pitch diameter to the number of teeth Then we have addendum is the radial distance from the top land to the pitch circle and dendendum is the radial distance from the bottom land to the pitch circle. Whole depth is the sum of addendum and dedendum. So this is the depth of tooth profile depth of tooth.

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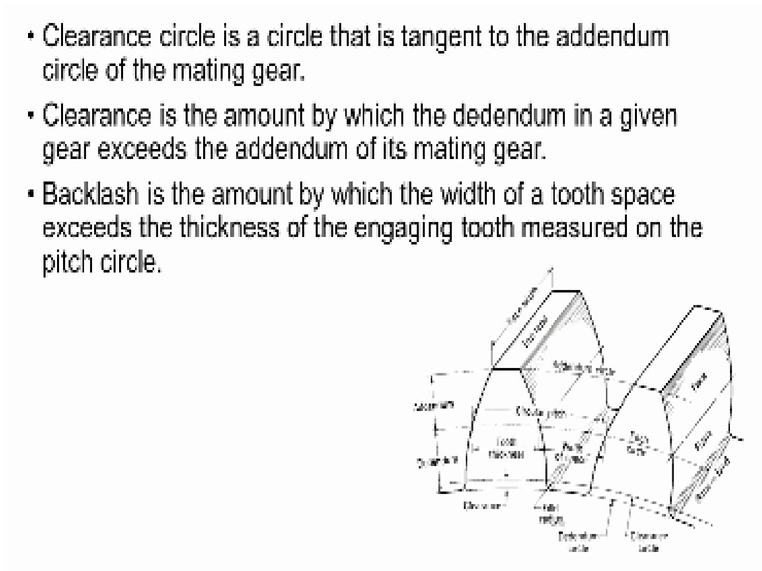

Clearance circle we have the clearance the circle here clearance circle is a circle that is tangent to the addendum. It is a tangent to the addendum circle of mating gear clearance the amount by which they dedendum in a given gear exceeds the addendum of its mating the gear and most commonly.

We use other terms that is a back lash it is the amount by which the width of tooth space exceeds the thickness of the engaging tooth thickness there will be another engaging tooth between these 2 there will be a small gap which is known as the backlash. So it is the amount by which the width of tooth space exceeds the amount of exist the thickness of engaging tooth measured on the pitch circle.

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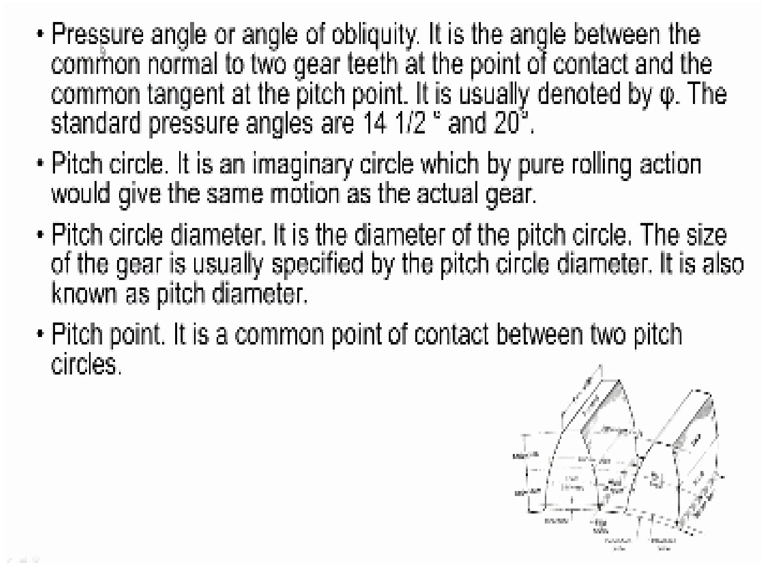

Now we will discuss about the pressure angle is also known as angle of obliquity. It is the angle between the common normal common normal to the 2 gear teeth at the point of contact and the common tangent at the pitch point it is usually denoted by this particular symbol and the standard pressure angles used in the manufacture is 14 1/2degree and 20 degree.

So pitch circle it is an imaginary circle which by pure rolling action would give the same motion as the actual gear then we have the pitch circle diameter it is a diameter of a pitch circle the size of the gear is usually specified by the pitch circle diameter which is also known as the pitch diameter then the pitch point is the common point of contact between 2 pitch circles.

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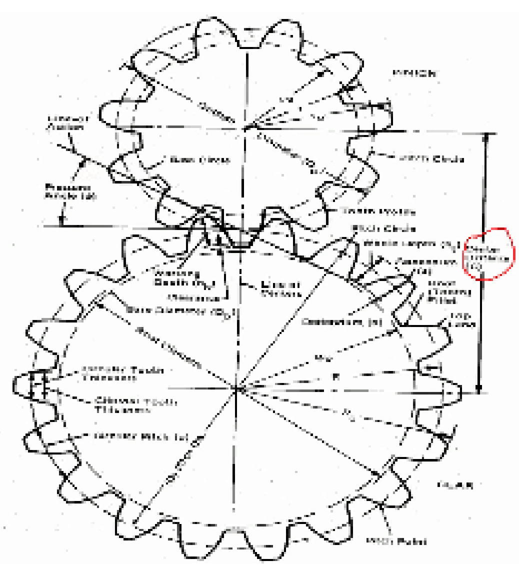

You can see some more terminologies here we have a gear and pinion mating together and the distance and the center of pinion to the distance of the center of gear so this distance is called center distance and you can see here the pressure angle and line of action base circle. This is the root diameter and then we have the circular tooth thickness so it is measured on the pitch line you can observe or in the case of the gear tooth.

So in the case of gear tooth the thickness will be vary the thickness will be varying from tooth to tooth. So here you can see this create a thickness, so as I move down from top land to bottom land the thickness of the tooth is varying. So when we want to measure tooth thickness, so we should not want depth at want to measure the thickness at the pitch circle. So we have the thickness which is called circular tooth thickness or chordal tooth thickness.

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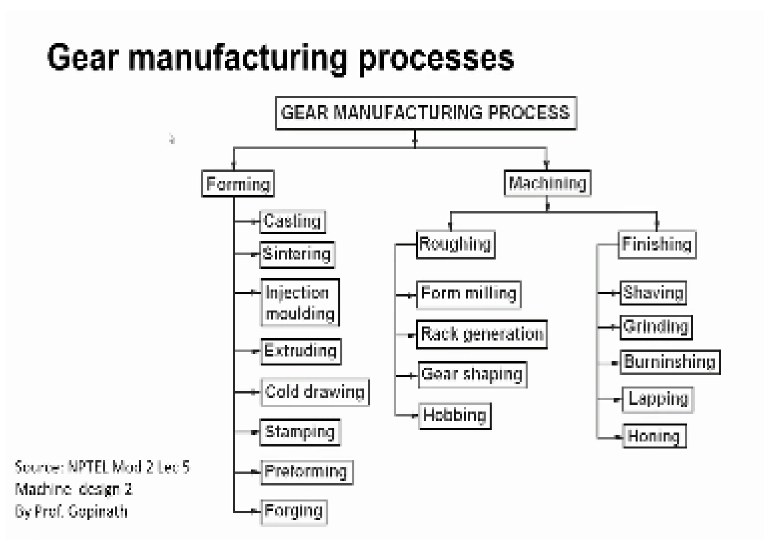

Now we will move to the gear manufacturing processes we can make the gear by forming the operation so it is a Chipless operation or we can machine the gear in the forming process the different methods are available casting methods if the gear is very big then we can cast the big gear and by centering also we can make the gears injection molding process, extruding process, cold drawing process.

If we want very thin the gears we can stamp the gears and performing forging so these are different forming operations by which we can make gears coming to the machining of gears. We have roughing operations and finishing the operation in rough machining operation we can form we can make the gears by form milling, rag generation gear, shaping, shaping operation, hobbing operation.

So like this we can make the gear by rough machining and then we can finish them by different operations called gear shaving, gear grinding, burnishing, lapping and honing process.

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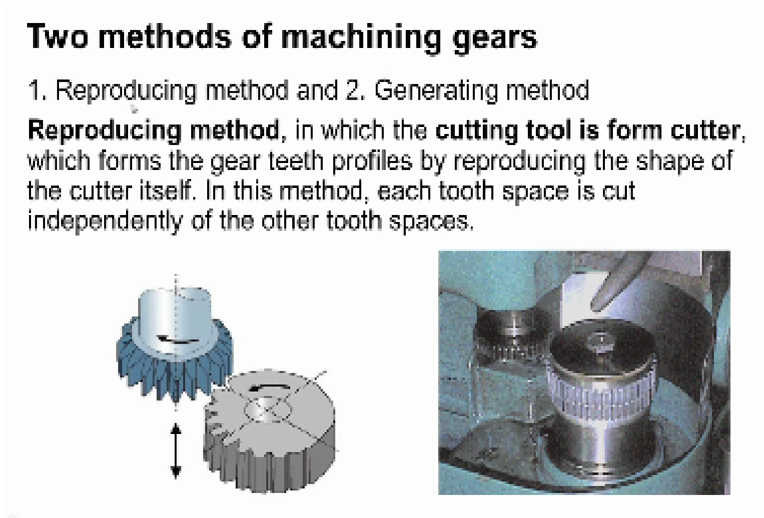

Now under machining we have 2 methods of machining gears the first one is reproducing method and we have another type generating method. Reproducing method in which the cutting tool is a form cutter it means the form that is available the cutter is reproduced on the blank. So which forms the gear teeth profiles by reproducing the shape of the cutter itself so in this method each tooth space is cut independently of the other tooth spaces.

Schematically you can see here the cutter is rotating as well as it is moving up and down and so at a time 1 tooth will cut you can see the photograph of reproduction method. This is the cutter and this will be gear blank.

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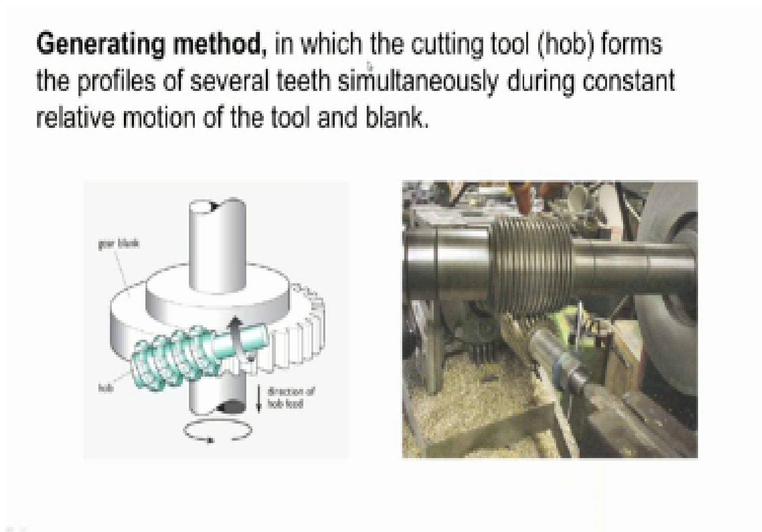

Now the second method of machining is generating method in which the cutting tool forms the profiles of several teeth simultaneously. So in this case with several teeth or cut simultaneously during constant relative motion of 2 tool and a blank, so this is the gear blank on which we want to make the gear and this is the hob the gear cutter the direction of hob feed in also you can see also the gear blank is rotated simultaneously.

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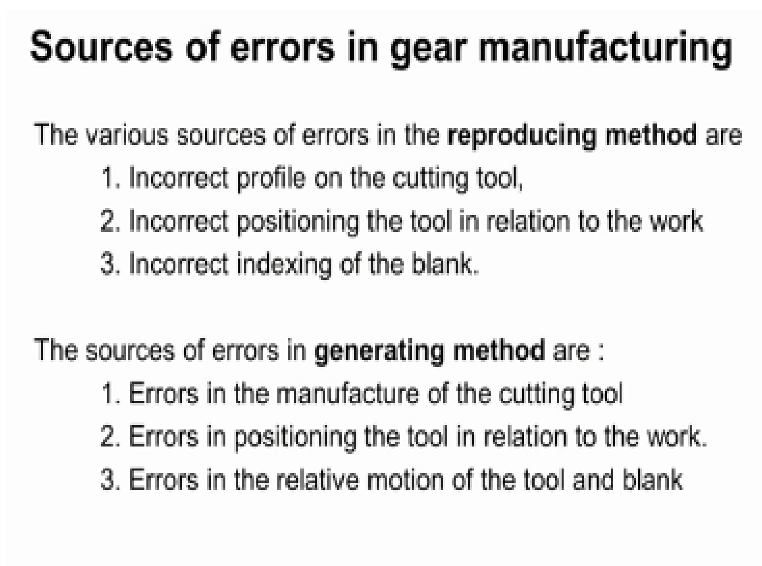

So there are the various sources of errors in gear manufacturing this lists the resources the surface of errors in the reproducing method or incorrect profile on the cutting tool that means they have selected a cutting tool which is having incorrect profile so that incorrect profile will be reproduced on the blank and hence we get a wrong or some error in the gear.

Incorrect positioning of the tool in relation to the work that means the proper angle proper orientation proper depth or not given during the machining operation and incorrect indexing of the blank. So improper indexing arrangement also leads to the error in gear in the case of generating method the errors in the manufacture of cutting tool again the cutting tool is improper or it is having some error.

So we get error in the gear that is we have cut errors in positioning of the tool in relation to the work that means improper orientation of tool and work and errors in the relative of tool and blank the relative motion between blank and tool are not correct they are not rotating the required the orientation or speeds or whatever it is hence we get the error in the gear.

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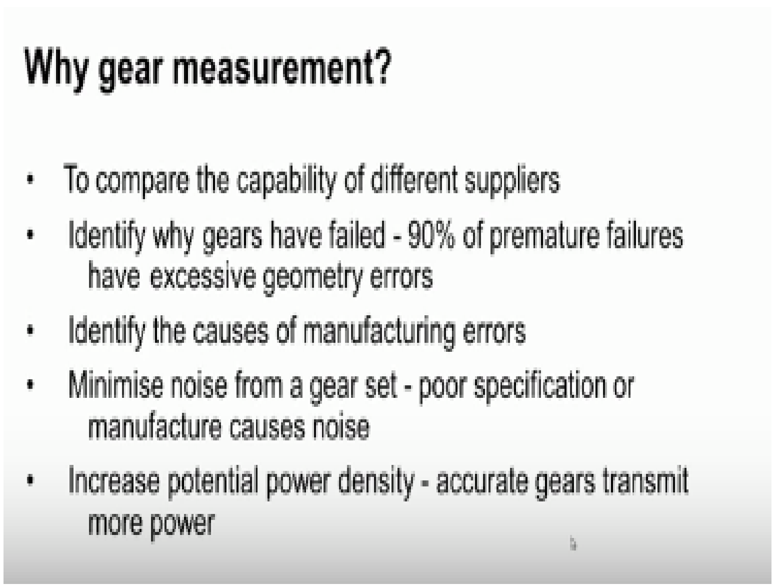

Now let us understand why what is the need for gear measurement why do we want to measure the various gear elements, so to compare the capability of different suppliers they are procuring gears from different suppliers and we want to access which supplier is supplying the better gear. So when we want to access the suppliers it is necessary that we should go for gear measurement.

So identify why gears are failing 90% of the premature failures have excessive geometrical errors so to identify what is a reason for failure we need to measure the gear and to identify the causes of manufacturing the error why the error is occurring. So to identify that we have to measure the gear to minimize the noise from a gear set poor specification or manufacturing of gear causes noise.

So when the gears are made to the specification and we can always reduce the noise increase to increase the potential power density accurate gear accurate gear transmit more power to achieve accurate transmission good transmission we need to check whether the gear for proper or not.

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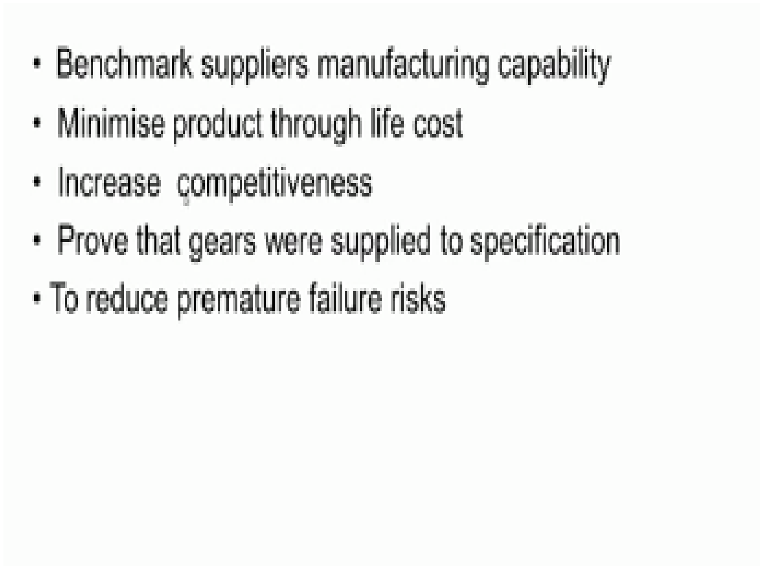

To benchmark suppliers for manufacturing capability so whenever we are in the process of benchmarking disciplines we need to measure the gear to minimize the product through life cause cost to increase the competitiveness. So when if we are manufacturer of gear we want to increase the competitiveness so we have to produce the goods gear.

So it is very essential that we should develop the quality of the gear produced to prove that gears are supplied to the specification, so to check whether all the gears are made the specification or not or if there are any errors if there are errors how to eliminate to study those things we need to measure the gear to reduce premature failure risks also we need to measure gears.

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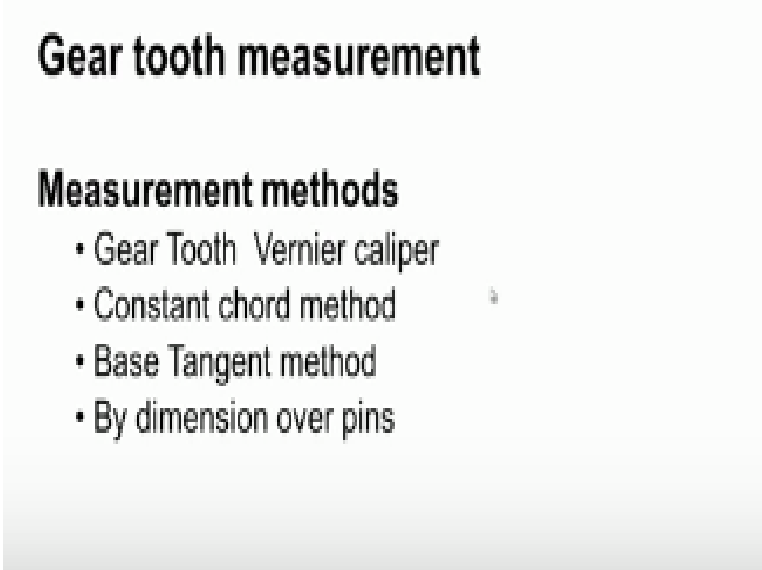

Now we will move to the gear tooth measurement different methods are available to measure the tooth thickness. So one very commonly measured parameter in the case of here is we are gear tooth thickness and the thickness gear tooth thickness can be measured by various methods gear tooth by using the gear tooth vernier calliper by constant called method, and use of waist tangent method and by measuring the dimensions over the pins. So these are some of the methods available for the measurement for gear tool.

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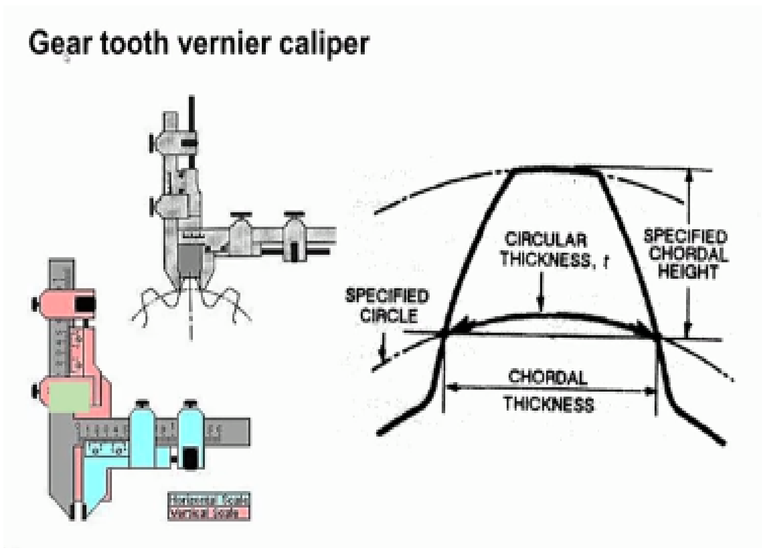

Now we will study the first method that is measurement of tooth by gear tooth vernier caliper so we have seen the conventional vernier caliper wearing there will be only 1 main scale and 1 vernier scale whereas the gear tooth the vernier caliper you can see here we have 1 horizontal scale and then we have 1 vertical scale so to scale well horizontal scales and 2 vertical scales are available we have one set of jaws you can see the jaws we have one set of jaws and here you can see there is a blade or sometimes it is called tongue.

So we have a blade here so which will move up and down, so this blade can be moved up and down under a jaw opening can be adjusted by moving the horizontal part again vernier caliper. Now we should know at what depth we want to measure the thickness, so this is thickness to thickness is very a different depths so we should not want depths.

We want to measure so that depth the that depth we should fix here by moving the blade the tongue should be moved up and down and the depth should be adjusted and then using the after adjusting the Tom the gear tooth caliper is placed on the gear tooth which is to be inspected and then the jaw should be move and the thickness should be measured.

If the chordal tooth thickness is to be measured then we should find what is the value of this chordal height and then that value we should fix here and then we can measure the thickness chordal thickness.

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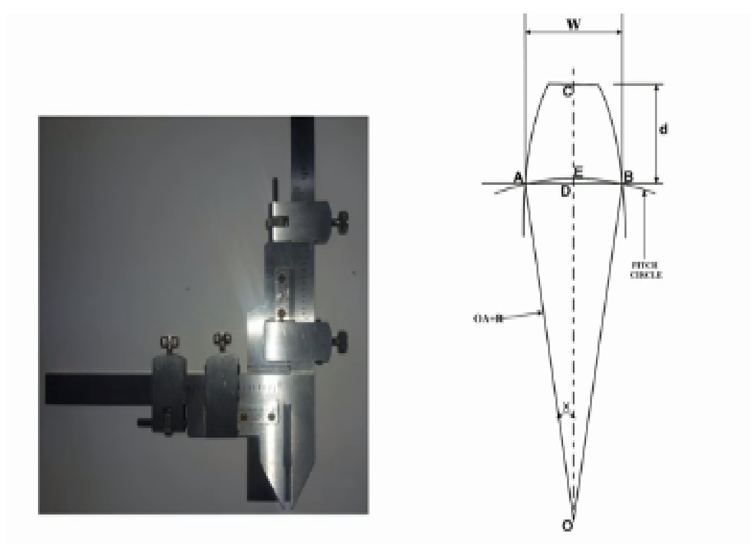

So this photo shows a gear tooth vernier caliper you can see the jaws here we have 2 jaws and then we have the horizontal scale with vernier and then we have a vertical scale with vernier here and this is the blade or tongue which will move up and down. Now you can see this geometry of the gear tooth so we have the pitch circle and in the top land and this O is the center of gear and OA is the radius and then C to D.

So this is the point C to D is the depth and then A to B,A to B is the chordal a thickness which is the term as W, so we should calculate what is the value of D and then we should take the move tongue and then we can measure the value of W it is chordal thickness.

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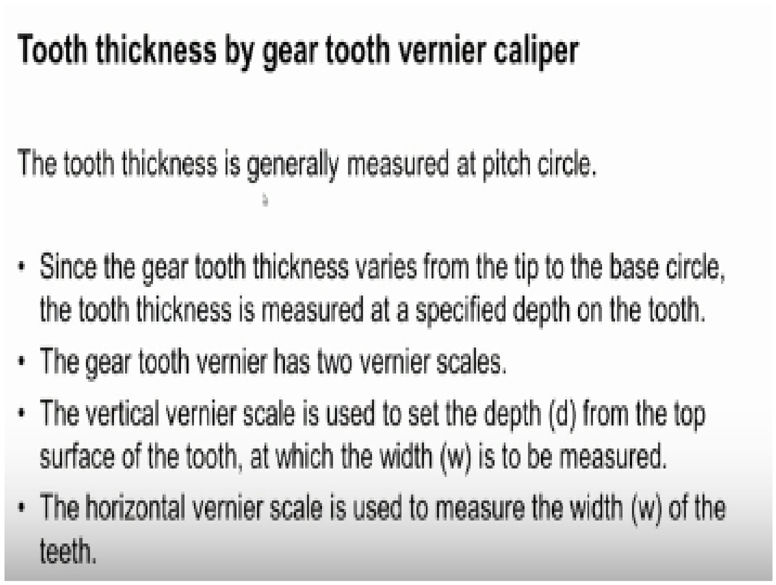

Now the tooth thickness is generally measured at the pitch circle since we gear tooth thickness varies from tip to the base circle the tooth thickness is measured at a specified depth depth on the tooth normally at pitch circle it is where measured the gear tooth vernier has 2 vernier scale has already discussed the vertical vernier scale is used to set the depth from the top surface of the tooth at which the width is to be measured chordal thickness.

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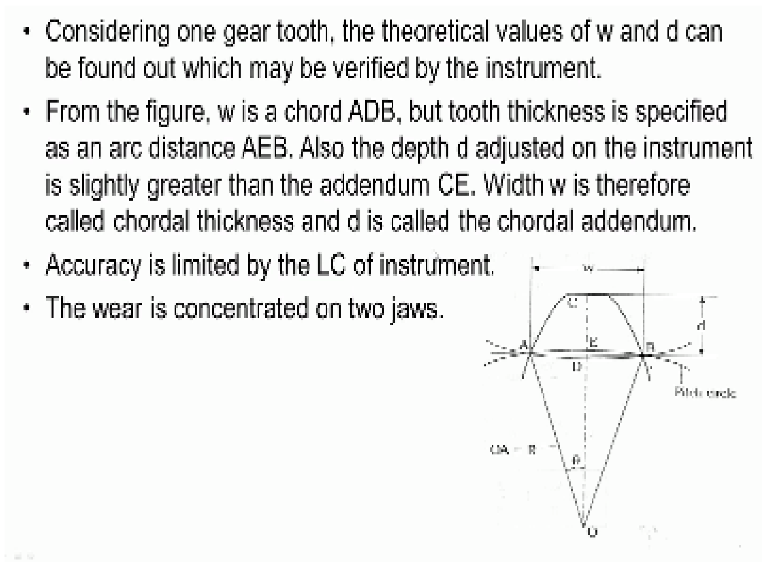

The horizontal vernier scale is used to measure the width of the teeth. Now we can see where we have considered one tooth here the theoretical values of W and d can be found out which then they the values are verified by the instrument from the figure W is ADBW=ADB, but the tooth thickness this w is called ADB is a chord but to thickness is specified as an arc distance AEB.

So we have A, we have E here, we have B. AEB is arc on the picture circle the 2 thickness is specified as an arc distance AEB also the depth D adjusted on the instrument is slightly > the addendum CE. So this distance from top line to the point E on the picture this is addendum whereas the D is slightly > the addendum.

So the D is more than the addendum by an amount ED width W is therefore called a chordal thickness and D is called the chordal addendum so the accuracy of measurement is limited by the least count of the instrument normally it is 0.05 millimeter and the wear is normally concentrated on the 2 jaws they get worn out more pickling.

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In the Δ^{le} ADO,

$$w = 2AD = 2 \times AO \sin\theta$$

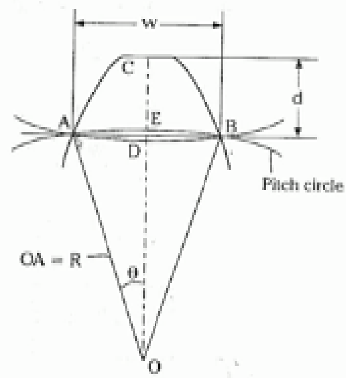
$$= 2R \sin\frac{360}{4N} \qquad R = \text{pitch circle radius}$$

$$\text{module } m = \frac{\text{pitch circle diameter}}{\text{Number of teeth}} = \frac{2R}{N}$$

$$\therefore \quad R = \frac{N.m}{2}$$

$$\therefore \quad w = 2 . \frac{Nm}{2} . \sin\left(\frac{360}{4N}\right)$$

$$\boxed{w = Nm \sin\left(\frac{90}{N}\right)}$$



Now from this geometry from the triangle ADO both ADO we have which = twice AD that is AD+DV this is twice AD, which is equal to 2 times AO sin theta. So we can using this geometry we can derive where this equation for w it is called chordal thickness which NM sin 90 /N, where N is the number of teeth, N is number of teeth and R is pitch circle radius. So this is OA=R which is pitch circle radius and M is the module N is number of teeth.

Now go also from this geometry so here we have the D chordal addendum =OC-OD so chordal depth =OC-OD and then we can derive the equation for D using this relationship so D that is chordal depth or chordal addendum =NM/2[1+2/N-cos(90/N)] where M is module and N is the number of teeth so we can understand from this derivation that the W and D they depend on number of teeth and module.

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Numerical problem

Calculate the gear tooth caliper settings to measure the chordal thickness of a gear of 45 teeth having a module of 4.

Solution:

Module = m =4

Number of teeth = N = 45

d = (Nm/2)(1+(2/N) – cos(90/N)) = (45/2)(1+(2/45) – cos(90/45))

= 4.086 mm

W = Nm sin(90/N) = 45x4xsin(90/45) = 6.28 mm

So the number of teeth varies then again we have to calculate what is the W under D, So we will solve a numerical problem. Calculate the gear tooth caliper settings to measure the chordal thickness of a gear having 45 teeth having a module of 4. So the data that is given in module M=4 and number of teeth N=45 we have to calculate the gear tooth caliper setting that means what is the depth?

So this is the gear tooth profile and we want to measure this will be a pitch line we want to measure the chordal thickness, so this is the card all thickness W so we should find out what is the value of D, which can be set in the vernier calliper and then we can measure the W so chordal depth=(NM/2)(1+2/N)-cos(90/N)) so we have to feed the values of N and M, N is (45x4/2)(1+(2/45) - cos(90/45)) this will a value of 4.086 millimeter.

So this value we have to set in the vernier calliper so the D is the pitcher circle and then chordal thickness so this is D=4.086 so we have to move the tongue of the vernier caliper and we are just this 4.086 millimeter in the instrument and then we can measure the thickness so theoretical value of thickness to thickness chordal to thickness = NMsin90/N. So, N is 45, number of teeth and M is 4 sine 90/45 millimeter, so chordal thickness is of 6.28 millimeter.

So this we can verify by using the vernier gear tooth vernier, so with this we will conclude the discussion in this session we discussed about the introduction to the gears what are the different types of gear manufactured, how they are manufactured and what are the various terms used in relation to gear and how the gear tooth thickness can be measured using the gear tooth vernier also saw a numerical problem we will stop at this point in the next class we will continue the discussion on the measurement of tooth thickness by other method. Thank you.