Gear and Gear Unit Design: Theory and Practice
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Lecture - 27
Design Verification – Including Key Ways
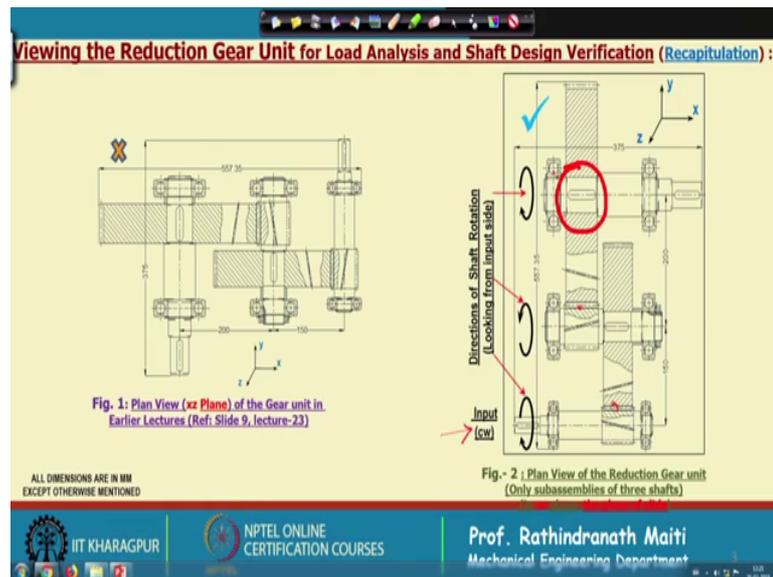
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Welcome to module 6 and this is also continuation of the design of general purpose industrial helical gear reduction unit and this is part 4, the almost the concluding part. Now this is the lecture number 27 where we shall go for design verification including the key ways what we have developed.

So, far we have developed the sub assemblies of the input shaft intermediate shaft and next the necessary verification watch for the key ways before going into the completing the detail drawing of the gearbox; that means, planned view elevation housing etcetera etcetera.

So, in this lecture basically I shall discuss about the first of all we shall make some comments sub assemblies and then design verification of selected case and then finally, again we will look into the alteration of the design.

Fig. 1: Plan View (xz Plane) of the Gear unit in Earlier Lectures (Ref: Slide 9, lecture-23)

Fig.- 2 : Plan View of the Reduction Gear unit (Only subassemblies of three shafts)

Now here I would like to mention again that in the design initially the we considered when we started drawing the which is shown in the left hand side, but later to match with the week 4 lectures we reoriented the gay sub assemblies in such a way that it matches with the problem which we started solving intermediate shaft solving in lecture 4.

Now, if we therefore, if we concentrate on the figure in 2 which is given here what we find here that say this is the input and it is in the clockwise directions. So, this means that the here this teeth is coming off; that means, on this shaft load is downwards whereas, on the intermediate shaft load is upward directions.

Whereas, here if we consider this one again this one is the pushing it is rotating in the anti clockwise directions, this one putting the pushing the output gears apparently towards the backside of the slides and therefore, here is also force in the upward directions; that means, in the intermediate shaft both the tangential force are in the upward directions. Whereas, here it is in the downward direction on this shaft and ultimately the output shaft will also be in the downward directions.

Now, next we have almost finalized the design of these 3 sub assemblies, only what we found that bearing lives in case of inputs shaft and output shaft it was more than what was required in intermediate shaft the life of the bearings were almost to double. So, we can rethink over that portions, but while we are designing the output shaft it is also shown that the portion where the gear is hitting the shaft diameter is just satisfactory.

This is because of the reason that we have taken a material C 40 and it is just without any heat treatment we have used there and there then the question comes that whether the key what we have selected that is also satisfactorily, satisfactory for transmitting the torque or we need to change it.

So, in fact, finalizing this drawing of the plan view what we will do, we shall now examine the design of the case.

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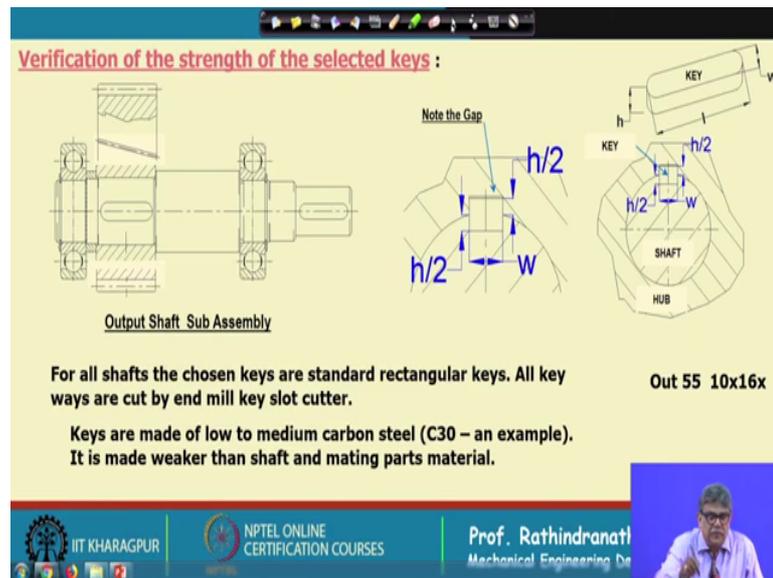
Now it is very important that the case should be such that if there is any failure comes or or in other words if there is over leading comes then the key should fail then the gear or any other components. So, key is used if we look into this key is used to assemble the gears on the shaft or at the output end the coupling to this input sorry this is output end this is output shaft, sub assembly it shown.

Now, we if we consider the failure of the key first of all we should know how the key are fixed, now the keys are of there are many features many type of keys are used among that most commonly used are the flat keys and it is cross section each rectangular shape usually it is the width is more than the height width is more than the height. So, this is the height, height is h and say if we consider this one this is the height which is given by h and this is the width which is designated by w and the length of the key.

Now, next the question is that why we are using this type of key, then if we think of the machining of the key ways on the shaft, then we have to think of that we have to make a groove on the shaft so, that we can put this key. Now if you think the cutting process there are 2 methods or there are other methods of course, mainly 2 common methods, one is that we can use a end mill cutter we can use an end mill cutter and that we can say this is end mill cutter of this size and this will move from this point to this point and this groove will be generated.

Alternatively we can use an side and face cutter which will cut the groove, but you should keep in mind to have the required depth we have to cut a more length in this directions and in this direction also. So, that we can use a key up to this length because this groove on the if we make it by side and face cutter it will be something like this where this is the cutter diameter.

So, but this if we cut the key ways in this way this will be not convenient. So, best thing if this key way on the intermediate position then we should make it with the end mill cutter it will look like that. Now, there are again after cutting this key ways there are 2 options, one is that we can move the key up to this point not for the circular part this means that a rectangular key what we can put it there, but this is again there will be some gap right hand side and left inside.

So, there are special keys are made for which not special these keys are also standard this heads are rounded like this so, that we can directly put inside this groove. Now, this again in this chart we will look into the chart for the key ways or in other words which is the product catalog of the keys there the length is mentions the length in case of this round head the length is the full length is mentions. Whereas, in case of rectangular fully rectangular key the same length is mentioned, but while we calculate the strength then we have to consider this carefully I mean coming to this point.

Now, another point who I would like to mention for all shafts the chosen keys are standard rectangular keys these are called rectangular keys also called parallel keys all keys key ways are cut by end mill key slot cutter here that we have used end mill cutter at this portion of course, we could have used the side and face cutter also, but still it is better to cut this key way also with the help of the end mill cutter.

Now, keys are made of low to medium carbon steel. So, for example, C 30, C 20 is the mild steel C 30 means 0.3 percent carbons it is medium low medium carbon steel you can say it is slightly stronger than mild steel. The philosophy behind it that that key must be the material wise weaker than the shaft and the gear material usually alloyed steel. So, definitely key will be weaker than the gear material, but if we consider the shaft, shaft these also made of media medium carbon steel. Suppose if we take the shaft C 40 then it is better to use a mild steel key or C 30 of that level C 30 is that level means 0.3 percent carbon.

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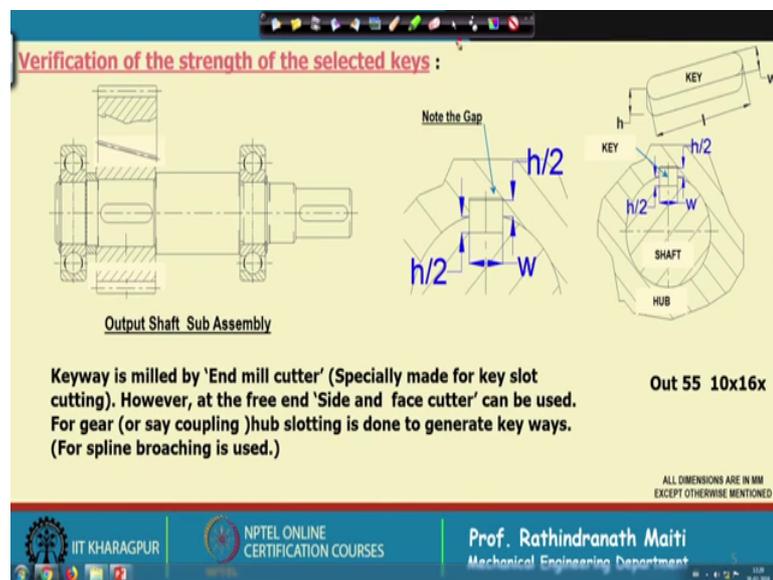
Now, the as I have mentioned it is milled by end mill cutter; however, at the free end side and face cutter can be used at this side already it is this is discussed for gear or say coupling hub slotting is done in to generate key ways; that means, when we are making the key ways in the hub this is the hub, this is the hub; that means, this is the in this case this is the gear when we are making the slot in the gear.

Then we are using a slotting process because they are the milling may not be possible special milling of course, possible, but best way is we can cut this grove by the slotting machines there are special cutter for that keyway cutting and we can use that one. Now, the key ways are made in such a way the half of the key height that h we sit in shaft and other half in hub then this is quite interesting.
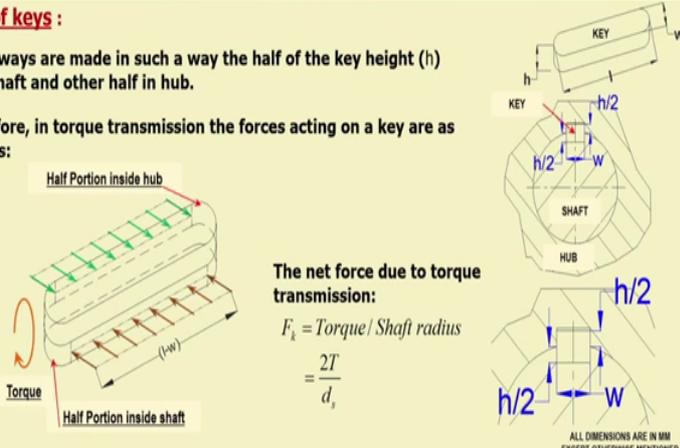
If we look into this say this figure then in that case actually shaft is going like this. So, if we take half of the height h by 2 from this point; that means, if we make this is h by 2 then after cutting this groove actual height of the key inside the shaft will be less then h by 2. On the other hand in the on the same philosophy that on the half it will be less same geometry we would say from the same geometrical point of view if we make the half groove there this will be more than the actual depth.

So, what is there particularly in shaft, the depth of cut is made a little more than the h by 2. So, that we can have actual depth inside the shaft is h by 2 and then again half it is also h by 2, but; however, there is a clearance at the top of the key in the hub. So, that by no means the stress comes in this directions there is no stress in this directions.

This is very important because if we make the total groove height is exactly equal to the key height in that case if there is some error then a stress will be here and due to that there will be some clearance will be generate between the hub and the gear whatever small it might be this may generate and this will be failure in torque transmission there will be failure in torque transmissions.

Now, if we consider then the failure of this key then what may happen one is that the area will be shear or there will be crash, I am coming to that before that I would like to say that this is the force acting on the key. Now if we say suppose this is the direction of

the torque which is shown here this is the direction of the torque, then in that case then definitely hub each transmitting the torque or if we consider the shaft.

The shaft is transmitting the torque passing the torque to this and in that case what we find there will be this torque is coming from the gear to hub. So, there will be forces in the top side inside the hub and on the shaft it is at the bottom side bottom hub there will be forces and summation of this forces can be calculated by this equations that is the torque divided by shaft radius we will get the total amount of force.

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Now, if we look into their failure of the shaft then it might be failed due to the shear if the developed shear stress exceeds the allowable shear strength of the key material, then it will fail and this failure is like this you can say that due to this upper half and lower half. They will be simply shear out and this is the common failure this is the expected failure in case there is overload.

However, the and this shear stress if you calculate for this key with round head then we shall consider this F k and then we have to consider this full area which can be calculated by if this is the length minus w is the width into width; that means, this rectangular area and then one circular area which is calculated by this that is the total shear area, although the force are being applied at the middle, but we can consider that this is the average area which is being taken by the key.

Now, in case if we use a rectangular key for which the completely rectangular in top sides then the size of the key will be this much.

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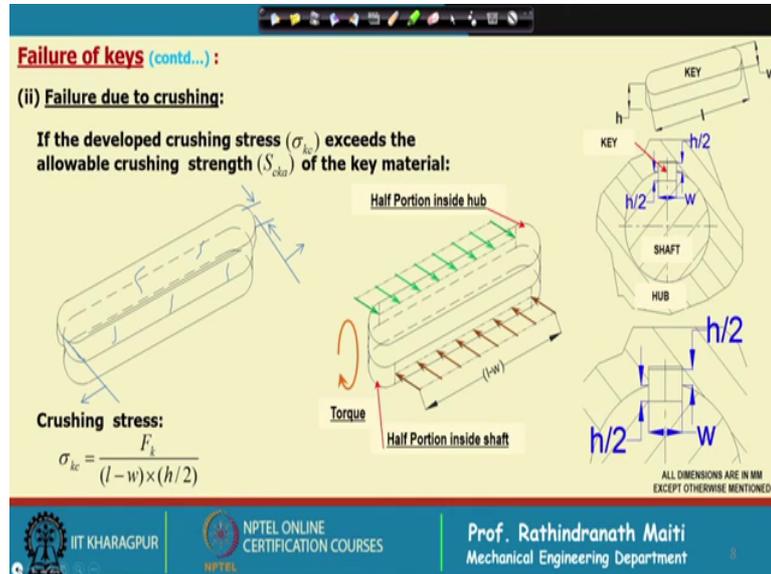
Although the groove is made with rounded, but the size of the key will be this, then in that case the designated l by the manual l length by the manufacturer is this much. So, to consider that key we have to consider the equation this w will not be there l into w at the same time this area will not be there; that means, in that case for that if it is a completely rectangular key we are using then F k that is the total force divided by forces on the key divided by the l into w that we should remember depending on the key we have to calculate accordingly.

Now, again this key may fail due to the crushing, what is crushing, as the forces are acting in this way this way and this way then the upper portion will try to be compressed or you can say bottom portion will be trying to be compressed in one way an upper portion will try to be compressed in other way opposite directions. Then probable failure it might be like this say bottom portion as it is sitting firmly inside the groove whereas, in case of the hub the groove is like that this end other end is free.

So, therefore, you may see this upper portion may slightly bulge out maybe this will be compressed this h will this w will be reduced it will be compressed like this whereas, this length at the top will slightly try to increase this l plus it will try to increase and then the actual failure it may not be observed, but it is like that this half portion will become loose

and there we have some micro cracks like this on top and bottom so, that is called that is failure due to crashing.

Now, it is to be me remember for this material any material discussing a level strain and shear level strains that different as well as the crushing area on which the pressure is there and this shear area these are 2 different so, we need to verify both.

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However, there is also another issue that is to be considered that is called bearing strength, now normally if the key is verified for the crushing strength and the shear strength we need not verify for the bearing strength because of the reasons usually the bearing capability of the key is more than the crushing area for the bearing is also same as the crushing; that means, this area as you see here the formula this is the same area.

But what is this bearing, this bearing failure means this surface on which the load is acting, it somewhat it fails due to the contract strength not crushing, but the contract strength and due to that failure means there will be that small pitting sort of things. Now usually for this type of case this will not happen, but if we consider the spline, spline is the another option of fittings where the hub length is small and one single key is not enough even if we put 2 keys it may not be enough, 2 keys we can put at the 180 degree or side by side, side by side means on the shaft it can be put like this.

Sometimes it is used like this, but these are very rare sorry these are very rare. So, better to use only single k or else we should go for spline, if you have the idea about this spline splines are like that on this hub grooves have like this and on the on the shaft also it is cut like this. It is usually done by broaching and in that type of fittings it is not like this key, where this key, here it is tight fit in this case it is not tight fit like that rather the in inside of the inside spline of the on the half and at the root of the shaft they are matching.

So, therefore, at this side this means here there will be some a small clearance and due to the dynamic load when this is coming over there again and again, then there is also possibility of the we should consider over the bearing strength which is a different from the crushing strength, but anyway it has been seen for the key way if it is not filling for the crushing strength, it will never fail due to the bearing strength unless it becomes loose. So, we need not consider checking this bearing strength for this type of keys right.

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Now, the key dimensions which are shown here a sample h shown here, now our if we remember the input shaft we have kept 25 millimeter and bearing we have kept their 30 millimeter, 25 millimeter and output shaft the diameter we have kept 40 millimeter. So, here we have shown this table only from starting from 17 22, 58 65 right and. So, that we can select the key for either from here for the input and for the output shaft we can take it from says this is in the range of 40 whereas, we had the gear is hitting it is 55. So, this chart is made like that as a sample.

Now, what are the dimensions are given, the first of all it is cross section for example, the shaft the diameter if it is between 17 and 22 it is 6 by 6; that means, cross section is also fully square, but above that it is 8 and 7; that means, 22 38 and 7, 8 is the width 7 is the height.

So, it is after that it is of that size that mean width is always higher than the height and if we look into the length of the key then for example, 30 to 38 for this one we find 22 110. So, 22 is the smallest size and 110 is the and in our design mostly we have selected the keys which is length usually not more than 40 and maximum it is the 60 millimeter. So, that will be available within this.

Apart from that what is more important dimensions that on the shaft depth t 1 is say for example, if we consider the input shaft on the shaft we the height is 8 millimeter. So, h by 2 is 4 millimeter, but t 1 on the shaft it is say this one it is. So, this is t one this is 5 millimeter whereas, on the half it is 3.3 millimeter, here this is 3.3 millimeter which is t 2 and what else on the key say if we consider the key corner radius is 0.25.

It may be radius at the corner or maybe chamfer also which is r 1 into 45 degree say r 1 is point 0.25. So, we can make so, in this case 0.4 and 0.55; that means, either 0.55 into this key and made 0.55 into 45 degree chamfer or 0.55 corner radius sorry this r 2 it is it is r 2 not r 1 it is r 2, r 2. So, key means this r 2 is made 0.25 or in this case 0.45 of sample.

Whereas on the groove it is the radius so, here this radius corner which is given by r 2 right. So, that is 0.4 in this case 0.4 r 0.4 millimeter, this means that the end mill cutter what we are using the teef is having this 0.4 corner radius. So, that the key can safely sit inside this and most importantly that there is a gap this mass may maintain show that there is a no pressure from the top and many people make a mistakes that on the same area of this shear they consider that there will be the crushing load from the top and that they try to calculate, but this is not true crushing means this will be failure here and shear means the failure will be here.
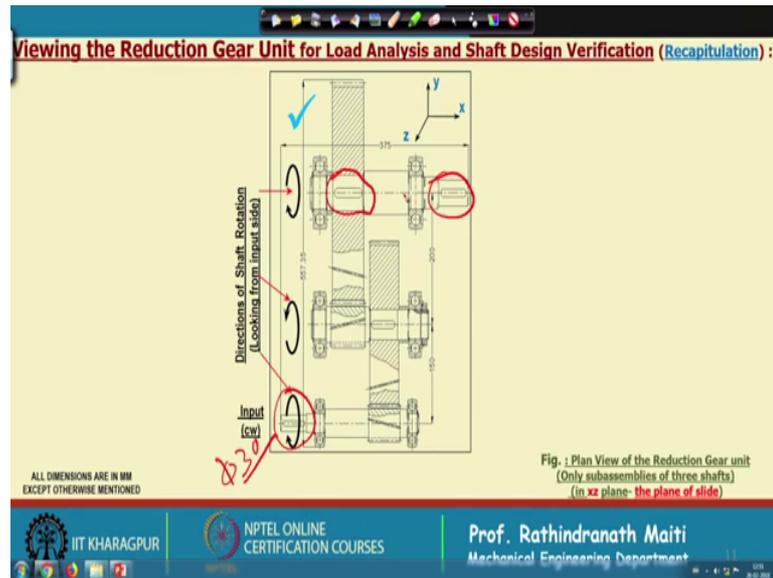
Now, so, depending on this shaft diameter and others we can select that what the key will sit on this shafts, here we have taken input shaft is 30 millimeter and for which we find that 8 and 10, 8 millimeter is the height and 10 millimeter is the width, this key it put there and the material of this initially we selected C 30, but later we found that here if we take C 30, then this will this may fail as well as here also particularly in the output side that may fail, what we have considered that strength, allowable strength is for the crushing is 2 times less than the yield strength.

Whereas shear strength all most 4 time less than the yield strength that is to take care of that severity of the operations and either we can multiply this factor with the applied load; that means, from nominal torque while we are considering from on which basis we are calculating the F k there itself we can consider the load is more due to the severity of the operation or in the allowable strength of the keyway we can consider that.

This key way I mean selects the verification of the strength of the key and etcetera that will be done to the assignments, but what I have verified in that case all the key sizes are being satisfied what the material should be at least C 40, if we take the C 40 materials there is no harm because our 2 shafts the input and intermediate shafts are made of alloy steels the pinion material the same material as in pinion.

Whereas in case of output shaft it is C 45 and it is preheated before milling machining before machining. So, this will have more strength than if we take the key material C 40.

So, this is the end of this lecture and next we shall go into detail drawing of this plan view and there we will consider reconsidered the shaft size and the bearing if necessary otherwise we can complete the design keeping all this selected bearings key way everything unaltered. So, next lecture I shall go for the land view of this gearbox and there I will again discuss if there is any change why we have made this change.