IC Engines and Gas Turbines
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Lecture – 17
Engine Friction, Lubrication Systems, Forces on Piston

So, we will continue our discussion on IC Engine. Today we will discuss about Engine Friction a Lubrication which is required to minimize the friction.

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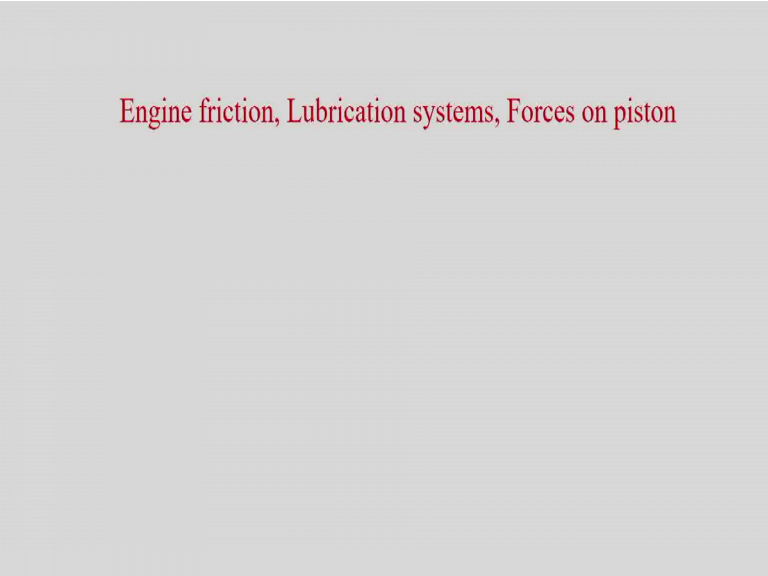

And finally, we will discuss about the forces that is being applied that is rather acting on the piston. So, to start with since we will recapitulate what is friction and you know where it is present while we are talking about internal combustion engine rather operation of internal combustion engine. More specifically we will discuss that why or from where friction occurs and why it is occurring. And that we need lubrication to minimize we cannot completely remove the frictional rather we rather we can do that we can minimize the frictional effect.

So, we will discuss today you know that what is friction. So, we know that friction basically it is a reverse the forces acting between mechanical components. So, as I discussed many a times that whenever we are having two stroke or four stroke engine. In fact, we have discussed that piston is moving inside the cylinder and to save the piston life sometimes we use piston ring only to increase the piston life.

But even though we cannot reduce the, we cannot you know completely eliminate the fictional losses. So, fictional losses are there so what we can do? We can minimize and to minimize rather to reduce the frictional losses we need to have lubrication. And we will have a lubrication system in the engine we will discuss in detail today. So, I write that what is friction very important.

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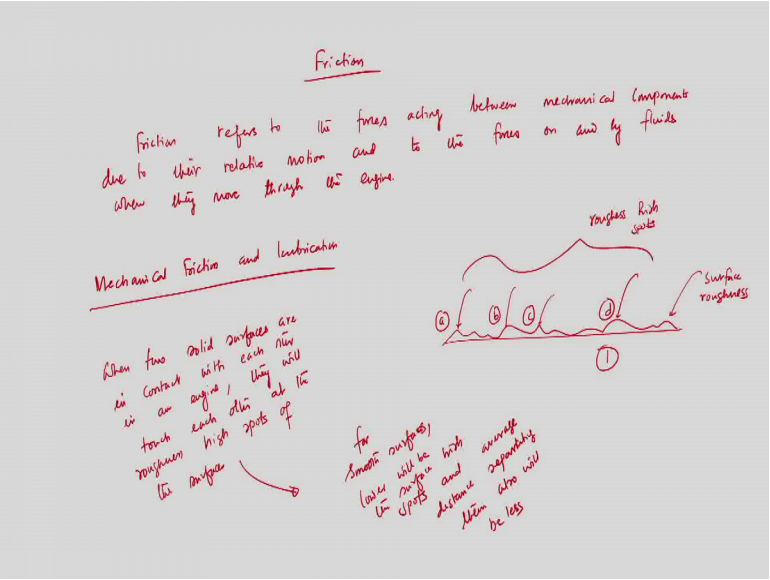

We have studied this in mechanics, but again I am writing that friction which refers to the forces refers to the forces acting between mechanical components acting between mechanical components due to their relative motion. Why? Is very important; due to their relative motion. If we do not have relative motion at all we may have static friction, but whenever we are discussing about whenever we have relative motion between the component mechanical components due to their relative motion we cannot ignore friction.

So, motion and to the forces on and by fluids when they move through the engine and to the forces. So, it refers to the forces acting within mechanical components to their relative motion not only that it also refers to the forces refers forces on and by fluids forces on and by fluids on and by fluids. By fluids when they move through the engine when they move through the engine. So, friction is always there now question is there is a relative motion between the mechanical components in the internal combustion engine because piston is moving where cylinder is you know stationary.

So, relative to the cylinder we have a motion of the piston and we have friction. Not only that even we tried to reduce friction not only that if we try to you know minimize the friction we need to supply lubrication. And when we are supplying lubrication still there are shear forces acting in the you know in a lubricating or the layer of the lubrication lubricating oil. So, and rather when fluid is moving or where moving part is there then relative to the fluid you know moving there when you know relative to the moving part.

So, there will be a shearing shear force on the fluid layer. So, we cannot reduce the frictional losses. To be very honest we need power output from the internal combustion engine. But this the friction which is very important because a percentage of power generated within the engine cylinder is lost due to friction. So, we have discussed in the context of you know torque power generated they are little bit we have discussed about that we can what is indicated power what is brake power and what is the frictional power.

So, the power a significant portion of the power that is being generated or whatever power we got we normally obtained from the internal combustion engine is lost a significant percentage is lost to overcome the fictional losses. Therefore, you know not only engine cylinder there are parts within the internal in the internal combustion engine where friction is also present.

Like you know concept also you know connecting dot there we still have fictional effect frictional force is there. So, we need to supply lubrication only to reduce their only to reduce friction and rather to increase their life. So, this is all about the you know sources of friction now when we talk about mechanical friction and lubrication. Very important see as I said you that when two surfaces are in contact when two surfaces are in contact in an engine they will touch each other at the roughness high spot of the surface.

See it is very difficult to have or it is very difficult to manufacture a surface which is atomistically smooth. So, we cannot have a surface where we have you know we should not have that we would not have surface roughness. So; that means, when two such solid surfaces are in contact in an engine either cylinder piston connecting rod (Refer Time: 07:08). There they touch each other you know at the roughness high spot of the surfaces. So, I mean if I try to draw a surface if I try to draw a surface there will be you know irregularities like this.

So, this is surface roughness is very important because we cannot manufacture we cannot have a surface which is atomistically smooth. So, we still have a surface roughness so when two solid surface surfaces are in contact with each other are in contact with each other in an engine. When two solid surfaces are contact with each other in an engine definitely they will touch each other at the roughness high spot of the surfaces.

So, these are the roughness high spot, these are the roughness high spot, these are the roughness high spot. So, these are the location of a b c d these are the location of you know roughness high spots. So, abcd you have identified these are the location of roughness high spots. So, now, when the surface are in contact with another surface they will definitely touch at that roughness high spot of the engine of the surface in engine. So, now, a question is very difficult as I you it said is very difficult to have a very smooth surface, but what I can do that, if we can increase the lower will be the surface you know. so what we can do.

So, the smoother will be the surface you know the smoother rather smooth surface. If we have a smooth surface right for smooth surface or surfaces lower will be the you know surface high spot lower will be the surface high spots. And not only the so if we have a smooth surface which is a difficult to have I mean it is very difficult to have atomistically smooth surface.

But what we can do? We can have a we can reduce the you know surface roughness and relatively smooth surface. If we have then we will have that surface high spots will be less not only that the relative the average distance separating them will be less not only that an average distance separating them also will be less. So, smoother the surface lower will be the high spot not only that the average distance between the high spot also will be also will be reduced.

So, now that is the different issue altogether if we can able to if we can prepare a surface of that is you know you know level of smoothness then only it is possible. Otherwise we will have a high spot and whenever we are having high spot and particularly I have drawn this and this surface when is in contact with another surface they will touch each other that high spot not. And if that surface is in you know motion question is whenever say the surface if I say the surface one when the surface 1 is in contact with another

surface let us say 2. Then they will touch each other at this roughness high spot not only that.

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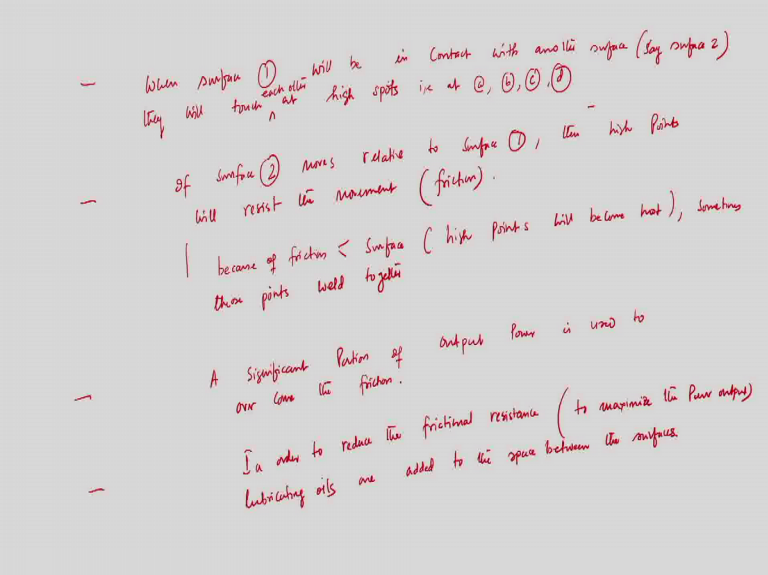

Now if now. So, what am writing that when surface 1 will be in contact with another surface. They will touch at high spots high spots this is true. So, when surface one high spot that is at a comma b comma c comma d. So, when surface 1 will be in contact with another surface they will touch each other at they will touch each other at high spot that is at a b c and d. Not only that if one surface move relative to other.

Now, if surface 2 surface say surface 2 surface 2. If surface 2 you know moved moves relative to surface 1 surface 1. Then the high points high points will the then the contacts at high points the high points will resist the movement resist the movement which is nothing, but the friction right. So, we have seen that when two surface touch each other definitely they will touch at high spot.

And if one surface moves relative to another surface then of course, they will touch at high points that is true. And that high points will resist the movement and that is which is known as friction. Sometimes what happens that, that the points of contacts will become so hot sometimes they are trying to volt together. Now because of the friction we sometimes say because of the friction the surface temperature will be high. And not only that because of the friction surface that is high points high points will become hot

sometimes those points you know trying to weld rather weld together rather weld together right.

So, because of the friction temperature of the meeting surface will be high sometimes the temperature of the rather temperature of that high points will be so high rather the high points will be so hot that they weld together. So, instead of our entire objective was to have a relative motion between the two meeting surfaces. So, instead of having two relative motion between two meeting surfaces we can have only the rather we can have you know these two surface will weld together.

So, we should not have a motion at all. So, what is friction we have understood that when we prepare a when we manufacture a surface it is very difficult to have atomistically smooth our we always try to have a you know better smooth surface rather better to have a better smoothness. So, higher will be the smoothness if we do not have a smoothness at all, but even though we can have smoothness we cannot really make it zero that there should not be no there should not be high points at all.

So, we can reduce that high points. So, if we can reduce the high points by creating a smooth surface. So, those high points will be reduced not only that a smooth surface will have a relatively the average distance. Separating this two high points will be less for a better smooth surface. Now question is when that surface is in contact with another surface let us say 2 they will touch each other that high points. And suppose surface 2 is in motion rather the surface 2 moves relative to surface 1, then those high points will try to resist the movement and that is what is known as friction.

And because of the friction temperature of that of those two meeting surfaces will be high sometimes it becomes so high that this two surface I mean instead of having relative motion of surface two motion of surface two relative to surface one they will weld together. So, this friction is very important and to overcome that friction we need a significant portion of the power output is used. Now so our efficiency drops down. So, now, question is to reduce that friction is very important that we have understood that source of friction.

That is there in the internal combustion engine. So, we have identified that when there is a relative motion between two smiting surfaces. So, one is of course, cylinder and piston piston and cylinder because cylinder is in a fixed, but piston is having relative motion

related to the cylinder also connecting rod and the crank shaft. So, these are the places where we should have friction. And to minimize the friction that rather instead of because a significant portion of the power is being used to overcome that fictional losses so, to we have to our target will be to minimize the frictional losses.

So, rather how can we minimize the fictional losses? So, as I said you that a significant portion of the power significant portion of power output or output power is used to overcome the frictional losses the friction right. to get you know relief out of this problem I mean to get to minimize this problem what is done that lubricating oil is added between the surfaces.

So, to reduce in order to reduce the frictional resistance in order to reduce the frictional resistance equivalently to maximize the power output this lubricating oils normally are used or rather added lubricating oils are added to the space between the surface between the surfaces. I am telling that lubricating welds are used between the surface between the surfaces it is not so easy.

We should have a proper system and that is what we need to know what is it, what are the lubrication system ok. We will discuss and so before we go to discuss about this what does a lubricating system you know do you know in the context of you know reducing friction in an internal combustion engine rather if we have a lubricating system at in the engine internal combustion engine what effect does it have I mean by how it reduce the frictional losses.

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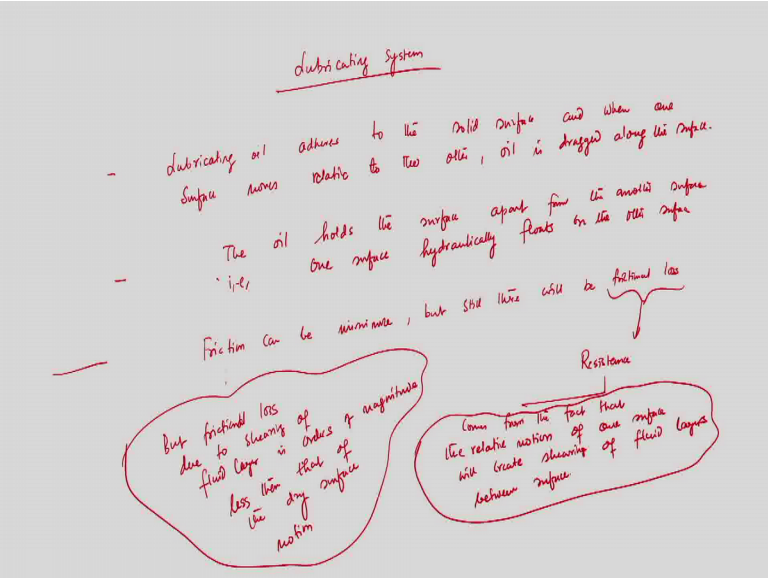

So, when one surface move relative. Suppose we have a lubricating system. So, we have understood that why we need lubricating system in an internal combustion engine. So, lubricating system is nothing, but a system where we can have lubrication oil either we can pump the lubricating oil to the desired locations of the internal combustion engine. Or sometimes the movement of the crank shaft itself allows the you know charging action of the lubrication lubricating oil.

So, that it will it will go to the desired places and it will reduce the frictional it will minimize a frictional losses. So, it is very important you know lubricating oil. So, it is very important that this lubricating oil adheres to the solid surface adheres to the solid surface. And when one surface moves relative to other and when one surface moves relative to the other oil is dragged along with the surface oil is dragged along the surface.

So, if we have a lubricating oil so what we can do? It. So, one surface. So, it is not it is very important that the oil holds on the surface the oil holds the surface apart from the apart hold the surface apart and one surface apart the oil holds the surface apart from another surface. That is one surface hydraulically one surface hydraulically floats on the other surface right.

So, we have a lubricating oil that will try to separate two surfaces and not only that. So, when one surface is moving related to other the oil is dragged on the surface. And always the oil will try to hold this lubricating oil will try to hold the surface one surface apart

from the other surface. And as if one surface is one surface hydraulically floats on the other. So, it does not that lubricating oil does not allow once another surface to come into contact with the high spots of the another surface. So, we can reduce the frictional losses.

But even though we cannot reduce we cannot make the frictional effect will be zero because although we have a lubricating oil, but still we have resistance and that resistance comes from the fact that from the relative motion of the fluid layers. Relative motion of the is shearing of the fluid layers between the surface. So, whenever although we have a lubricating oil we can you know minimize the friction we can you know allow both two melting surface not to come each other.

Even when they are you know in relative motion with respect to one side when we have a relative motion of one surface respect to other. But still we cannot make the frictional effect to be 0 because the frictional effect will can be reduced, but it will be still there. Because that that frictional effect will come from the fact that from the relative motion that is because of this when we will have a relative motion of one surface related to other that relative motion will try to shear in the fluid layer between the surface.

And, but. So, friction I can writing friction can be reduced or minimized. But still there will be, but still friction will be there will be friction loss frictional loss. And this frictional loss that is resistance this is essentially resistance that that comes from the fact that relative motion of one surface relative motion of one surface comes from the.

So, frictional losses will be there that is the because of the frictional where that resistance will comes from the fact that the relative motion of one surface will create a shearing of the fluid layer between the surface. So; that means, when you have a fluid layer between two meeting surfaces we can reduce the friction fictional losses because of the two solid surface which is coming from the contact between two solid surface. But we cannot really make it 0.

Because when one surfaces moving relative to the other between the fluid layer, fluid layer will try to. So, there will be a shearing action of the between the fluid layer which is there between the surfaces. So, rather shearing of the fluid layer between the surfaces will be there and that will eventually results in a frictional losses. But this friction so I can write that these friction because of the fluid layer, but frictional loss due to shearing

of fluid layers is ordered less orders of magnitude less than that of the dry surface motion is very important.

So that means, when instead of if we do not provide lubricating oil there will be a relative motion between two meeting surfaces. So, we have friction because of the dry surface motion. But if we provide lubricating oil and that lubricating oil will try to float one surface from the other rather one surface on the other and but we cannot make the frictional losses will be 0, there will be frictional losses because of the shearing of fluid layers.

But that losses will be even order of orders of magnitude less than the less then the frictional losses that is there between the relative motion of the dry surface between two dry surface. So, now very important so we have understood why lubrication systems is required. So, first we understood from where friction is coming we have identified the sources where you know rather identified the locations where friction is there.

Of course, piston cylinder between the meeting surface of the piston and cylinder crank shaft and the connecting rod. To reduce the frictional losses essentially or equivalent to obtain a high power output we should have lubricating system. That lubricating system and whenever we are having lubricating system by how it allows to reduce the frictional losses in a internal combustion engine and that is what I we have discussed we have identified now.

So, whenever you are talking about lubricating system rather lubricating oils. There are a few important characteristics that you know those are needed I mean for the lubricating oil. So, we cannot use any oil or any fluid or any liquid to be the lubricating oil for the internal combustion to minimize the friction in the internal combustion engine. So, there are a few important characteristics which are needed for the lubricating oil.

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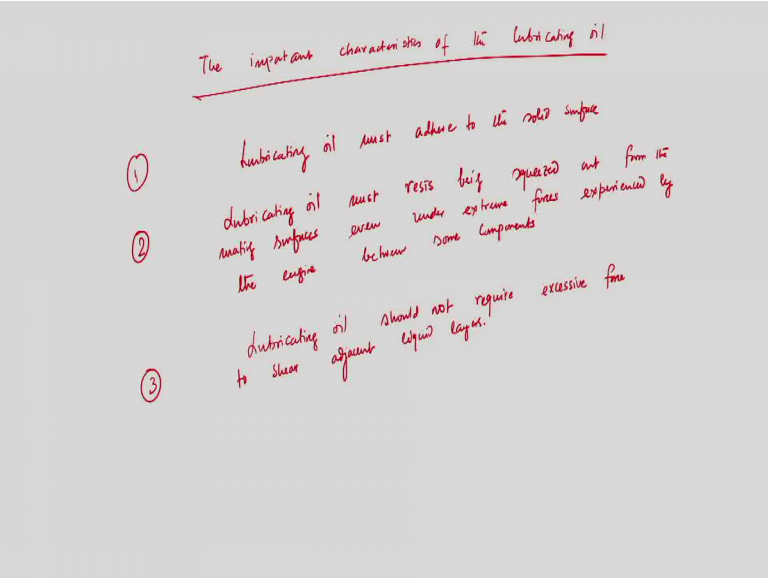

So, I am writing the important characteristics of the lubricating oil is very important. So, number 1; we cannot use any oil will be a to be the as a I mean any oil for the lubrication system rather. There are a few important characteristics which I mean which are needed in a lubricating fluid. first one is that lubricating oil lubricating oil must adhere to the solid surface very important.

So, lubricating oil must adhere to the solid surface it has to adhere the solid surface to the it has to adhere to the solid surface otherwise it is very difficult we should not have you know we cannot reduce. Number 2 is very important the this lubricating oils this lubricating oil must resist must resist being squeezed being squeezed out from the surface being squeezed out from the meeting surfaces.

So, maybe we are using one lubricating oil first qualities that, that lubricating oil must adhere to the solid surface. Not only that the lubricating oil must resist being squeezed out from the meeting surfaces. Even under extreme forces experienced by the engine between some components. So, there are a few components where maybe you know forces are very high.

Even that high forcing condition the lubricating oil be will be able to resist that is in a squeezing out tendency of getting squeezing out from the meeting surfaces. number 3is very important whenever we are having lubricating oil between two meetings surfaces where one surface is in motion related to the other. So that means, whenever as I said if I

try to go back to my previous slide that lubricating oil adheres to a solid surface and when one surface moves relative to the other oil is dragged along the surface.

So, when oil is dragged along the surface it is very important that lubricating oil should not acquire excessive force to shear adjacent liquid layers. It is very important that lubricating oil so when one surface is in motion oil will be dragged on the surface. So, when oil is dragged along the surface so that maybe the liquid layer which is very close to the you know moving surface that will drag along the surface.

And by virtue of you know pay a fluid properties that is viscosity, that information will be provided will be you know percolated into the next adjacent layer. So, that next adjacent layer also will be able to drag along the surface you know that another fluid layer I mean adjacent fluid layer. So, this is very important that lubricating oil should not require excessive force to shear adjacent liquid layer.

It is very important so as I said you that the liquid layer which is very close to the surface source in motion that will drag along the surface. But we that lubricating oil properties will be such that, it should not require huge force or excessive force that to drag the adjacent liquid layer otherwise we should not have instead of reducing friction we should have we require rather fictional effect will be high resistance will be high. So, as I said you that that whenever one surface is in motion.

So, the liquid layer close to the moving surface will move or will drag the fluid property by virtue of which that information is you know percolating into the next fluid layer is viscosity. So; that means, while we are telling that this will be an important characteristic this will be an important quality of the lubricating oil. So, the property that determines this property is viscosity and it is very important. So, viscosity will be such that we should not require excessive forces to see at the adjacent liquid layer.

So, this is very important that we have discussed about the you know important characteristics of the lubricating oil. Now very important that we have identified that what we have discussed about what is friction we have identified the location where frictional effect is dominant. Rather we have discussed rather we have seen that from where that frictional effect is coming also have discussed that providing lubrication or lubricating oil into the meeting surfaces where we have.

Where one surface is one surface is emotion related to the other we can reduce the friction, but we cannot make it 0. And we have also you know discuss about the important qualities rather important characteristics that a lubricating system lubricating oil I mean will have. So, now if I try to write that you know. So, we have discussed about that you know friction is very important. That friction we can classify friction as loss using a power terms right. So, we have we have discussed out friction, but as I said that a significant part or a significant portion of the power output power is being used to reduce the friction.

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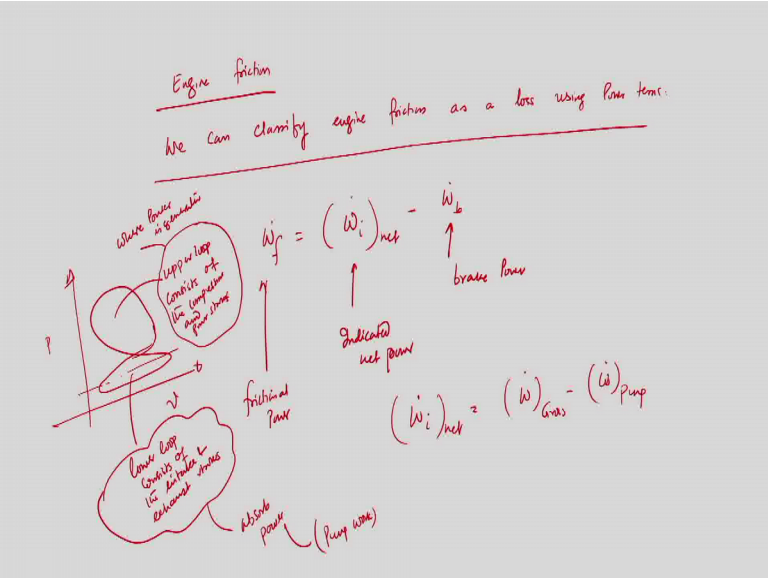

So, what we can do that in engine friction. Very important that engine friction is very important that friction can be classified you know rather we can classify engine friction we can classify engine friction as a loss using power terms. So, essentially friction is loss of power right because a significant portion of the power is required to overcome that frictional losses.

So, of course, we can classify we can write that engine friction which is nothing, but loss of power. So, we can classify that engine friction as a loss during using the power terms. So, what are the power terms? Even if we try to recall that we have discussed that. we have net power whether it is indicated then brake power and if I that indicated power that is power produced on the shaft power produced on the piston.

If I try to recall that we have discussed and we have also quantified in terms of power that the whenever we had combustion. So, the power produced on the piston face is the indicated power, but the power we get at the shaft is always less than that. So, what is the loss and you know what is the sources what are the sources of that loss? I mean indicated power is not equal to the power available at the shaft. So, of course, there is a loss.

So, what are the sources by virtue of which we are not getting that amount of power. So, friction is the in friction is an important source to reduce that power. So, indicated power is not equal to the brake power. So, the power available at the piston phase is indicated power available at the shaft is brake power. So, indicated power is not equal to the brake power rather by an amount indicated power is higher than the brake power.

So, so the difference between indicated power and brake power is the frictional power. So, if I try to write that if I wrote that W dot f equal to Wdot you know i of course, this is net minus W dot break. So, this is brake power this is indicated net power. And this is friction power. So, as I said you that the difference between indicated power and the brake power is essentially the frictional power fine.

So, where this W dot I, net is essentially W dot i gross minus W. i pump. So, this is what we have classified power friction as a loss as a loss using power terms. So, why the net indicated power is the gross minus pump because during if I again try to recall a gross power we are getting during the power stroke, so if I try to recall that you know indicator diagram right.

That indicated you know that upper loop which if I try to recall the indicator diagram is very important then we are getting between. So, maybe this is so the upper loop so this is indicated diagram this is v this is pressure power. So, this is pressure and this is volume. So, this indicated diagram this is upper loop you know consists consist of the compression and power stroke consists of the compression and power stroke this lower loop consists of the you know pump work intake and exhaust stroke exhaust stroke.

So, the upper loop which consists of compression power stroke where power is generated where power is generated. And lower loop that consist of interconnect exhaust stroke which absorb power and this is called pump work. Because intake and exhaust which is essentially the absorbed power because we need to power from flywheel and that is on

pump work. So, if I reduce the pump power from the gross power we obtain the net indicated power so this is very important.

So, this is the net indicated power which you obtain from this expression. So, not only that. So, we have that is why I W indicated net that is W gross minus W pump right. So, this is frictional power which is nothing, but the you know by indicated net power minus brake power. So, this is what we have classified friction as a loss using the power terms.

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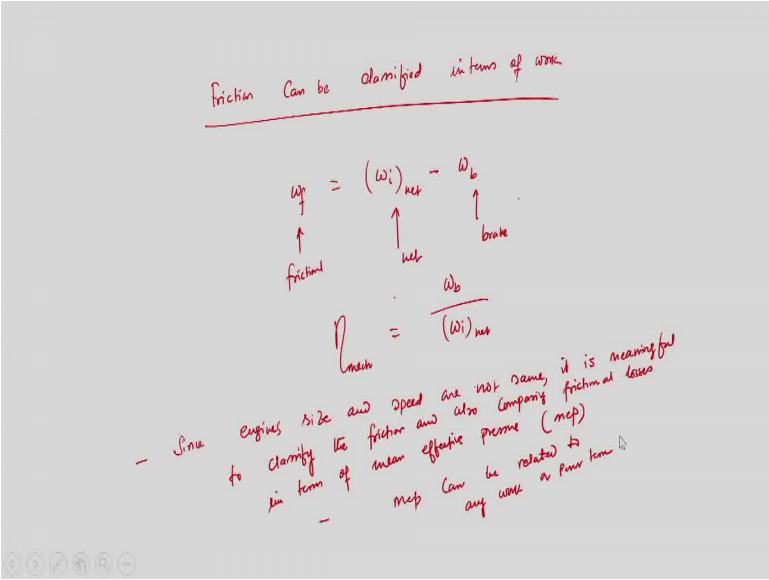

Similarly we can classify friction as a loss using a in the terms of work. So, what we can do that now we can classify this friction you know this friction can be classified in terms of work. So, we have classified friction as a loss in terms of the power. Similarly we can classify friction you know this is very important we can classify friction in terms of work in terms of work.

That is what that frictional work is equal to W i indicated net work minus the W brake so brake work. So, this is frictional, this is net, this is brake right. And since the brake power is not equal to the indicated power we had you know to define one efficiency was known as a mechanical efficiency eta mechanical that is W b by W i net right. So, that is what this mechanical efficiency was came into the picture.

So, so what I understood what we understood from this discussion is that that the power or work available on the piston phase is not equal to the brake power or brake work

because of the frictional losses. So, some portion of the work output or power is used to work on the frictional losses in an internal combustion engine. So, that is what is very important. So, and also we discussed that that engine size differ right and also they also operating a different speed engine sizes are not same and also they are operating a different speed.

So, instead of you know most meaningful. since as I said you since engine size and speed engine size and speed since engine size and speed you know engine size and speed are not same it is very important are not same it is convenient. It is meaningful it is meaningful to classify the friction it is more it is meaningful to classify friction.

And also comparing friction frictional losses in terms of mean effective pressure that is what we have discussed in terms of mean effective pressure which is mep which is known as mep. So, since engine sizes is that different engines are having different sizes and also their speed are not equal. So, it is meaningful that we should classify friction and also compare the frictional losses using the mean effective pressure mep. And this mean effective pressure this mean effective pressure mep can be related to any work or power term right.

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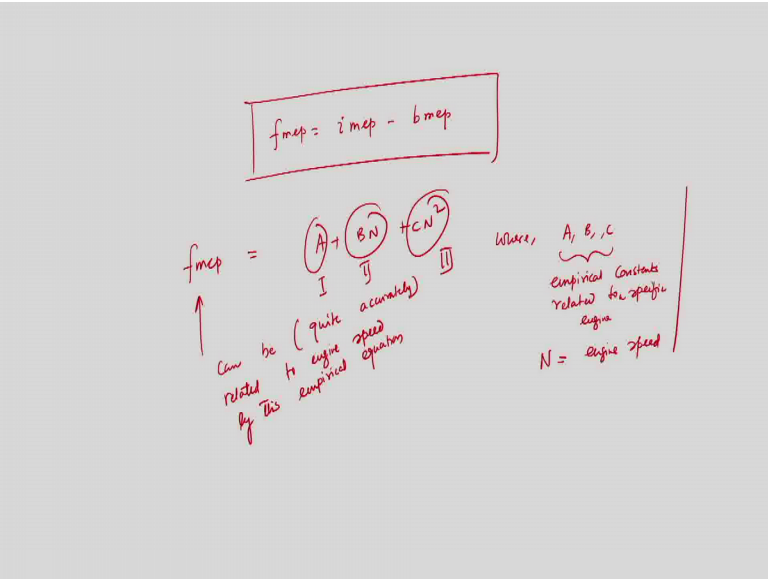

So, that is why I can write that frictional mean effective pressure is equal to indicated mean effective pressure minus break mean effective pressure. So, that is what I can write that is very important. that frictional mean effective pressure is equal to indicated mean

effective pressure minus the minus brake mean effective pressure. Because engine sizes may differ their speed may differ so definitely that power and work output will change.

So, it is very meaningful rather it is very convenient and it will be insightful to classify friction also to classify rather to you know compare the frictional losses using the mean effective pressure. So, I can write that the frictional mean effective pressure is essentially indicated mean effective pressure minus brake mean effective pressure. Now to obtain the frictional mean effective pressure need to carry out test in an internal combustion engine otherwise we cannot obtain it.

Now, but, but sometimes these frictional mean effective pressure you know can be rather can be or other quite accurately related to the engine speed by empirical relations that equal to A plus BN plus CN square. That are that is this frictional mean effective pressure can be rather quite accurately related to engine speed by this empirical equation. So, this frictional mean effective pressure can be you know written quite accumulative through this empirical relationship.

A plus BN plus CN square where ABC are constant A comma B comma C are the empirical constant. related to specific engine and N is equal to engine speed. So, this is very important that we can write that frictional mean effective pressure. We have to carry on thrust on an internal combustion engine to obtain the frictional mean effective pressures. Sometimes we can write this frictional mean effective pressure using this empirical equation which is not bad rather quite accurately.

We can represent where ABC are constant that that related to specific engine. And to A specific engine and N is equal to engine speed. So, very important now this very important that the first term. So, this is first term I this is second term II and this is third term III.

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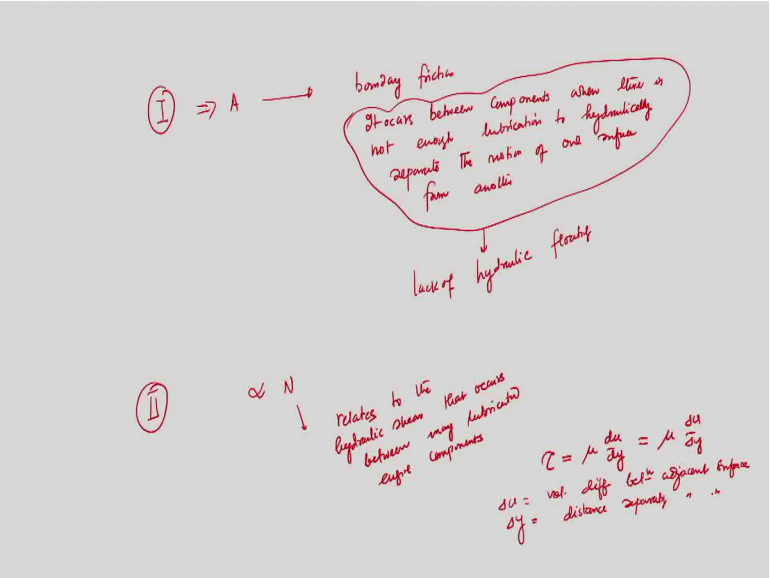

So, this first term a first term that is a it is very important is known as boundary friction this is known as boundary friction very important. So, it occurs between components. So, boundary friction and it occurs between components when there is not enough lubrication to hydraulically separate. So, there is not enough lubrication to hydraulically separate the motion of one surface from another.

So, the first term A which is the first term on the right hand side of equation that A which is known as boundary friction. And it occurs when components between components when there is not enough lubrication to hydraulically separate the motion of one surface from the other. It is very important you know that means it is very important. So, this is known as boundary friction this indicates that we are having lack of hydraulic floating.

So, this indicates lack of hydraulical in lack of hydraulic floating. So, when we have lack of hydraulic protein and this is known as boundary friction and that occurs piston rings cylinder wall interface at TDC or VDC. This is normally occurs you know piston ring and wall interface at TDC and VDC when there is no enough lubrication to separate the motion rather lack of motion of one surface from another that is lack of hydraulic floating.

And II is very important second term that is that is B into N that we written is proportional to the engine speed. So, the second term which is proportional to the engine speed we have identified and relates the hydraulics shear that occurs between lubricated

engine components. And this relates second terms which is proportional to the engine speed. So, second term is proportional to the engine speed that relates proportional engine speed and it relates to the hydraulic shear that occurs that occurs between many lubrication engine components many lubricated engine components.

So, this is basically so because we know that tau is equal to mu du dy therefore, equal to mu in to delta u by delta y. So, this is the velocity gradient between the surface and rather velocity difference between the adjacent surface delta u velocity difference between adjacent surface and delta y distance separating adjacent surface. So, this is very important.

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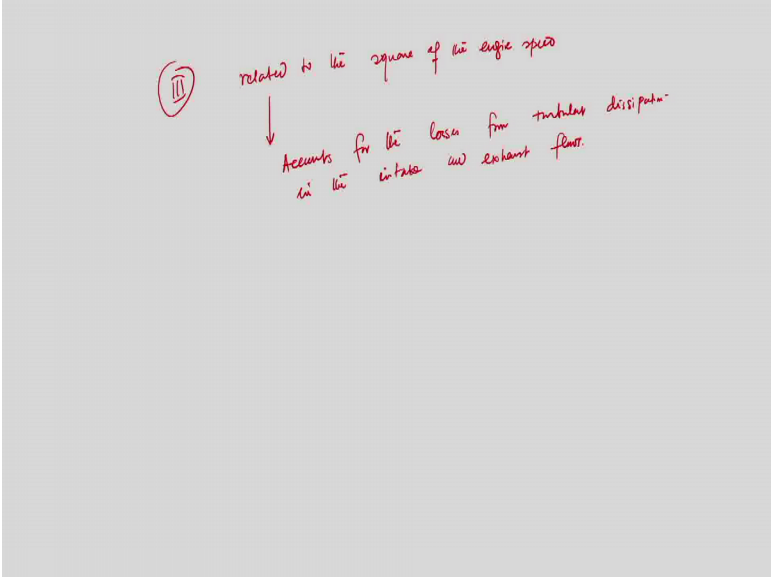

And third term is very important the third term which is you know you know third term is related to engine speed. So, it is related to the square of the engine speed right. And this term accounts for the losses for from turbulent dissipation in the interconnect exhaust flows. So, this term accounts for the losses results a losses from turbulent dissipation in the intake and exhaust flows in the intake exhaust flows right.

So, we have identified three different term. Third term is related to sqaure of the engine speed which accounts the losses because of the turbulent dissipation in the intake and exhaust flows. Second terms relates the hydraulics shear between the that occurs between the many lubricating engine components. And first part which is only because of lack of hydraulic floating. So, today we have discussed about the friction what is the definition

of friction from where from where it comes for from where it comes in the context of engine operation.

And we have identified by how we can reduce the friction, but we cannot make it zero. Then we need to have lubricating system; if we have a lubricating system by how it can reduce the frictional effect and what should be the important characteristics of the lubricating system that you have discussed.

And finally, we have discussed that friction can be classified in terms of work and also in terms of power and we have expressed friction through an empirical relationship which essentially depends upon the three important constant and the engine speed. So, with this I stop here today and I will continue our discussion in the next class.

Thank you.