Refrigeration and Air-conditioning
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Lecture No. # 44
Transmission and Distribution of Air

Welcome back in this lecture I shall discuss transmission and distribution of air so the specific objectives of this particular lecture are to present.

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Equations for estimating fan total pressure and fan power to estimate friction loss and circular and rectangular ducts to estimate dynamic losses through bends branch takeoff and entry sudden expansion and contraction to discuss static regain factor. And finally to discuss requirements and general rules in duct design at the end of the lecture.

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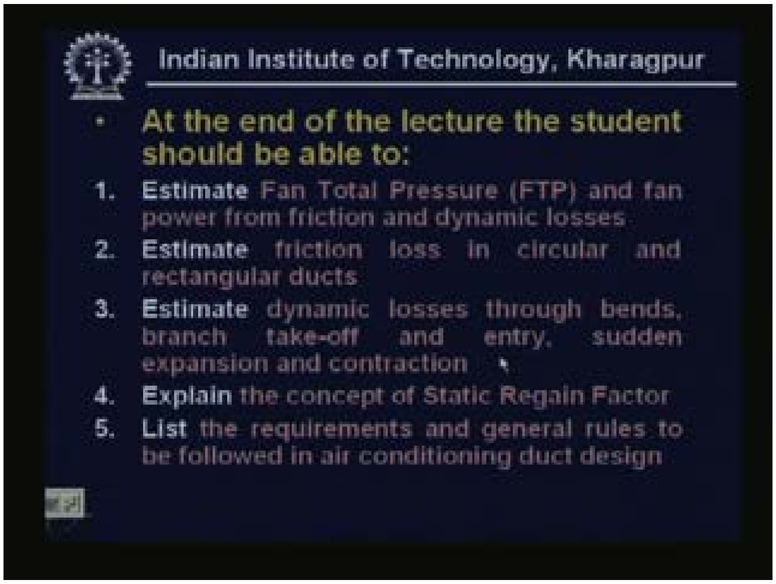

You should be able to estimate fan total pressure and fan power form friction and dynamic losses estimate friction loss in circular and rectangular ducts estimate dynamic losses through bends branch take off and entry sudden expansion and contraction explain the concept of static regain factor. And finally list the requirements and general rules to be followed in air conditioning duct design. So let me give a brief introduction.

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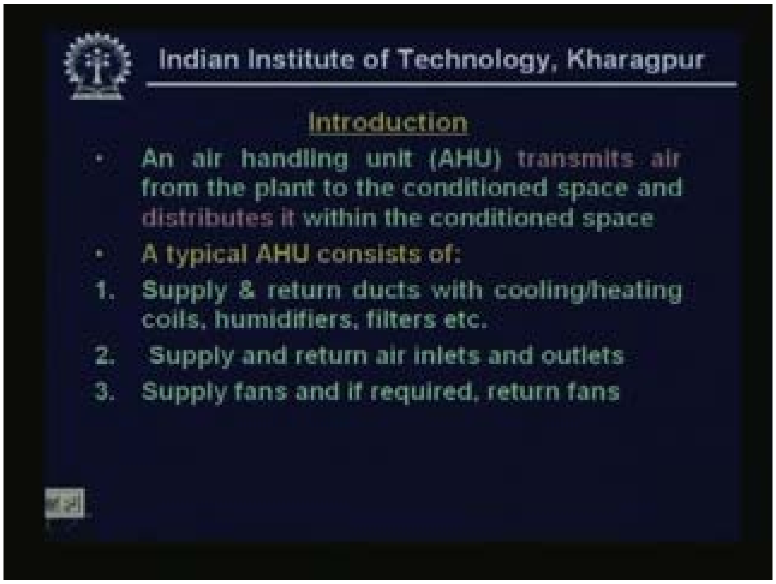

An air handling unit commonly called as AHU transmits air from the plant to the conditioned space and distributes it within the conditioned space. So it plays a major role in any air conditioning system the AHU a typical AHU consist of supply and return ducts with cooling and or heating coils humidifiers filters etcetera. It also consist of supply and return air inlets and outlets it also consists of supply fans.

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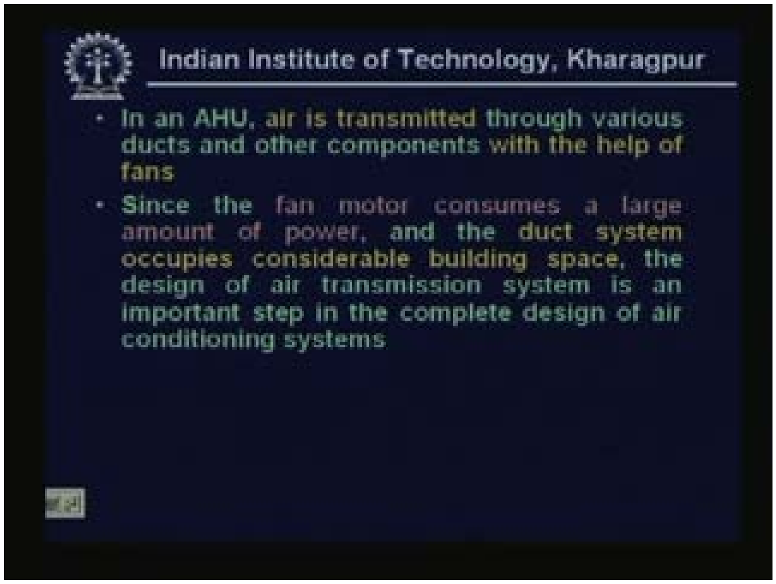

And if required return fans in an AHU air are transmitted through various ducts and other components with the help of fans we need fans to distribute and transmit the air. Since the fan motor consumes a large amount of power and the duct system occupies considerable building space the design of air transmission system is an important step in the complete design of air conditioning systems in order to design the system for transmission of air it is important to understand the fundamentals of fluid flow basically here the fluid means air through duct and various components of the duct.

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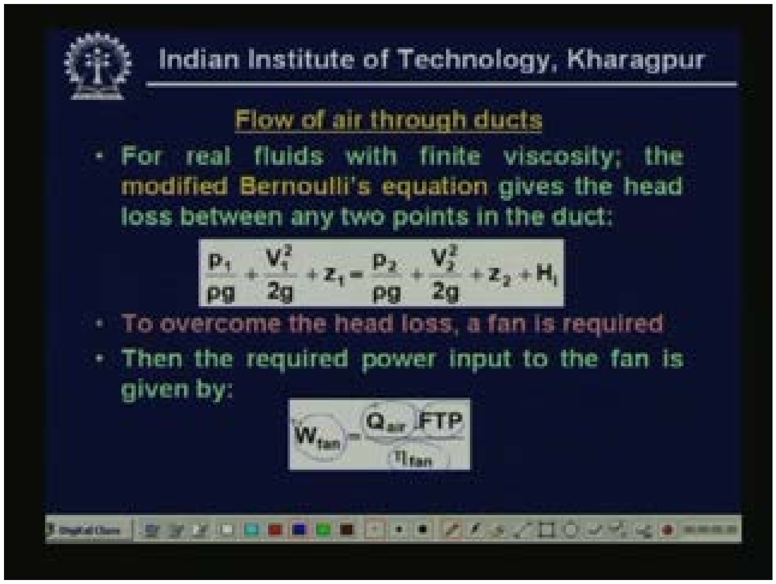

So let look at the equations these aspects I have discussed while discussing the fundamentals of fluid flow. So I assume that you still remember those things so straight away I go to the governing equation which is called as modified Bernoulli equation you must remember the assumption under which the Bernoulli equation is valid okay. So from for real fluids with finite viscosity the modified Bernoulli's equation gives the head loss between any two points in the duct okay. Any two points one and two the head loss is given by this equation p one by rho g plus V one square by two g plus z one is equal to p two by rho g plus V two square by rho g two g plus z two plus Hl where Hl is the head loss here all the units or example, if you remember, is known as static head this is your velocity head this is head due to elevation okay. Similarly this is the static head at point two this the velocity head at point two this is the head due to elevation at point two and Hl is the loss okay.

As the fluid flows from one point to the other and here we call it head if you remember because all these parameters have units of length okay. That means everything in meters if you are using SI units and to overcome the head loss a fan is required because you can see that there is a loss of head because the viscosity. So if you want the fluid to flow then a fan is required and when you use the fan you have put in some work input and the required power input to the fan is given by this equation W subscript fan is equal to Q dot air into FTP divided by eta fan where this is the power input in, let us say watts an dQ dot air is the volumetric flow rate of air in meter cube per second and FTP is what is known as fan total fan total pressure in Pascal’s and eta subscript fan is the efficiency of the fan. So if you know the volumetric flow rate of air and if you can estimate the fan total pressure FTP and if you also know the efficiency of the fan then you can find out what is the total power requirement to run the fan okay.

So this is one of the important objectives because you have to finally select a fan and you also have to find out how much power is required to run the fan okay. Because you have to you have to select a suitable fan motor okay so what is this FTP how do we find FTP?

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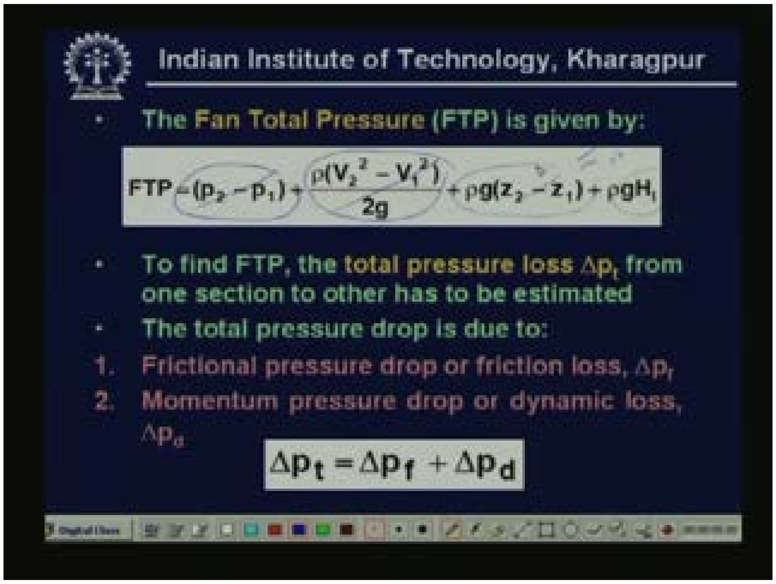

The fan total pressure FTP is given by this equation FTP is equal to p two minus p one that is the static pressure difference between point two and one okay. So rho V two square minus V one square by two g this is nothing but the velocity pressure difference of velocity pressure between point two and one and finally difference of elevation pressure between point two and one in most of the air conditioning calculations this parameter is negligible okay. Only in special cases this may have some effect otherwise it is normal negligible okay. So basically we have to deal the change in velocity pressure change in static pressure and finally the head loss okay. Pressure loss due to friction and other factors if in the duct, let us say that the initial inlet static pressure is same as the outlet static pressure. Then this becomes zero because p two is equal to p one and if you are using a uniform cross section duct then V one will is equal to V two if air behaving as incompressible fluid then this factor also becomes zero. Then you find that the fan total pressure is nothing but the pressure drop due to friction and due to other factors okay. So to find out FTP ultimately you have to find out the head loss okay. So that is what is mentioned here.

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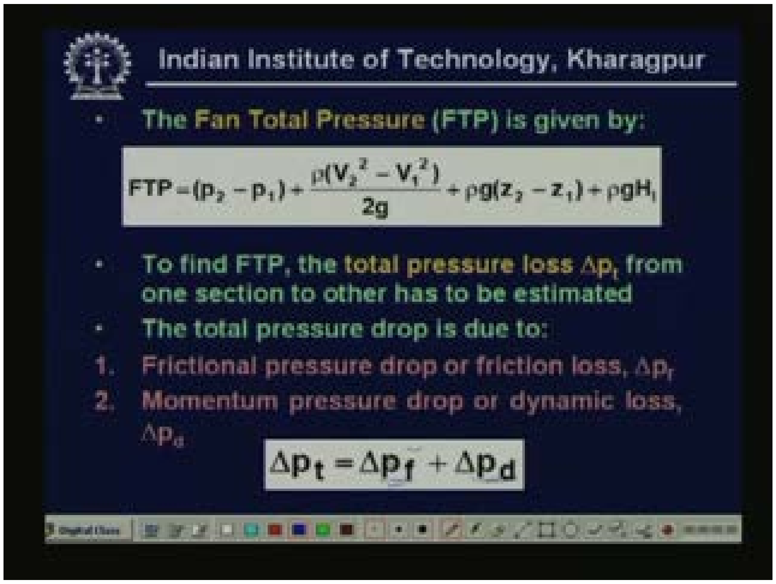

To find FTP the total pressure loss delta Pt from one section one to other section, let us say two as to be estimated so you have to find out what is the total pressure loss and the total pressure drop or pressure loss is due to two factors. The first factor is because of frictional pressure drop commonly called as friction loss delta p subscript s and the second factor is momentum pressure drop or also known as momentum pressure drop or also known as dynamic loss delta p subscript d. So find that total pressure drop delta p subscript t is equal to delta p subscript f frictional loss plus dynamic loss okay. So if want to find out this we have to first find out what is the friction loss what is the dynamic loss and if you add up you find the total pressure loss. So let us look at the estimation of friction loss.

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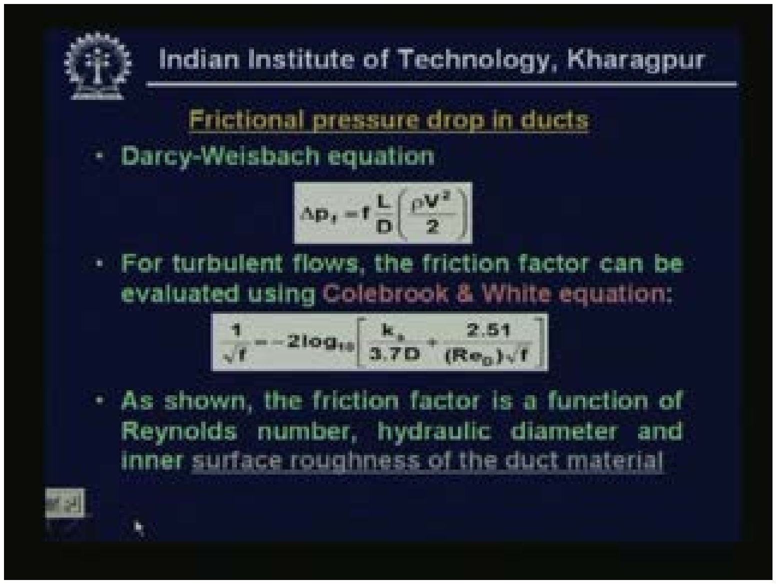

Frictional pressure drop in ducts is commonly given commonly this Darcy-Weisbach equation this equation relates the frictional pressure drop delta p subscript f with the velocity pressure rho V square by two friction factor f length of the duct L and diameter of the duct D. If you are using a circular duct then this is the diameter of the duct if you are using a noncircular duct we have to us e an equivalent or hydraulic diameter okay. So here V is the velocity of the air rho is the density and F as I said is the friction factor okay.

And for turbulent flows the friction factor can be evaluated using Colebrook and white equation. Of course you can use several equations depending upon the type of flow so most of the time in air conditioning ducts the air flow of turbulent in nature okay. So you have to use correlations for turbulent flow okay. For turbulent flow there are several correlations in fact I have discussed these correlations while discussing the fundamentals of fluid flow okay. So the most popular equation is what is known as Colebrook and White equation that is what is given here okay. So you can see the Colebrook and White equation where f is the friction factor Ks is the surface roughness of the duct or the, and D is the diameter of the duct and Re subscript D is nothing but the Reynolds number based on the diameter.

So if you know the Reynolds number and if you know the surface roughness you can find out what is the friction factor obviously Reynolds number depends upon the flow rate diameter density viscosity etcetera. So you know the definition of that one thing you can observe from this equation Colebrook and White equation is that the friction factor appears on both sides both left hand side as well as right hand side okay. So if you know the absolute roughness K subscript S and Reynolds number Re subscript D then you have to use the trial and error method to find out the friction factor f okay. And as shown the friction factor is a function of Reynolds number hydraulic diameter and dinner surface roughness of the duct material here k subscript s. Let me show typical surface roughness of typical duct materials.

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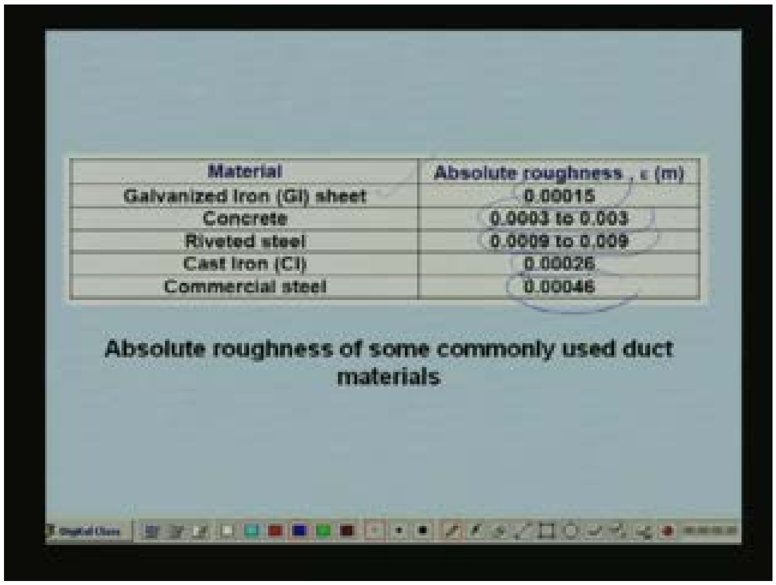

This table shows the absolute roughness of some of the material which are commonly used in air conditioning ducts first one is galvanized iron or GI sheet so it as a surface roughness of point three zeros one five meters this is most widely used okay. Sometimes concrete is also used so concrete as a surface roughness which vary from point zero zero three to point zero zero three meter and riveted steel has this roughness cast iron has this roughness and commercial steel has this roughness. So these are the material which are traditional used in various types of air conditioning ducts however now a day's people also use other materials like fiber plastics and people also use aluminum etcetera, okay. They have certain other advantages. So when you are using these materials like aluminum or fiber you have to use appropriate surface roughness okay.

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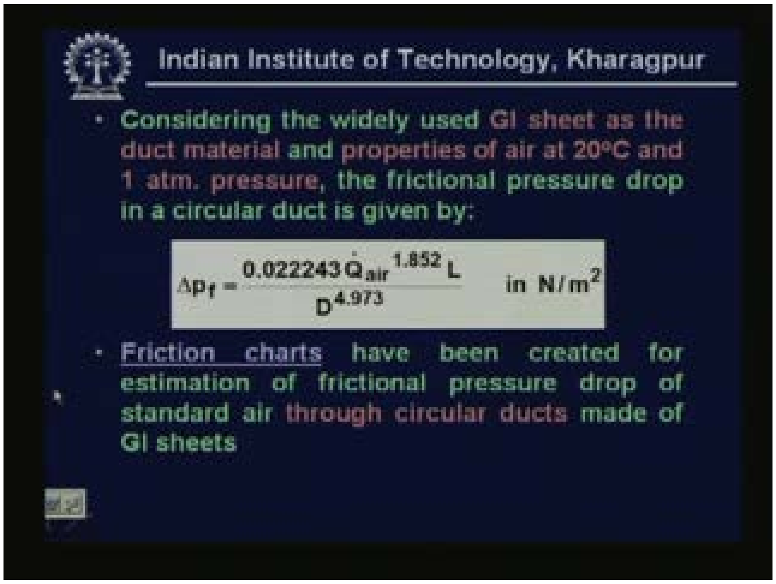

Now what is dine normally is as I said the GI sheet is most widely used so taking GI sheet as the duct material and properties of air at twenty degree centigrade and one atmospheric pressure the frictional pressure drop in a circular duct is expressed by the following equation delta Pf is the frictional pressure drop in Newton per meter square or Pascal. This is given by point five two two two four three q air to the power of one point eight five to into l divided by D to the power of four point nine seven three. Here as I said Q air is the volumetric flow rate of air meter cube per second and L is the length of the duct in meters and D is the diameter of the duct in meters. So this equation is valid only for circular ducts okay, and this valid strictly for GI sheet material and for air at twenty degree centigrade and one atmospheric pressure and using this kind of an equation friction charts have been created for estimation of frictional pressure drop of standard air through circular ducts made of GI sheets okay. Standard friction these are called as standard friction charts let me show one typical friction chart.

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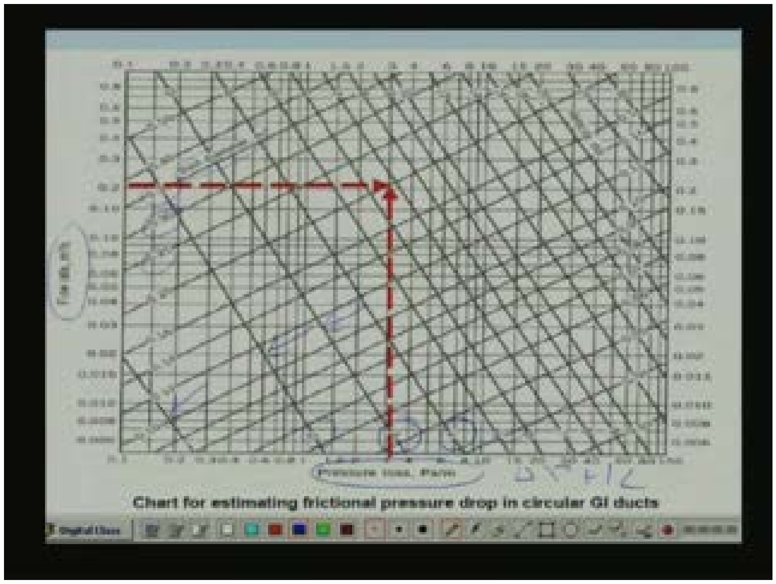

So these shows a chart for estimating frictional pressure drop in circular GI ducts here on the x axis you have pressure loss per unit length that is delta Pf by L okay. Pressure drop per unit length and on the y axis you have the flow rate in meter cube per second okay, and you also have constant duct diameter lines these are the duct diameter lines. For example point three five point three point two five these are all the duct diameters you also have the velocity constant velocity line these are the constant velocity lines okay. For example this one has two meter per second three meter per second four meter per second five meter second per second like that okay.

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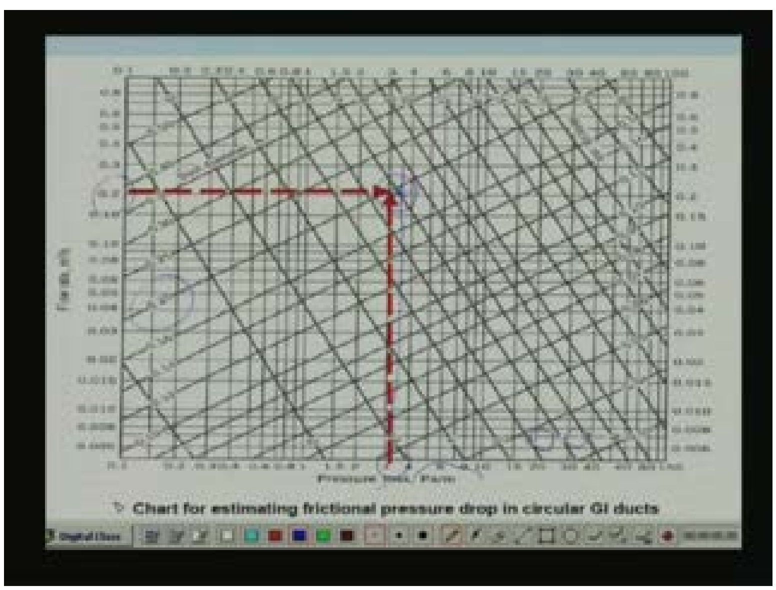

So using these friction chart standard friction chart you can find out the required parameters if any two parameters are known any two parameters out of flow rate duct diameter and pressure loss. For example let us say that I would like to design a duct for a flow rate of point two meter cube per second and I would like to have a frictional pressure drop of three meter per three Pascal per minute okay. So that means I am fixing the frictional pressure loss per unit length and I am also fixing the flow rate then you can see that you have to choose these two lines if you draw a vertical line this and a horizontal line like this they intersect at this point and this point the required diameter is point two meters okay.

So that means for this flow rate and for this particular frictional pressure drop I have to use a circular duct of diameter point two and at this point you can also find out velocity. For example at this point the velocity lies between this line and this line. That means between six and seven meter per second so by interpolation you can find out the velocity at that point okay, you can also do this problem in a different way. Let us say that you are fixing the diameter of the duct and you fix the flow rate then you can find out what is the friction pressure. So if you know any two out of these three you can find out the third parameter. o this is very useful and is a very commonly used in air conditioning duct design.

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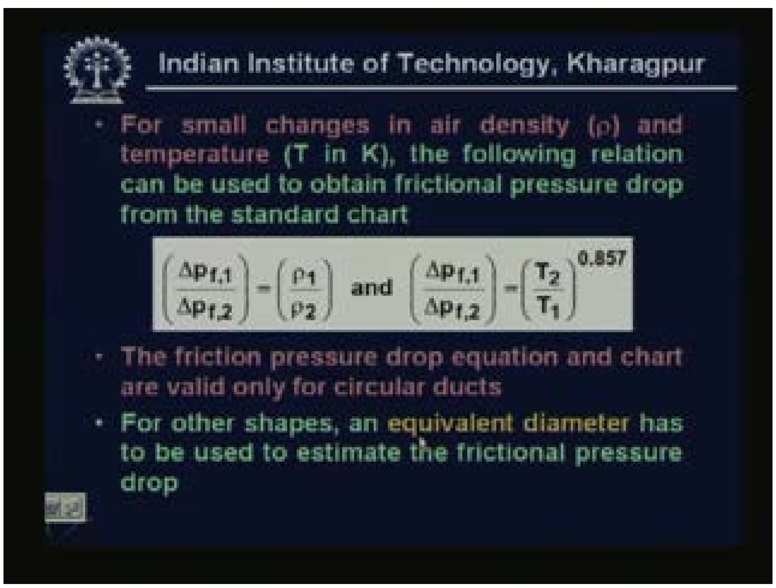

As I said these are valid for circular ducts only okay.

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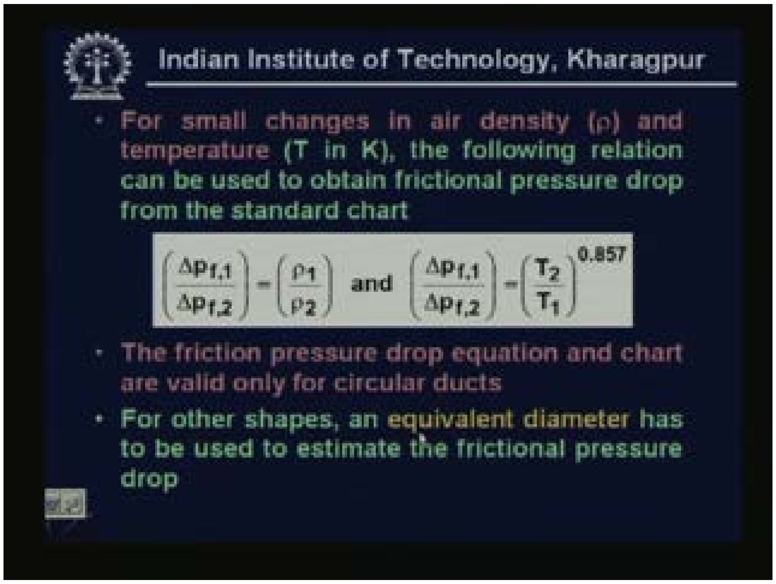

And for air at standard conditions what happens if air is not at standard conditions as I said the friction chart is valid for air at twenty degree centigrade and at one at atmospheric pressure. But you may have a condition where the air is not at twenty degree centigrade. But it is at some other temperature. Let us say ten degree centigrade and the pressure is not atmospheric but something else okay. Then I would like to estimate the friction loss for this new conditions okay at different temperature and different pressure because of different temperature and pressure the densities will be different okay. So if you take, let us say condition one as a refers condition that means twenty degree centigrade and one atmospheric pressure and condition two as the actual condition. That means ten degree centigrade and some other pressure and I want to find out what is the friction pressure loss at the off design conditions okay. Then you can use the simple equation given here which is valid for small changes in air density and temperature okay.

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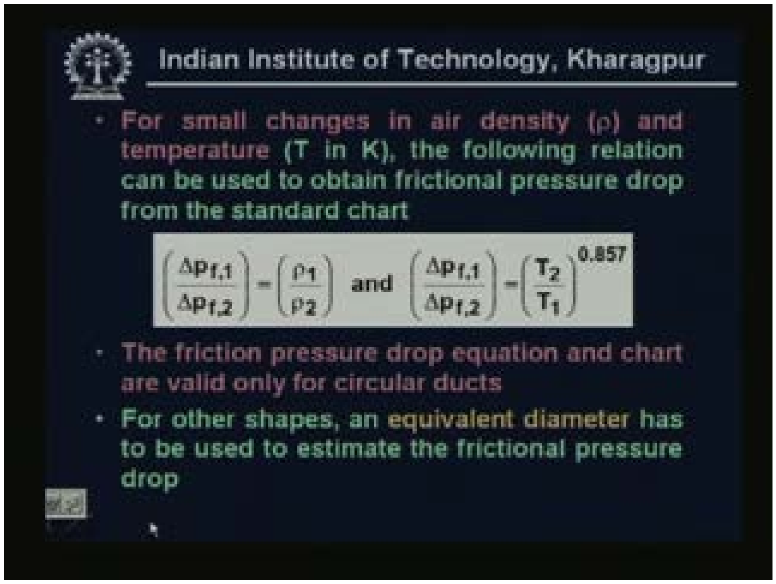

So the relationship is like this for variation density delta pf one divided by pf two is simply equal to rho one by rho two that means delta pf is directly proportional to density. So if I know pf one and the density rho one and if I also know the density at off design actual condition rho two then I can find out what is the friction loss okay. From the standard friction loss delta pf one similarly the relationship between the friction loss and temperature is given by this equation it is inversely proportional to the absolute temperature to the power of point eight five seven okay. If I know this, and this, and I can find out what is the friction pressure loss at a different temperature okay.

And these are generally valid for small temperature changes and small changes in air density which is an actual case in an air conditioning duct okay. You do not come across very large temperature changes the friction pressure drop equation and chart. As I have said are valid only for circular ducts okay, for other shapes for example for rectangular duct or for square ducts an equivalent diameter has to be used to estimate the frictional pressure drop okay. let us see how to do this.

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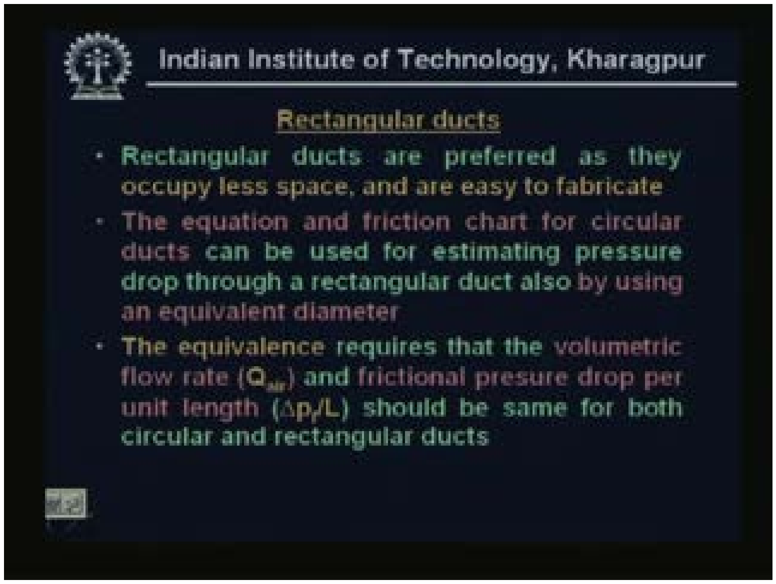

First of all let us look at non circular ducts the most widely used duct geometry is that of rectangular duct okay. Why rectangular duct is most widely used, because these ducts are preferred as they occupy less space because they match with the building. For example if you have a flat roof then a rectangular duct matches with a flat roof better than a circular duct okay. So that the reason that is one reason why rectangular ducts are referred a second reason is that it is easier to fabricate rectangular ducts out of sheet metals compared to a circular duct okay. So the fabrication is also easy because of these two reasons rectangular ducts are most widely used however some performance point of view that means from friction loss point of view a circular duct is the best circular duct is not used because of other consideration not because of performance.

Since a square comes closest to the circle at as far as possible the rectangle should be as close to square as possible okay. So narrow rectangles are not preferred, so since the rectangular ducts are most widely used we could like to find out what is the friction losses in rectangular ducts the equations and friction charts for circular ducts can also be used for estimating pressure drop through rectangular ducts by using an equivalent diameter okay. So if you use an equivalent diameter in place of the circular diameter then you can use the same charts and equation that you have used for circular ducts what do you mean by equivalents here the equivalents requires that the volumetric flow rate and frictional pressure drop per unit length should be same for both circular and rectangular ducts okay. So this is the condition for equivalents so if you apply the condition.

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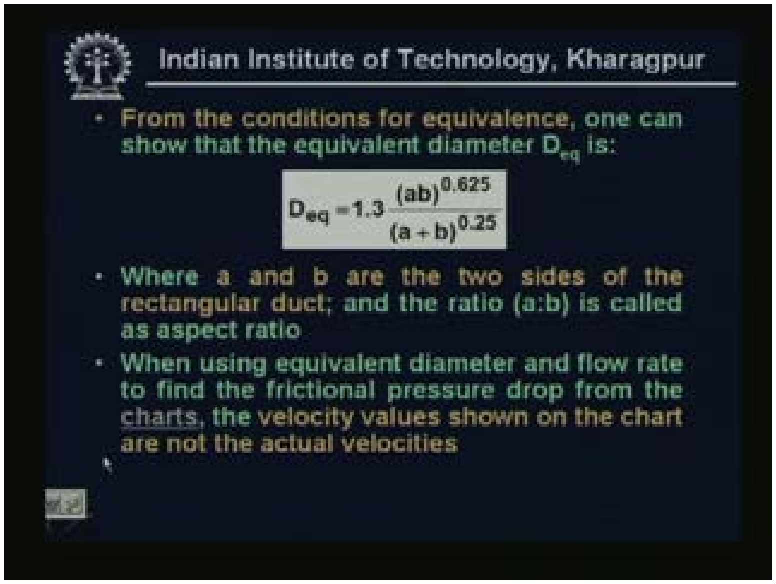

For equivalents you can easily show that the equivalent diameter D subscript eq of a rectangular duct is given by this equation D subscript eq is equal to one point three into ab to the power of point six two five divided by a plus b to the power of point two five where a and b are the two sides of the rectangular duct okay. So they are the two sides and the ratio a, is to b is called as aspect ratio right. So if you know the two sides of the duct then you can find out the equivalent circular diameter circular duct which will give the same volumetric flow rate and also the same friction loss okay. That is the, that, what you have to keep in mind and when using equivalent diameter flow rate top find the friction pressure drop from the charts the velocity values shown on the chart are not the actual velocities okay.

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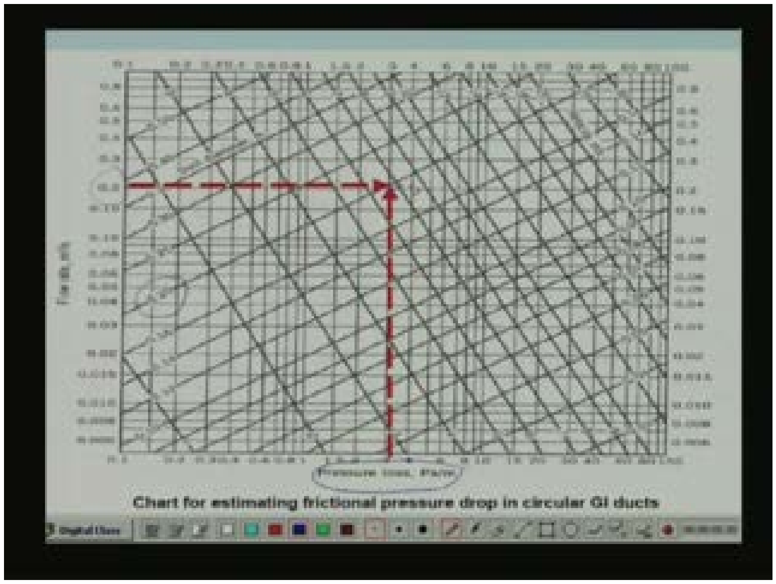

For example let me show the let us say that as I mentioned earlier this is valid for circular duct this particular friction charts standard friction chart okay. And I have a flow rate of point two meter cube per second same earlier. Example and I have a pressure loss three Pascal per meter okay, and I am using a rectangular duct. So the rectangular duct should have a equivalent diameter of point two okay, because this is where the two lines intercept. So I should have a rectangular duct which has an equivalent diameter of point two which I can get from this standard chart but the actual velocity will not be between six to seven meter per second. So you cannot use the velocity values that you obtain from the chart you can use only the equivalent diameter values from the chart okay.

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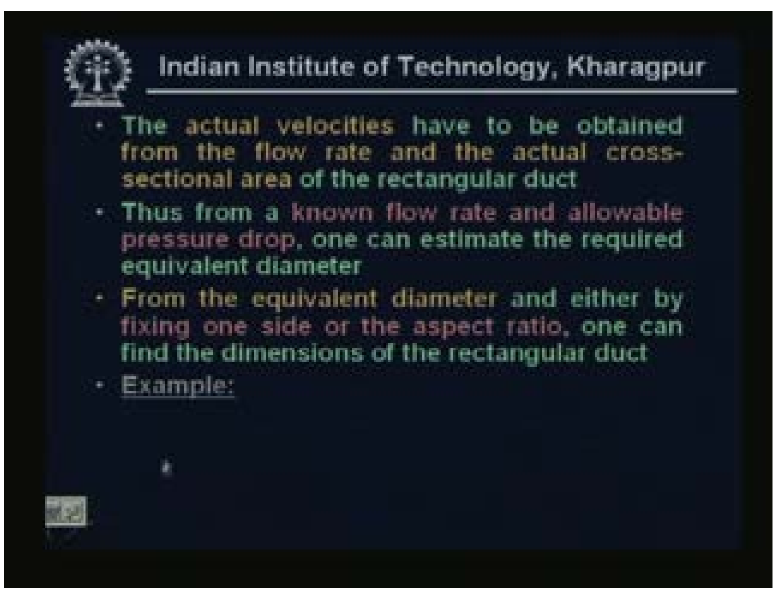

Then how do you find the actual velocities? The actual velocities can be found very easily from the flow rate and the actual cross section area of the rectangular duct if you know the volumetric flow rate then you divide the volumetric flow rate by the cross section area that is nothing but a into b then you get the actual velocities this actual velocity will not match with the velocity obtained from the chart. Thus from a known flow rate and allowable pressure drop one can estimate the required equivalent diameter as I have already explained from the equivalent diameter and either by fixing one side of the aspect ratio one can find the dimensions of the rectangular duct okay. So if you have to fix one more parameter either one side or the aspect ratio then you can find out the dimensions of the rectangular duct let me show a simple example.

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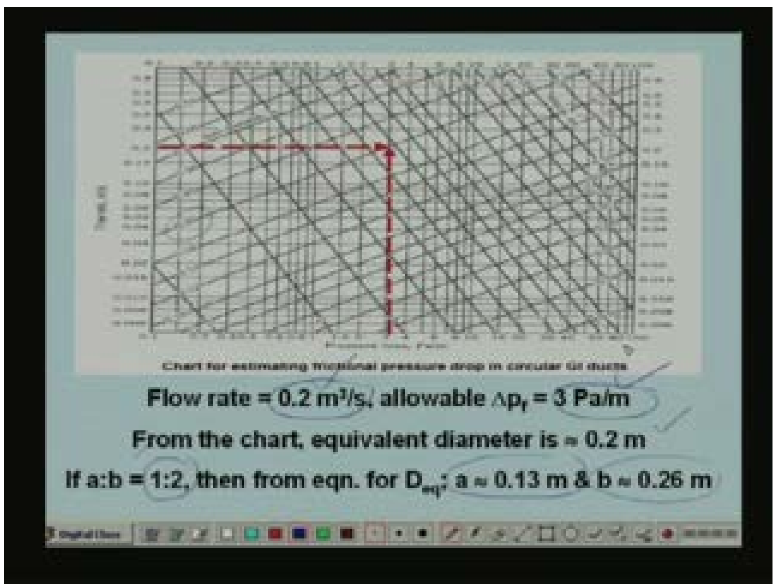

Again I use the same data that means I have to design a duct which has a flow rate of point two cube per meter second and the allowable pressure drop is three Pascal per meter right. So from this chart I find that the diameter of an equivalent circular duct is point two meter okay. So, and from the equation and, I am also fixing the aspect ratio here that means I fix that the ratio of a, is to b is equal to one point one is to two. So from this diameter value and this aspect ratio one is to two if i use the equation for equivalent diameter I can easily find out that the value of a is point one three meter and value of b is point two six meter. So the rectangular duct having one side of point one three meter and the other side of point two six meter will give me this flow rate and this pressure loss per unit length okay. So that is how you can easily find out the dimensions of the rectangular duct.

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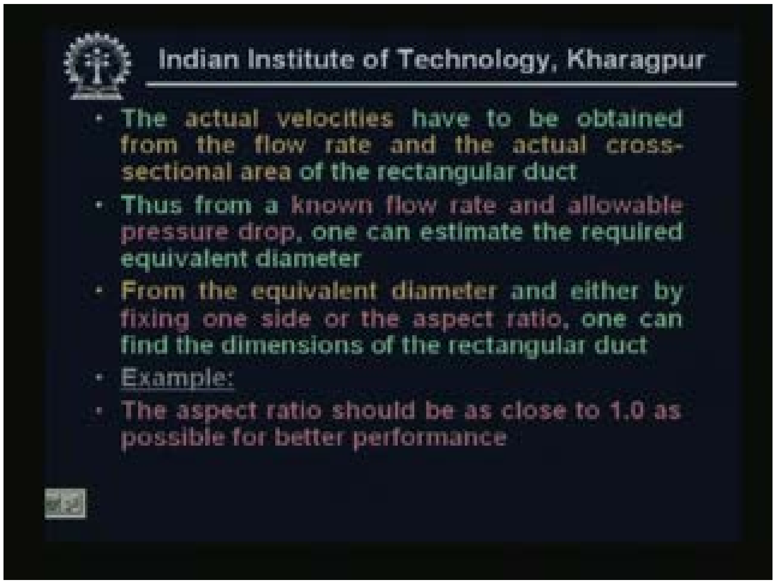

And as I have already mentioned the aspect ratio should be as close to one as possible for better performance okay, aspect ratio one means it is a square okay, the cross section is square in nature right. So it should be as close to one as possible and the equation for equivalent diameter that I have given the previous line is valid for an aspect ratio of one is two eight okay, less than or equal to one is to eight it is not valid the aspect ratio is greater than one is to eight or it will give large error if you are using it for large aspect ratios and in air conditioning ducts. Normally you ever come across a duct having aspect ratio greater than one is two eight okay.

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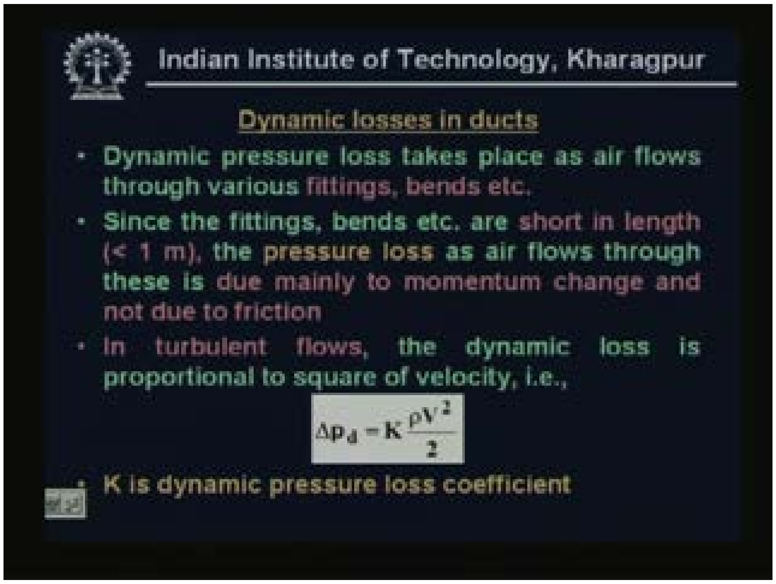

This is as far as the estimation of friction loss is concerned okay. So once again I will. I would like to repeat whatever I have said. First you have find out the friction loss for the finding out the friction loss normally the flow rate is known and the length of the duct is generally known okay. From the location of the inlets and outlets etcetera. Then if you are using a circular duct straight away you can use a friction chart or the equation and you can find out the, what is friction pressure drop per unit length okay. So if know the length and you can find out the total friction pressure drop if you are using a rectangular duct then first you have to fix either one side or the aspect ratio and then you have to fix the allowable pressure drop and from the allowable pressured drop and from the flow rate you can find out the equivalent circular duct diameter and then using the equation for equivalent circular diameter and either the aspect ratio or one side you can find out the other side okay. So that is how we can find out the frictional pressured drops. Now let us look at the estimation of dynamic pressure losses.

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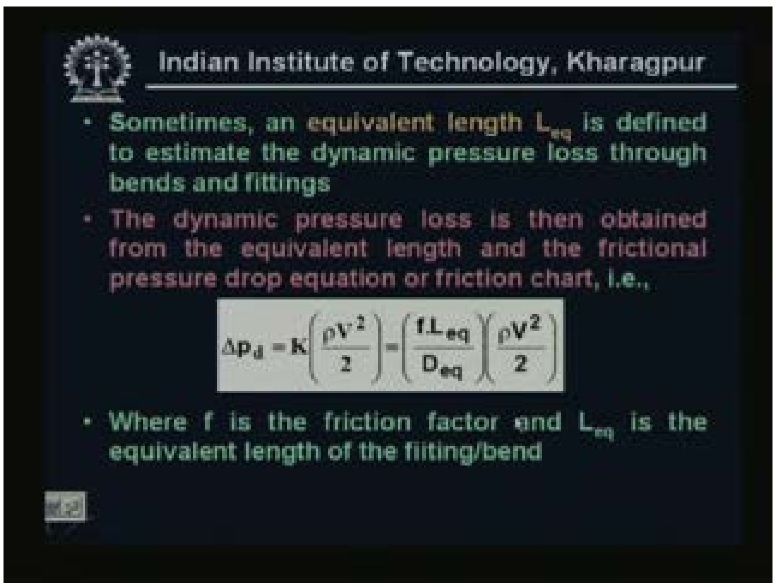

First of all where do we encountered dynamic pressure losses? Dynamic pressure loss takes place as air flows through various fittings bends etcetera in a typical air conditioning duct we use a large number of fittings bends etcetera. For example you may have to bend the duct by ninety degrees by sixty degrees by thirty degrees depending upon the construction of the building and depending upon the duct layout. So air as to take a turn right whenever there are bends in addition to the bends you may have to enlarge the duct at some points you may have to reduce the cross section area of the duct at some other points okay. So that air alpha under goes expansion or contraction okay. Because of the change in the cross section area of the ducts.

So the these enlargements or contractions and in the bends the air undergoes additional losses okay these losses are known as dynamic losses and these are also known as moment losses because here the pressure loss is because of the change of the momentum okay. Momentum changes because air, because, as that it changes its velocity or changes its direction okay and normally the fittings, for example bends sudden enlargement or concentrations etcetera or short in length because your rarely the length of these fittings exceed one meter.

Since the length is small you find that the pressure loss in these fittings is mainly due to momentum change and not because of frictional losses okay. That means major pressure loss is because of momentum not because of friction and in turbulent flows it is absorbed that the dynamic loss is proportional to square of actually velocity pressure or square of velocities. So that is given by this expression here this is the dynamic pressure drop or dynamic loss which is proportional to velocity pressure rho v square by two okay. And the proportionality constant k is known as dynamic pressure loss coefficient right.

So if you know the dynamic pressure loss or loss coefficient and if you also know the velocity pressure then we can easily estimate the dynamic loss of course the major problem or major task is to estimate the dynamic pressure loss coefficient okay. So once you estimate that you can find out the dynamic loss. So let us look at how to estimate the dynamic pressure loss coefficient for various types of bends and fittings and sometimes what is done is an equivalent length L subscript eq is defined to estimate the dynamic pressure loss through bends and fittings. That means what is done is if you have, let us say a ninety degree bend okay. The ninety degree bend is equated to the pressure loss that takes place in a straight duct of the same diameter. But which has an equivalent length, okay that means one bend. Let us say that I say that one ninety degree bend is equal to twenty meters of straight duct right. So these twenty meters is what is known as equivalent length of the fitting okay.

So once I know the equivalent length then I can use the friction charts okay standard friction charts as a friction equation to find out the dynamic loss okay. That means I am expressing the dynamic loss in terms of a friction loss by using an equivalent length the equivalent length obviously depend upon the momentum change and dynamic loss due to momentum change etceteras okay. That is shown here in this equation.

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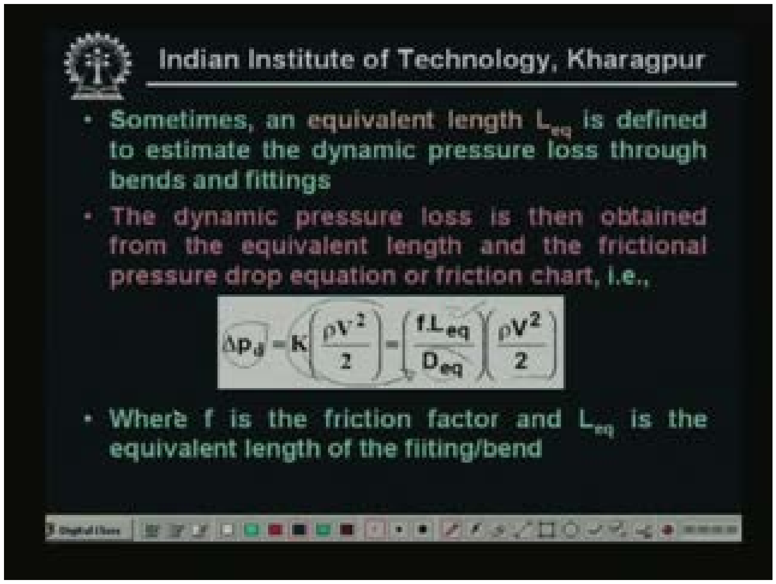

The dynamic pressure loss is in obtained from the equivalent length and the frictional pressure drop equation or friction chart for example the dynamic pressure loss which is actually given by K into rho v square by two. And it is expressed as f into L eq L equivalent divided by D equivalent multiplied by your velocity pressure rho v square by two. So we can see that from these two equations the dynamic loss coefficient K is equal to friction factor multiplied to the equivalent length divided by D equivalent length. So if somehow if I know what is the equivalent length then I can use the friction charts to estimate the pressure drop due dynamic losses also okay.

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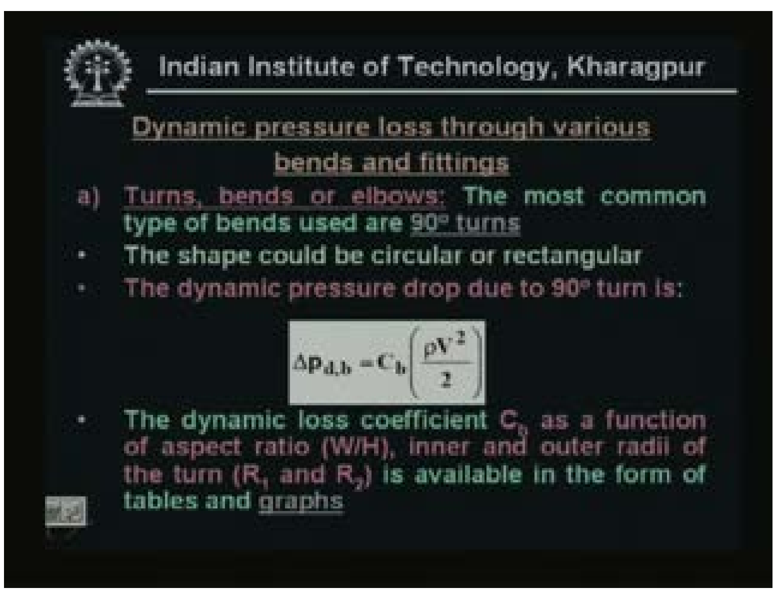

Now let us look at some individual fittings and bends and see how to estimate that dynamic pressure loss first let us look at the most common type of bend that is known as ninety degree turn. So dynamic pressure drop due to turn bends or elbows sometimes it also called as elbows and as I said the most common type of bend is used as is a ninety degree bends okay.

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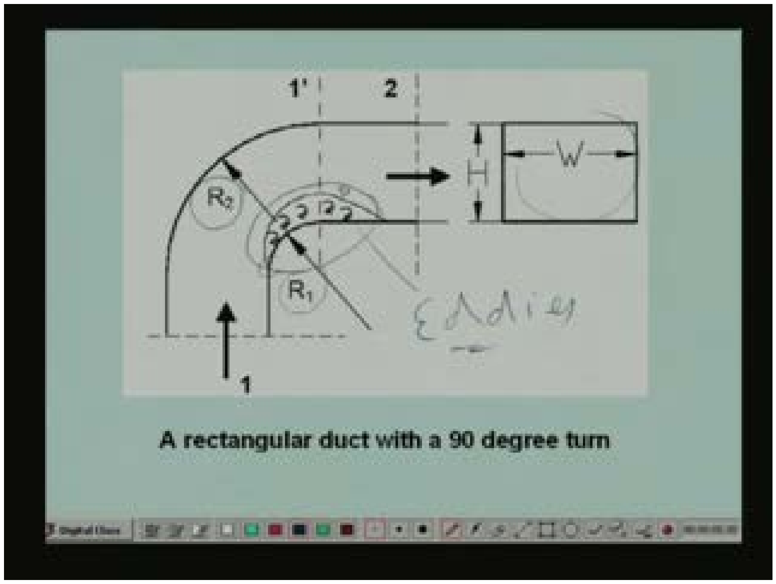

So this is what is shown here so this is called as a ninety degree bend because this angle okay. This ninety degrees so air enters like this okay then it takes a turn a ninety degree turn and leads a duct like this okay. So you have to for example I have a duct okay, and I have to suddenly change the dimension direction of the duct that the air as to come like this and it has to go this way then I have to use this kind of a fitting here okay. So that air can come like this take a turn and go this side and this is where the dynamic pressure drop takes place because air is changing its direction okay. Air may not be changing its velocity but it changes its direction okay. And you can see from this picture that a ninety degree bend is specified in terms of the inner diameter inner radius r one and the outer radius r two okay. Normally you do not have a sharp bend here. So you have to provide some radius here and some radius here and what happens actually is that as the air takes a turn here boundary layer separation takes place okay. It starts somewhere separation starts somewhere and boundary layer separates and as a result you have a reason okay. Where eddies are formed okay because these eddies the dynamic pressure losses take place right. So the pressure here will be lower than the pressure at this point right and here I have shown a rectangular cross section but you can also have a circular cross section okay. You can have any cross section right this is what is known as ninety degree turn and we would like to find out what is the dynamic pressure loss as the air flows from point one to two okay.

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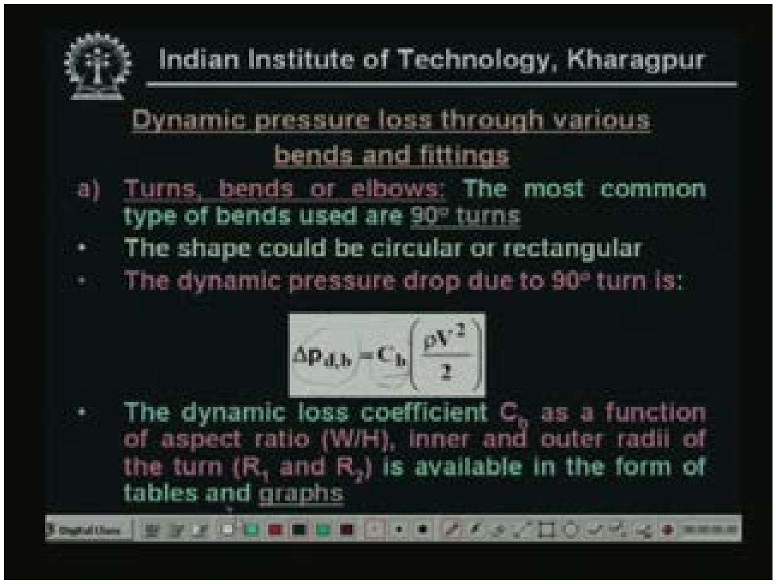

And the dynamic pressure drop due to ninety degree turn is expressed by this equation delta p d d stands for dynamic pressure loss and b stands for bend okay. So these are general equation this is valid for not necessarily ninety degree turn it is valid for any degree turn okay. And Cb is what is known is dynamic loss coefficient due to the bend right rho v square by two as you know is the velocity pressure v is the velocity and for ninety degree bend the dynamic loss coefficient Cb is expressed as the aspect ratio W by H and inner and outer radius of the turn r one and r two and it is also available in the form of tables and graphs okay. let me show a typical graph.

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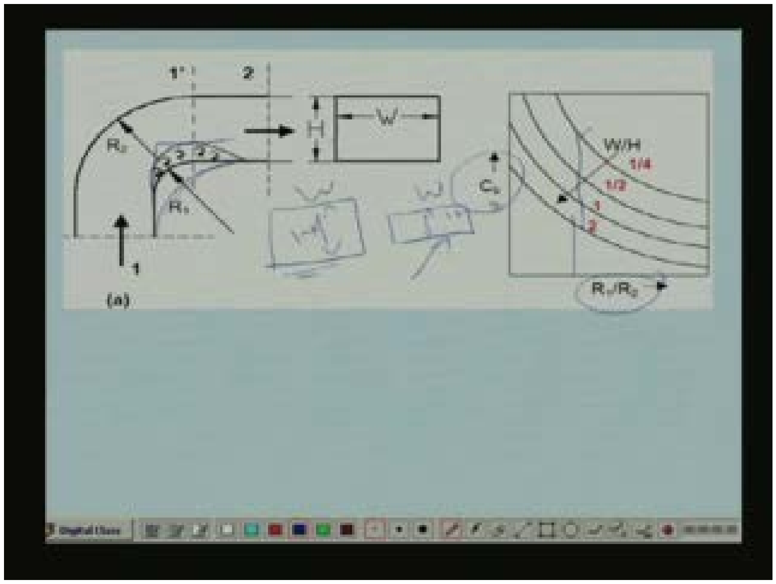

Okay, so as I said this is your ninety degree bend and here the dynamic loss coefficient Cb okay, is plotted on the y axis and on x axis you have the radius ratio. That means inner radius divided by the outer radius of the bend for different aspect ratios aspect ratio means this w divided by h okay. So what do you absorb from this one from this graph you observe that as r one by r two increases for a given aspect ratio as r one by r two increases the dynamic loss coefficient reduces and the pressure drop also reduces. That means you have to, you cannot have a very sharp bend here it is better to provide as the higher radius as possible at this point okay. So if you a, if I increase the radius the boundary layer separation is delayed and the eddy losses are also minimized okay.

So the inner radius to the outer radius ratio should be as high as possible okay, and you can also see that for a given radius ratio as the aspect ratio is increased then the dynamic loss coefficient reduces. That means instead of having large this thing compare let us say that we compare to okay, same width different heights okay. So you find that this will give you less dynamic pressure drop compared to this okay. So that is what is obtained from this particular graph and equations are also available for estimating the dynamic loss coefficient Cb in terms of r one by r two and in terms of the aspect ratio.

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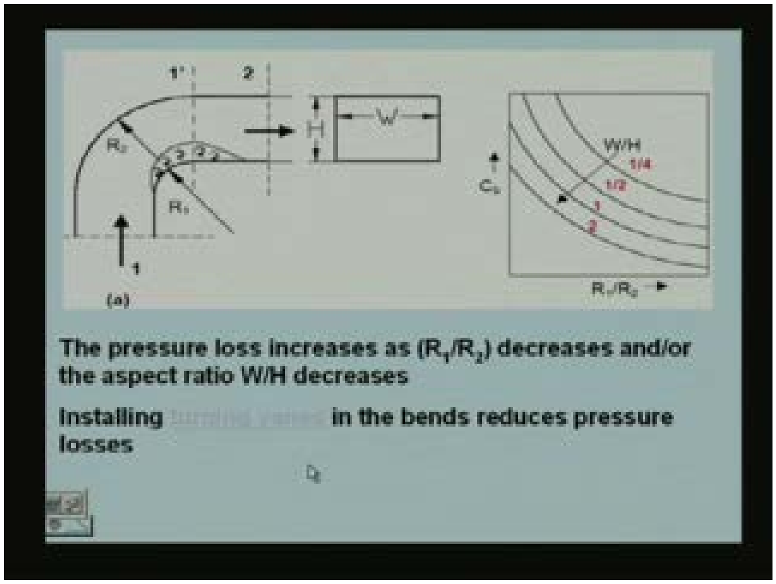

So as I said the pressure loss increases as r one by r two decreases and or the aspect ratio WH W by H decreases okay. So what is normally done is normally turning vanes are installed in the bends to reduce the pressure losses okay. So whenever you have sharp bends you normally use aturning vanes so what you mean by a turning vane.

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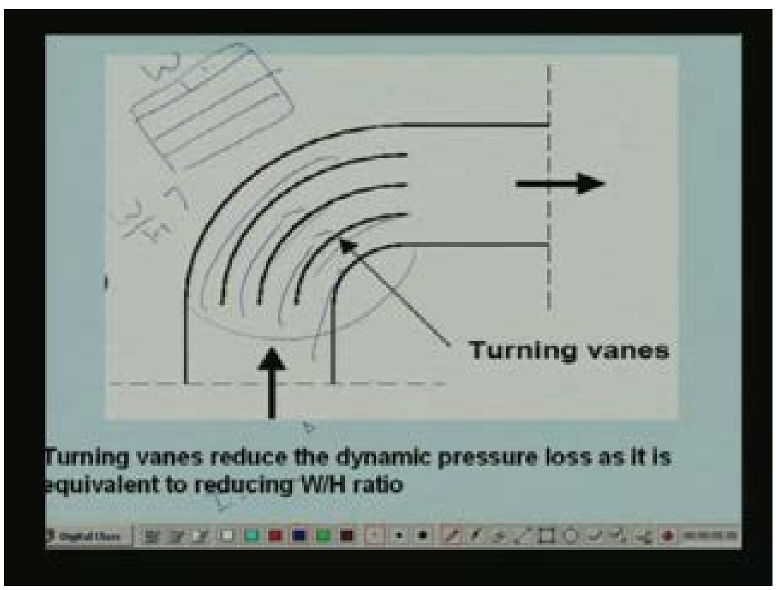

This is the turning vane okay. So instead of having an empty duct like this they put some vanes here. So that air flows through this vanes okay. So as a result of this the dynamic pressure loss reduces why does the dynamic pressure drop reduces the turning vanes reduce the dynamic pressure loss as it is equivalent to increasing the, I am sorry this is a mistake increase in the W by H ratio okay. The moment I am putting this one that means I am dividing this portion into many small ducts each having a same W but a reduced H so you can see that W by H ratio increases because of the turning vanes as a result dynamic loss coefficient reduces and the pressure loss also reduces okay.

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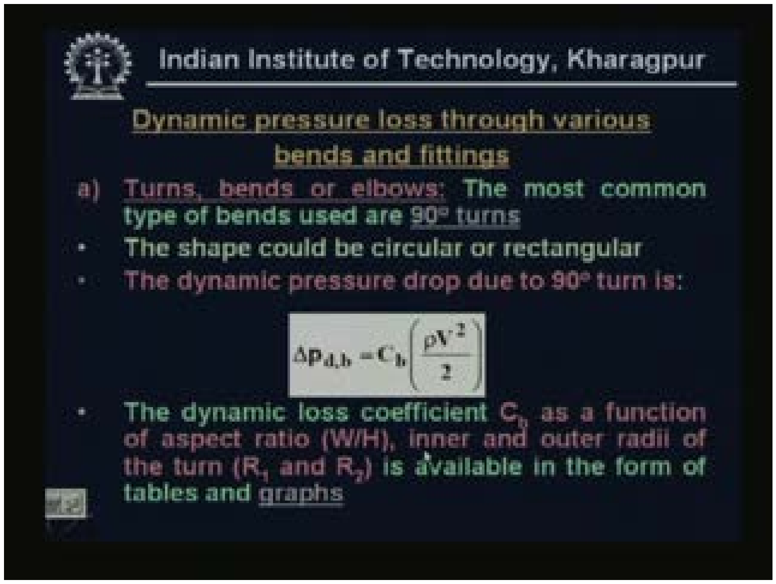

So this is as far as ninety degree turn or bend is concerned in practice you may also have bends which are not necessary ninety degree bend okay. You can have bend which is thirty degree or forty degree or fifty degrees or whatever it is okay. We can have different angles so obviously these different angles the dynamic loss coefficient Cb values will be different depending upon the angle of the bend okay. So ASHRAE data books and other air conditioning data books give charts for estimating dynamic pressure losses through bends as a function of the degree of the turn okay. That means angle of the bend right for different angle thirty degrees forty-five degrees sixty degrees like that okay. So you have to refer to those data books to find the dynamic pressure drop in bends of different angles okay.

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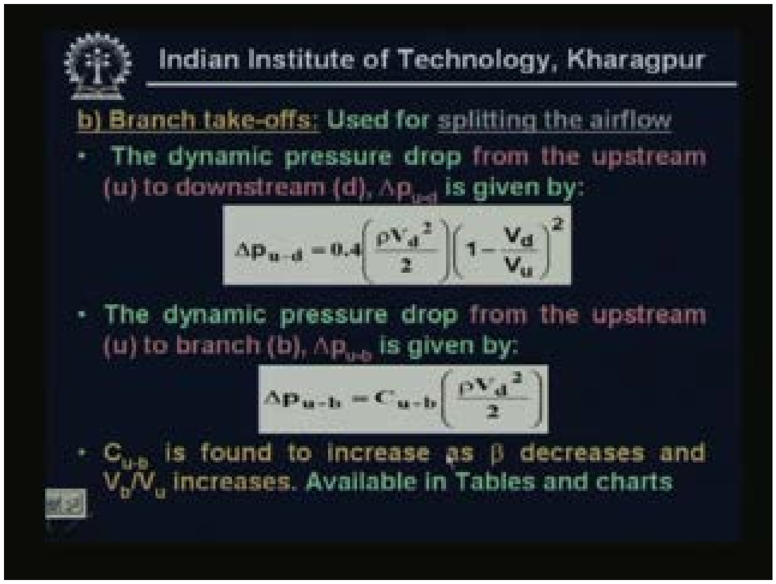

Now let us look at branch take -off what do you mean by branch take -off this branch take-off s are generally used for splitting the air flow okay.

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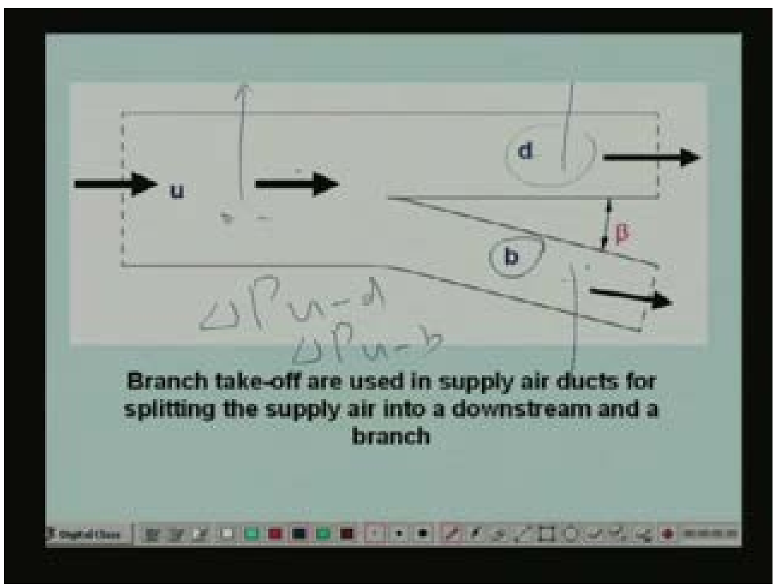

So let me show a typical branch take off so this is the branch take off supply air let us say enters the larger ducts at this point this is the upstream U is for the upstream and its flows through the duct to some extent and at this point I would like to split the flow right. That means I want to sent some amount of air let us say two to one room and some amount to air to another room okay two different rooms. So I have to obviously split the flow at this point. So whenever I have to split the flow I have to use this kind of a fitting okay.

So you connect the duct on this side and you connect the duct which goes to this room at this point and which goes to this room at this point okay. So this is what is known as a branch take off. Of course theoretically you can also have a branch take off of this nature okay, I am, air can go this side air can go this side okay. Now whenever you are using the branch take off pressure drop takes place pressure drop takes place.

Now you have some static pressure here, some total pressure at this point some total pressure at this point. But the upstream static and total pressures are same you will also have different; you may have different dynamic pressures. Because the velocity here may be different from velocity at this point that means pressure drop takes place as air flows from upstream to the branch and as air flows from upstream to the downstream. That means you can have delta p upstream to downstream delta p upstream to branch and they may not be equal okay. So we should be able to estimate what is the pressure drop from upstream to downstream upstream to branch okay.

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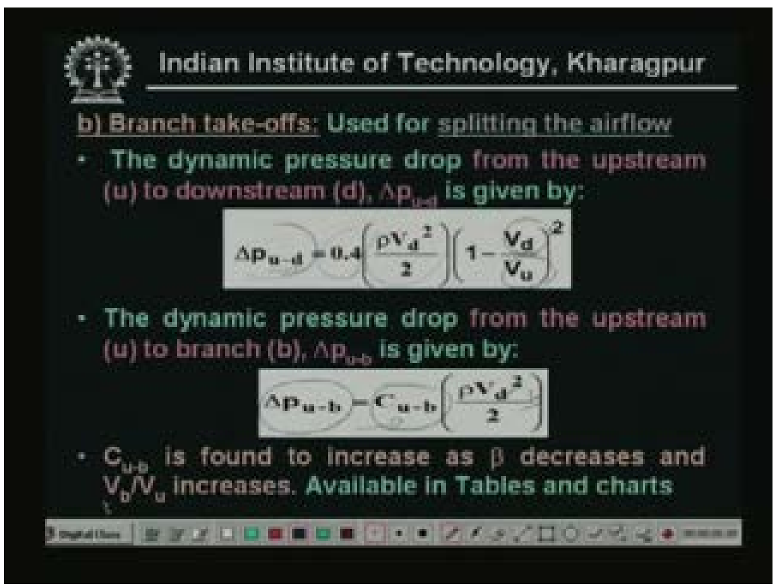

So for the dynamic pressure drop from the upstream to downstream that is delta p subscript u to d is given by this equation delta P u to d is equal to point four multiplied by the velocity pressure in the downstream rho Vd square by two multiplied by one minus Vd by Vu whole square okay. So here Vd is the velocity of air in the downstream duct and Vu is the velocity of air in the upstream duct okay. So using these equation and if you know the dimensions of duct and if you know the flow rates through each portion. Then you can find easily find out all these parameters and you can find out what is the dynamic pressure loss because of the branch take off from upstream to downstream normal. It is absorbed that this pressure drop is very small compared to this pressure drop okay.

That means the pressure drop dynamic pressure drop from upstream to downstream is negligible compared to the dynamic pressure drop from upstream to branch okay. That is delta P u to b delta P u to b is given by this general equation. This is equal to the velocity pressure in the, I am sorry, this should have been ub, vb. That means the velocity pressure in the branch multiplied by a dynamic loss coefficient from upstream to the branch okay. And obviously the major task is to find out this c u to b and let us absorb that the c u to b that is the dynamic loss coefficient from upstream to the branch increases as beta decreases okay. And as vb by vu increases that means the branch to upstream velocity ratio increases right these values are available in tables and charts okay.

So if you look at any standard air conditioning design data book we can find out this value as a function of this angle beta okay. And as a function of this velocity ratio vb by vu okay. So this is for branch take off.

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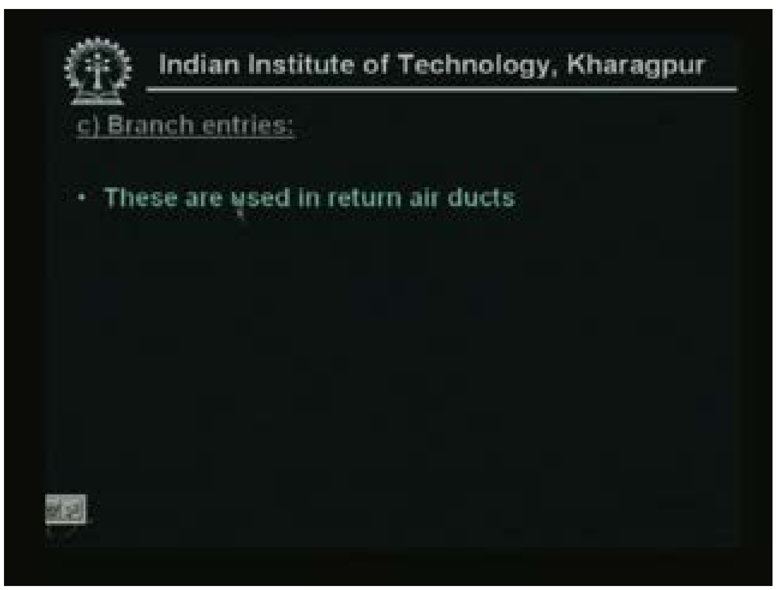

Then you can also have branch entry okay. What do you mean by branch entry these are normally used in return air ducts okay.

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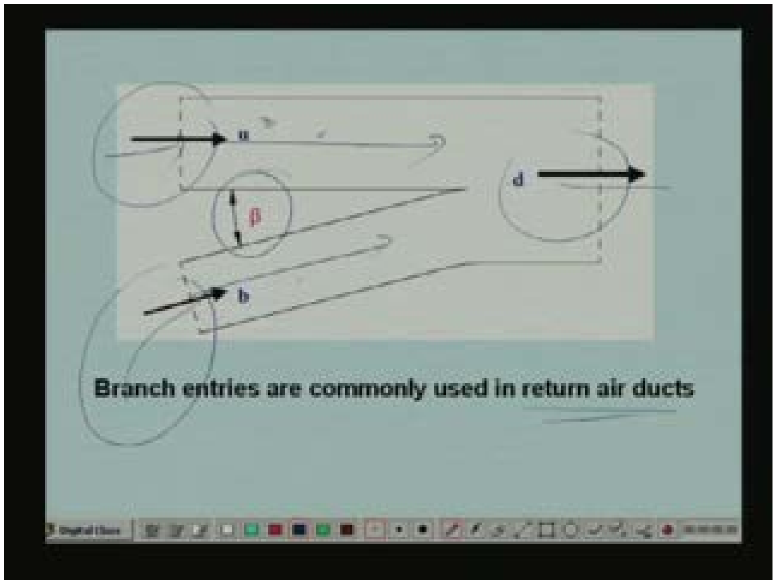

Let me show a typical this reverse of branch at takes off here what happens is air from return air from one room. Let us say located in this point comes this side this way and from another room comes like this and both air return air's have to be mixed and sent to the cooling coil okay. So they are used in return air duct so air in this direction air is coming in this direction and it is getting mixed here and the mixed air goes to the cooling coil right. So this is known as branch entry and again branch entry pressure drop depends upon what is this angle beta what is the ratio of velocity vu by vd from delta p from this point to this point and what is the velocity vb by vd for pressure drop form branch to the downstream okay. This is upstream this is branch and this is downstream okay.

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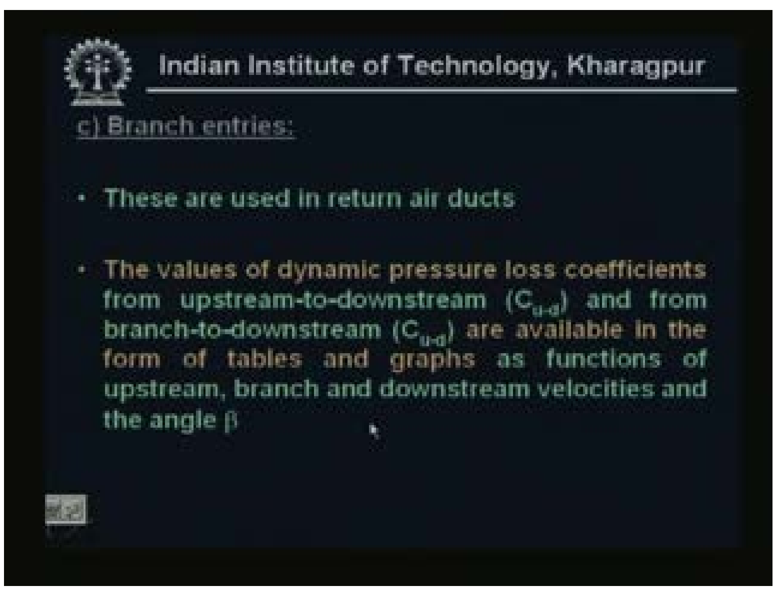

And as I said these are commonly used in return air ducts and values of dynamic pressure los coefficients from upstream to downstream that is C subscript u to d and from branch to downstream that is C subscript u to d are available in the form of tables and graphs and these are functions of upstream branch and downstream velocities and the angle beta okay. So if look at air conditioning data books you can get this data. So once you know the for these three types of, let us say fittings that is bends and branch take off and branch entry the important thing is to find out the dynamic loss coefficient okay. Once you know the dynamic loss coefficient and if you also know the, either the velocities or the flow rates and the duct dimension then you can find out the dynamic pressure loss okay. Because of the fittings right.

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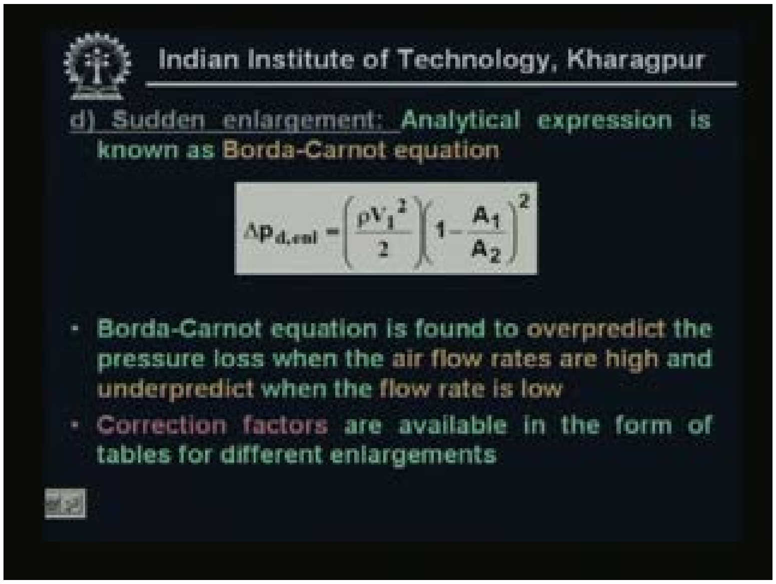

And you can also have other types of fittings, for example sudden enlargement okay. Let me show the picture of sudden enlargement.

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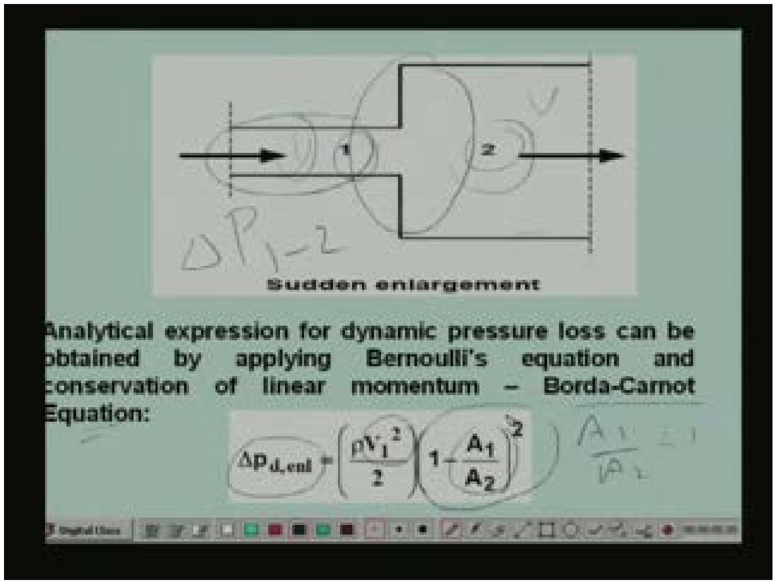

This is the sudden enlargement. This is not generally recommended but sometimes you can avoid this okay. So air comes like this through a narrow duct and suddenly it has to be enlarged okay. It enters into a large duct; let us say okay this portion is known as sudden enlargement okay. There is sudden change in the area because there is sudden change in the area there a sudden change in velocity okay. Here the velocity will be much lower than the velocity in this point because the flow rate is same we are talking about steady flows the volumetric flow rate will remain same since the cross section area is high the velocity will reduce okay. For this kind of sudden enlargement analytical expressions for dynamic pressure loss have been obtained using Bernoulli's equation and from conservation of linear momentum okay. Of course this analytical expression is subjected to certain assumptions and the analytical expression is known as Borda-Carnot equation okay.

So the Borda-Carnot equation gives the dynamic pressure loss due to sudden enlargement that means from point one to two that is delta p one minus two right. So this is given by this equation rho v one square by two where v one is the velocity before the enlargement right multiplied by one minus a one by a two whole square okay. So a one is the area at this point a two is the area at this point okay. So a one by a two whole square obviously a one by a two is less than one right. So as a one by a two reduces you can find that the pressure loss increases. That means if have very narrow portion here and very large this thing okay, then obviously the dynamic pressure loss increases and comparing this with your general equation you find that her the dynamic loss coefficient is equal to one minus a one by a two whole square okay.

As I said this is a, an analytical expression subjected to certain assumptions right and this is very famous equation and it is called as Borda-Carnot equation.

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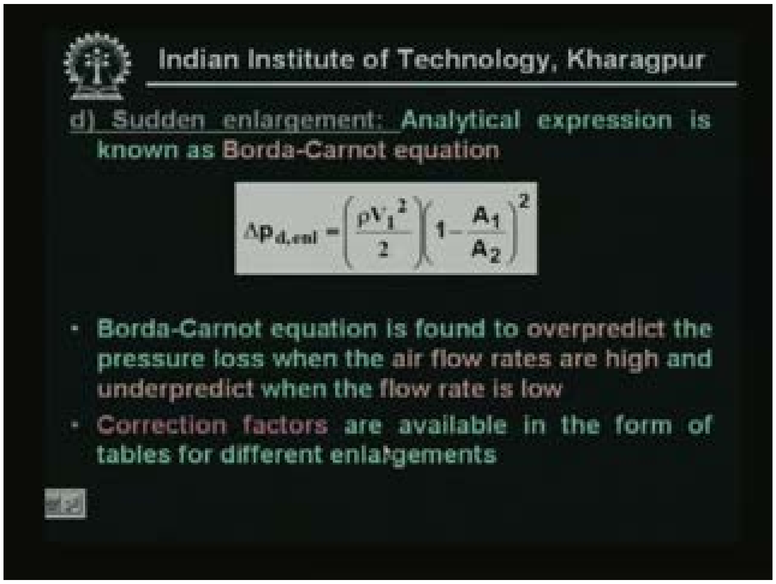

And it is observed that from experimental results that Borda-Carnot equation is found to over predict the pressure loss when the air flows rates are high and under predict when the flow rate is low that means it doesn't give you exact results either at very low flow rate or at very high flow rates okay. Of course what is very flow rate where high flow rate is again a thing to be decided okay. But in general in the absence of reliable experimental data you can use the Borda-Carnot equation. Because all that you have to know is a area rate in the flow rate then you can find out what is the pressure loss okay. However for actual design calculations they use correction factor to this Borda-Carnot equation and correction factor again depends upon your area ratio velocities etcetera. So if you know the correction factor then using the Borda-Carnot equation and the correction factor you can find out the actual pressure loss due to sudden enlargement okay. Similar to sudden enlargement you can also have you can have sudden contraction okay. Let me show a sudden contraction.

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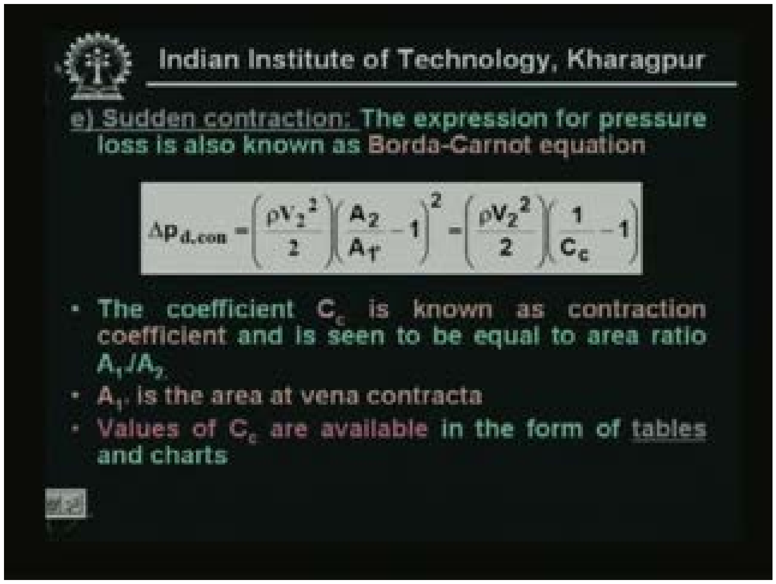

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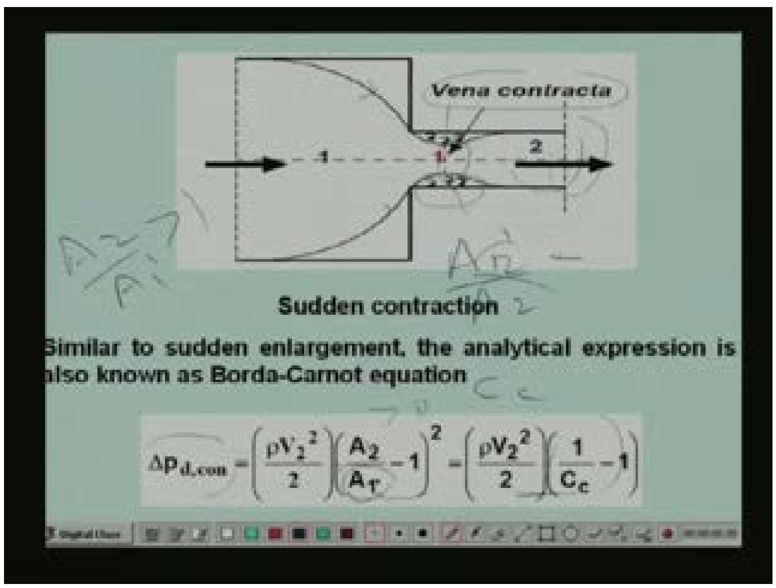

Sudden contractions this air is flowing in a large duct and suddenly it has to be the cross section area as got to be reduced okay. So you call this as sudden contraction an physically what happens is when that is sudden contraction you find that for example a stream line okay. Let us say that stream line is flowing like this and you have a sudden because of the sudden contraction there is a boundary layer separation here okay. And there is a reason at which the cross sectional flow area flow area becomes minimum and that cross section is called as vena contract or region is called as vena contract.

Where the area of flow area is minimum right and what do you have above that you have a region where you find eddies okay. So this is what leads to your dynamic pressure losses right the formation of eddies due to boundary layer separation right this a very well known phenomena the formation of vena contract due to sudden contractions and again the analytical expressions subjected to certain assumptions is also known as Borda-Carnot equation okay. Exactly like your sudden expansion right, the Borda-Carnot equation is given by this expression the dynamic pressure drop due to sudden contraction is equal to rho v two square by two. That means the velocity pressure in the downstream multiplied by a two by a one dash minus one whole square where a two as you can see is nothing but the cross section area in the downstream and a one dash is the area of cross section at the vena contract okay.

At this point right, obviously a one dash by a tow will be greater I am sorry, a two by a one dash. A two by a one dash is greater than one so this will be greater than zero okay. So and when there is no vena contract obviously this will be zero and there is no pressure loss. But there will be pressure loss because vena contract form due to boundary layer separation and this is generally written in this form okay. That means this a two by a one dash ratio is replaced by one by cc where c subscript c is known as contraction coefficient which is nothing but a one dash by a two okay.

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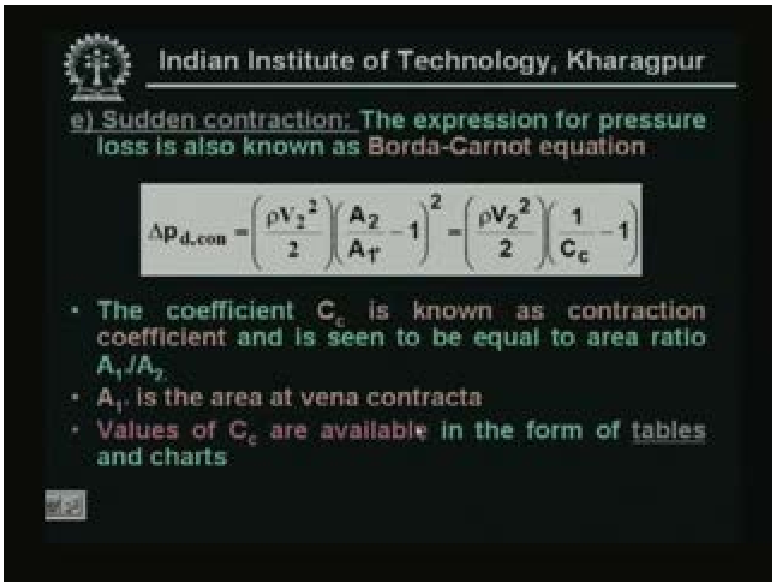

So as I said the coefficient c subscript c is known as contraction coefficient and it is seen to be equal to area ratio a one dash by a two and a one dash is area at vena contract and values of contraction coefficient are available in the form of table and charts. So let me show a typical table.

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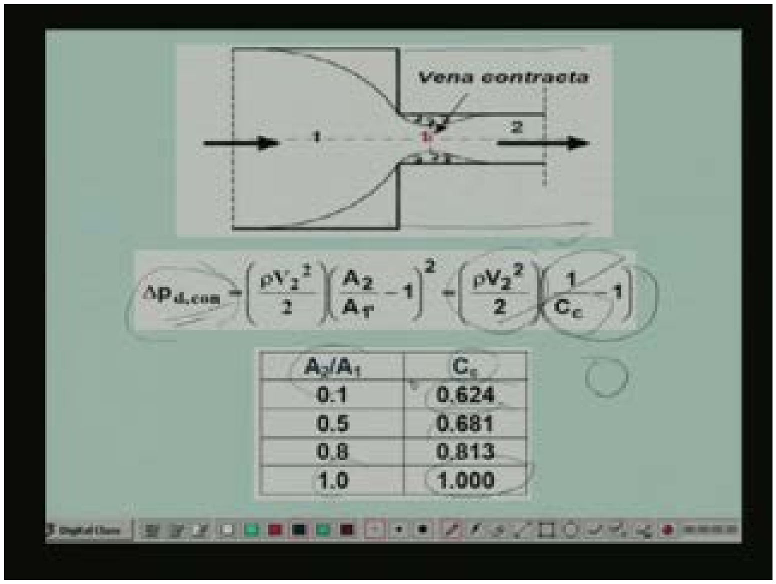

As I said again this is the geometry and this is the expression for finding the dynamic pressure drops and if you know the contraction coefficient then you can find out dynamic pressure drop okay. Because normally we know this from the flow rates and from the dimensions of the duct so here you can see the contraction coefficient is expressed as a function of downstream cross section area by upstream cross section area that is a two by a one. So you can see that when a two by a one is very small okay. The contraction coefficient is very small as a result the dynamic pressure loss will be large okay. Because the cc is small means this is large so dynamic pressure loss will be large. So as area ratio increases obviously the contraction coefficient also increases and in a limiting case when the area ratio is equal to one that means there is no contraction but it is straight duct the contraction coefficient is obviously equal to one so that this becomes zero okay.

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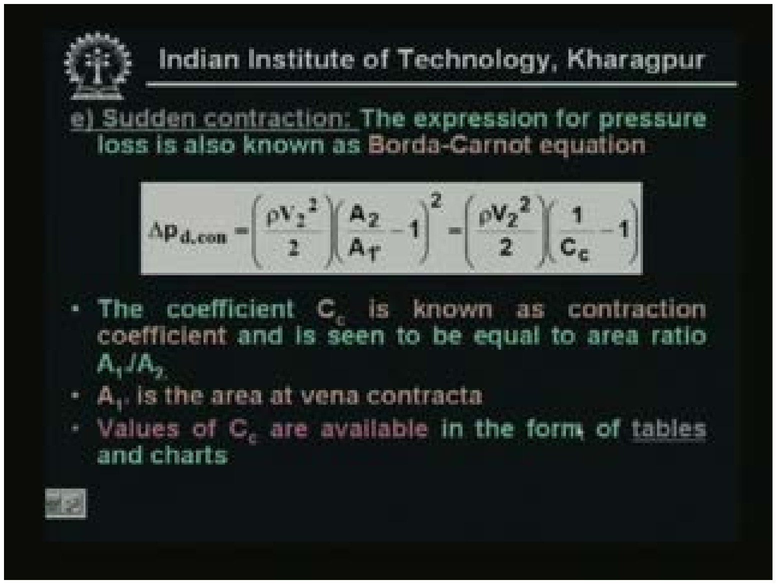
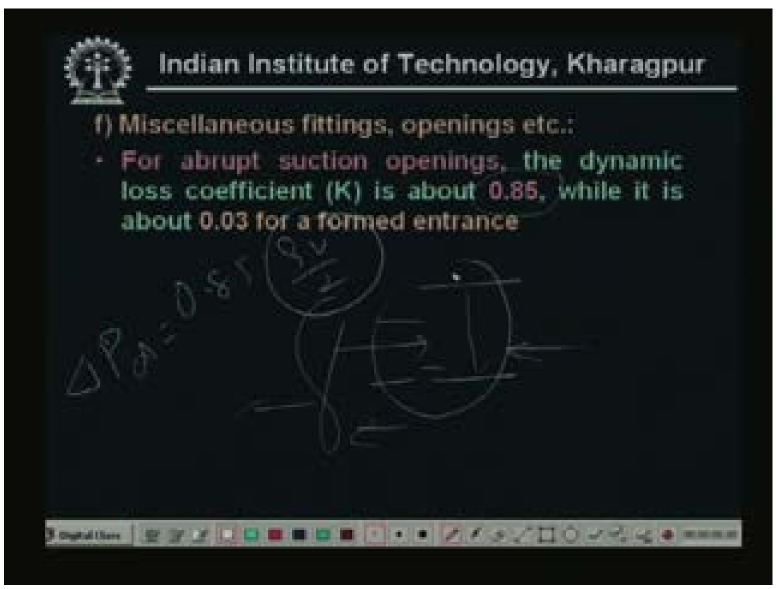


Again as I said this Borda-Carnot equation is an analytical equation if you use right value of contraction coefficient which is obtained from experiments then you can use the Borda-Carnot equation for estimating the dynamic pressure loss due to sudden contractions okay. (Refer Slide Time: 00:47:21 min)



Now we may also have other miscellaneous fittings and openings etcetera. For example you can have abrupt suction openings okay. Suction openings means, for example you have let us say that you have a fan and suddenly air has to flow oh from a fan you have the opening and suddenly it has to flow into this okay. So you have again a fitting here so this is known as a sudden suction opening or you can also have a flow in this direction okay. You have the fan sucking air in this direction so suddenly air as to enter like this. So for this kind of sudden or abrupt suction openings the dynamic loss coefficient K is found to be about point eight five. That means the dynamic pressure drop delta pd okay, is equal to point eight five multiplied by rho v square by two where rho v square by two is the velocity pressure in this opening right instead of sudden this thing if you have formed enters.

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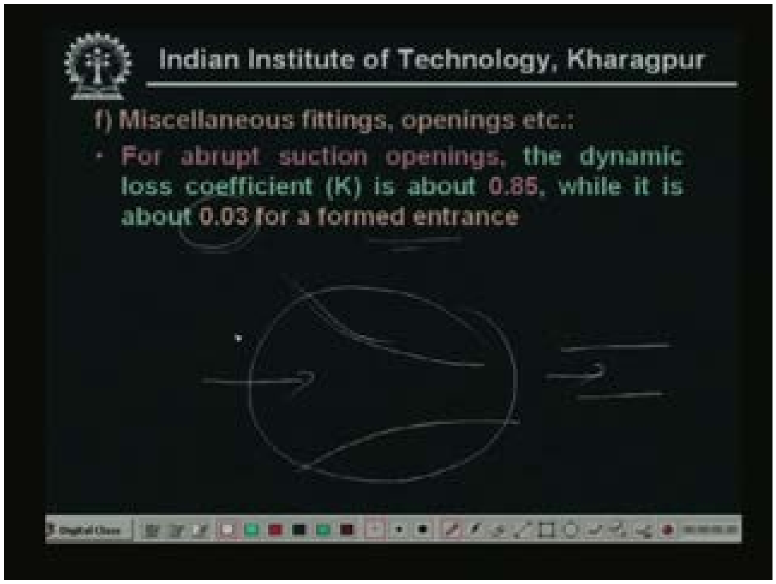

That means air enters like this okay not suddenly but air enters the formed or gradual entrance then the there is a dramatic reduction in the dynamic loss coefficient it reduces from point eight five to point zero three. That means the dynamic pressure losses are reduced very much okay. So as far as possible you should avoid this sudden entry so you must always try to use this form or gradual entry okay. So for this kind of suction openings you can use the dynamic loss coefficients and find out the dynamic pressure drop for discharge openings.

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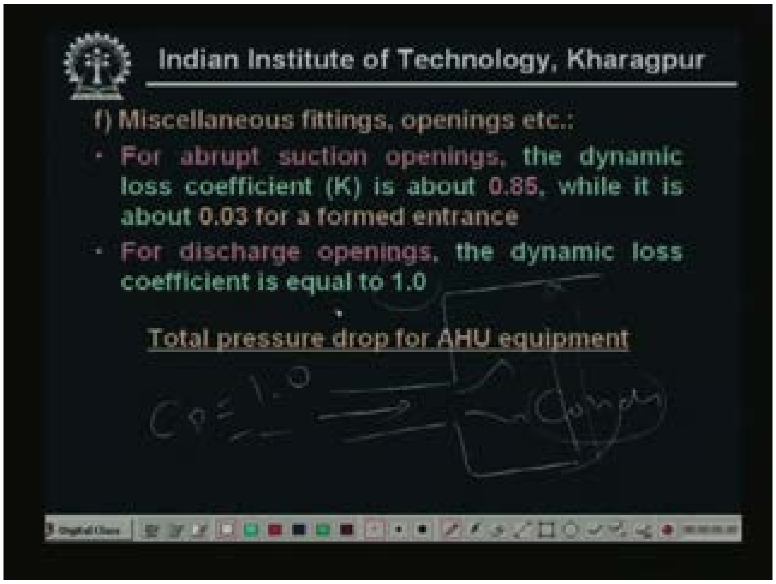

Okay, that means you have the duct okay, well you have the, let us say you have the duct and suddenly you have the conditioned space okay. So supply air is entering like this and suddenly it is discharged here okay. So again there is a sudden change of cross section and here this area is very large and here you have atmospheric conditions pressure as atmosphere and something like that. So here you cannot strictly speaking you cannot use the sudden expansion this thing because this ratio is very large okay. For this kind of discharge openings the dynamic loss coefficient is found to be equal to one because all the kinetic energy is simply dissipated okay. So Cp is equal to one for this kind of discharge openings okay. Now the total pressure drop for AHU equipment we have to find out the total pressure drop for AHU equipment.

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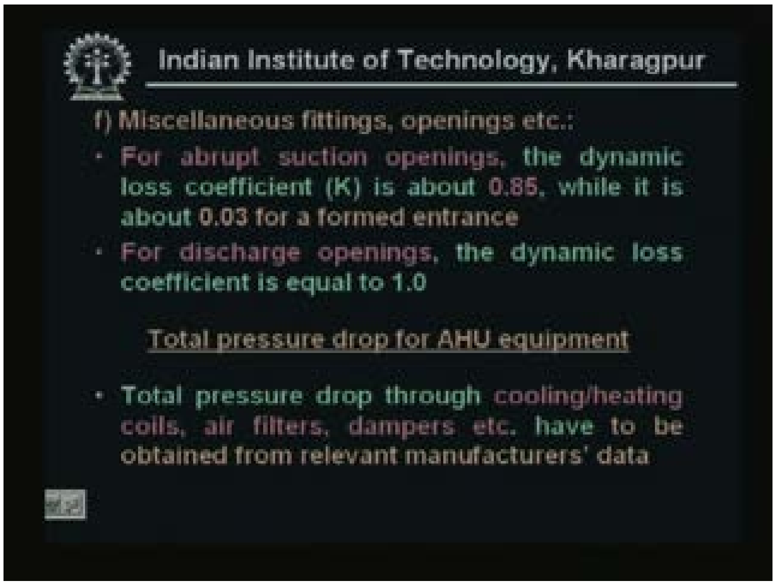

Total pressure drop through various cooling and heating coils air filters dampers etcetera. They have to obtained from relevant manufactures data because it depends very much on the specific design of this equipment. So you have to use the manufactures data now.

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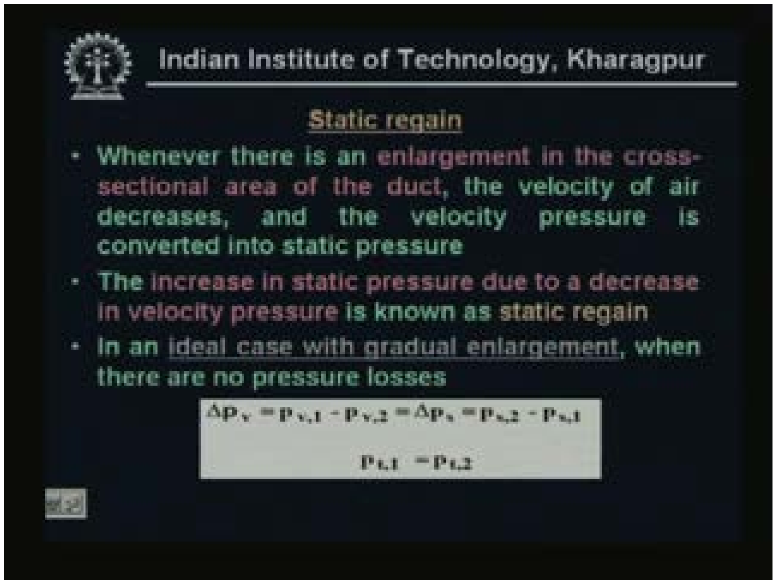

let us look at a factor called as static regain factor what is the static regain whenever there is an enlargement in cross section area of the duct the velocity of air decreases and the velocity pressure is converted into static pressure okay so when you are enlarging velocity obviously reduces because the flow rate remains same so velocity is converted into static pressure the increase in static pressure due to decrease in velocity pressure is known as static regain okay in an ideal case with gradual enlargement when there are no pressure loses you find that the static regain factor is equal to one okay.

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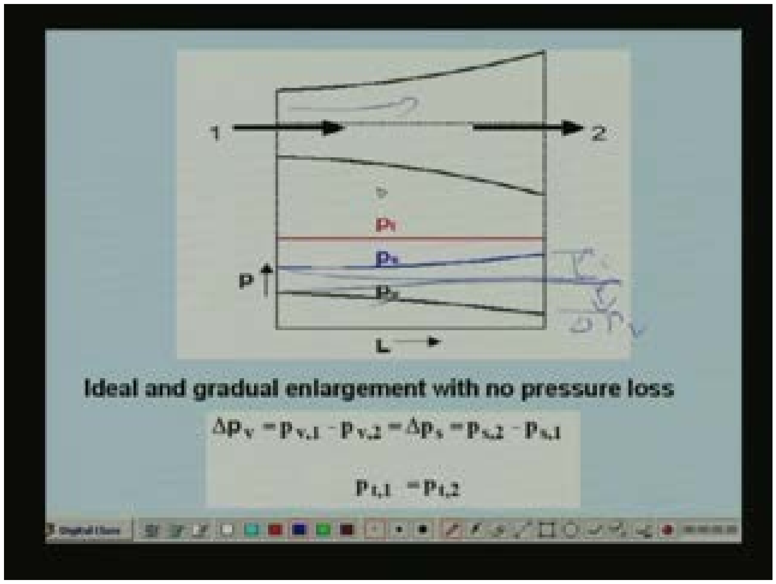

That means this is the case where there is a increase in cross section area but this is very gradual okay. The area is increasing very gradually okay. So the gradual this thing so as the area is increasing velocity reduces so the velocity pressure reduces in this direction okay. So this is the drop in velocity pressure delta pv due to enlargement at the same time there is an increase in static pressure okay. Because of the conversion of velocity pressure into static pressure okay.

So this is the increase in the static pressure since this is an ideal enlargement you find that reduction in velocity pressure is exactly equal to the increase in the static pressure as a result the total pressure remains constant throughout. That means this an ideal case where there are no pressure losses right this an ideal enlargement.

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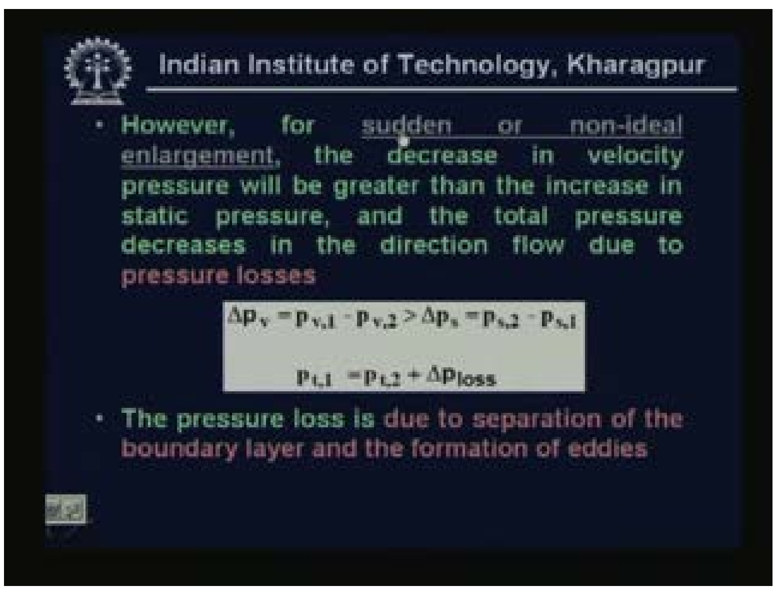

However for sudden or non ideal enlargement you find that the decrease in velocity pressure will be greater than the increase in static pressure and the total pressure decreases in the direction of flow due to pressure losses okay.

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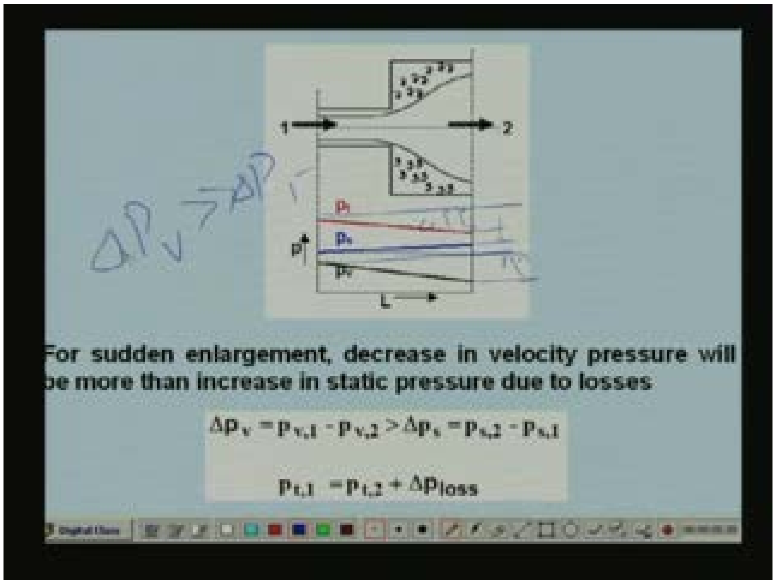

For example this is also an enlargement but this is a highly irreversible type of an enlargement that is a sudden enlargement okay. When there is sudden enlargement there is a drop in velocity pressure okay. This is a drop in velocity pressure but this is not converted into static pressure or very less of it is converted into static pressure. So delta pv is much greater than delta ps okay. Increase in static pressure is much smaller than decrease in velocity pressure okay. And you find that as a result of which there is a total pressure loss okay. So this a pressure loss takes place this is equal to the difference in between delta pv and delta ps right.

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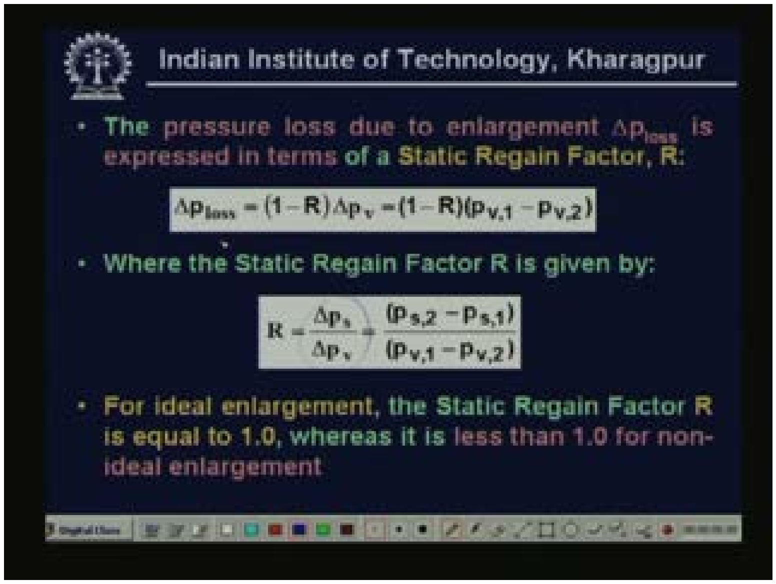

And the pressure loss here is due to separation of the boundary layer and the formation of eddies and the pressure loss due to enlargement delta p loss is expressed in terms of static regain factor r and the static regain factor r is defined as the ratio of delta ps by delta pv okay. This is the ratio that means the raise in static pressure divided by the drop in velocity pressure okay. So using the static regain factor we can find out the pressure loss due to enlargement as one minus r into delta pv okay, delta pv is equal to pv one minus pv two okay, where r is the static regain factor obviously for ideal enlargement r is equal to one. So delta p loss is equal to zero for non ideal this thing r is less than one so there will some pressure loss okay.

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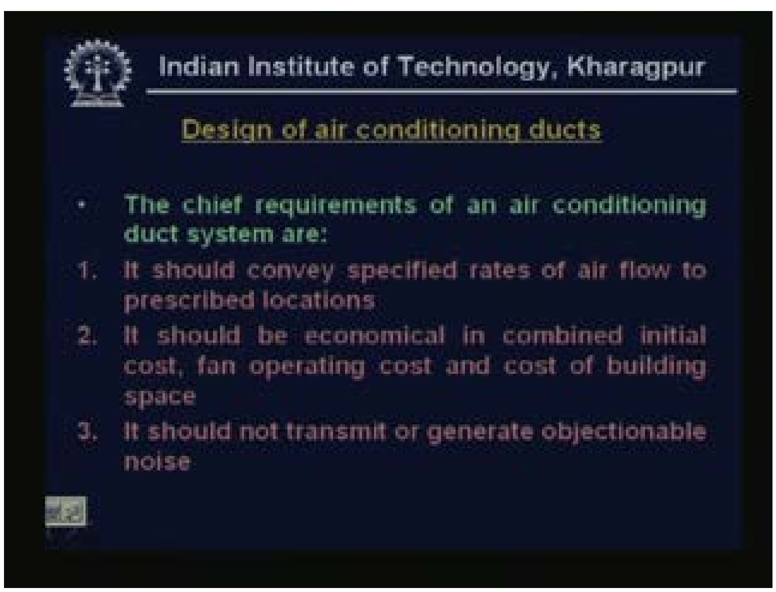

Now let us quickly look at design of air conditioning ducts and what are the chief requirements of an air conditioning duct system the chief requirement are that it should be conveyed the air should be conveyed to the required locations at specified rates. So this is first important requirement second requirement is that it should be economical in combined initial cost fan operating cost and cost of building space so this second requirement third requirement is that it should not transmit or generate objectionable noise okay. So you have to design it so that there is no noise generation.

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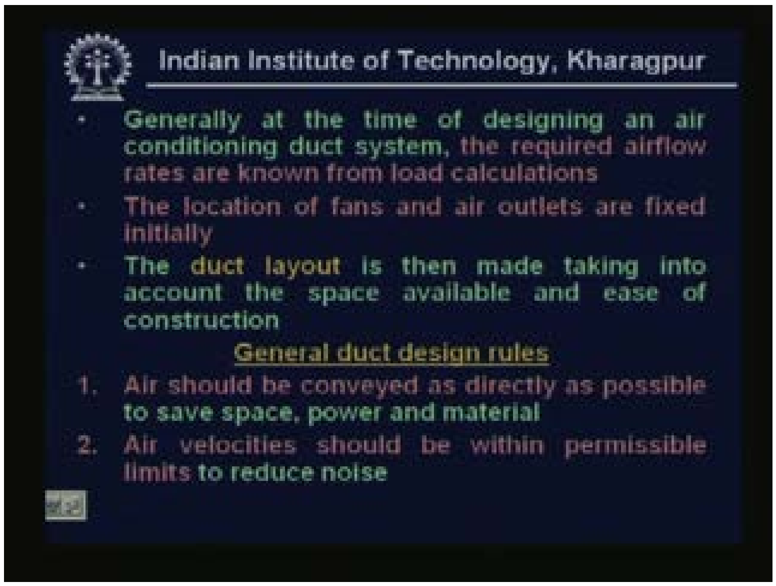

And generally at the time of designing an air conditioning duct system the required air flow rates are known from load calculations. So we know the air flow rates and the location of fans and air outlets are fixed initially depending upon the building layout and the duct layout is then made taking into amount the space available and ease of construction okay. So that means at the time of duct layout you have to have this input right and there are certain design rules which have to be followed while designing the ducts.

So what are the design rules first rule is that air should be conveyed as directly as possible to save space power and material. That means unnecessary bends turns should not be there okay. You have to convey it as directly as possible which will give rise to lower space cost power cost and material cost second requirement is that or second rule is that air velocity should be within permissible limits to reduce noise you cannot have very high velocities or you cannot have very low velocities.

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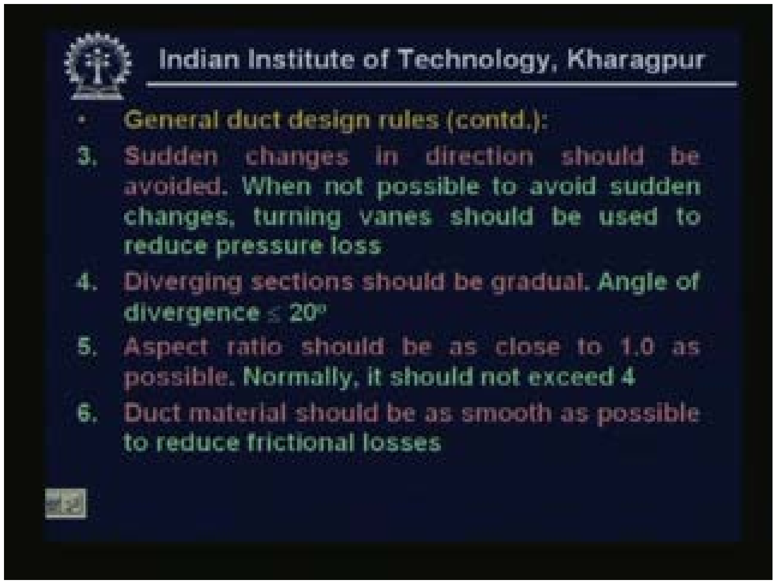

And the third rule is that sudden changes in direction should be avoided okay. Because we have seen that there if there is a sudden change there will large dynamic losses. So this should be avoided and when it is not possible to avoid sudden changes we have to use turning vanes to reduce the pressure loss and fourth rule is that the diverging section should be gradual and the angle of divergent should be less than or equal to twenty degrees. That means again this from the static regain factor point of view you would like to regain the drop ion velocity pressure. So you have to have a gradual diverging section okay, and the aspect ratio should be as close to one as possible. I have already explained this and normally it should not exceed four and the duct material should be as smooth as possible to reduce frictional losses okay. So these are the general rules to be followed at this point I end this lecture and let me quickly summarize what is that we have learned in this lesson we have seen the equation for estimating fan total pressure and fan power. And then we have seen how to estimate friction loss in circular and rectangular duct and we also discussed estimation of dynamic losses through various fittings and bends and we have also discussed static regain factor. And finally we have looked at the requirements and general rules to be followed in the design of air conditioning ducts okay. So in the next lecture I shall discuss various duct design methods okay, what are the different methods for designing the air conditioning ducts.

Thank you.