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Refrigeration and Air-conditioning
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Lecture No. # 45
Transmission and Distribution of Air (Contd.)

Welcome back this lecture is a continuation of a earlier lecture. In the last lecture we have discussed how to estimate frictional and dynamic losses in air conditioning ducts and I also mentioned briefly the design rules to be followed while designing air conditioning ducts. So the specific objectives of this particular lecture are to discuss classification of duct systems.

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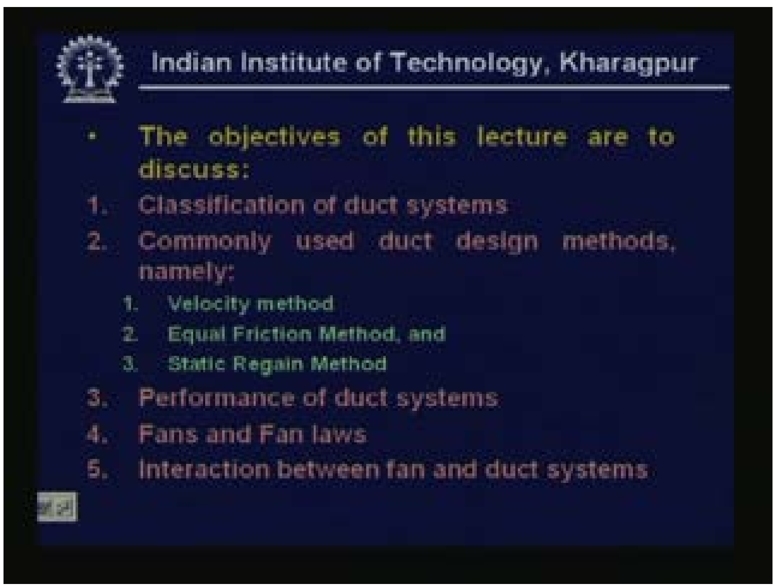

Discuss commonly used duct design methods namely velocity method equal friction method and static regain method and then discuss briefly the performance of duct systems and discuss fans and fan laws and finally discuss briefly the interaction between fan and duct systems.

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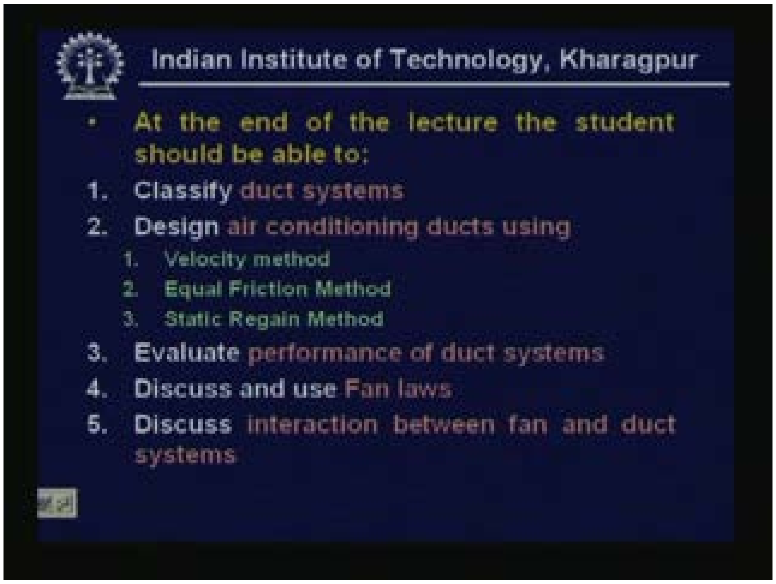

And at the end of the lecture you should be able to classify duct systems design air conditioning ducts using either velocity method or equal friction method or static regain method. Then evaluate performance of duct systems then discuss and use fan laws finally discuss interaction between fan and duct systems.

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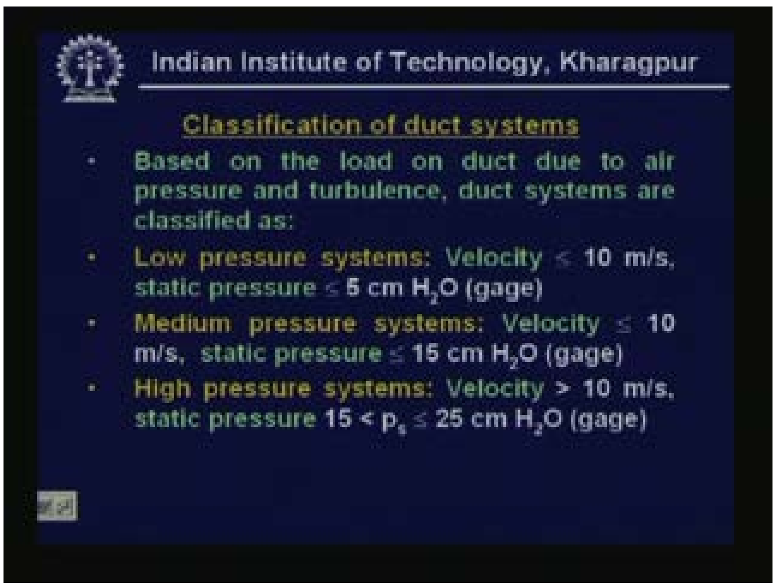

So let us first look at classification of air conditioning duct systems how they are classified based on the load on duct due to air pressure and turbulence duct systems are classified as low pressure systems.

Where in the air velocity is less than or equal to ten meter per second and the static pressure is less than or equal to five centimeters of water column. These systems are known as low pressure systems. Then you have medium pressure systems where the velocity is still less than or equal to ten meter per second. But the static pressure is between five centimeter to fifteen centimeter of water then finally you have high pressure systems where the velocity is greater than ten meter per second and the static pressure is between fifteen to twenty five centimeters of water column okay. This how normally the air conditioning systems are classified.

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Now high, what is the, you, effect of velocities high velocity in the duct in the ducts results in smaller ducts and hence lower initial cost and lower space requirement since the velocity is high for the same flow rate we can reduce the cross section area that how you get smaller ducts okay.

However if you have high velocities you will find that the pressure drop will be higher as a result the fan power consumption will be higher okay. So this is the disadvantage of velocity systems in addition to this due to high velocities there will be increased noise and hence high velocity air duct systems require a noise attenuation okay. So these are the effects of high velocities. Now the typical recommended air velocity it is in supply ducts are as follows for residences normally the velocities are between three to five meter per second and in theatres the velocity is between four to six point five meter per second whereas in restaurants it can be between seven point five meter per second to ten meter per second. As I said one of the important criteria for selecting the air velocity is noise okay. So in residence normally noise is not tolerated so you have to maintain low noise whereas in places like restaurants and all whereas such you have high background noise we can effort to have higher velocities.

So because the higher noise generated because higher velocities is not a problem okay. These are the normally recommended values of however there are some special applications where one may have to go for still higher velocities for example in air craft air conditioning systems or in ship air conditioning systems the air velocities can be as high as about thirty meter per second okay. So here it is noise is not the main important criteria but the size of the duct is very important okay. So should you would like to minimize the size as a result people normally use higher velocities okay. So the velocity is selected based on mainly on noise criteria okay. Also on fan performance and the power consumption of the fan okay.

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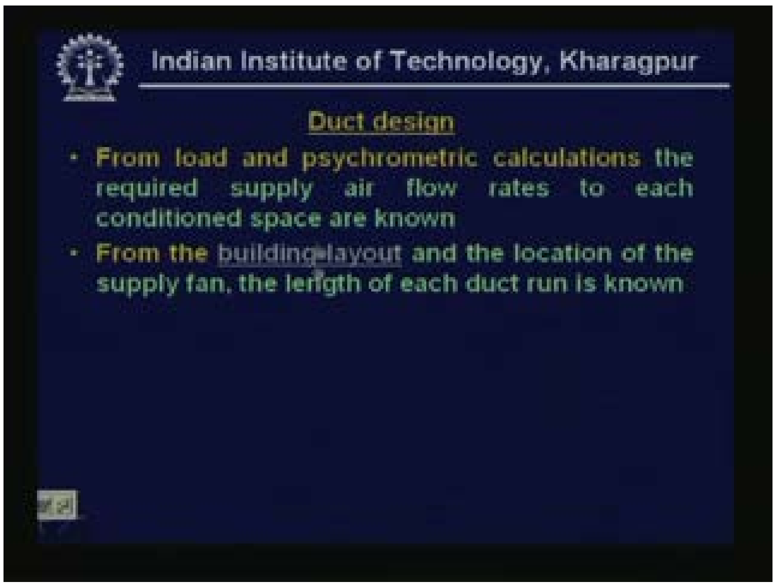

Next look at duct design normally what is the input for duct design from load and psychometric calculations the required supply air flow rates to each conditioned space are known this we have discussed earlier then from the building layout and the location of the supply fan the length of each duct run is known. For example, let me show a typical building layout.

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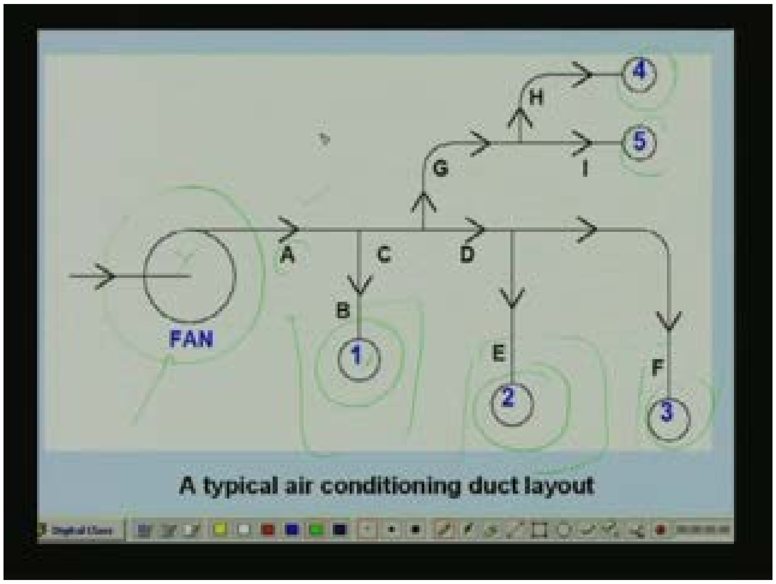

Let us say that this is a typical air conditioning duct layout we locate the, let us say the plant here. So you have the fan located somewhere here and these are the outlet supply air outlets that means these are the different zones where your conditioned spaces are maintained. Let us say so one two three four five okay. So the ABC etcetera are the duct portion. So you can see that for these kind of a duct layout you have the fan here and the location of these outlets one two three four five etcetera are fixed by the design of the building okay. And you also know where from the location of the fan what is the distance for example from this point to this point okay. Similarly from this point to this point so physical location is known so you know the distance and once you know the distance you know what is the length of the ducts. So normally the length of the ducts is known okay.

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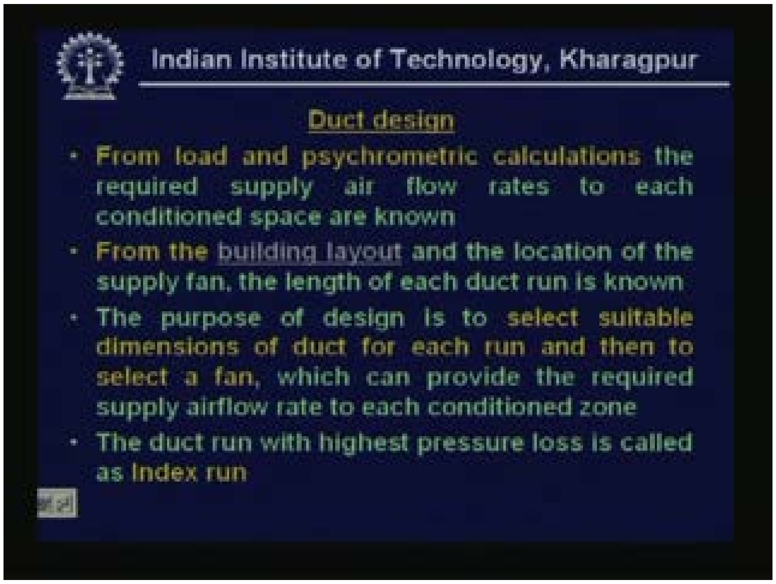

Then from these given input we have to design the duct and what is the purpose of the duct design the purpose of duct design is to select suitable dimensions of duct for each run and then to select a fan which can provide the required supply air flow rate to each conditioned zone. That means from the taking the input from the cooling load calculations and from based on the building specifications and the location of the plant room we have to design a duct system okay. Design of duct system means mainly selecting the dimensions of the ducts okay. If you are selecting a circular duct what is the diameter if it is rectangular duct what are the two side okay. Because the lengths are known and once you select the dimensions you also have to select a suitable fan which can provide the required amount of air flow rates to each of this conditioned zone okay. So this is the purpose of a duct design the duct run with highest pressure loss is called as index run okay I will explain this a little later.

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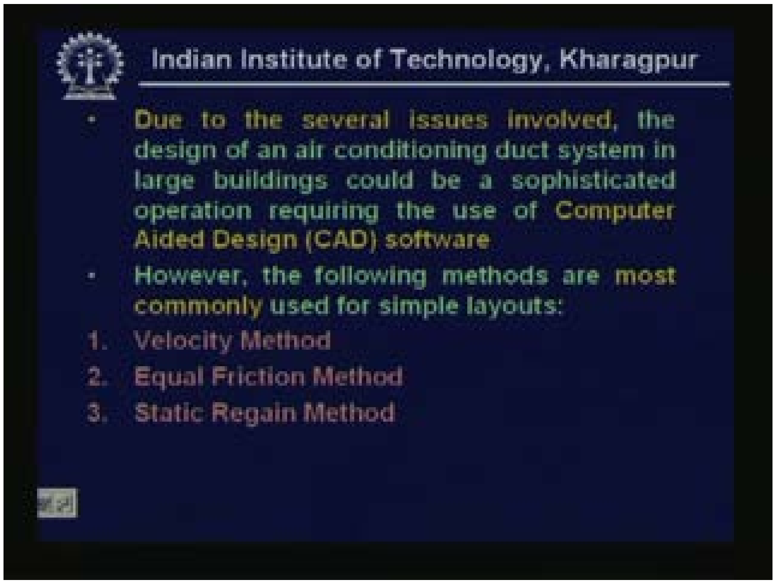

Due to the several issues involved the design of an air conditioning duct system in large buildings could be sophisticated operation requiring the use of computer aided design or CAD software now a days. When you have very large buildings requiring say hundreds of room with different conditioned spaces located at several points then the duct design or duct layout can be extremely complicated okay. What I have shown is a relative simple duct layout but a actual duct layout in large buildings can be very complicated. So if you want to design it optimally then you have to use advanced methods and you may also have to use some computer aided design software for designing the ducts okay.

However we in this lecture we shall discuss some simpler methods which are normally used for simple layouts what are these simpler methods. These simpler method first methods are known as velocity method. Second one is known as equal friction method third one is known as static regain method. So I shall discuss only these methods in these lecture.

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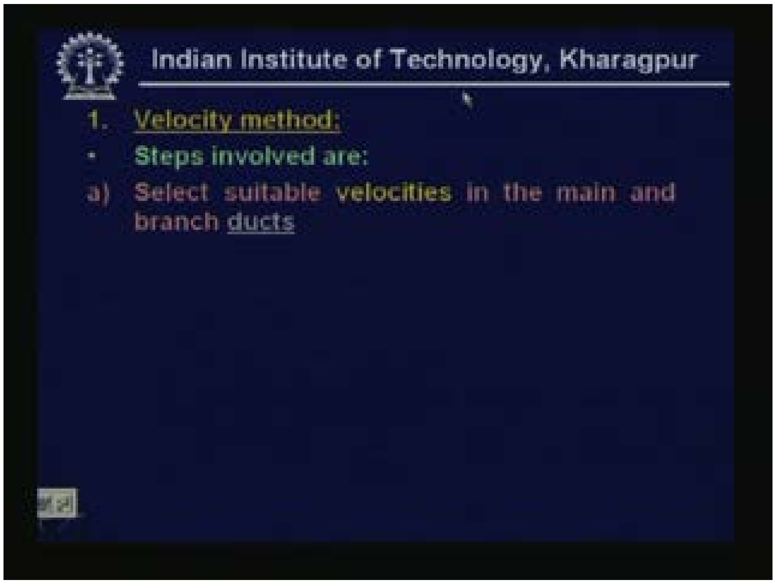

First let us look at velocity method the various steps involved in this particular method are first select suitable velocities in the main and branch ducts okay that means. Let us say that again.

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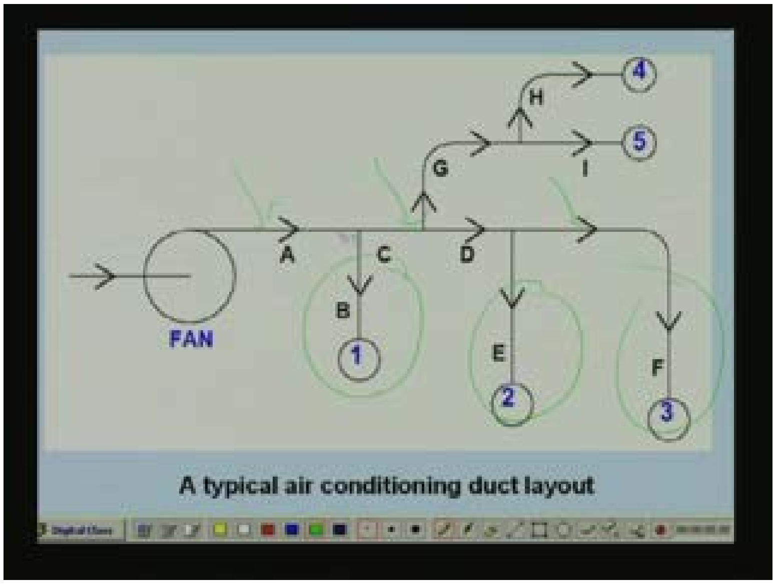

Let us go back to this one. Let us say that this is our duct layout so in the velocity method the first thing we do is we select velocities okay, in different runs, for example this duct run is known as your main okay, whereas these duct runs are called as branch branches okay, different branches. So first what we do is we select velocities in main and in the branches okay. Based on, let us say noise criteria or a based on the space considerations or fan power consternations etcetera. We have to select suitable velocities in the main and in the branches this is the first step in velocity method.

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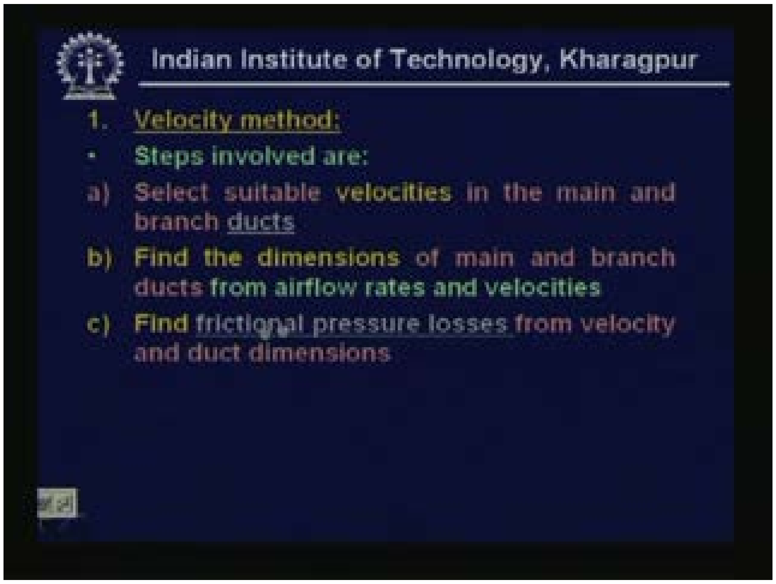

Once you select the air velocities we can easily find out the dimensions of the main air branch ducts from air flow rates and velocities remember that we know the air flow required air flow rate from psychometric calculations okay, so you know the air flow rate and once you select the velocities air flow rate is nothing but cross section area multiplied by velocity. So flow rate is known velocity is known so you can find out what is the required cross section area so if you are selecting a circular duct let us say then from the cross section area you can easily find out the diameter.

If you are selecting a non circular duct let us say a rectangular duct even then you know the cross section area. So you have to f ix either one side or the aspect ratio so that you can find the other side okay. So it is very easy once you know the flow rate and velocity finding the dimensions of the duct are easy okay. So this is the second step in the velocity method okay, then the third step is find frictional pressure losses from velocity and duct dimensions either using the frictional friction chart or using the frictional pressure drop equation.

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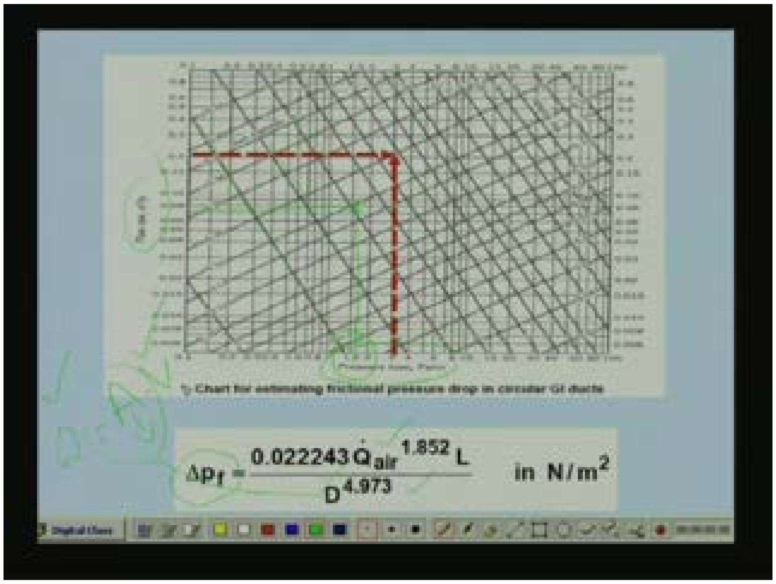

This I have discussed in the last lecture as I was telling once you know the flow rate Q this is known and once you know the dimensions okay. Because as I said Q dot is equal to A into Velocity. So velocity is known Q dot is known so first find out A once you know A you can find out D okay. So d is also known to us Q dot is also known to us, so we can find out the frictional pressure drop using this equation which I have discussed in the last lecture or you can also use the friction chart for example in the friction chart if you remember this was discussed in the last lecture we have the frictional pressure loss per unit length on the x axis flow rate on the y axis and different constant velocity lines these are the constant velocity lines okay. Once you select the, let us say velocity okay and if you know the flow rate then you can find out what is the frictional pressure drop per unit length okay. So this is the third step in the velocity method.

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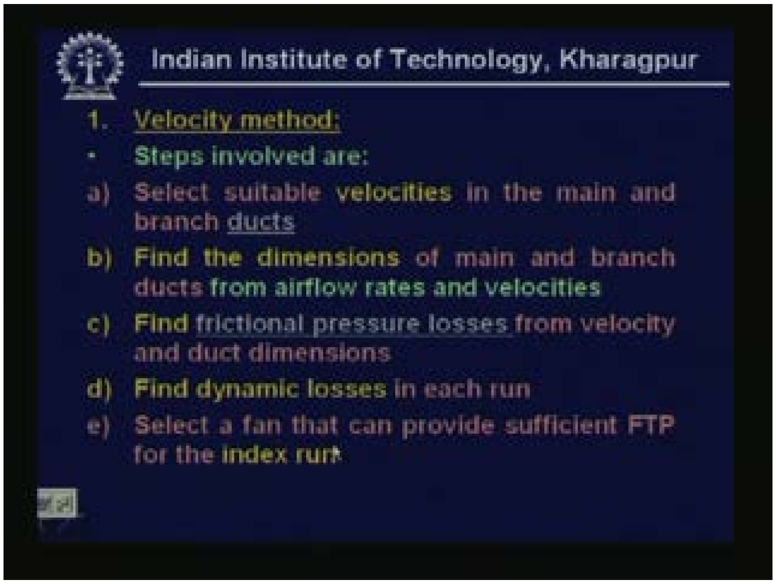

Then we also have to find dynamic losses in each run I have discussed how to find dynamic losses in each run in the last lecture then we have to find selective fan that can find that can provide sufficient fan total power fan total pressure for the index run okay so having estimated the dynamic and frictional pressure losses in each duct run you have to find out what is the duct run that gives the highest pressure drop okay so that is known as the index and we have to select a fan which can provide sufficient fan total pressure for the index run. That means for the maximum possible pressure drop conditions okay. So for example let us again look at this duct layout.

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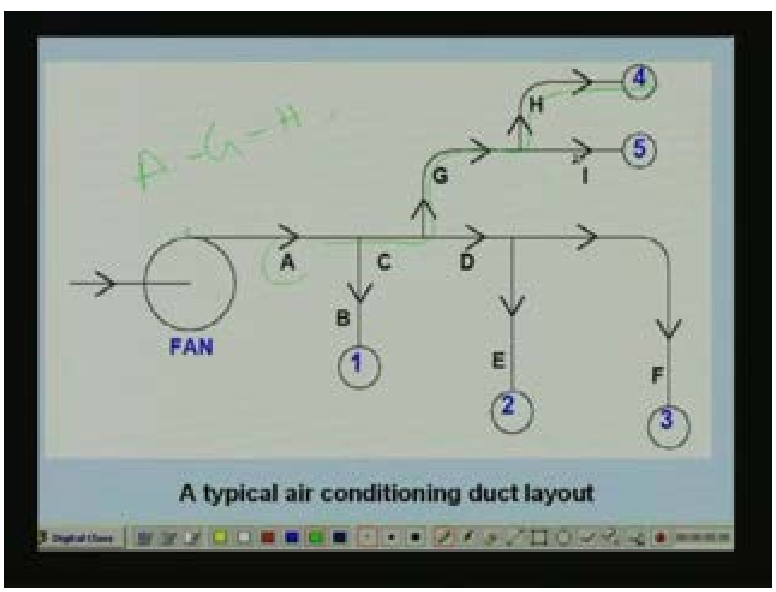

Let us say that our index run is here okay, like this let us say that means A to G to H okay, that means the pressure total pressure drop from this point to this point is the highest compared to other pressure losses okay. Pressure in the other duct runs then you call this AGH as the index run because the total pressure loss in this particular duct and is the maximum okay. So we have to select a fan which can provide this maximum pressure loss.

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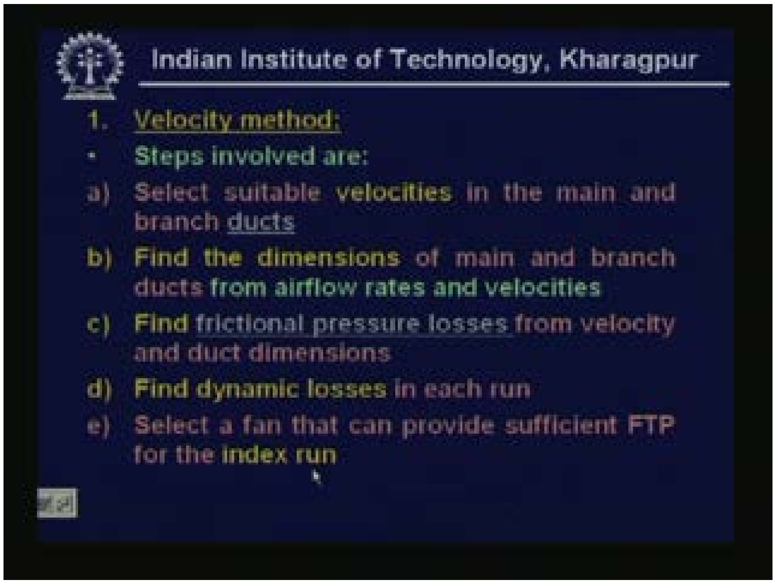

Okay so this is the method. So first select the velocity is this very simple method as you can see first select the velocities suitable velocities since flow rates are known from the velocities find out the dimensions. Once you know the dimensions and the flow rates you find out the frictional pressure drop and then from the duct layout depending upon the branches and bends turns etcetera. You find out the dynamic losses then you add up frictional and dynamic losses for each duct run okay. And find out the duct run which gives the maximum pressure loss that particular duct run is called as the index run and you select a fan whose FTP is equal to the total pressure loss of the index run okay. So this ends the design purpose and the procedure as far as velocity method is concerned okay.

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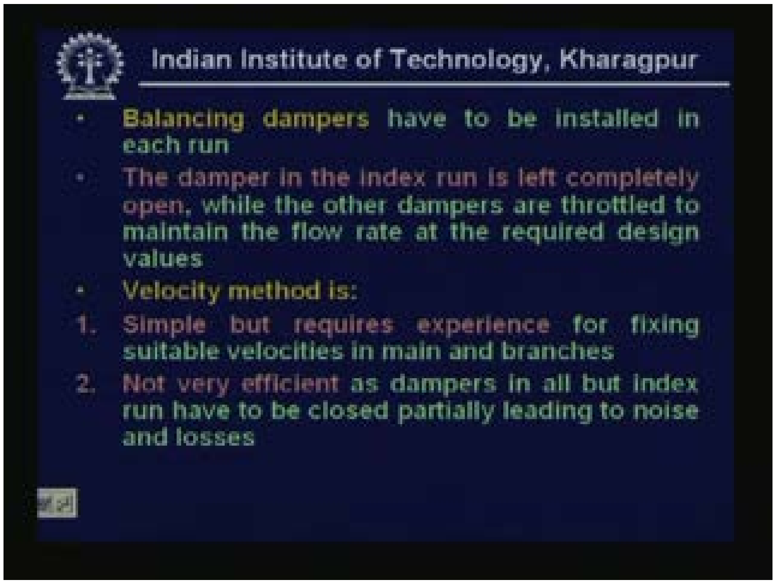

Now what is to be done is, the we have to use balancing dampers in each run and what is the purpose of balancing dampers. The damper in the index run is left completely open while the other dampers are throttled to maintain the flow rate at the required design values okay. So again if you go back to the duct layout let us say that in the index run the total pressure loss is hundred Pascal’s okay. I select a fan which gives me a FTP of hundred Pascal’s but in a, in one particular duct which is not the index run but another duct run the total pressure drop is ten Pascal. Let us say, so if I am using a fan which develops hundred Pascal of FTP and it is connected to a duct run which is having ten Pascal only then you cannot maintain the flow rate. The flow rate will be higher in this particular shorter duct run okay.

So what we have to do is we have to artificially introduce some friction okay or some resistance so that for each duct run ultimately the total pressure loss will be same which is equal to the FTP okay. That is the reason why we have to use dampers and in the index run the total pressure loss is equal to the FTP. So the damper as got to be completely left open whereas in the other runs where the total pressure loss is less than the FTP you have to adjust the dampers in such a way that the additional resistance offered by the damper plus the actual resistance will be equal to the total pressure loss. So that is how the system has got to be balanced okay. So this is the in brief the velocity method and what are the typical characteristics of velocity method as you can see velocity method is very simple. But one important thing is that it requires experience for fixing suitable velocities in main and branches. So this is the first step in any velocity method you have to select suitable velocities.

How do you know what is suitable velocity okay, so this depends upon the experience okay. So depending upon the application depending upon various other considerations you have to fix suitable velocities. If you do not select proper velocities then you will end up with a non optimal duct design okay. So success of this method depends upon fixing the suitable velocities okay

next this method is not very efficient because as dampers in all but index run have to be closed partially leading to noise and losses so as i have explained we use dampers in all the run okay and the dampers in index run is completely kept open whereas in the other runs we close the damper so as to introduce additional resistance okay.

This is actually introducing a loss deliberately okay because by closing the damper partially you are introducing losses okay. And this will lead to not only loss in efficiency but also the generation of noise okay so the use of dampers is not very efficient okay. As a result the velocity method which requires adjustment of dampers for maintaining the FTP same in all duct runs is not very efficient from this point of view okay.

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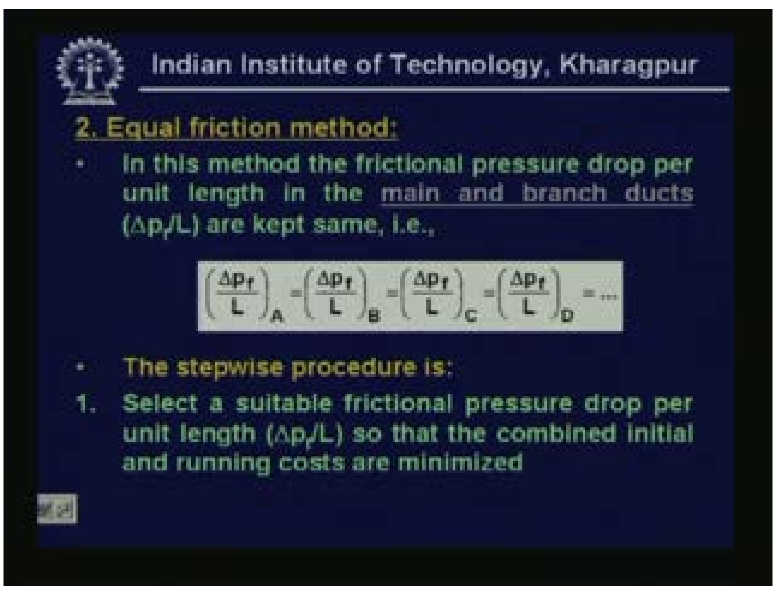

Next let us look at second method known as equal friction method in this method the frictional pressure drop per unit length in the main and branch ducts are kept same okay. That means everywhere.

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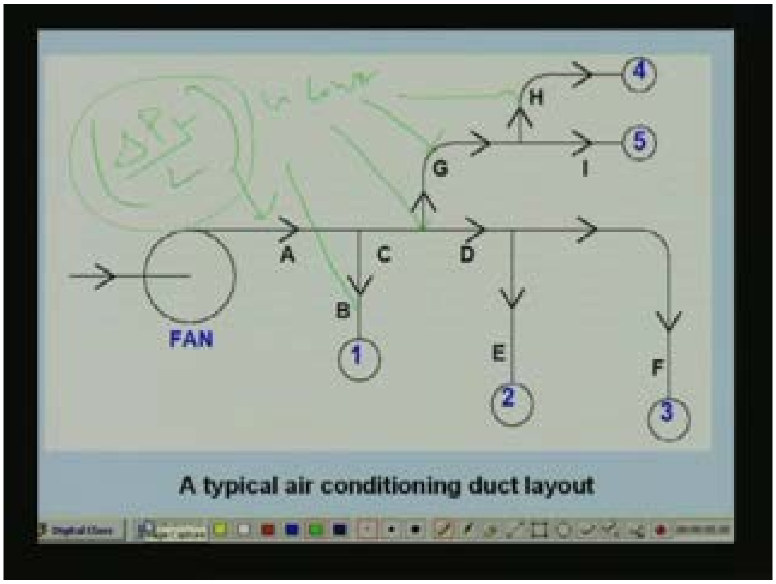

The frictional pressure drop per unit length, that means delta PF by L is constant okay, constant, for example this main for this part of the main for this branch for this branch for this branch etcetera. Every where this parameter is same this is the principle of equal friction method that is why I call it as equal friction method okay.

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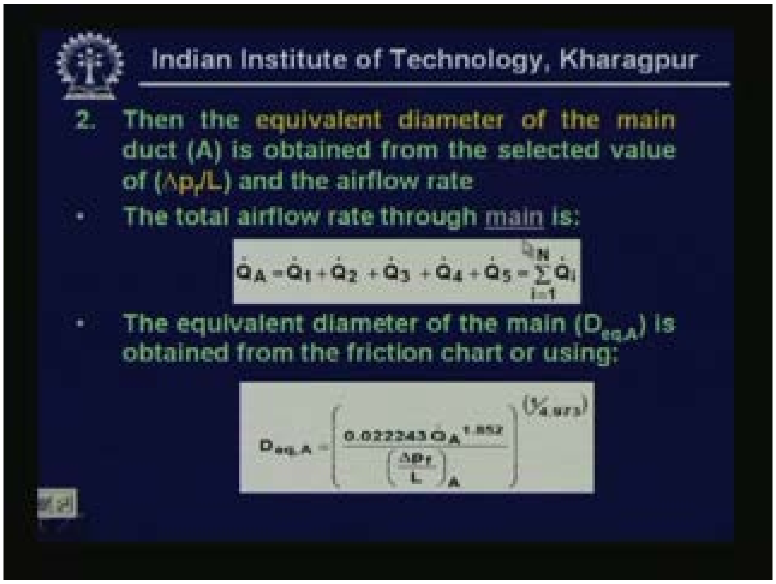

So that means delta Pf by L of duct run A is equal to delta Pf by L of duct run B that is equal to delta Pf by L of duct run C etcetera okay. Then the step wise procedure is as follows select a suitable frictional pressure drop per unit length. So that combined initial and running cost are minimized okay. So in the earlier method we have fixed the velocities where as in this method we have to select a suitable frictional pressure loss per unit length okay. That is the first step then the equivalent diameter of the main duct is obtained from the selected value of delta Pf by L and the air flow rate. For example the total air flow rate through the main is given by this Q dot A is equal to Q dot one plus Q dot two plus Q dot three plus Q dot four plus Q dot five.

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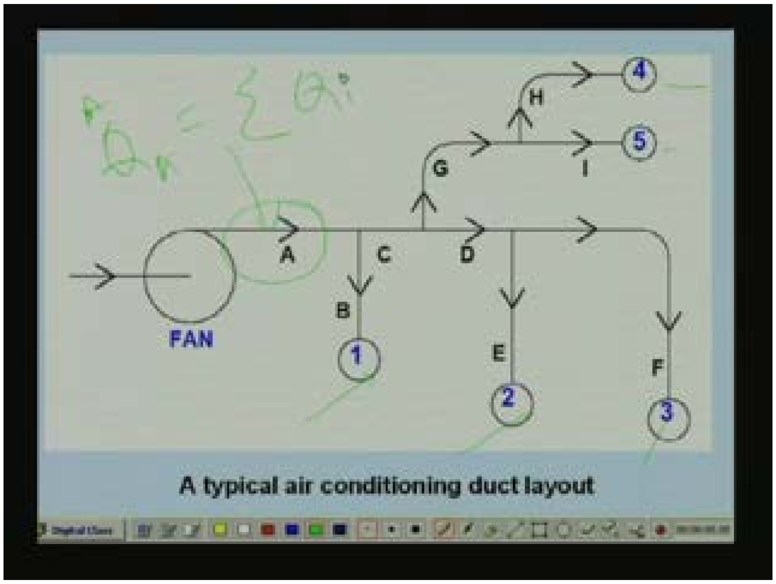

For example if you look at the figure this is the air flow rate Q dot A okay, sorry, Q dot A through this main duct run A you can see from the mass balance or volume balance that Q dot A is nothing but Q dot one plus Q dot two plus Q dot three plus Q dot four plus Q dot five okay. So this is equal to summation of different Qi's okay. So which is known to us right.

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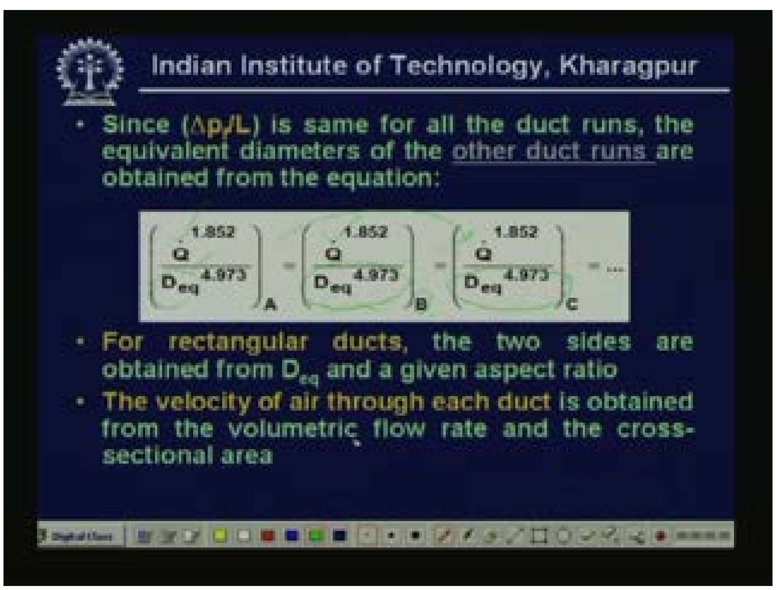

So Q dot A is known from the air flow rates in different condition zones then from the Q dot A and using the delta Pf by L value the equivalent diameter of the main duct is obtained okay. Either using the friction chart or using the flowing equation okay. So you know that I have discussed this equation before we know this and we have fixed this. So you can easily find out what is the equivalent diameter of duct run A since delta Pf by L is same for all the duct runs the equivalent diameter of the other duct runs are obtained from the equation followings equation is used Q dot to the power of one point eight five two divide by D, D equivalent to the power of four point nine seven three of A of is equal to this of B which is equal to this of c etcetera okay and we know this we know okay.

We have calculated D equivalent just know I explained you have calculated this from the frictional pressure drop per unit length and the Q. So this is known to us and this is also known to us so you can find out this. That means the equivalently diameter of duct run B can be obtained by exuviating this two similarly by equating these two we can find out the equivalent diameter of duct run C okay. So this procedure is followed for finding the equivalent diameter of all other duct runs okay. So this is as far as the circular duct is concerned if you are using non circular duct such as rectangular duct the two sides are obtained from the D equivalent value and a given aspect ratio. I have discussed this earlier if you know the equivalent diameter of a rectangular duct how to find the two sides either you have to specify the aspect ratio or you have to specify one side. So that you can find the other side have also specified an equation or I also given an equation which was derived from the equivalents of these two ducts, how to find the two sides from the equivalent diameter okay. This was discussed in the last lecture so the velocity of air through each duct is obtained from the volumetric flow rate and the cross sectional area.

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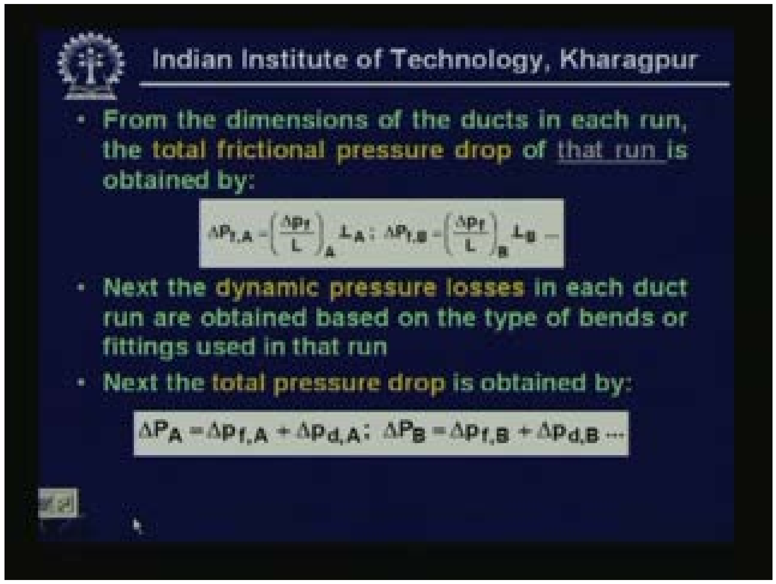
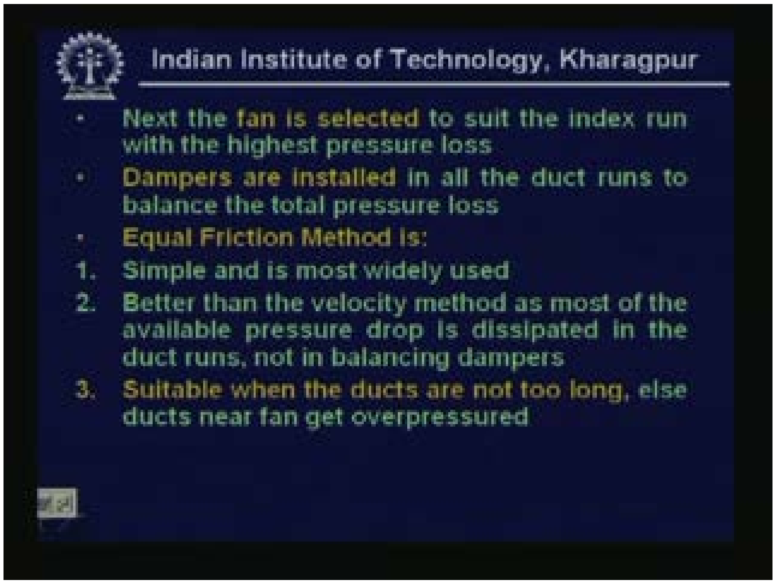


Now from the dimensions of the ducts in each run the total frictional pressure drop of that run is obtained by this equation delta Pf A is equal to this is very simple this is nothing frictional pressure drop in A is nothing but frictional pressure drop per unit length in A multiplied by length of duct run A LA is the total length of duct run A similarly in B the frictional pressure drop in B is equal to frictional pressure drop per unit length in B multiplied by length of B in this particular method delta Pf by L of A is equal to delta Pf by L of B etcetera okay. So we can find out what is the frictional pressured drop in each duct run now after you find the frictional pressure drop we have to find what is the dynamic pressure loss in each duct run okay. As I have explained in the last lecture the dynamic pressure losses depends upon the velocity and it also depends upon the duct layout how many bends you have how many whether you have a branch take off or whether you have any other coil etcetera.

But depending upon this information one can calculate the dynamic pressure losses, so once you find out the frictional pressure losses and dynamic pressure losses of each duct run the total pressure loss of that particular duct run is nothing but the sum total of dynamic and frictional pressure losses okay. So that how we can find out the total pressure loss in each duct run okay. So that is given here the total pressure drop in for example duct run A is equal to delta Pf A plus. delta Pd A similarly for B and so on (Refer Slide Time: 00:21:37 min)



Next the fan is selected to suit the index run with a highest pressure loss okay. As before a dampers have to installed in all the duct runs to balance the total pressure loss okay. So in brief this is the equal friction method. So let me again summarize equal friction method this equal friction method starts with selecting suitable value of frictional pressure loss per unit length okay. So this is the first step in this method. So once you know the frictional pressure drop per unit length then you can find out the duct dimensions because you know the flow rate okay. So flow rate is known frictional pressure loss per unit length, is known. So from these two you find out the duct dimensions once you know the duct dimensions you have find out the velocities from the duct dimensions and the air flow rate.

So once you know the velocities you can find the dynamic pressure losses in each duct run then you have to sum up the dynamic and frictional pressure losses of each duct run and you have to find out the index run. That means the run which gives the highest pressure loss okay. So this is known as index run and you have to select a fan whose FTP or to the fan total pressure is equal to R greater than the total pressure loss of the index run okay. Then since the total pressure loss of other duct runs are less than that of the index run we again have to install dampers and dampers have got to be adjusted. So that you get the required flow rate in each supply air outlet okay. So this is the equal friction method now the equal friction method is simple and is most widely used oaky, among all the conventional method this is the most widely used method. And this method is better than the velocity method as most of the available pressure drop is dissipated in the duct runs not in balancing dampers oaky. So this is better than the velocity method because what we can do is if you have frictional pressure drop available then you can reduce the dimensions of the duct.

So that you can dissipate the available frictional pressure drop in the ducts itself there by you can go for smaller ducts right, rather than wasting it in the dampers okay. So that how this method is slightly better than the velocity method and this method is suitable when the ducts are not too long okay. If the ducts are very long what happens is the ducts near the fan get over pressured okay. Then this system is not very good or recommended for this kind of air conditioning systems okay, and equal friction method can be used for both supply as well as return ducts procedure is same for both supply as well as return ducts.

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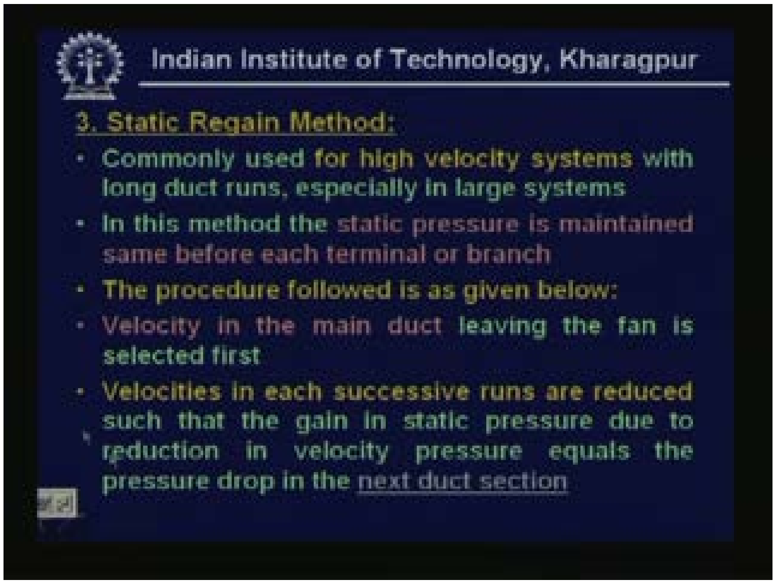

Next let us look at the third method that is static regain method. This method is commonly used for high velocity systems with long duct runs especially in larger systems. That means large capacity systems we normally use static regain method because you will find that this method is more efficient compared to velocity method and equal friction method. In this method the static pressure is maintained same before each terminal or branch that is why the name is static regain method. And the procedure followed is as given below first velocity in the main duct leaving the fan is selected. You do not have to select velocities in all duct runs but you just have to select the velocity in the main duct okay. Then velocities in each successive runs are reduced such that the gain in static pressure due to reduction in velocity pressure equals the pressure drop in the next duct section okay, so let me explain this.

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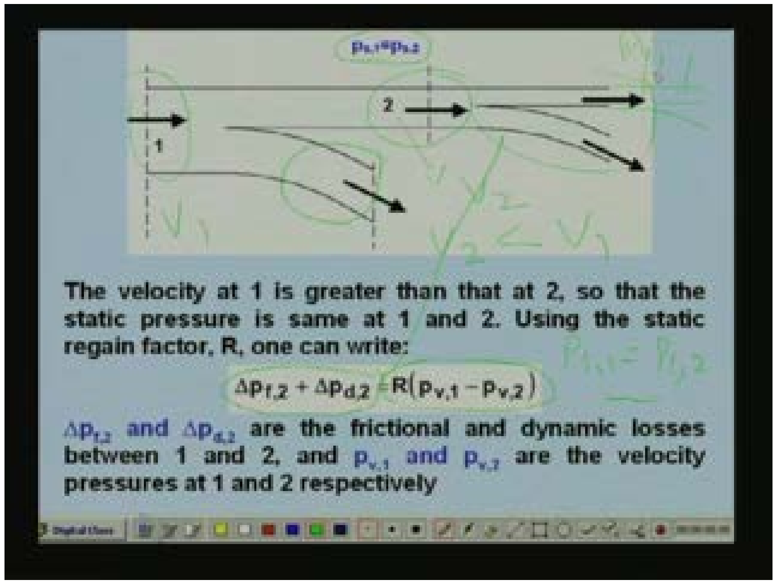

Let us say that this a typical duct run let us say that air is coming here and you have one branch here and then you have the upstream branch, let us say I am sorry downstream branch you have upstream here downstream and the branch okay. So what is done in this method is in the, for example if I am taking about the downstream, you have velocity at the point two section two is V two. Let us say and the velocity in section one that is upstream is v one right. So what is done in this method is, V two is reduced that means V two is less then V one. So when you are reducing velocity what happens there is a conversion of velocity pressure into static pressure raise. So this I have discussed in the lecture this is what is known as static regain factor okay.

This raise in static pressure due to reduction in velocity pressure is such that it matches with the frictional and dynamic losses in the section form point one to two okay. That means whatever is the frictional losses from point one to two is equal to the static regain factor R multiplied by the velocity pressure at point one minus velocity pressure at point two okay. Pv one minus Pv two Pv two is always lower then Pv one that’s how you select the dimensions of the downstream duct okay. So find that because you balancing exactly the drop in velocity pressure with that of the losses, you find that the static pressure at point one and two will remain same that means Ps one will be equal to Ps two right.

So P what is section two? Section two is nothing but the upstream for the next downstream section and the branch okay. So you keep the static pressure here equal to static pressure here similarly if you have further branches and down streams again at this point also you have to select these duct dimensions such a way that the static pressure in the downstream will also remain same as that of the upstream okay. So this is the velocity this the static regain method okay.

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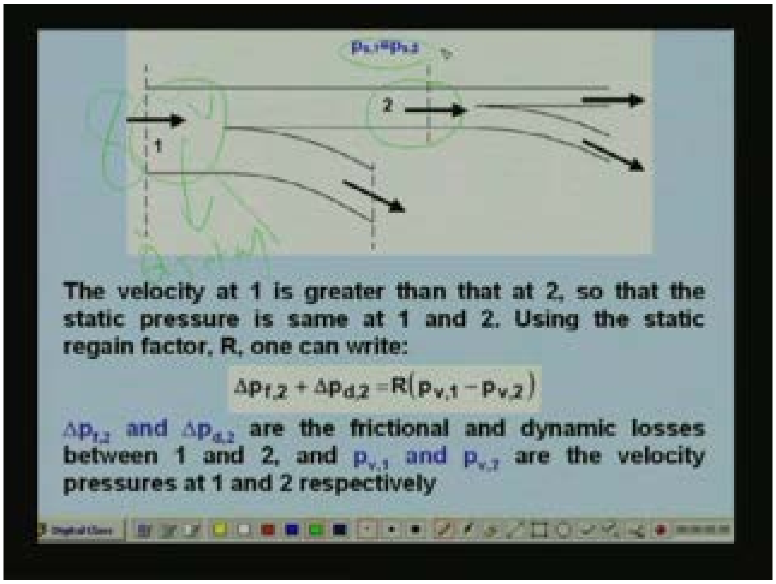

Now if section one is the outlet of the fan then its dimensions are known from the flow rate and velocity okay. What I mean is, let us say that you have the fan here okay, and then we know what is the total air flow rate here q total is known because this is nothing but the sum total of all the air flow rate flows rate to each outlet. So this is known to us right and we are selecting a suitable velocity here. So once you know Q dot and V then you can find out what are the dimensions here okay. The dimensions are known here, and then what we have to do is we have to reduce the velocity. Here you may have to increase the dimensions for that purpose so you reduce the velocity such that the static pressure remains constant okay.

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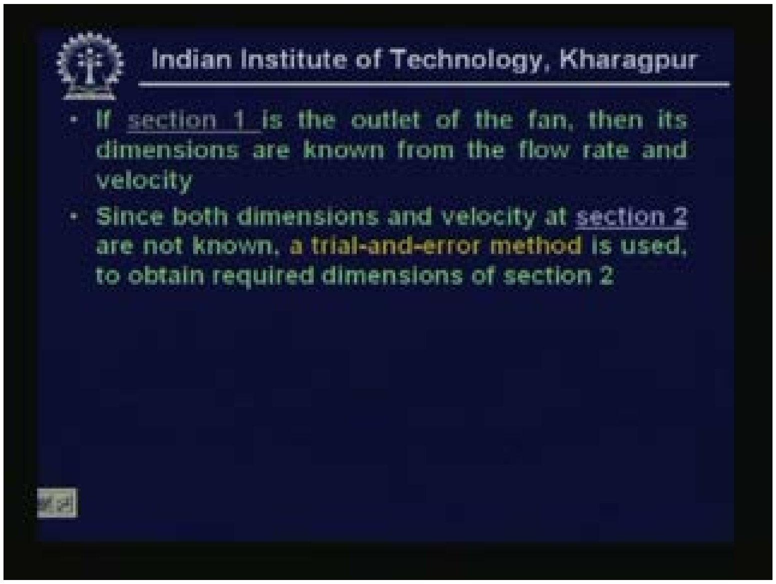

However since both dimension and velocity at section two are not known before hand we have to use a trial and error method to obtain the required dimensions of section two.

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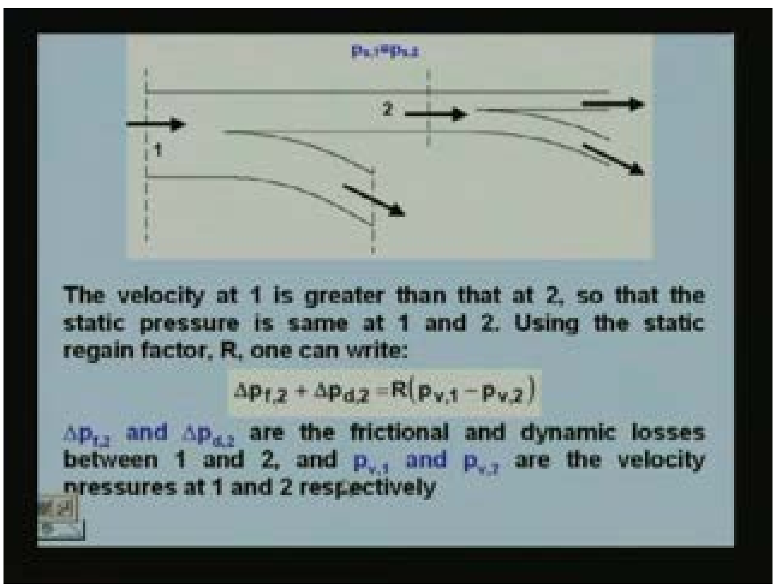

What it means is, we have to use this equation okay. This equation as got to be used to fix the dimensions of section two right here you have v two on this side and this side also you have V two which is not known okay. So we have to use a trial and error method because we do not know the dimensions since hence we do not know velocity also. Since velocity appears on right hand side as well as left hand side you may have to use a trial and error method. So that this equation is finally satisfied okay, so this is the procedure for static regain method. And this procedure is continued in the direction of air flow and the dimensions of the downstream ducts are obtained okay. All the downstream ducts are obtained by following the same method okay.

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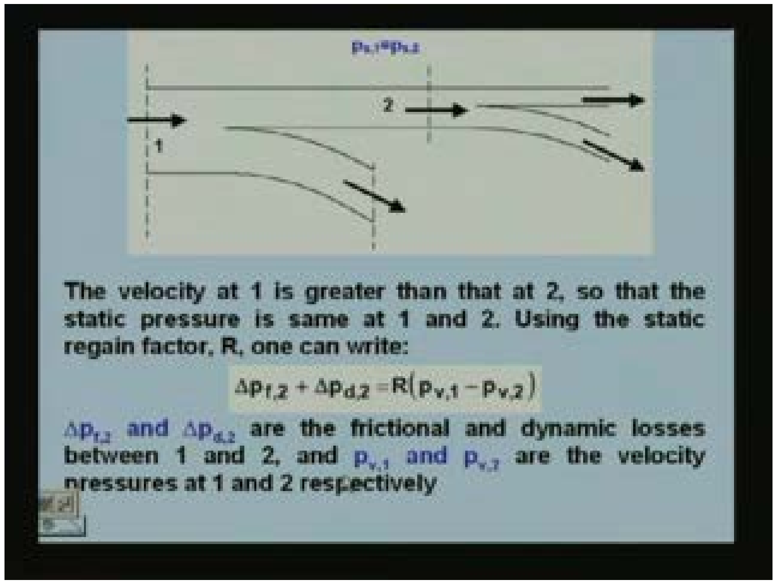

Keeping the static pressure constant before each branch or terminal okay, so this is the principle and then the total pressure drop is obtained from the pressure drop in the longest run and a fan is accordingly selected thus this step is same for all the methods okay. The fan as got to be selected finally to suit the pressure loss in the largest duct run longest duct run I am sorry, that means the duct run with the highest pressure loss okay.

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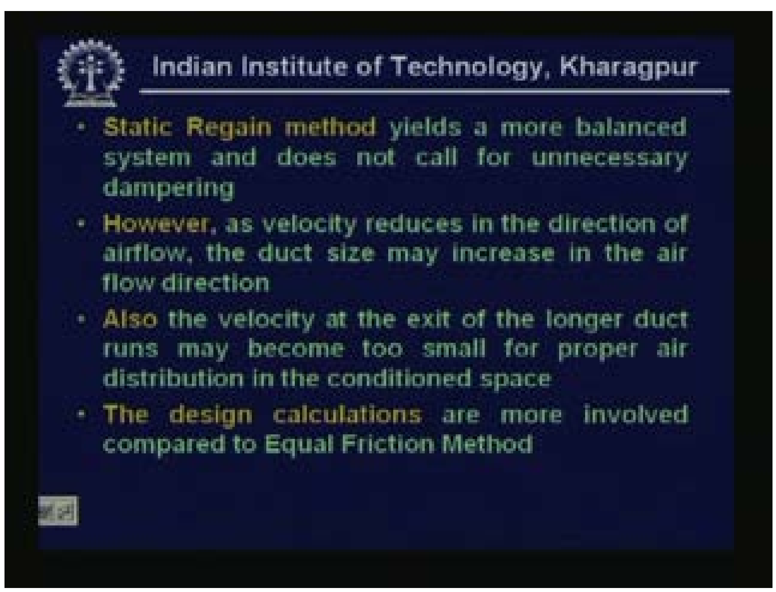

So the you will find that the static regain method yields a more balanced system and it does not call for unnecessary dampering okay. The dampers are required in velocity method and equal friction method for balancing whereas in static regain method you are changing the dimensions in such a way that the static pressure remains same. So you do not really require dampering okay since dampering is not required efficiency will be higher however there are certain problems with static regain method what are the problems as velocity reduces in the direction of air flow the ducts size may increase in the air flow direction okay, so this one major problem okay. So you have to progressively in reduce the velocity okay. So as a result the duct size may go up second problem is that as the velocity reduces in the direction of airflow the velocity at the exit of the longer duct runs may become too small for proper air distribution ion the conditioned space, okay.

That means, let us say that you start with some velocity in the main okay. Then you go on reducing the velocities in the direction of the air flow and finally at the outlet supply air outlet you may find that the air velocity is too small okay. Too small means for too small for proper air distribution inside the conditioned space okay. Because you have to reduce the velocity because you are trying to convert the velocity pressure into static pressure raise okay so that is the principle of this method. So as result when you are using this method velocity reduces in the direction air flow but if you if it reduces too much then it may affect the air distribution in the conditioned space okay. This is another problem of static regain method if such a problem occurs what is to be done is you have to again go back and increase the velocity of the main duct which you have selected in the first step okay.

So that means it require some kind of a trial and error or hytracesion method. So initially you select some velocity and make sure that the velocity at the supply air outlets is sufficient for proper air distribution if it is not sufficient you have to go back and either increase are decrease the velocity okay. You have to decrease the velocity if the; if you find that the velocity is too high or you can you have to increase the velocity if you find that the outlet velocity is too low okay. So you find that as a result of this the design calculations are more involved compared to equal friction method okay. Velocity method and equal friction methods are simpler whereas static regain method is more complicated.

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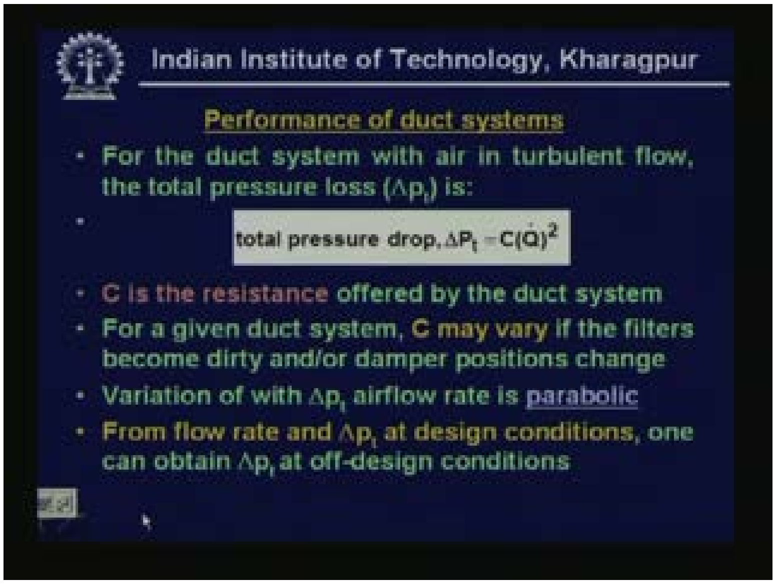

Now let us look at briefly the performance of duct systems for the duct system with air in turbulent flow the total pressure loss delta Pt is found to be proportional to the air flow rate okay, total pressure drop okay. Total pressure drop includes frictional as well as dynamic losses so it is observed that when if the air flow is turbulent in nature this is proportional to air flow rate square of air flow rate okay. That means you can write delta Pt is equal to C into Q dot square where C is the resistance offered by the duct system and for a given duct system C may vary if the filters become dirty and or dampers position change theoretically, let us say that the filters do not get dirty filters stay as they are and if you do not change the damper position then the resistance value remains same okay. For a given duct system given duct system means a duct system with given dimensions right and given length etcetera. And variation of delta Pt with air flow rate is parabolic you can see from this equation that if you plot total pressure loss or total pressure drop verses Q dot you find that you get a parabolla okay. You get a curve of this nature.

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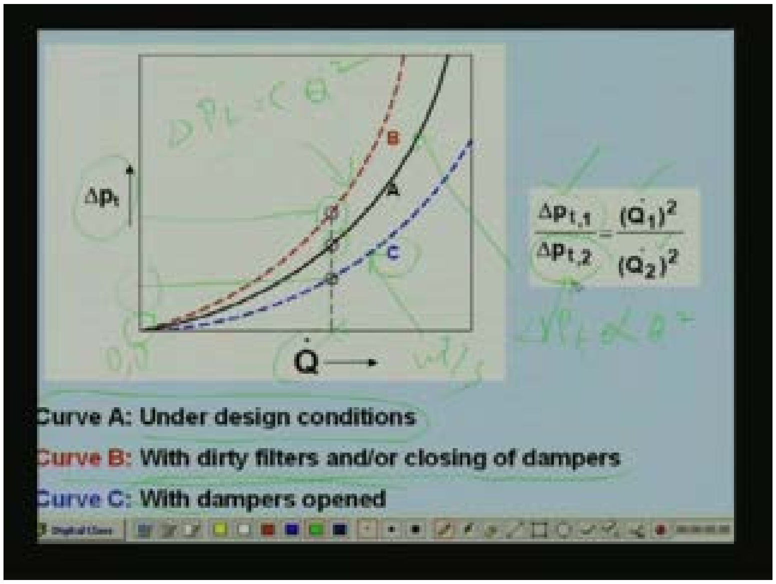

Okay, so for a given duct system as I said this is the delta Pt total pressure loss and this a air flow rate meter cube per second right. So we have seen that delta Pt is equal to C into Q dot square so you get a parabolla which passes through the origin okay. That means when Q dot is zero delta Pt should be zero right. So let us say that this curve A is under design conditions okay. So that means at the time of design or for design you have selected this kind of a duct performance curve or duct characteristic curve but however with usage the filters may become dirty or you may close the damper okay. If the filters become dirty or if you close the damper you get this curve okay.

That is curve B with dirty filters or closing of dampers what is happen when the filters become dirty or when you are closing the dampers for the same flow rate the pressure drop increases obviously okay. Resistance increases so pressure drop increases right now if you open the damper, let us say that the filters are clean but you have opened the dampers more compared to the design condition then you find that the duct performance curve is given by this blue line C, okay. This is with dampers opened right so for when you open the dampers you find that for the same flow rate the total pressure drop will be less okay. Because the pressure loss across the damper is reduced because of the opening so as result you get less total pressure loss okay. So these kinds of curves are known as duct performance curves okay. What is the use of this curves you can see that since delta Pt as I have written here is proportional to is proportional to Q dot square if you know the delta Pt value at one point let us say okay, at one and if you know flow rate at two. Then you can find out what is the total pressure loss at the second condition two that means if one is the design condition at design condition you know what is the total pressure loss and the flow rate and you what find out an off design condition where the flow rate is different, we can easily find out what is the total pressure loss using this equation okay. So that is the use of duct performance curves.

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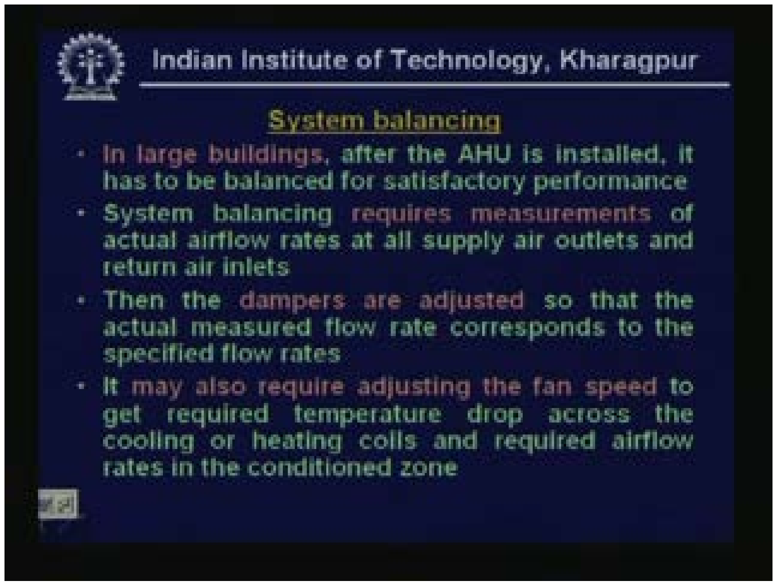

Next let us look at system balancing very briefly what do you mean by system balancing in large buildings after the air handling unit consisting of ducts coils etcetera is installed it as to be balanced for satisfactory performance. So what do you mean by balancing system balancing requires measurements of actual flow rates at all supply air outlets and return air inlet. So you have to do elaborate measurements carry out elaborate measurements of air flow rates at all air outlet and inlets.

Then the dampers have to adjusted so that the actual measured flow rate correspondence to the specified flow rates and sometimes as i part of systems balance, balancing, it may also require adjusting the fan speed to get required temperature drop across the cooling or heating coils and required air flow rates in the condition zone okay. Ultimately why do we do system balancing let us say that you have you carried out the cooling load calculation then you designed the ducts you have selected the fan you have installed everything right. So finally you have to get the required performance that means you have to get the required temperatures in the conditioned space oaky. The, this depends upon the temperature of the supply air and also depends upon the supply air flow rate okay. So you have to make sure after you install everything that you are getting the right amount air at the right temperature okay. So what is done is since several assumptions are involved at the time of design it does not happen automatically. So some kind of adjustment is required to get the required conditions okay.

So this is known as system balancing and this involves several steps and it is carried out in different manners. So basically what it involves is the measurement of, for example temperature and air flow rates at all supply air outlets and return air inlets okay. So that means you have to have accurate instrumentation and you have to measure all these parameters and if you find that the supply air flow rate is let us say more than required okay. Then you have to reduce the supply air flow rate then you can reduce the supply air flow rate either by changing the damper position or by varying the fan speed of course if you are using a fan for all the same fans for all duct runs then if you are varying the fan speed then it will affect the air flow rate in other spaces also right.

So fan speed variation may not be possible always normally the option left for us is to vary the position of the damper in that particular zone to get the required air flow rate, okay. So you vary the damper position again measure the flow rate and see that you are getting the required flow rate okay. So this process as to be continued till you get the required amount of air flow rates in all the conditioned zones okay. So at this point the position of the dampers are fixed then sometimes it may also require you may also require the variation of fan speed for example if you are finding that the required temperature drop across the cooling coil is too small or too high okay. Which may lead to too much of dehumidification or right or too less of dehumidification you may have to adjust the air flow rate okay. So again this requires adjustment of fan speed right.

So this procedure is known as system balancing normally system balancing is the last part of the air conditioning system installation and design and installation and after system balancing normally the air conditioning plant is handed over to the building owner okay. Normally large air conditioning systems the system balancing can be very costly business and it may take lot of time and effort right. Because it requires measurements of temperatures and velocities precisely at several locations okay. So most of the times in smaller buildings and all people may skip this procedure all together okay. They may do it in a trial and error bases if you find it too cold you have close the damper or if you find it too warm you may open the damper okay, not by taking any measurements okay.

But however in large systems system balancing is always recommended because once you balance a system properly you get the maximum possible benefit from the system okay. So system balancing as to be done at least in the large air conditioning systems okay.

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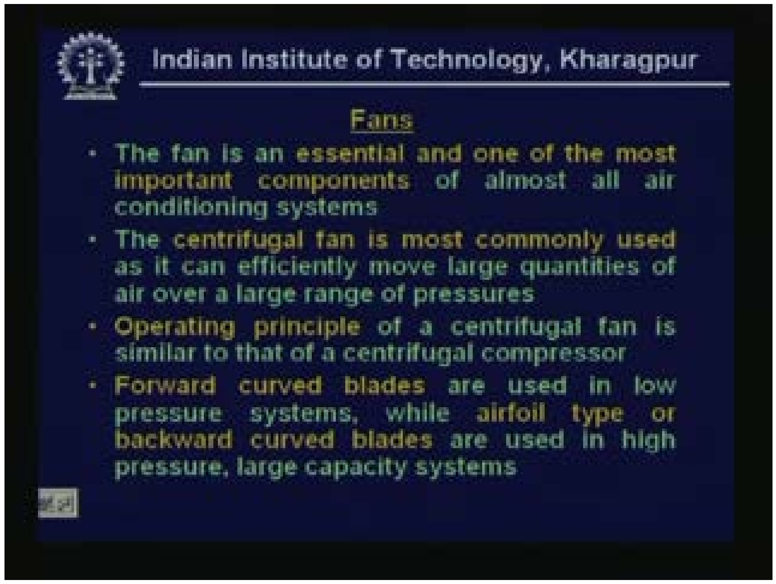

Next let us look at fans okay. Very important component of any air conditioning system the fan is an essential and one of the most important components of almost important components of almost all air conditioning systems small or big you have to use a fan for circulating air okay. Fan is a costly component it consumes lot of power okay and it also generates noise right. So it is source of noise it consumes power it also incurs lot of initial cost so you have to select the fan properly okay. If you incorrect selection of fan can be give rise to bad performance or poor performance okay. Normally the centrifugal fan is most commonly used in all air conditioning systems because it can efficiently move large quantities of air over a large range of pressures okay.

Generally you find that in almost all air conditioning systems centrifugal fans are used the other type of fan namely the axial flow type fan is very rarely used in some special applications and the operating principles of centrifugal fan is exactly similar to that of a centrifugal compressor. We have discussed the operation principle of centrifugal compressor how a centrifugal compressor increases a pressure of refrigerant okay. Similarly a centrifugal fan increases the pressure and kinetic energy of air okay. So the principle is almost same. Normally forward curved blades are used in low pressure systems okay, whereas air fall type or backward curve blades are used in high pressure large capacity systems okay. Compared to forward curved blades centrifugal fans the air fall type or backward curved blades give higher efficiency okay. Since efficiency is important in large systems normally large systems use air fall type or backward curved blade fans okay. Normally the air falls blades are costly that mean the centrifugal fan based on air flow profile is costlier compared to forward curve blades okay. So in smaller systems forward curved blades are used in larger systems air fall types or backward curved blades are used.

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Next let us look at fan laws these are very important and extremely useful what are fan laws the fan laws are a group of relations that are used to predict the effect of change of operating parameters of the fan on its performance okay. If a particular operating parameter changed how the fan is performing okay, so that is the use of fan laws okay. And these laws are valid for fans which are geometrically and dynamically similar okay. If the fans or geometrically and dynamically similar you can apply the fan law if they are not geometrically or dynamically similar you cannot use. Then for example you cannot use the fan laws or you cannot use the fan laws for comparing performance of a forward curved blade with backward curved blades

Okay. They are not geometrically similar so you cannot use fan laws to these two however you can use the fan laws to one forward blade that of another forward curved blade fan of different size may be okay. This is what is known as geometrical similarity right.

Similarly also have to have dynamic similarity. That means the force ratios for these two fans have got to be same right so for these geometrically a dynamically similar fans one can use the fan laws. Now what are the important operating parameters the important operating parameters are density of air which depends on the air pressure and the temperature then rotative speed of fan. That means RPM or RPS of the fan then the size of the fan what is the diameter width of the impeller etcetera.

So these are three operating parameters out of these three size of the fan is important at the time of design okay. At the time of operation we are mainly concerned with density of air and rotative speed of fan okay. We would like to know for a given fan okay. How the variation in density effect the fan performance how the variation fan speed effect the fan performance okay. So the fan loss that I am going to present are related to these two operating parameter that is density and the rotative speed of the fan okay.

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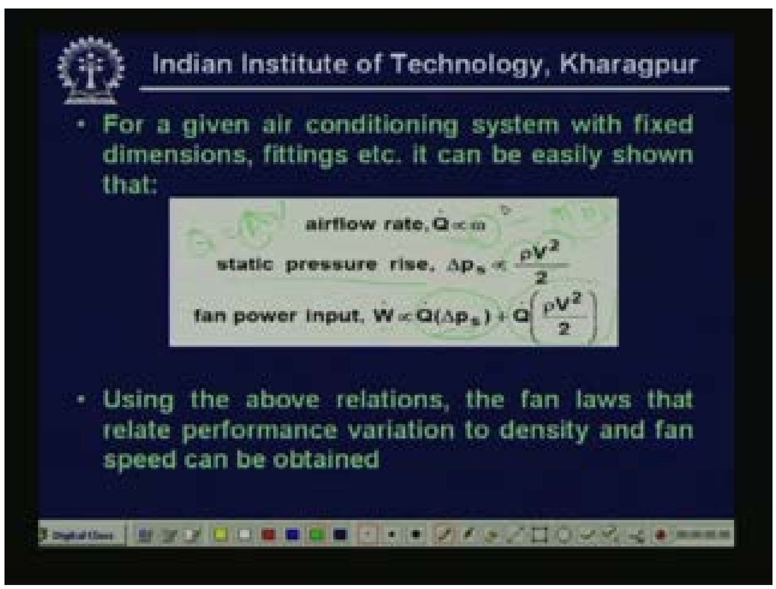

Now for a given air conditioning system with fixed dimension fittings etcetera. It can be easily shown that the air flow rate Q dot is proportional to omega okay. Omega is the rotational speed in let us revolutions per second okay. So remember that this is for a given air conditioning system that means the dimensions etcetera are fixed the cross sectional area is fixed okay. So for a given air conditioning system Q dot is proportional to speed only. Because you know that Q dot is equal to A into velocity so for a given duct system cross section area is fixed. So the air flow rate depends only on the velocity of air okay. And the velocity of air directly depends upon the rotative rotation speed of the fan oaky. As a result you can write Q dot is proportional to rotational speed of the fan okay. Similarly the static pressure raise delta Ps is proportional top rho av square by two this is the static pressure raise remember where rho is the density of air and V is the velocity of air in the duct right.

Next the important performance parameter is fan power input okay. W dot fan power input is proportional to Q dot into delta Ps plus Q dot into rho V square by two okay. So the power input to the fan consist of two parts you can see that right hand side you have two parts the first part is the power input required to raise the static pressure of a certain amount of air okay. So this part is utilized for raising the static pressure of the air the second part is this. So this part that accounts for the power input required to increase the kinetic energy of the air okay, of given flow rate right. So it consist of static pressure raise part and kinetic energy part so these are the typical relations which relative the important performance parameters like air flow rate static pressure and the power input to density and rotative speed. Now using the above relations the fan loss that relate performance varies to density and fan speed can be obtained okay. So we use these three relations to arrive at the required fan laws okay.

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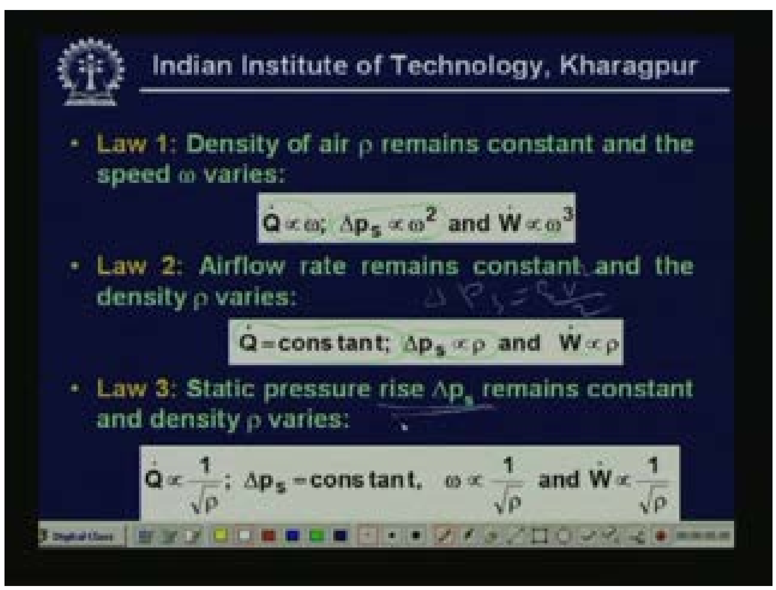

First law with law fan law one fan law one is applicable when density of air remains constant and the speed omega varies okay. So this law is valid under these conditions so when the density of air remains constant and when the speed varies from the previous relations we find that the air flow rate varies with rotative speed okay. Q dot is proportional to rotative speed that means if we increase the speed Q dot increases directly okay. Whereas the static pressure raise is proportional to omega square why it is proportional to omega square static pressure raise is proportional to V square and V is proportional to omega. So static pressure raise is proportional to omega square and the power input is proportional to omega cube remember that omega is the rotational speed okay.

Revolutions per second or revolutions per minute or even radiant are per second okay. So the power input is proportional to cube root of rotative speed whereas the static pressure raise is proportional to square off, I am sorry it is cube of rotative speed square of rotative speed for static pressure raise and directly proportional as far as the air flow rate is concerned okay. So this is valid for constant air density right. So what is the use of this law the use of this law is that for example when the density of air is remaining constant and i increase. The, let us say that I double the velocity okay, the fan is running at ten RPS ten revolutions per second i keep the density constant and increase the rotative speed to twenty revolutions per second okay. So I would like to find out at these new conditions what si the new flow rate.

So from this fan law one states that Q is directly proportional to omega. That means if you double the rotative speed Q also becomes double okay. And static pressure raise is proportional to square of the rotative speed so if the rotative speed doubles then the static pressure raise increases by four times okay. And the power input is proportional to cube of the rotative speed so if you double the rotative speed the power input increases by eight times okay. So you can easily find out what happens when the rotative speed varies using this particular law okay. Next comes second the fan law two this is valid when air flow rate remains constant and the density varies okay.

So this law is valid for this condition we are keeping the air flow rate constant but density is varied right. So when you keep the air flow rate constant Q dot remains constant and density is varying so the static pressure raise is proportional to density. So if the density becomes double static pressure raise also becomes double if density becomes half static pressure raise becomes half okay. And the power input is also varies directly with density okay this relation comes from the, if you remember from the expression of for example delta Ps is equal to rho v square by two okay, we are keeping Q dot constant. That means we are keeping the velocity constant okay. If you keep the velocity constant static pressure raise is directly proportional to density okay, similarly the power input is also directly proportional to density the third law is a valid under these conditions where the static pressure raise okay, delta Ps remains constant and density varies okay.

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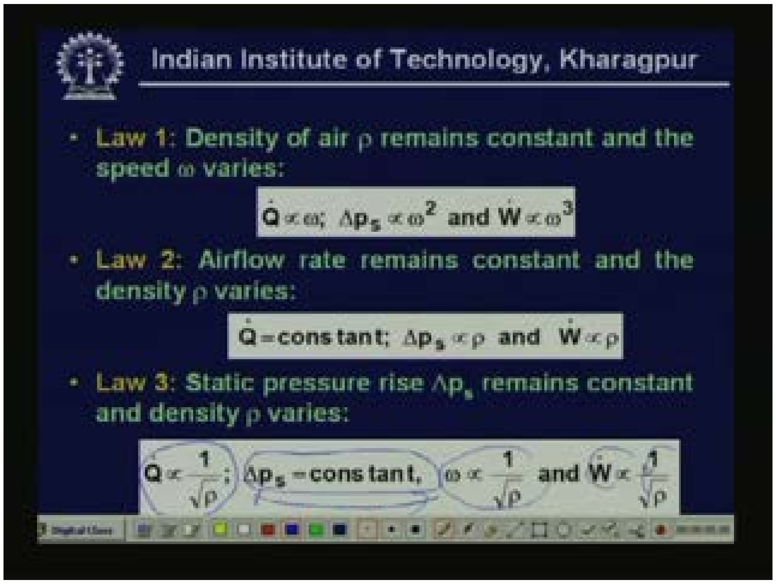

So when static pressure raise remains constant and density varies you find that the air flow rate varies like this Q dot is proportional to one by square root of density and static pressure raise remains constant okay. So that is the condition of the law and rotative speed also varies inversely with square root of density right that is the reason why the flow rate also varies like this and finally the power input to the fan also varies in this fashion okay, one by square root of density okay. So these are some typical fan laws you also can arrive at different fan laws for example if you take the size also into consideration you can derive more number of fan laws okay. Now let me give a small example which will show you the usefulness of the fan law.

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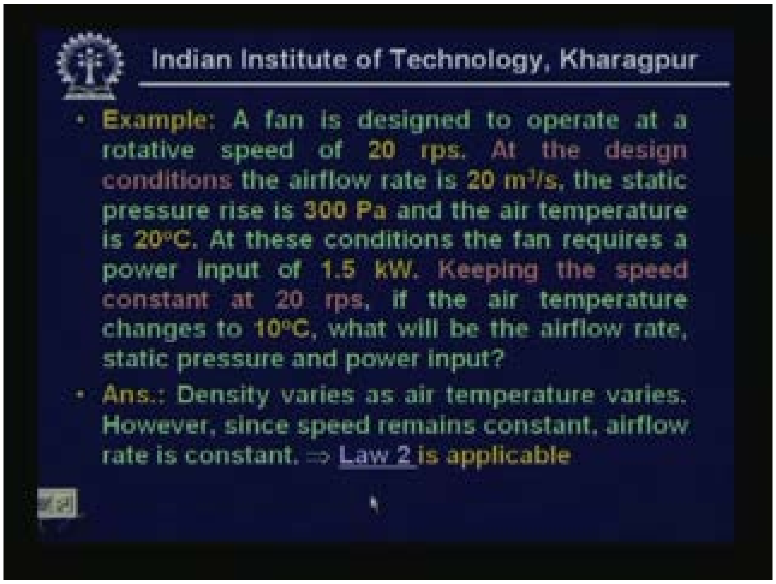

Okay, example, a fan is designed to operate at a rotative speed of twenty revolutions per second and at the design conditions the air flow rate is twenty meter cube per second the static pressure raise is three hundred Pascal and the air temperature is twenty degree centigrade at these conditions the fan requires a power input of one point five kilowatt. Keeping the speed constant at twenty RPS if the air temperature changes to ten degree centigrade what will be the air flow rate static pressure raise and power input okay. So how do we do this first we are varying here the density varies because air temperature varies right however since speed remains constant air flow rate remains constant oaky. That means you have to apply fan law two okay what is fan law two say?

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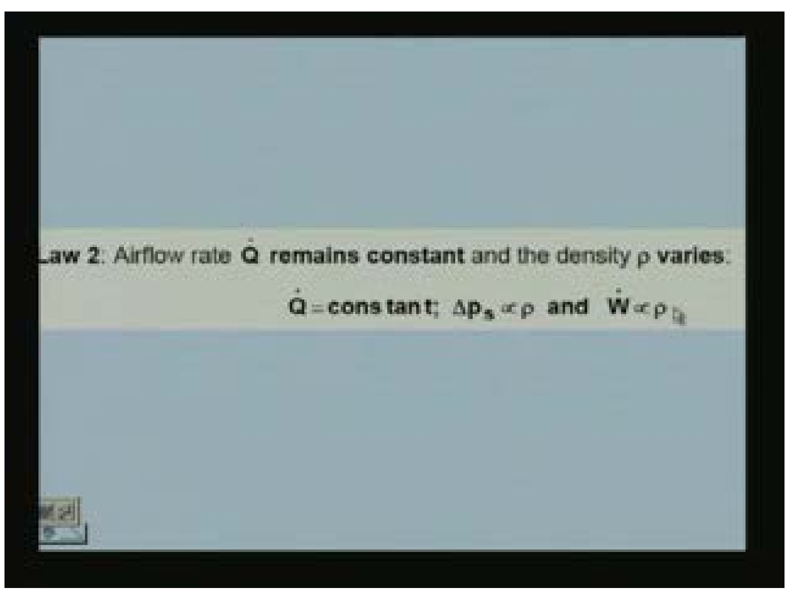

Fan law two is this air flow rate Q dot remains constant and density rho varies so and according to this law static pressure raise is directly proportional to density and power input is also directly proportional to density okay.

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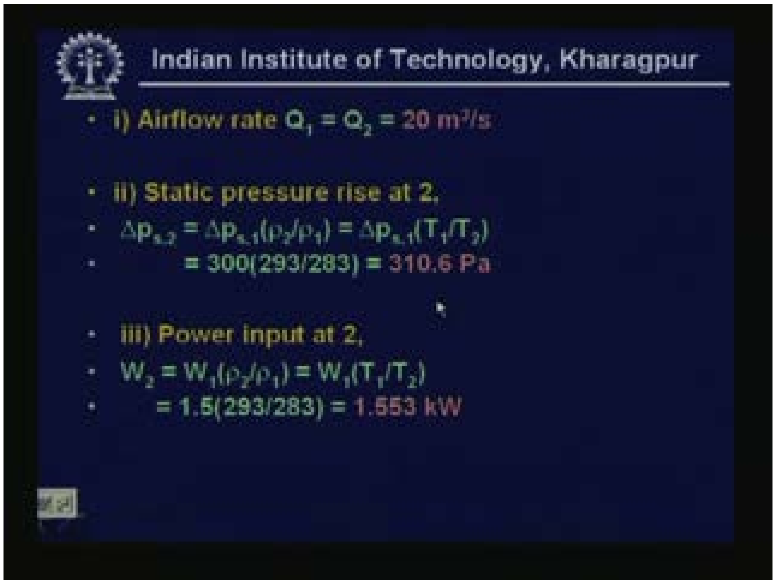

So using this you can easily find out for example air flow rate remains constant at twenty meter cube per second and static pressure raise delta Ps at condition two is directly proportional to density and density is inversely proportional to absolute temperature. So you can find out delta Ps two is equal to delta Ps one into rho two by rho one which is equal to delta Ps one into T one by T two T one T two are temperatures absolute temperatures as I said.

So that is equal to three hundred into two ninety three by two eighty three which is equal to three ten point six Pascal's okay. Next power input power input is also directly proportional to density that means power input at new condition two is equal to power input at condition one multiplied by the density ratio rho two by rho one. So if you substitute the values you find that the required power input is one point five three kilowatt okay. So you can see that you can see how useful the fan laws are, for example if you do not have any fan laws it may be required to test the fan or take measurements to find out what will be the new air flow rate what will be the new power input etcetera right. But by using the fan laws we can avoid testing under all possible conditions, it is not practical to test fan under all possible condition are test all kinds of fans which are geometrically and dynamically similar okay. So under these conditions you can use these simple fan losses and find out performance at one condition if the performance ta other condition is known okay. So this is the usefulness of fan laws.

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So finally let us look at interaction between fan and duct systems okay.

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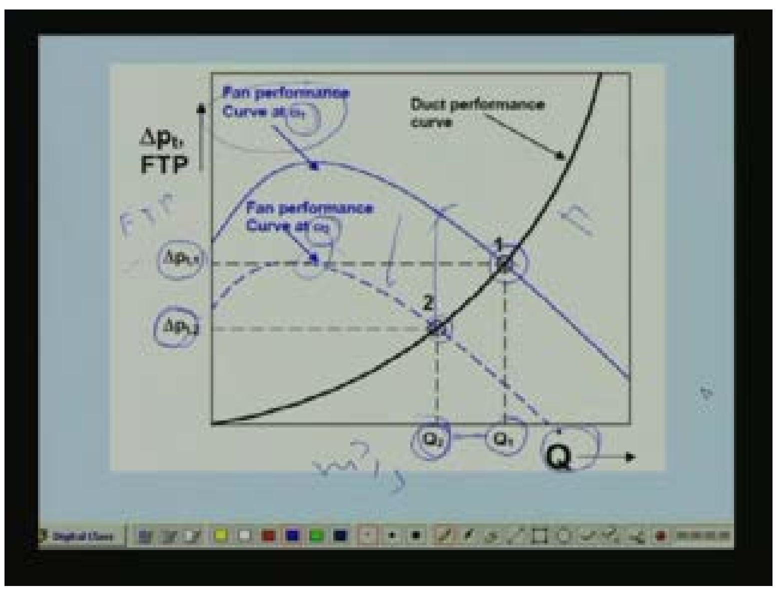

This particular curve shows the performance, fan performance curve okay. This is fan performance curve at rotative speed omega one this a fan performance curve at rotative speed omega two and this is your duct performance curve okay. Both are plotted verses air flow rate Q dot in meter cube per second right. As I said the duct performance curve is a parabolla and fan performance curve of a centrifugal fan varies like this and there is a point of intersection. For example at a given rotative speed omega one the duct performance curve intersects the fan performance curve at this point. So this point is known as the balance point at this flow rate and at this flow rate the total pressure loss is equal to delta Pt one which is equal to FTP one. That means the fan total pressure developed by the fan so at this point very thing is perfectly balanced. Let us say that now the, we have to reduce the air flow rate and if the air flow rate is reduced to Q two okay.

At the reduced air flow rate you find that the total pressure loss of the duct is reduced okay. That is delta Pt two however if you do not change the fan you find that the fan total pressure is here, this higher then, this, so if you again want to balance a system you may have to reduce the speed of the fan so that again you get a new fan performance curve such that when the intersect the flow rate will be Q dot two and the total pressure loss is equal to fan total pressure obtained by the fan okay. So if you have this kind of matching curves you can easily find out the balance points this is the use of these curves.

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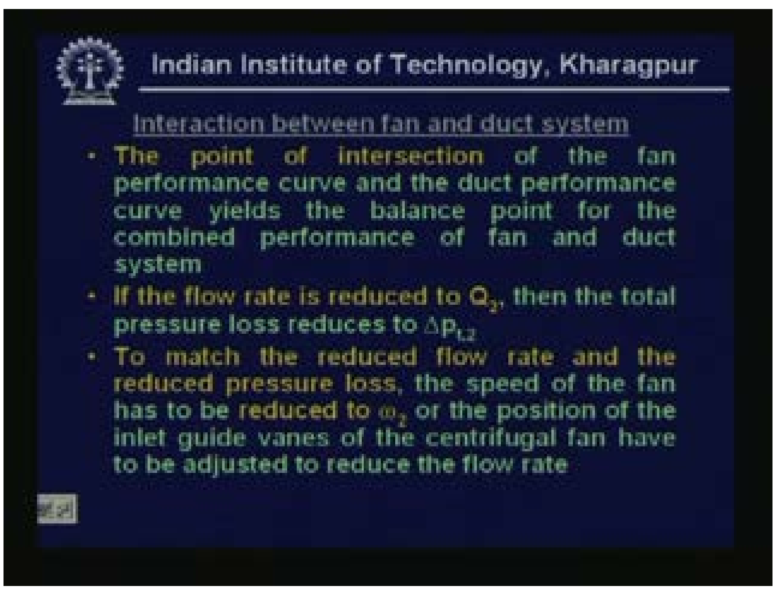

Okay, so this I have already mentioned the point of the intersection of the fan performance curve and the duct performance curve yields the balance for the combined performance of fan and duct system. If the flow rate is reduced to Q two then the total pressure loss reduces to delta Pt two to match the reduced flow rate and the reduced pressure loss. The speed of the fan as to be reduced or the portion of the inlet guide veins of the centrifugal fan have to be adjusted to reduce the flow rate okay. So you have to balance both fan as well as the duct at every changed condition okay, at all points they have to got to be balanced okay. So if you have the performance characteristic curves using them you can find out the balance points okay. So at this point i end this lecture let me quickly summarize what we have learned in this lesson.

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In this lecture the following points are discussed classification of duct systems commonly used duct design methods. That is velocity method equal friction method and static regain method then we have also discussed very briefly the performance of duct systems. Then we have discussed fan laws and what is the use of fan laws and finally we have discussed very briefly the interaction between fan and duct systems okay. At this point I end this lecture and I continue this in the next class.

Thank you.