INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

NPTEL
ONLINE CERTIFICATION COURSE

On Industrial Automation and Control

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Topic Lecture – 44
Energy Savings with Variable Speed Drives

Welcome to lesson of industrial automation and control.

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In this lesson which is entitled energy savings with variable speed drives. We are going to explain and demonstrate that for a kind of application which is very predominant in the industry very common how, what are the firstly we are going to see.

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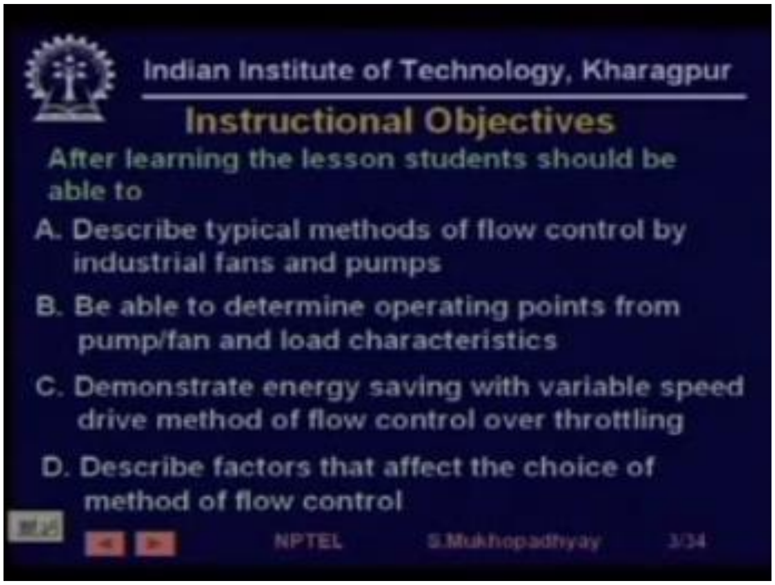

What are the various kinds of flow control applications that is the application that we are trying to consider. So flow can be of gas or liquid, so accordingly we have either what are known as fans or blowers or we have pumps fans blowers and pumps constitute an enormous, a very significant fraction of the loads which are driven by motors and motors which consume a large amount of electrical power in the industry.

So they are very common and common applications and very significant from the energy point of view. So we are going to see that in such applications how flow is to be controlled and then we are also going to see that if you flow is typically controlled by driving a pump by a motor, but if you drive the pump by a motor then it will drive a certain amount of air let us say, if you have a pump it could be water.

Now the demand for this air or water is not the same all the time, so the flow has to be controlled. Now there are, so firstly how do we, when we connect a machine to the pump what is the amount of flow that is established that depends on the pump characteristics, that depends on the machine characteristics. So we are going to see that how when you connect a pump or a fan with a, so called load how is the operating point established, what will be the pressure but with the flow.

It is actually much like, you know establishing an operating point when you connect a battery with the circuit or a load right. So we are going to see that and we will see that depending on how we can vary this operating point, see we have to value this operating point because we need to vary the flow. Now the flow can be varied by various ways of varying the operating point and it is so, some of these ways are maybe very simple but maybe, may not be efficient in from an energy point of view while others may involve more complex technology but possibly would be more energy saving.

So we are going to look at two of the most common techniques and show that how their energy characteristics are going to be different. In fact that will motivate the next few lessons in this course that we are going to have on industrial drives probably this lesson would show why industrial drives are, I mean show at least one side of the story that why variable speed drives are such an important thing, I mean such an important technology in industrial automation control.

So finally we would also see in this, in the course of discussion that when to choose what type of flow control or drive right. It is not that you always energy saving is the all important criterion. So we will discuss little bit on that.

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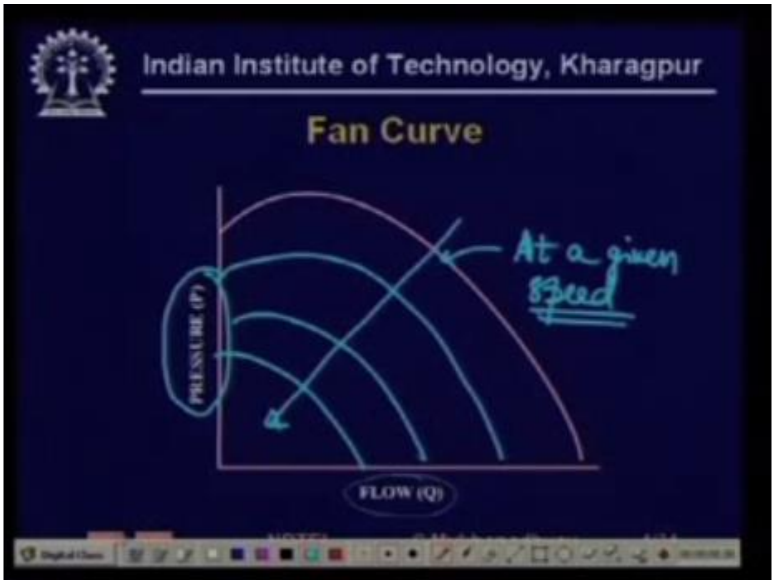

So let us look at a basic characteristic of a fan right, so here we are, the fan is this is the intrinsic characteristic of the fan itself irrespective of what the load is. So the fan actually develops a pressure at it is outlet and also develops a certain flow and this it develops when the fan is rotated at a certain speed so when we have plotted this curve.

Which is whose one axis is flow and the other axis is pressure so it shows the pressure is you know somewhat like voltage and flow is somewhat like current so in that sense it is like since we are many of us electrical engineers so this is some somewhat like a VI characteristics of a battery or an energy source and we must remember that this curve is drawn at some speed at a given speed of rotation.

So if the speed of rotation will is changed then the then this characteristic will shift up and down actually you will get a family of characteristics with decreasing speed right so this is the characteristics of the fan as such now if this fan is now connected to a load right the load means that it could be various things for example typically fans are used in furnaces so in the furnace typically if you go to a power station you will find that you have big boilers and these boilers are heated by furnaces and these furnaces have two huge fans one is called an induced draft fan another is called a forced draft front.

So these are you know like I mean the furnace is like a like a like a Chula so you need to blow water blow air into it for combustion so this fans actually blow that air and the induced draft fan actually I mean sucks out the after combustion air most full of carbon dioxide so these are so this so it is the furnace which is the load so if you connect the fan to the furnace then at a certain speed of the fan a certain operating point or a certain pressure flow will be established so basically how do we get that so we.

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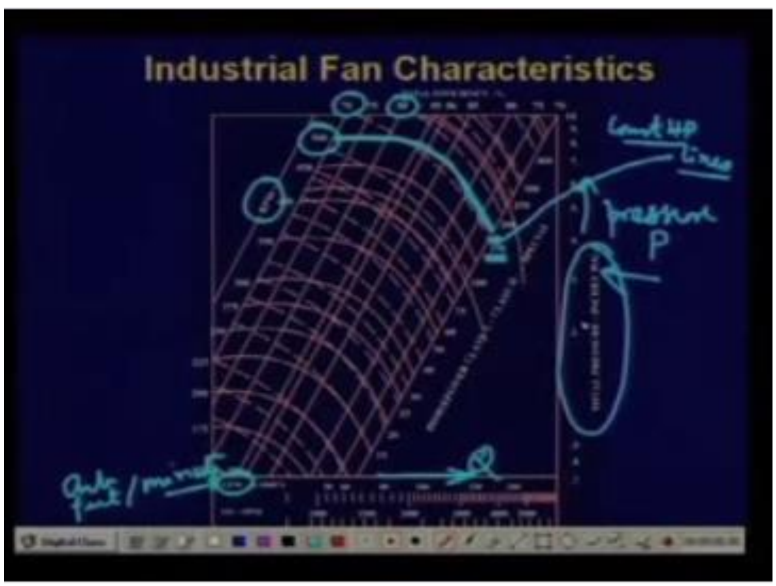

We this is this is a fan characteristics which will which will come back to a little later this is a little complicated actually basically okay let us have a look at it basically what is being done is that this is this actually gives a family of curves right so on this axis on this axis you have this CFM means cubic feet which is an unit of volume per minute so this is nothing but volume flow rate.

So this axis is Q right and this is total pressure in inches of in inches of water column right so basically this is pressure or P now so the so is it part of the fan characteristic is shown and you can see that a family of curves are shown so what are these family of curves so basically the various operating point for example these are if you see these constant lines I will draw it here so for example these line this line it starts with this number 500 and here it is written RPM so which means that this is the if the fan is made to rotate at 500 RPM then the pressure flow characteristic you follow this curve.

Similarly you have a family of curves for various speeds on the other hand look at this dotted lines so this dotted line this dotted line it says 150 so this is a these are constant horse power lines so these are constant horse power lines so if you operate it along this curve then you have a you have you or you always spend 150 horsepower similarly you have a number of curves right. Similarly you can have efficiency constant efficiency characteristics say this seventy percent line this is the eighty percent line and so on.

So basically this curve shows that if the fan is operated at various speeds what are going to so basically pressure flow characteristics with something constant either the speed is constant or the energy is constant. So that you can conveniently find operating points and in fact we will use this curve later onto find out to actually compute the energy savings, right.

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So having understood this let us move on and we will we will come back to this curve in a while.

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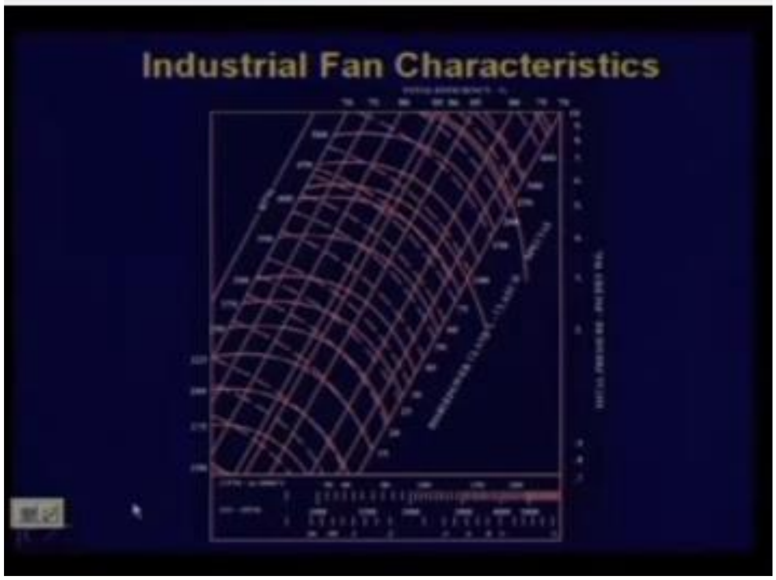

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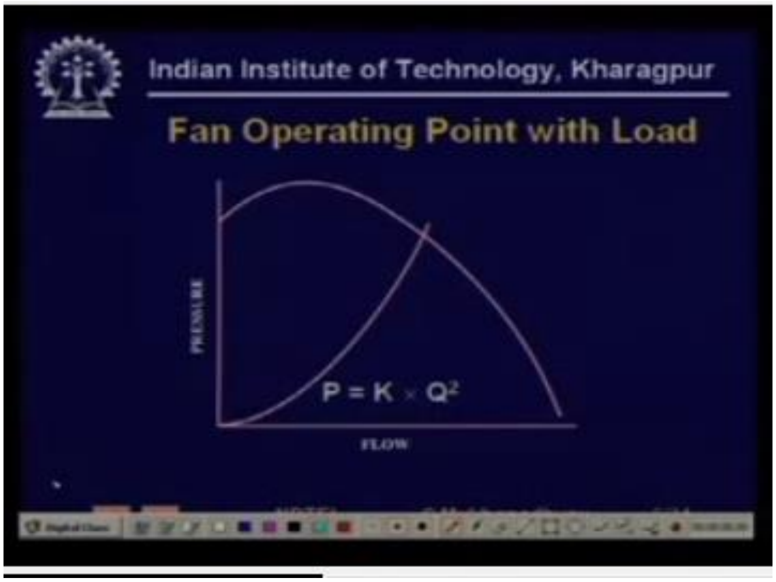

Yes so here now we come back to how an operating point is established, so see just like remember that when we when we computed operating points in our circuits courses we drew what is known as a load line, right. So on the other hand you have a load has a certain characteristic means that if you want to create a certain amount of flow through that load in this case maybe through the furnace.

You need to create a certain amount of pressure difference right suppose you take a pipe then two then to be able to create a certain amount of flow through the pipe you need to create a certain amount of pressure difference across the two ends of the pipe. So that is the characteristic of the pipe that to create a given amount of flow how much pressure difference is needed and typically turns out that it follows a square law.

Basically that occurs because of Bernoulli flows when you have what is known as turbulent flow that means when that when the when the flow velocity is high then there is a there is a law called Bernoulli's law which we are not going to now from which you can derive that the pressure flow relationships through any constriction if the flow velocity is sufficiently high that is if the Reynolds number is so high that the flow can be called turbulent.

Then typically the pressure flow relationship is quadratic. So the load typically follows such an equation.

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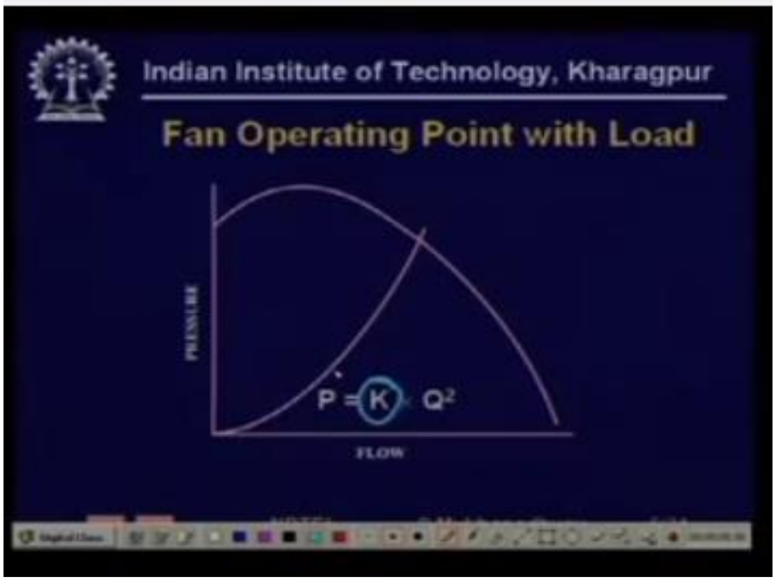

With some constant K so it is a narrow constriction this value of K is going to be high if it is a open construction value of K is going to be low and so, so if you connect such a load.

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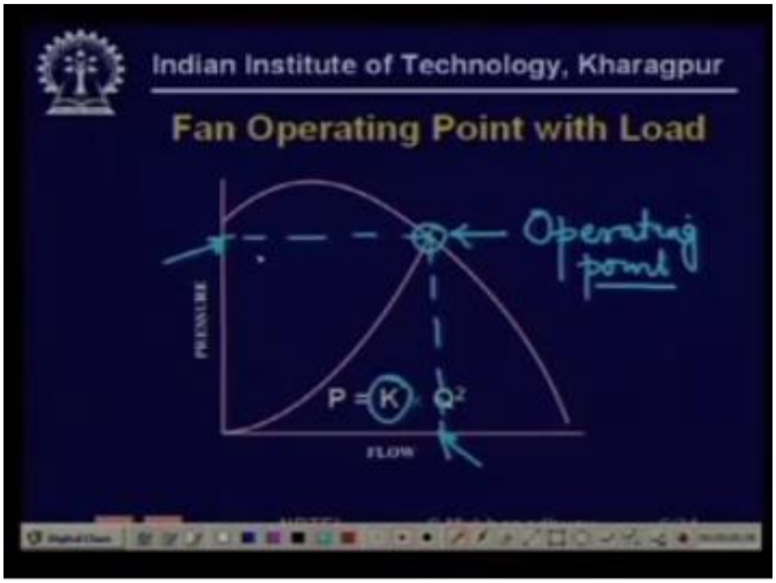

Across the pump then they will they will intersect and this is the operating point, so this is the operating point. So immediately if you if you connect this is the flow and this is the pressure which will be which are going to be established so the pressure which will be established if you connect this pump with this load this flow will be established and this pressure will be established, right.

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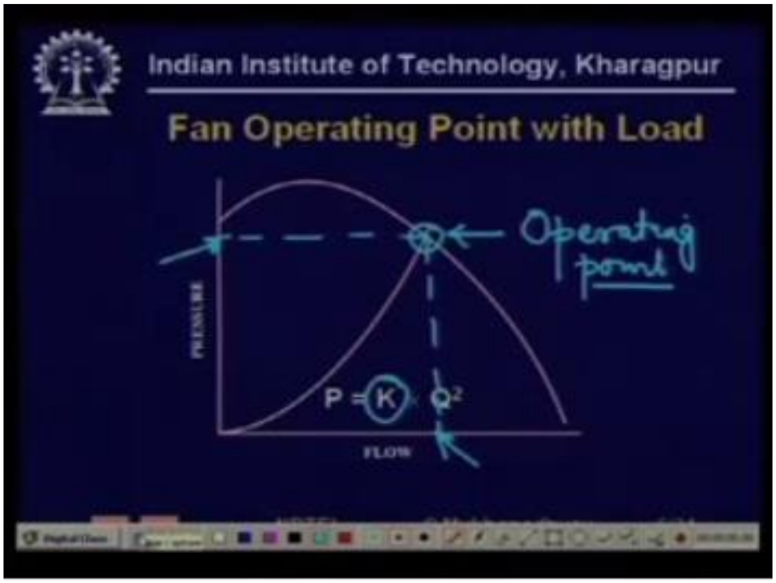

So now let us talk about varying the flow because we need to depending on the load characteristics for example if your electrical energy demand decreases then you need to reduce the rate of combustion. So you need to reduce the flow air flow into the furnace right.

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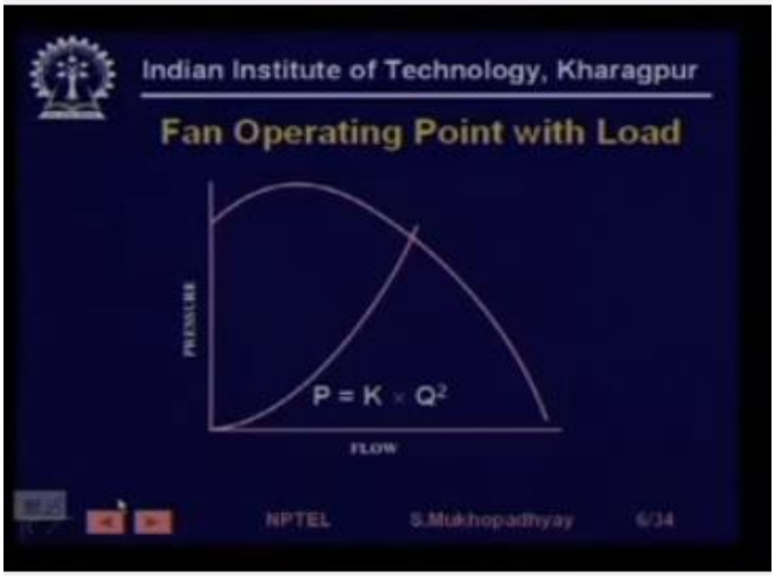

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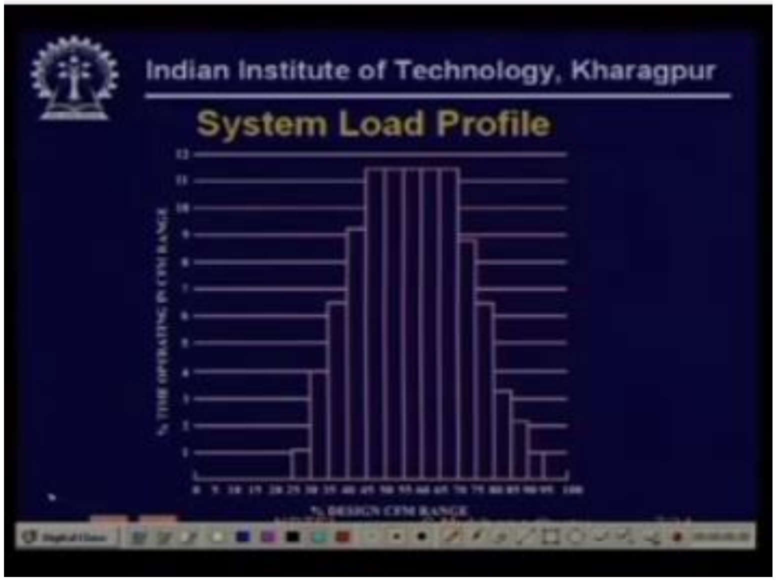

So how do you do that so typically it happens this is a this is a typical case it is we have we are we are calling it a system load profile which means that the system to which we have connected the load how do we what do you mean by the load we mean by the load we mean flow rate.

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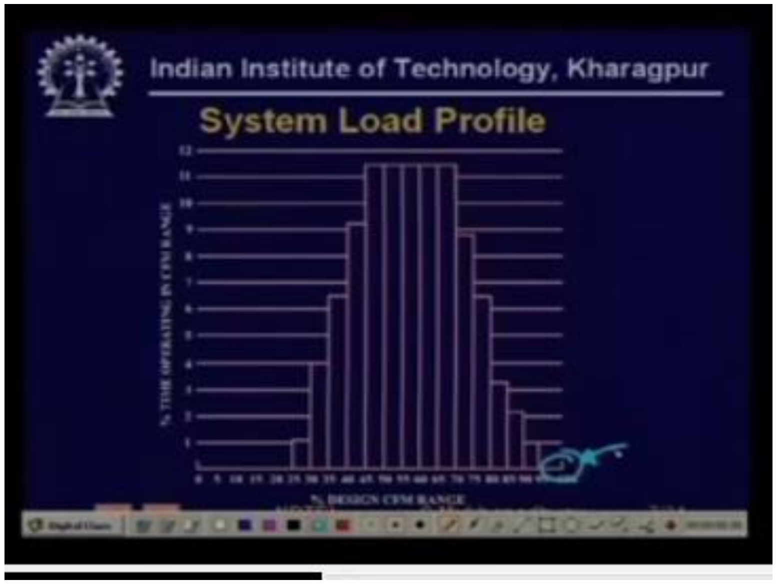

So you see that this is the this is the demand a typical demand profile so it says that this is let us say let us say that this is the maximum flow is 100 that can occur that we are calling one hundred percent so since we must have kept some amount of safety margin.

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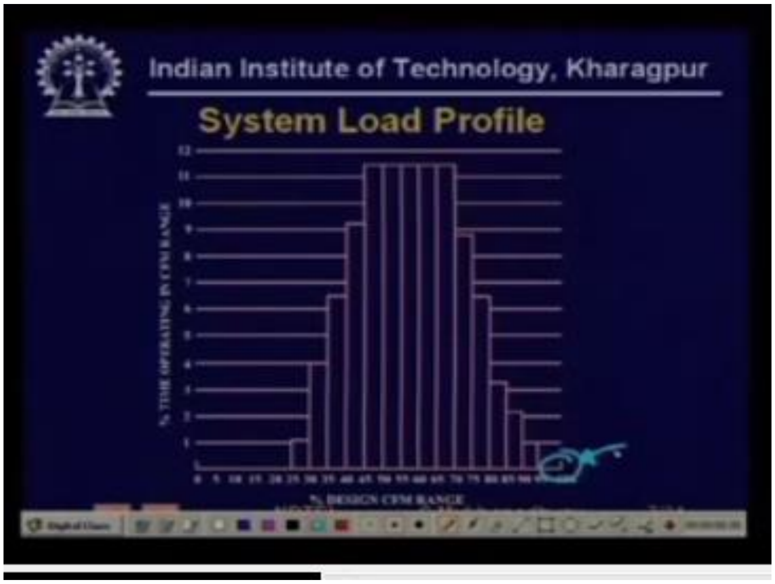

So probably maximum flow hardly ever occurs maybe does not occur at all or maybe aquifer is very small time.

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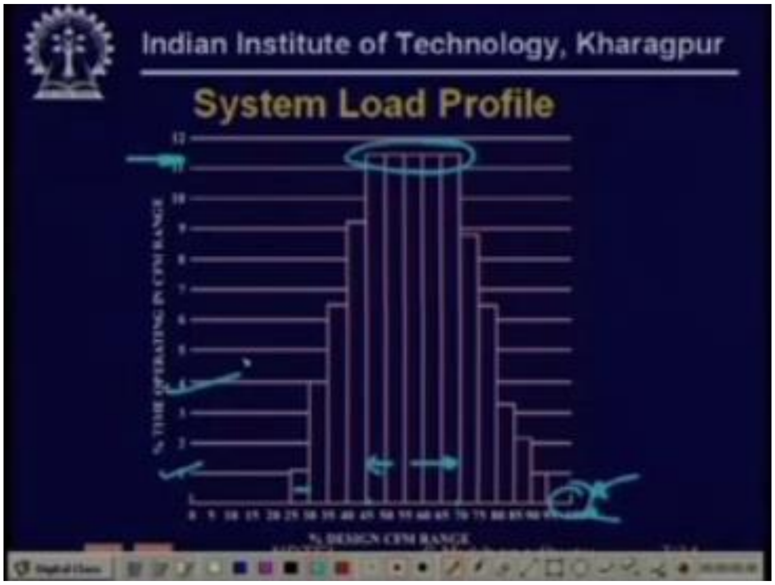

So most of the time that is the flow is actually between you see about 45 to 70 % so this maximum time the flow stays within 45 to 70% of the design flow range. Similarly it stays at it stays between 40 and 45% for so that is about you know 11 point something this percent of the time, so 1, 2, 3, 4, 5 so but more than 50% of the time it stays within this flow range and similarly it stays within 25 to 30% for 1% of time and 30 to 35% over 4% of time and so on.

So this basically shows that in the of the total operational time let us say D what I mean what is the loading if you take a loading of say 40 to 45 or 50 to 55 particular loading level for how much does it say what percent of the time. So there are some things which are important to note here firstly.

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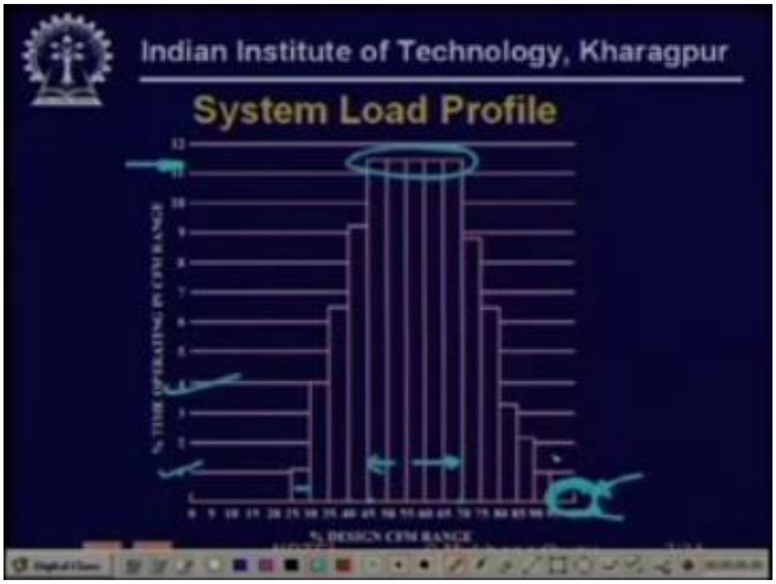

Note that the fan size must be selected based on the 100% consideration, so because the fan for however small time the 100% demand comes if you, if you select the equipment such that, that demand will be met then the fans as size will be selected by the 100% but most of the time it will not operate at it will not operate at that level.

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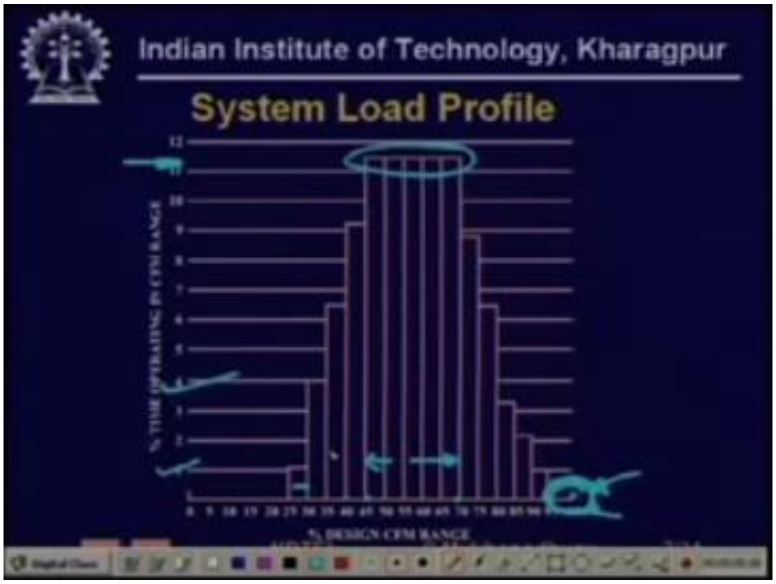

So rather it will operate most of the time at half level and it will also operate at very low levels for a very small amount of time so this is a typical load characteristic. Now let us see what happens so we need to shift this operating point right all the time.

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So let us see now what happens if we shift the operating points, so this is summarized so it says that it this is like you know roughly suppose because we are going to see an example so suppose in our example 100% CFM, CFM means again basically flow cubic feet per minute this is CFM means Q so 100% flow stays for 10% of the time 80% flows stays for 40% of the time, 60% for 40% of the time and 40%, 10% of the time. Imagine such a case okay, then.

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Now let us see that what are the various ways of controlling, what are the one of the easiest way of controlling airflow is to switch on and switch off a fan, you know this happens regularly if you see a if you see a home air conditioner, you must have noticed that the fan I mean the in the in that case the compressor switches on and off right. So it is a kind of on off control, so in a similar way if you want to control flow then you can also switch off and switch on the fan, so what will happen if you do that.

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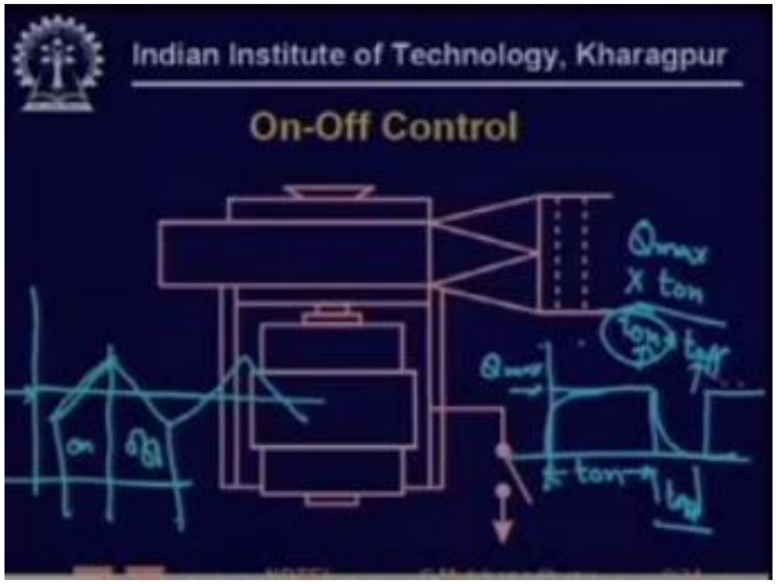

So you see if you switch on the fan suppose the flow rate will rise for a little time then it will fall again and then you will switch it on and then switch it off, so you will be able to establish an average flow, and this average will actually depend on what is known as the duty ratio so this is on, this is off so basically the average value will be or rather actually what will happen is that if you it will not rise slowly because the time constant will be fast enough, rather it will be like this.

So for the moment you push switch it on some flow will be established the moment you switch it off that flow will fall this is an approximation actually the flow will rise fast and we will flow fall fast, so if you approximate it as a square wave. So again if you switch it on and switch it off so basically the if this is the flow rate Q max then the average flow rate will be given by Q max x t_{on} by $t_{on}+t_{off}$ this is very easy to know, this is t_{on} and this is t_{off}.

So the average flow you can change by simply increasing t_{on} by simply changing T on and T on these are this is probably the simplest way you need nothing you need you only need the motor and the power of the motor on the fan you anyway need but as far as equipment for driving the motor is concerned you need nothing you just need to switch on the motor switch off the motor at a certain frequency as a certain rate for that also you need some equipment but that is very simple.

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But this is hardly ever used because of the fact that there will be flow pulsations and you know these kind of fans are typically used for industrial processes we need we use them for cooling for things like conversion so what will happen in the furnace for some time to suddenly lot of air will come so when a lot of air will come if there is see what we want to do is we want to have we are giving fuel and we are giving air.

So we to get the maximum thermal efficiency from the fuel we need to have a fuel air ratio perfect fuel air ratio such that full combustion of the fuel will take place so if you put more air then also air is wasted and if you put less air then the fuel will not burn so in other words that that pulsating value of flow is not good for combustion flow control so similarly another major application for flow control is for cooling.

So it is not good too so if you sometimes if you send coolant and sometimes if you do not send it then the temperature on the equipment will be pulsating and this temperature may affect reaction rates it may it may cause thermal stress on the equipment so in general for industrial flow control problems we cannot tolerate such pulsations so therefore this on-off control method is not good.

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So we go for other methods so what are the other methods.

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So another very simple method is so out of control is the simplest of control there is step there is going to be temperature fluctuation basically flow fluctuation will cause may cause temperature fluctuation sometimes for home applications it is used when you have less load and you have a large volume so if you so there is a lot of you know you know thermal capacitance so little bit of flow variation will not be felt because of large volumes of room.

So sometimes for home applications ventilation HVAC applications this kind of control is used but generally not used industrial.

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The next control which is used is called the outlet damper control for the fan so outlet damper means basically a damper means you know you see it is like a set of veins you know just like this you know sometimes on the you must have seen what is the word of this call there when you put something on the windows to keep out the sun so you know they are there you can change gaps you can you can move them either you can keep them like this or you can keep them like this so that some air can flow.

So basically dampers are also similar things so what you do is you put a damper at the outlet of the fan so basically the damper puts are resistance and does not allow air to flow clearly so by that you try to reduce the flow that is the way it is a relatively simple method of flow control because the controls required for creating a particular resistance in the damper or creating a particular dampener angle is actually very simple.

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But what is the third method the third method and which is the which is the very energy-saving method is variable speed fan control so you do not put any damper but you rather change the speed of the fan and reduce it when you require less flow but for that you require a variable speed drive of the motor and that is much more sophisticated technology is required especially when the motor is large compared to you know dampers and or valves.