Control Engineering

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Lecture - 1

Introduction to Control Problem

Well, friends I start with the introduction of the control problem which you are going to solve as a control engineer. I intend to devote two lectures to this. In today's lecture I will concentrate on control system terminology. In the second lecture which is going to follow, I will give examples of control systems, many of them very well known to you and some of them you will be coming to know later. So we start with today's lecture which is on control systems terminology.

Well, as we know, today control systems are playing an important role in development of modern civilization and technology. Every system we come across today, you see, has some type of control engineering involved in it. Take for example, a home heating system; a refrigerator, an air conditioner, an automobile; all these are examples of control systems. Take any sector of industry, you will find control systems everywhere. Say, inventory controlled of manufactured products, automatic assembly line, machine tool control, well the space technology and weapon systems, the robotics, the power plants all are the industrial sectors where you find control systems, applications and the role control engineers have to play there.

Well, feedback control theory principles have been effectively utilized in problems like inventory control, socio economic systems as well. Our course is going to concentrate on the so-called engineering system wherein the physical system to be controlled obeys certain physical laws. The socio economic and biological systems coming under the area of cybernetics we will not be able to handle in this course. Let me come to the basic terminology used in control systems.

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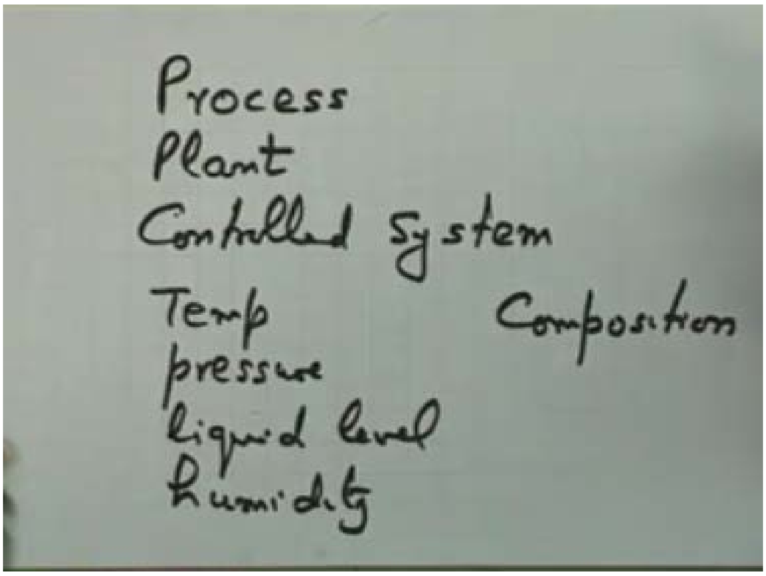

The system to be controlled is given different names. The most common being a process or a plant or the controlled system itself. In process industries, particularly chemicals, petroleum, steam power etc there are applications where we require the control of temperature, pressure, liquid level in vessels, humidity, composition and the like. All these applications have been referred to as, in the literature, as process control applications.

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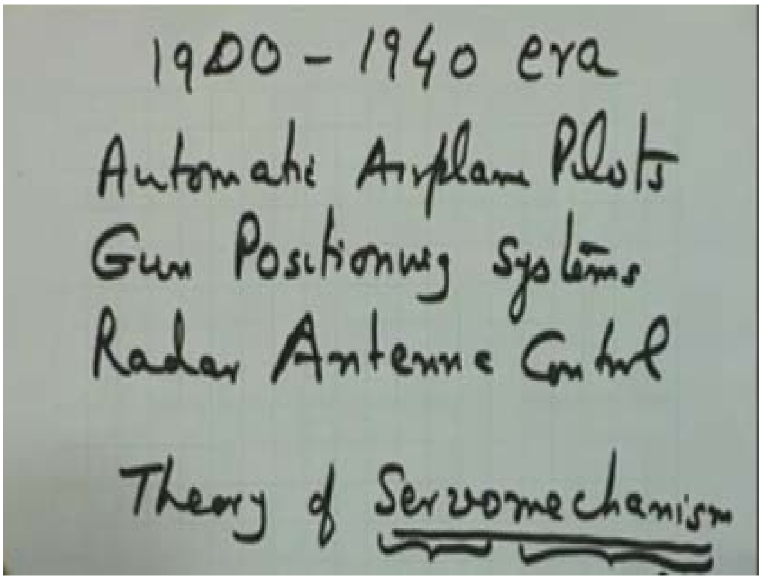

Actually the application of the controlled techniques historically speaking started in the area of process control only. This is typical of 1900 to 1940 era. During the Second World War the need of automatic airplane pilots, the gun positioning systems, let me write for you, automatic airplane pilots, the gun positioning systems, radar, antennae control systems and the like were felt. To solve these problems theory of servomechanisms was developed theory of servomechanisms. Note that the word servomechanism originated from the words servo means the slave or the servant and the mechanism. So it means a servo system is a system which is slave to the command and this was the requirement of the weaponry system during the World War II.

Well, the theory of cybernetics, the theory of servomechanisms, the process control all these are converging now and a unified feedback control theory has emerged. And the terminology I am going to refer to is the terminology of unified feedback control theory, meaning thereby, it is applicable to all the three subfields I have mentioned.

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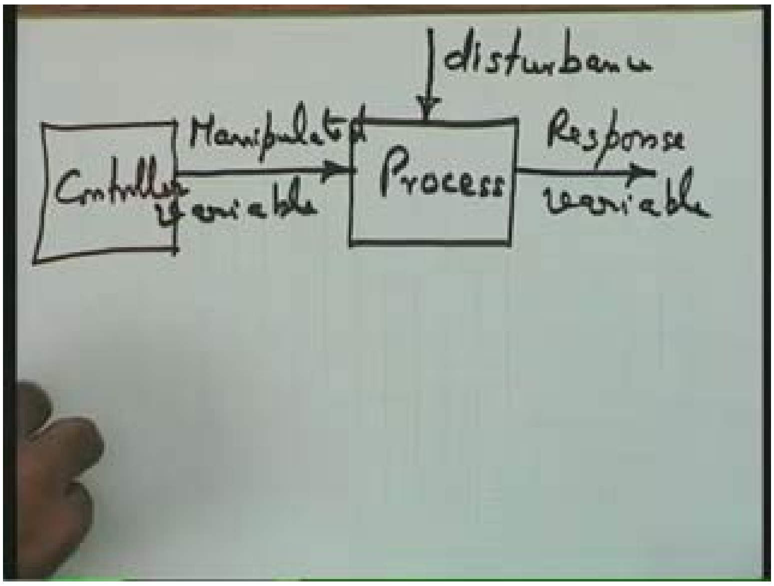

So, in the basic terminology let me first take up a block called the process. Or as we have said it could be termed as the plant as well, or a controlled system. The output of this particular process I will name this as the response variable, the variable or the attribute of the process you want to control and this controlled will be exercised by, what I will refer to as, the manipulated variable. The manipulated variable is subject to control by the controller we are going to design. And the requirement of the control is that there is unavoidable and undesirable disturbance acting on the process. This point maybe very carefully noted. The disturbance is uncalled for and it is beyond your control. The disturbance may be originated outside the process environment or the disturbance may also be originated from within the process. For example, the parameters of the process are subject to change with time. You have designed a controller for specific set of parameters but with time these parameters may change and hence your controller will not be as effective as it was at the time of its design. So this is a disturbance on the process originated from within.

There are examples, I will give you many examples of systems and the examples of types of disturbances acting on the system will also be given. However, this point may please be noted that this is a signal which is beyond your control which is random in nature; the characteristics of this signal are unknown to you. The manipulated variable is the variable to which the process is going to react and the reaction of this process to the manipulated variable is going to make the response variable follow your commands. So it means, naturally speaking, the manipulated variable must be under the control of the controller. So I can put a block over here so it means there is a controller here (Refer Slide Time: 8:37) this controller is going to control the manipulated variable and the function of this controller is to make the response variable follow the system commands. So I think I can draw a neat block diagram now defining all these variables.

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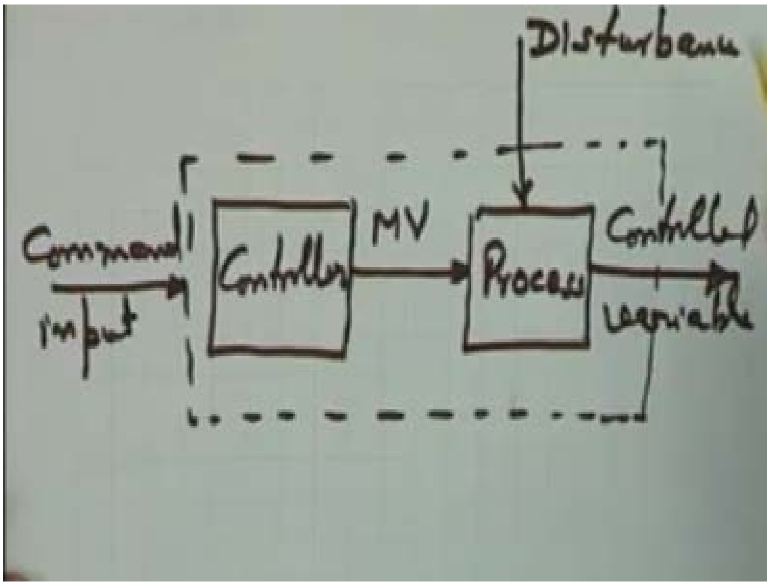

Here I have a process, the output of the process, the attribute of the process under control may be referred to as the controlled variable; here I have a manipulated variable, here is a controller and the information given to this system, let me put it this way is the command signal. These terms will be very frequently used in the sequel and therefore must be very carefully noted. This is the command input to this system (Refer Slide Time: 9:45) and here I have the disturbance. Though the disturbance has been shown schematically as if it is coming from outside the process environment this again I will like to emphasize that it is an attribute it is a signal which may be generated from within the process as well the parameter changes is a specific example.

Now in particular case, the requirement of this particular system or the requirement of this controller is to force the controlled variable follow the command in spite of random unknown disturbances acting on the system. Now let us take the schemes, the possible schemes which can achieve this objective. One of the possible schemes the simplest possible I will say is the following:

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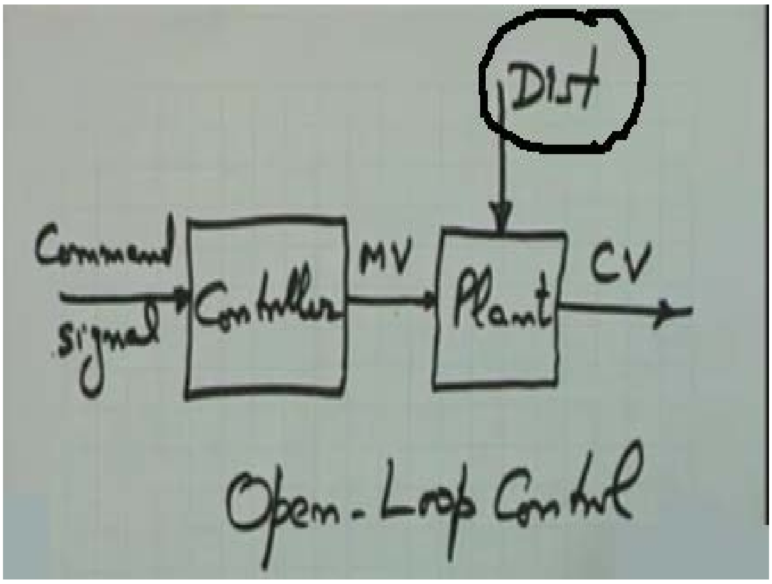

Take the process here or let me write the plant now. This is your controlled variable (Refer Slide Time: 10:46) and here is your manipulated variable. Let us say that the controller directly gets the information about the command signal from the user. This information which the controller gets from the user as a command signal is effectively utilized by this controller. The controller acts upon the signal to generate a manipulated variable whose function is to force the controlled variable follow the command. So, in this particular case the only information available to the controller is the command signal.

Now please note this point. What is the problem with this type of structure or with this type of scale? Let us say that the plant information this controller was intelligent about the plant information at certain point of time and a controller was designed to realize the objective of the controlled variable following the command signal. But in due course if the disturbance on to the plant changes because of the reaction of the environment or because of the changes within the plant what will happen, your controller is ignorant about those changes. It means the controller which was designed earlier for a specific information about the disturbance is no more effective in making the controlled variable follow the command. So it means there will an error between the controlled variable and the command signal because of the changes in the disturbance variable and hence this type of controlled structure which in the literature is referred to as open-loop control this term is the standard term for this type of control structure an open-loop control, the open-loop meaning that the loop has not been closed to give you the information about the controlled variable.

In the next slide I am going to give the closed-loop control wherein you will see the controller is intelligent and it gets information about the current status of the controlled variable as well. So in this particular scheme you say that if this random effect comes on the process in that particular case the controller becomes ineffective to track these particular disturbances or to take action so as to nullify the effect of this disturbance on the process. So what we require, we actually require that our controller should be more intelligent.

What is the intelligence required?

The additional information the controller requires is the disturbance. It should get the information about the disturbance also so that it knows that in spite of that disturbance the manipulated variable is to be manipulated, is to be controlled so that this variable follows the command. Now actually this is a random signal (Refer Slide Time: 14:01) giving information to the controller about this signal is difficult. So what is done in the process? Let this signal affect the plant so the effect of this particular signal on the plant will appear on the controlled variable.

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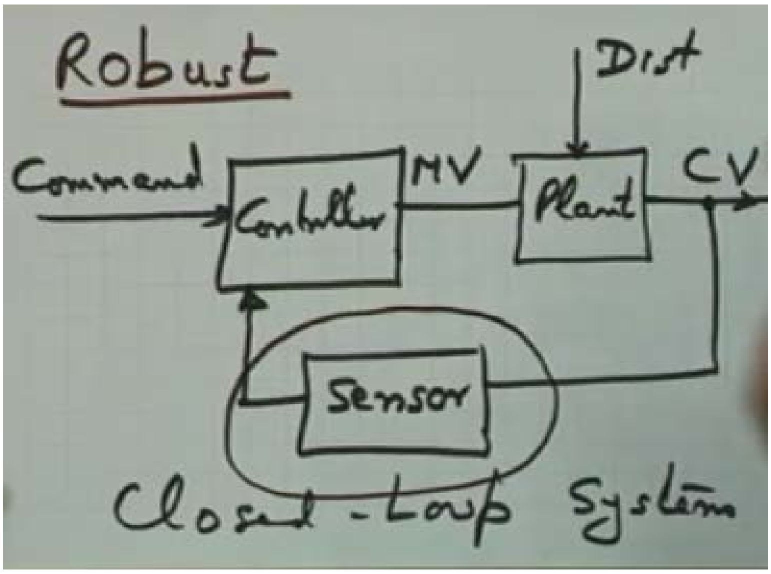

So in that particular case what I do, I take the plant here. This is your controlled variable (Refer Slide Time: 14:27), here is the disturbance acting on the system, this is a manipulated variable and here is a controller…… command. So this controlled variable now, well this can be measured easily and there is a sensor here, this particular sensor gets the information about the controlled variable and passes on this information to the controller.

So you will please note that controller is not intelligent, it gets the information about the disturbances indirectly through the controlled variable, it does not get the information directly in this particular feedback structure.

Now the function of the controller is the following:
It compares the actual controlled variable, the information available from the sensor from the command signal and generates an error signal and that error signal it utilizes to generate a suitable control signal and that control signal manipulates the signal to the plant so as to reduce the error to zero. So this particular system is an error self-nulling process wherein we will find that the error between the command and the actual variable is reduced to zero because of the controller action. This particular system in the literature is referred to as the closed-loop system, the name is evident from the structure of the system or it is also called a feedback control system. And we will be mostly concerned with this particular feedback structure.

Now look at the problems we are going to face using this particular structure. You see that the major source of the problem in this particular structure is the sensor itself. Recall that in the earlier structure on open-loop control the sensor was not there. This is the additional hardware you have introduced in this particular structure because of the requirement of making the controller more intelligent. Now this sensor when this piece of hardware is introduced in this particular loop it is going to introduce problems of noise. So you see, in the process of measurement it generates high frequency noise and this high frequency noise also gets injected into the loop. So the plant and the controller in addition to getting the useful signal about the command signal and the controlled variable gets this noise signal which is a high frequency signal and the plant will react to that signal as well and your control may not be effective. This particular problem was not there in the open-loop structure. However, suitable noise filter can be installed in the loop so that this particular problem of noise can be taken care of.

Now, once we say that the noise problem is taken care of then let us see what is the requirement on the controller. The requirement on the controller I will say is to make this particular system robust. The word robust is used in the control literature to emphasize the need of control so as to make it insensitive to disturbances and parameter variations. So, if, in spite of disturbances in certain range and the variations in the parameter of the plant the controlled variable is able to follow the command signal accurately in that particular case we say that the system under control is a robust system, it is giving robust performance. And the requirement of the feedback structure, one of the primary requirement of the feedback system is to make the controlled system a robust one.

Now you see that you will like this controlled variable to follow this particular command very accurately (Refer Slide Time: 18:43). That is the error between the controlled variable and the command signal should be minimized and in addition the follow up of the controlled variable to the command signal should be as fast as possible. So it means accuracy at steady state, speed of response and the other requirements are the primary requirements put on the controller.

Now, as we will see later that one of the disadvantages or problems associated with the controller, with the feedback structure is this that, as you increase the requirements on system accuracy there is a loss of stability. So it means there is a trade off. There is always a limit to the accuracy which you can achieve. However, reconciliation of these requirements on system accuracy and stability is the primary accomplishment of feedback control theory and the design of feedback control is concerned about this reconciliation. And we will see methods how a suitable tradeoff between the system to build accuracy and laws of stability can be accomplished.

Now you see that there are problems with the feedback structure we have referred to, but in spite of these disadvantages the basic requirement of robust control makes the feedback control systems almost indispensable. This point I will like to make it very clear. But for the requirement of robustness, but for the requirement of filtering the disturbance effects, feedback controlled structure would not have been required because open-loop controlled structure can meet the requirements of system accuracy very effectively. The problems of feedback control can be avoided. But, however, this structure, as I mentioned, is indispensable because of the requirement of filtering of disturbances and the effects of parameter variations.

Now let me come to the design aspects we are going to use. So, in this particular feedback controlled structure let me come back to the same diagram.

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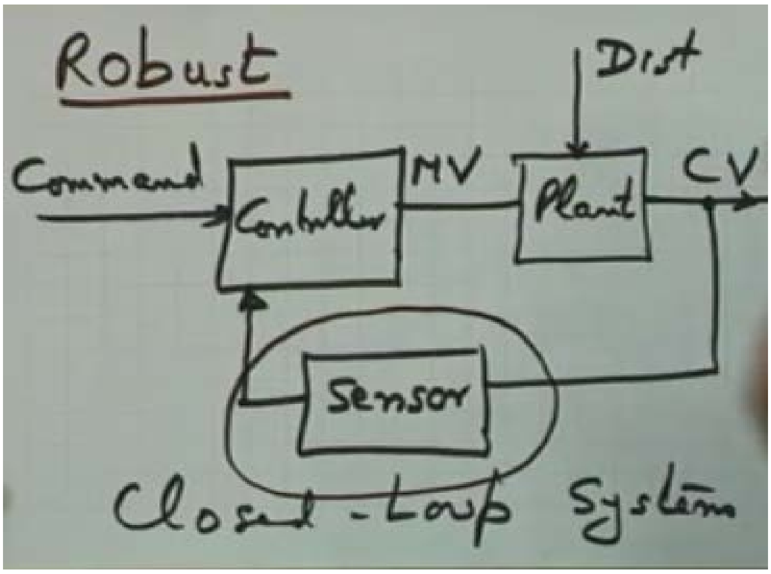

So, the design is that of the controller. Now how to design this controller? There are various approaches which are possible and some of the approaches I like to highlight and I like to mention as to which is the specific approach we are going to follow in this particular course; one approach could be the experimental approach, so-called the experimental approach. In this approach what I do is, I install a controller based on the experience practical experience on the process or the plant. This particular controller which I install there are certain parameters of this particular controller which I can then adjust online and see and get the parameters so that the controlled variable follows the command to an accuracy acceptable to the process engineer, acceptable to the user. This particular experimental design in the literature is referred to as the controller tuning.

This is a method which is extensively used in process control applications. Because the requirement there; one, the information about the process is not available so as to model it accurately it is a highly non-linear process model and therefore instead of relying on the quantitative information about the process we rely on the experimental knowledge about the process, about the operators experience about the process install a controller and then tune the parameters of the controller so that an effective tie up between the controlled variable and the command signal is achieved; a process known as controller tuning and I may say that this is nothing but an Ad hoc approach of design, an Ad hoc approach.

Now let me take the other approach which I call as the model based approach or the analytical approach. In this particular approach, why do I need this approach, for example, if the requirements on the control are high or if the system is too complex to be tuned using the Ad hoc approach in that particular case I will like to go for the model based approach. So what I do in this particular approach. I capture the dynamics of the model in a suitable mathematical form may be a differential equation, a transfer function or a state variable model. A suitable mathematical model is formed which captures all the important dynamics of the system quantitatively. Now once this mathematical model is available we are more knowledgeable about the characteristics of the system quantitatively and this quantitative information is used to design a controller using analytical methods of design. So once I design such a controller using analytical method I hope to get and I do get better control on the system.

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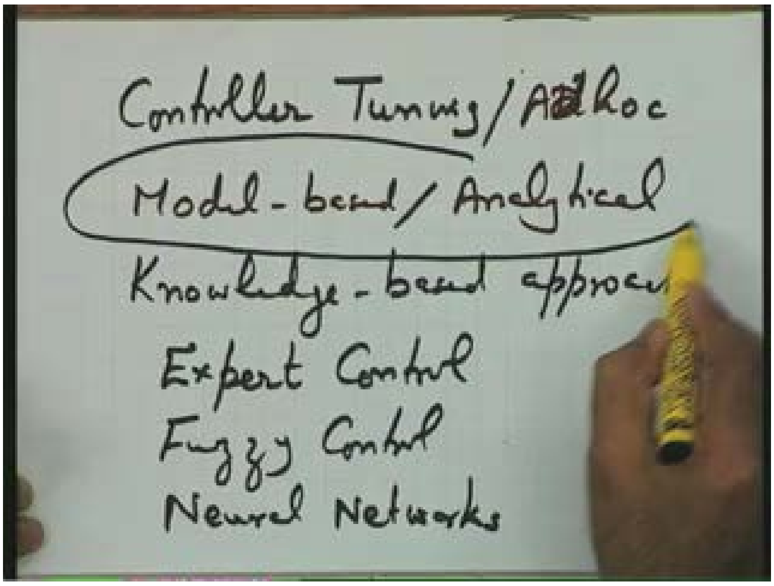

And the third method let me say is the knowledge based approach is under the stage of active development particularly during the last decade this particular approach has become quite effective and quite useful in industry. Many industrial applications have used this knowledge based approach. As you know in this approach we have what is called the expert control. We place the expert, the operator in the loop through certain qualitative guidelines, certain qualitative rules about the system. The fuzzy control, the neural networks are playing an important role in this particular field of knowledge based control and in this course we are primarily concerned about the model based control.

It means the approach will be for a physical system which is our plant. We are going to derive a mathematical model first. A mathematical model may be derived as you will see. These are the approaches we are going to study in this particular course. This you can derive using the physical laws or using the experimentation. Using the physical laws of physics we are able to capture the dynamics of the system in a set of differential equations which can later be transformed into a convenient model like a transfer function or a state variable model. If this is not possible alternatively we conduct experiment on the system, get the input output information and this input output information is captured into a suitable differential equation or a transfer function model, a field referred to as system identification in the literature.

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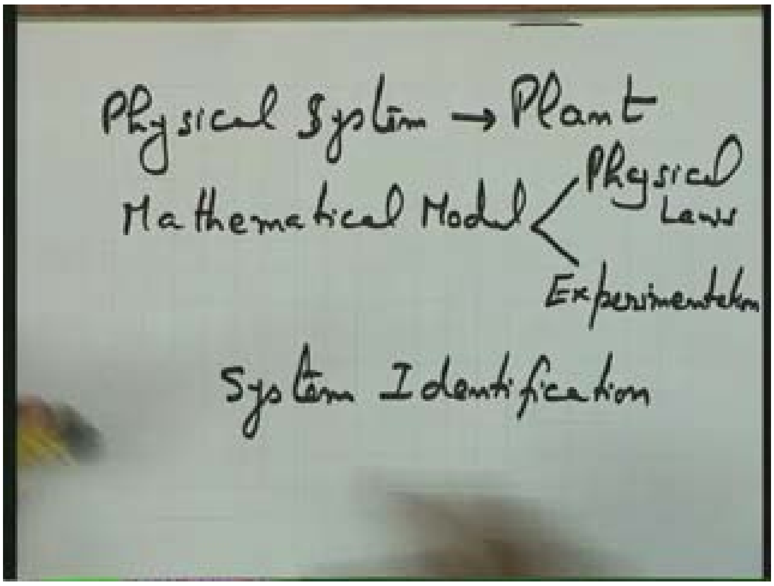

Again let me mention, in this particular course we will be primarily concerned with the modeling using physical laws. The other field will be outside the scope of this particular course though it is quite important from the point of your practical applications of control theory.

Now, coming to the model based control algorithms I will like to mention that during the 1940 1960 era during this particular period the frequency domain design methods were developed. Some of the techniques developed during this period particularly during 1940 to 1950 when theory of servo mechanisms was developed are the Nyquist techniques, the Nyquist Stability methods, the Bode plots, the Root Locus plots. In the literature these methods, the frequency domain design methods are referred to as the classical methods of design.

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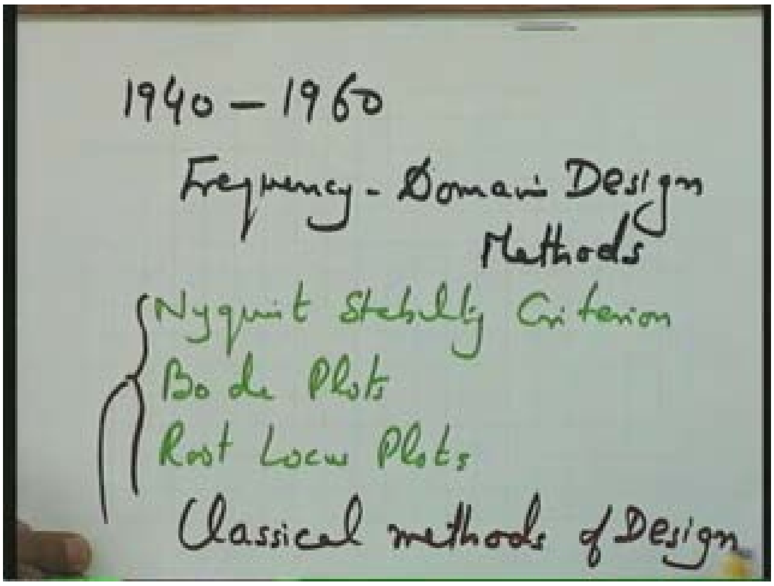

Well, if these methods are classical well there should be some methods which are so-called model. Well, the requirements of space vehicle control, well, the launching, the maneuvering, the tracking this led to a theory which is based on state space techniques.

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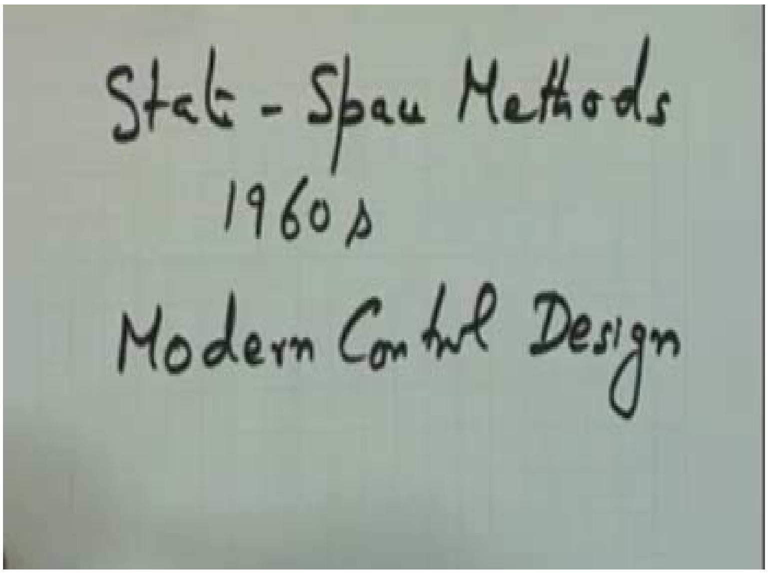

So let me mention over here that state space methods of design came into existence during 1960s onwards and this particular domain of design has been referred to as Modern Control Design. Well, you may say, as if, the earlier methods of frequency domain they are classical, they are no more in existence and the so-called modern methods of design based on state space techniques should be in existence today. Well, it is not the situation. In industrial control applications effectively 75 percent of the industrial control problems today are being handled using the classical methods of design. So as such the term modern control design is misleading. It really came into existence from the particular requirements of tracking in space vehicles. So, in the industrial control it is still, the classical method of design are still in the existence are being extensively used. Rather it is being debated as to which methods of design are more robust. Robustness being the primary requirement whether the classical control methods or the modern control methods have designed. So I think let us give up this terminology of the classical control and the modern control methods.

For this particular course I will like to concentrate on, or rather this course will concentrate on the frequency domain methods of design all through. The state variable methods will be introduced in this course not from the point of view of the design but from the point of view of system simulation. As you will see that system simulation is effectively done, is conveniently done when the state variable formulation is utilized and therefore an introduction to the state variable methods will be given in this particular course from the point of view of system [simulates 00:31:20].

Now, with this terminology I think we can go now to the controlled system basic structure. And to define the controlled system basic structure I will like to give you the examples of controlled systems which we see in our day-to-day usage or which you are going to design later when you go to industry.

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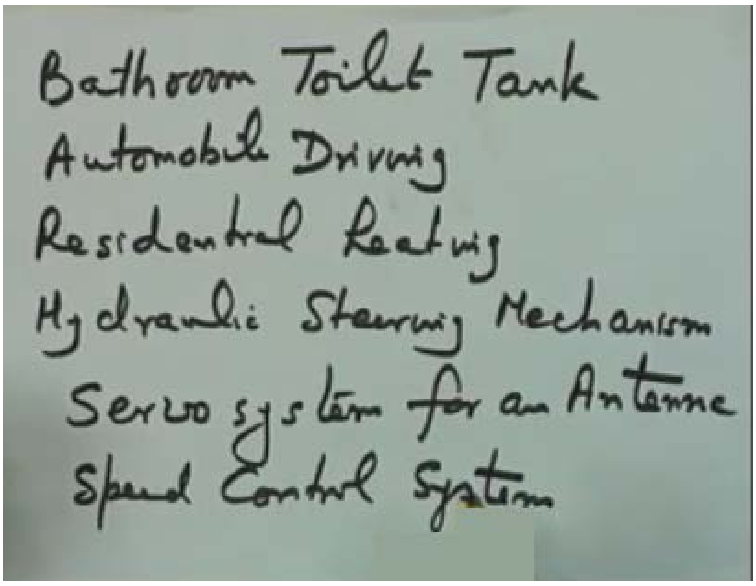

Some of the examples I like to take here, well let me take a very well known example of a feedback control structure, a bathroom toilet tank. I will prove to you is actually a feedback control example. Let me take the example of an automobile driving, an example of residential heating. I will take the example with you of hydraulic steering mechanism. All these are the examples which are very well known to you but we will put them into the controlled system structure. In addition, the steering control or the servo system for an antenna and a speed control system will also be given as an example here. Through this example the variety of control variables will also be illustrated and in addition I will give a basic control structure in which you find that all these systems will properly fit in. and I intend to take up these examples in the next lecture. Thank you