Dynamics of Machines

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Module No. # 07

Lecture No. # 01

In our previous lectures, you have noticed that we are gradually improving our design of the machine; the steps which we follow to design a machine or a mechanical system.

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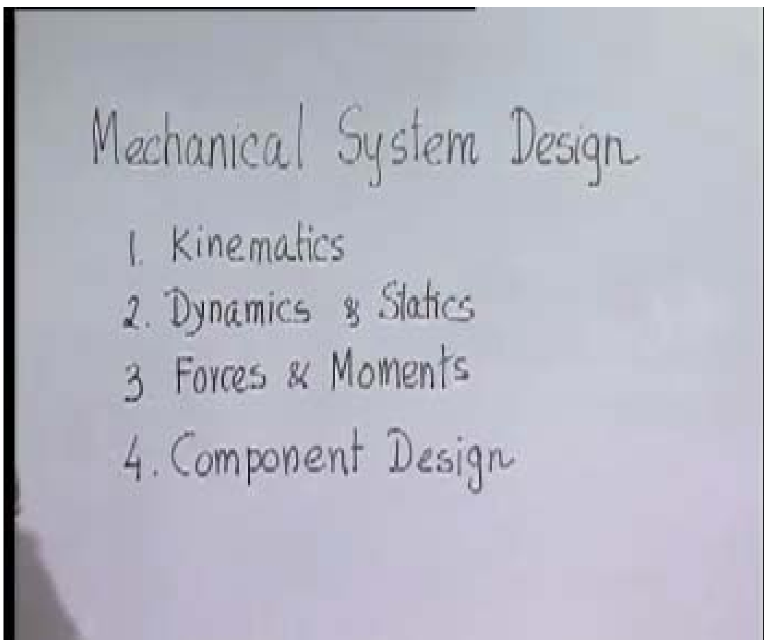

The first task which we accomplished is, analyzed the kinematics, which tells us about the movements of various components and part of the bodies in a compositely prescribed task. Next, after the basic kinematics is taken care of, our next subject or topic is dynamics and of course, that also will be a part of it. In this type, what you find out is the actual resultant total forces and moments acting on various members and components.

Next we get the forces and moments. Once, we get forces and moments acting on the various components and once the chosen material we prescribed is there - top allowing spaces and such things, we can find out the dimensions of the component design. At this stage it is possible for us to find out the dimension of cross section of these; or all kind of actual dimension, which will be used in making the machine. However, apparently it may look that our task is over.

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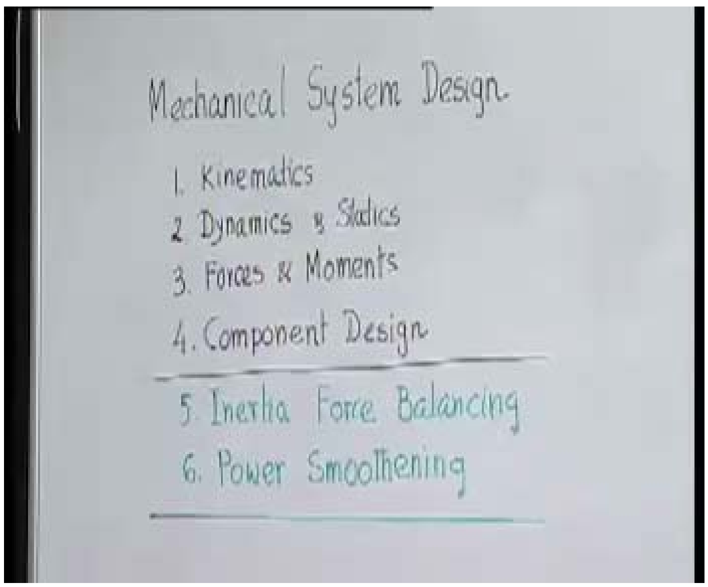

We have got the dimensions of components of the machine, which will subscribe to the kinematics prescribed; that means, the relative moments necessary to accomplish the task. However, you have seen that the task is not over. Next, what we have do to make the system run in a nice manner without showing too much of vibration or instability? We balance the inertia forces that make the running of the system much smoother. That was necessary to provide a reasonable length of life for the machine which we have designed.

Next, we find that was not enough to have a smooth operation; it was also necessary to go to a stage, which we call as power smoothening. How we did it? We have seen in our previous lecture; we add artificial inertia in the form of flywheel that smoothes out the fluctuation on the operating or running speed. Is the task over? That is the question now. That means, can we consider, now we have come to the final stage of our design, where the machine can be fabricated and expect it to give the required result? In fact, the task is still not over. In this module, we will see what next is to be done. Why the task is not over? Let us examine the question.

Any mechanical system we design - which run - generally, we will find that all this kinematics, the dynamics etc. which we have gone through, to do that, we have had to assume some operational speed with which the system is running in the normal condition; and we design the whole system based on that.

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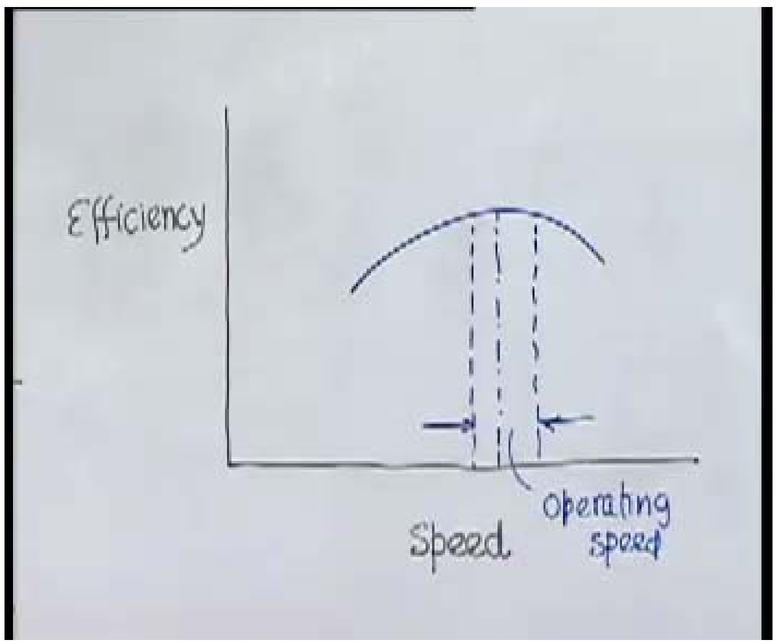

Therefore, as a result what happens is that, if we plot or find out any machine, engine or anything, we find out its efficiency of operation. We plot against the operational speed we will get a curve and where this is the rim in which we should remain (Refer Slide Time: 05:55). Though ideally, you should consider only one speed at which it must run but, in practice it never really happens; but at the same time, we cannot neglect the speed too much from the optimum speed at which we get maximum efficiency.

So, our final objective is to remain very near the optimum operational speed. Why you need this? Let us see examples of an engine. An engine when you design, we are very concerned about its efficiency or the turbine, we are very concerned about the efficiency because the consuming fuel and producing power. It is known that such machines or engines must be run at the operational speed where it runs at high fuel efficiency.

Therefore, it is necessary irrespective of situation or circumstances, the engine always runs as the designed speed or very near the designed speed. There are other cases or situations where some kinds of speed control is necessary. A very common example will be remember our old gramophone, where the input or the source of power is the spring - a twisted spring, which stores a lot of potential energy and it is gradually released and the recorder plate rotates and the machine runs. You have seen a toy; where we give lot of twist to the spring and it is loaded and then we will leave it. We expect the system to run at an approximate constant designed speed.

For example, if it is playing music, we do not want the frequency of the whole operation to change and we expect that the drum where we have the spikes, which really drives the leads to produce the music must rotate at constant speed. But the input torque, which is coming from the spring is gradually reducing because it is unwinding. In such a situation, how it is possible to maintain a constant speed? Even this spring loaded or mechanical clock; we provide the energy in the form of loaded spring or twisted spring.

The arms of the clock - they rotate at a constant rpm; though the driving torque which is coming from the spring is gradually reducing. Therefore, this is another situation where we need to control the speed though the input is varying.

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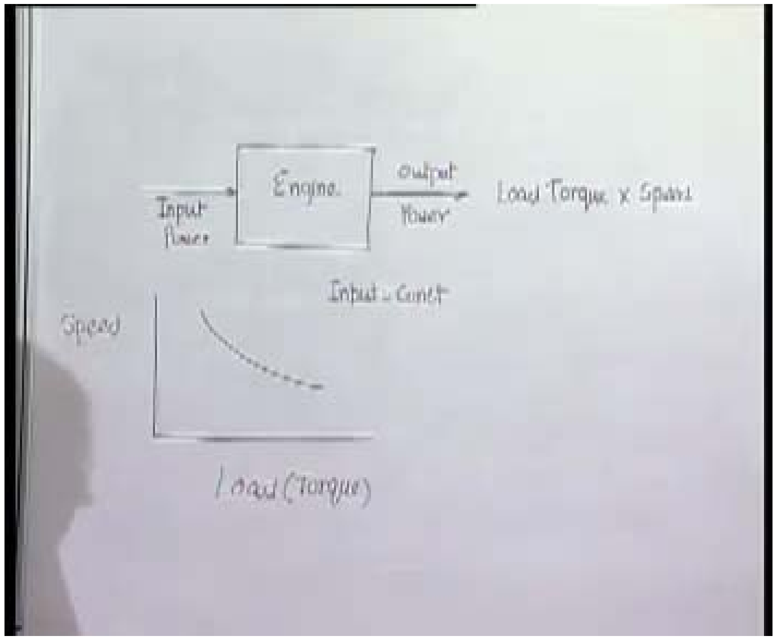

Now, let us see how or what are the parameters from which speed of running an engine - let us take the example of an engine, will depend. In a schematic form of an engine or general mechanical system, there is input power in the form of heat or whatever it may be in case of engine and we get output power. For example, engine is generating current or pumping water or running a machine tool whatever it may be and this output power – it means what? Load torque multiplied by operational speed.

Now, the input power remains constant; we do not do anything, we do not manipulate. Load we are indicating by torque and we are plotting running speed of an engine and input is constant. It is obvious that output power will also remain constant when the load increasing. Since input power is constant, approximately, you can say that output power will also remain constant. What does that mean? It means, if we shoot up the load torque, input speed remains constant, obviously. In that mode if an engine is running in some machine, suddenly the load torque increases the speed is obviously going to fall.

Say for example, a pump, if the weight increases or somehow we want to increase the capacity of pump whatever it may be you may have, you will find that increase of load may cause this to sink. Therefore, such a system or such an engine or such a situation, is not acceptable. We want our engine to run at maximum efficiency, which can happen only when it runs at the designed speed.

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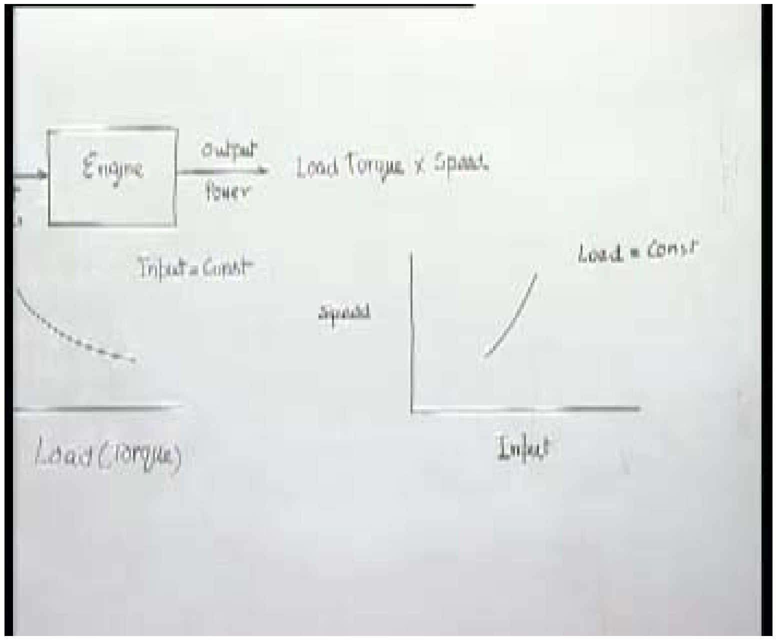

Similarly, if a load remains constant, sometimes it may happen; in a gramophone recorder etc., a load is nothing but a constant friction or something. Here we will find input slowly changes. Therefore, the speed we will find will be drawn something like this; if input falls this will also falls because the output is approximately equal to input and load is constant (Refer Slide Time: 12:30). Therefore, if input falls it means output also fall and load will be constant, this will be also constant. This is another kind of equation, some examples we have already given; the more commonly encountered situations is like this.

Now, how to maintain the speed so, it become obvious to us that if it is here (Refer Slide Time: 12:57), the load torque is increases and if we want to maintain the same speed which is equal or very near to designed speed, there is no way but to manipulate the input power; we have to increase the input power. That means schematically the situation will look like this. This is our system - engine; it could be other machine also. Our speed information about the speed is to be kept; some signal - say voltage, which is produced by tachometer or tacho generator we take.

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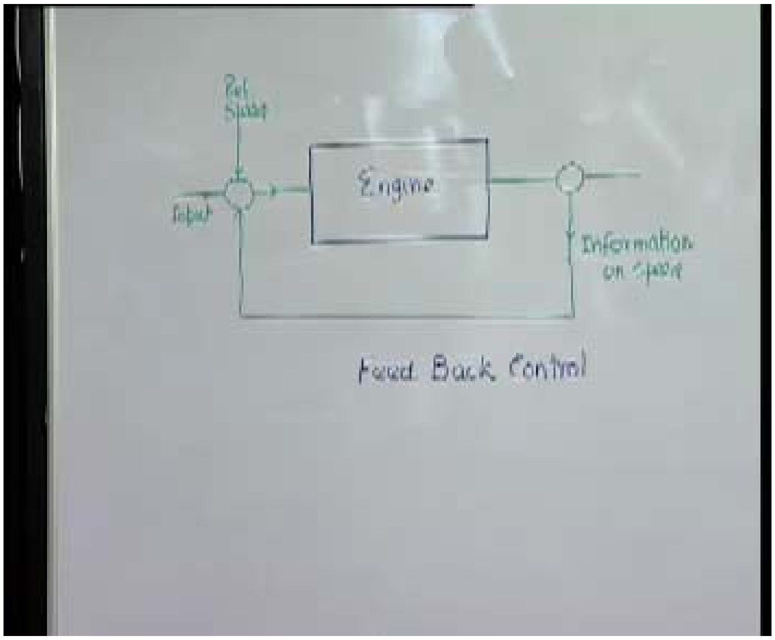

We compare it with some reference speed and we find that it is nearer; either this speed is more than this or less than this; depending on that, we manipulate the input. If the speed is as follows, we increase the input till this speed matches our reference. If it is found to be more, then we come down the input so that the speed decreases, till we reach the reference value. This basic concept or principle is called Feed Back control and this is what we achieve a mechanical system with the help of governors.

So, this will be our topics of discussions governor and governor mechanism. In modern engineering, feed back controller of control is a very important subject by itself. However, in mechanical system it is very primitive concept of feed back control is achieved through application of governor and governor mechanism for the past few centuries. In this lecture, we will discuss some of the common techniques of governor design.

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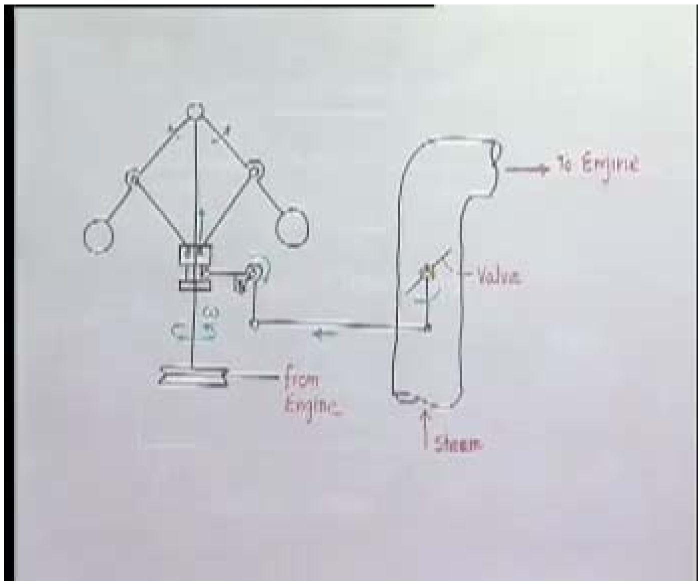

The first thing just give you the history of the governor mechanism, which is nothing but feed back control device was by James Wattin I think, late seventeen centuries. So, the basic scheme like this (Refer Slide Time: 16:19). Let us explain the simplest feedback control device - first device by James Watt, how it works? Engine is somewhere here, which is running. What is the source of energy to any engine - thermal engine? It is steam. So, steam is going through this pipe there is hole here and this being supply end (Refer Slide Time: 19:06).

The engine which is running with the help of some kind of belt drive, another vertical shaft is being rotated; whose speed related to the speed of the engine, because of this rotation what happens? These balls due to centrifugal action, it tries to fly down. If the speed increases from the designed speed, it will try to go up. So, this sleeve will be lifted up; if the sleeve lifted up, then this lever will rotate about this fixed thing (Refer Slide Time: 19:45).

If it rotates, then this link will be pulled in this direction, this will rotate in this direction that means valve is closed.

As you can see, what will happen the valve tends to close, this steam supply will be cut; if the input is cut down obviously the engine speed will come down and max the design speed. Suppose, if the speed is below the designed speed then what will happen? This will fall below, if it falls below because the centrifugal force is less now, speed of rotation will be less than design speed then obviously, it will rotate in this direction, pushing the rod in this direction and opening the valve (Refer Slide Time: 20:28). So that more speed and more input energy is produced. This type of governor, this governor mechanism also obvious name of James Watt and which we call it governor. This is the most primitive and the first application of the feedback control for maintaining the speed using governor principle.

Let us, now of course, a lot of work has been done after that currently, the governors are more sophisticated before we discusses a few of those, it is must better to have got a view about the whole system of governor mechanism.

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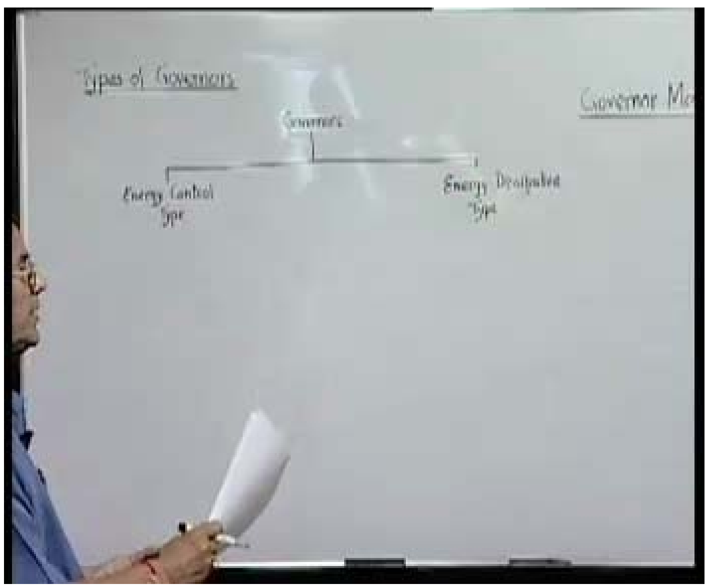

Let us see, what are the various types of governor? We will use spin diagram for classification and exact passion. First we divide all types of feeding governor mechanism into two classes: one class as we have discusses that we control the input with the help of the governor mechanism; we call them energy control type governor like this one, where you are controlling the input energy.

Another class of governor mechanism, which will discusses may be in next lecture where you do not have first elaborate arrangement, it has to miniature form or may be the nature of the problem is such there, we have always more energy supplied to maintain the speed by controlling dissipation of energy in suitable way. These kinds of governing mechanism are called energy dissipating.

As you can see this is the very wasteful at all of speed control by allowing energy excesses, energy loss to description. Obviously, you cannot use for major equipment arrangement only for small devices, where energy involve itself in not very large and dissipating a part of that is not going too much. So, it is only for special cases in the small and miniaturize of system.

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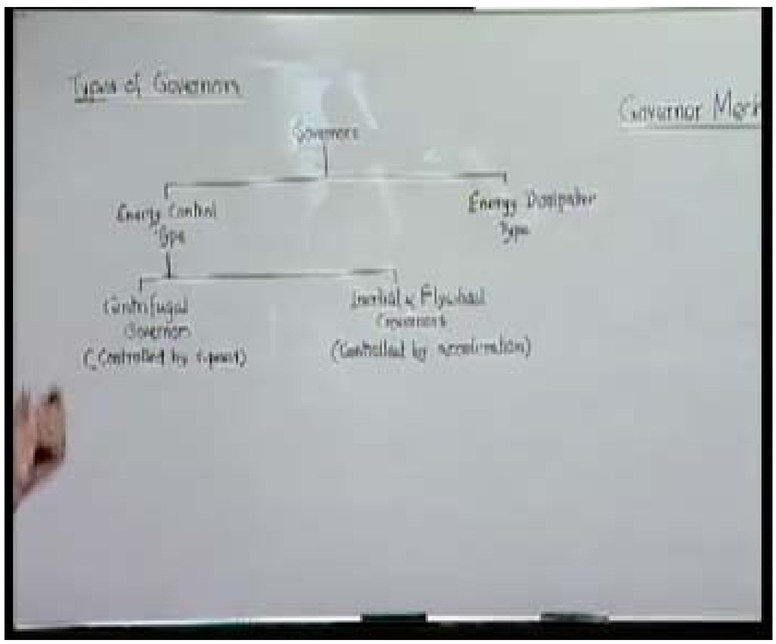

Now, this energy control type governor can be further classified into two groups: one is called centrifugal governor, we have discusses here, what governor is centrifugal type of governor. Here what happened that as the speed of rotation of the governor, beside the location of this very clear that this will be the location of speed that will beside location. Therefore, you can see they are control by velocity or speed.

Another kind of governor call (Refer Slide Time: 25:10). We will discuss this type of governor also where the tensing of the change is done not from the tensing the change in speed but directly from the acceleration, which is going to represent if the speed is changing. Therefore, the control is accelerate obviously, you can see it is acceleration which is instantaneous the presentation of change in speed; it will be more sensitive where as here you have to allow some time to change the speed to itself. Then only you can sense that something is different it must an action. So, this will be more sensible.

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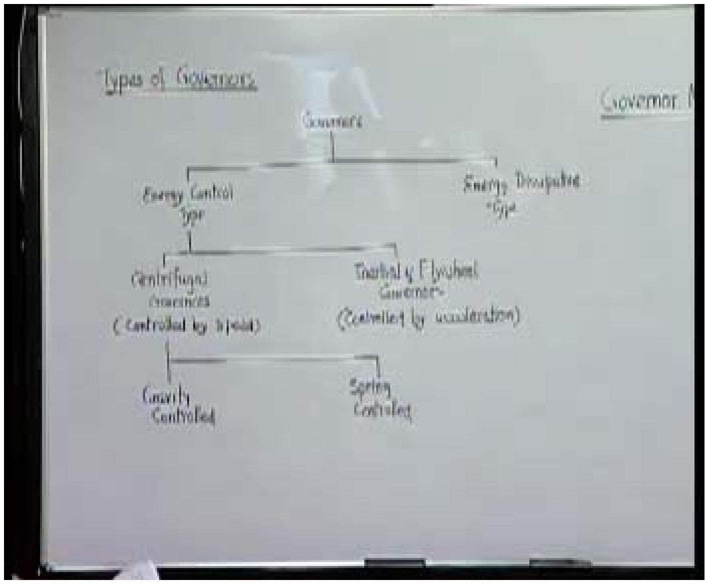

Now, here again this types of governor are further classified, depending on a control that means, there is a restoration mechanism here what actually tells? This governor comes back of the ball come down and take this speed below; if the speed reduces it is mainly because deflecting force, centrifugal force, which is being balance or which is balancing by some restoration is noting but the gravity. It is the gravity with spring down of a system or it stores the governor always lowest position or collapse position; there are cases, where the governor system of the design, where restoration to come back to some design position all the time is two spring.

So, we classify them further into two groups: one is gravity control and another one is spring control obviously, you can see that gravity control that means to generate enough force to operate the whole mechanism etc. If the help of gravity the mass of the rotating sphere will have to be quite substantial they are quite heavy and bulky. On the other hand, you can generate substantial amount of force of expiration using the small acceleration of very speed or small speed; such devices are definitely very compact compare to the typical gravity control governors, consider the centrifugal governor that means, which are control by the speed of operation.

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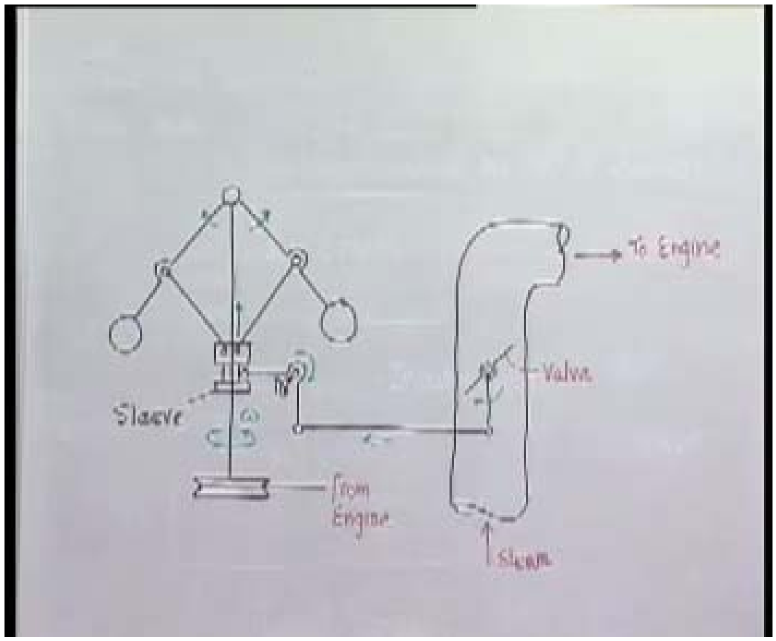

Now, let us consider some important characteristics; here is some basic point one is always remember before discussing or designing this kind of governor. Now, one point is sleeve; this is the sleeve, which actually controls the mechanism to operate default the sleeve will be at lowest position, where engine develop maximum power (Refer Slide Time: 28:20). Next important thing is if the load is suddenly removed, this sleeve brings to the top position that means, should saying high speed situation very quickly should not be struggle.

Next, for normal operating condition the sleeve should plot between the two extreme position at the top and bottom generally, it should store response to changing speed should be very fast as I mention. This governor mechanism should have enough capability to generate adequate force to operate the all control mechanism. if I do everything but if it force generate etc very small that if cannot have overcome whatever fictional loss etc in operating whole control mechanism, where it cannot be taken care of then obviously, the whole purposes is lost.

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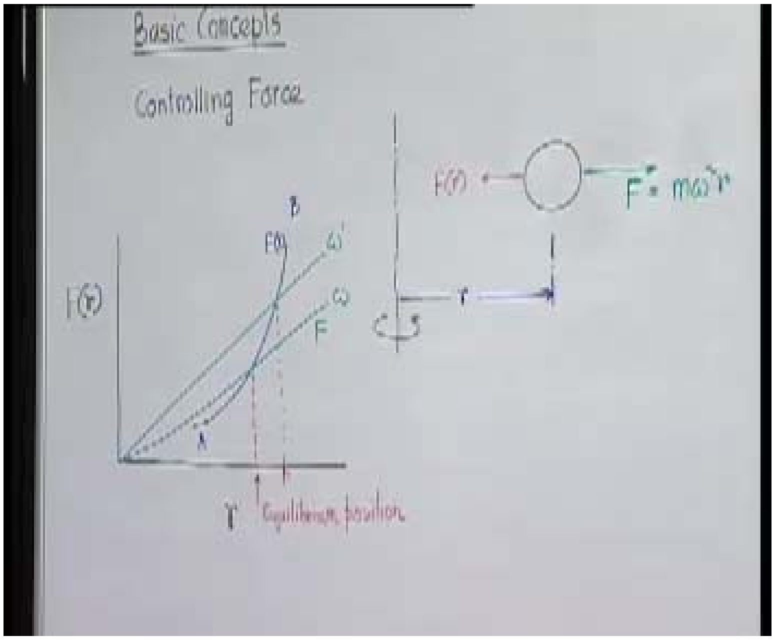

Let us look into the basic definitions and concepts. The first important point you have to keep in mind is controlling. What is this controlling force? This sphere is rotating like this one, from the central axis of the governor at any particular instant the distance is r, which we call as radius. Suppose, let us consider this, it is not rotating then the ball will not remain at the higher position, it will always come below because of gravity. Keep it up at this particular radius r what we can do? It is just a static condition not rotating, what we can do?

We can pull this by outward force in such a manner that it remains static or stable at this distance r. What does that mean? That means various restoration mechanisms, either it is by a spring or by gravity whatever it may be, at this radius effectively it will produce a force towards the inward direction.

This is nothing but the resultant effect of all other gravity pool differential engine etc anything together, it generates or it is consider be equivalent to radially inward force, which is nothing but restoration force for the whole system and equal to control force. To find it out, to keep it up to this position, we apply a force in outward direction. What is this force? If you use the gal amber principle, you will find that this is nothing but centrifugal force.

In a rotating condition this force can be there because of this gal amber principle, we can treat this rotating condition or non inertia form of system in to equilibrium inertia system, if we consider centrifugal force. That means, when the centrifugal force is equal to controlling force, then this remain as the location that is the equilibrium position.

Therefore, this controlling force of governor is very important concept and it defects lots of characteristics cycle. It is needless to mention that this control force is going to depend up on the radius of distance from the central rotating axis of the governor. So, you can easily feel that some time force is required to keep it at a position by horizontal pool giving more and more, you may have little force but gradually you have to increase.

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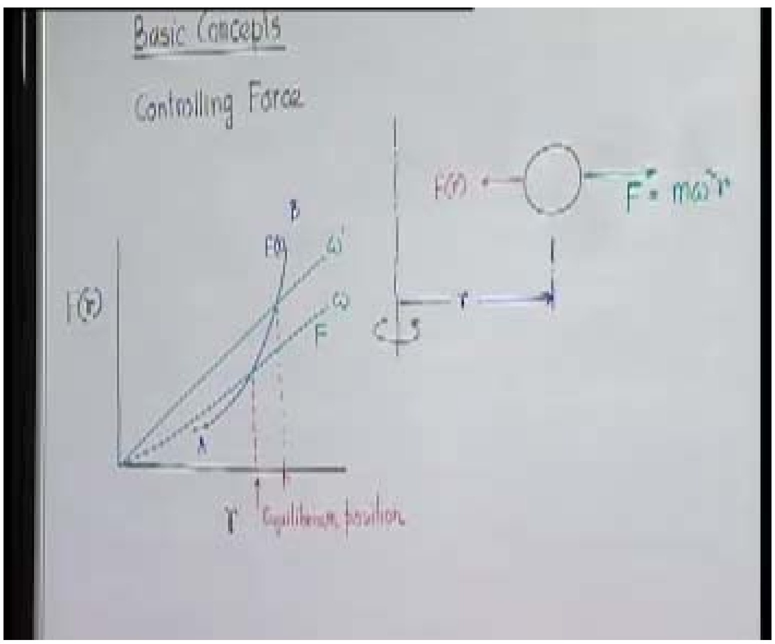

This control force is the function of radius, so you can say it can be something like this; in general, it will be a curve something like this (Refer Slide Time: 34:33). When it is rotating at some speed this force will generate centrifugal force, which is nothing but m omega square r, where m is the mass of the sphere. If you plot this for a particular speed, omega is a straight line, this is F and this is Fr control force.

The equilibrium position is indicated by the situation or radius where both of them are equal. At a particular speed depending on the control force characteristics of the governor will run at a particular radius that means, this ball is rotating with the particular radius from the centerline. What happened if speed is increased, which is very obvious that this go from one speed to another speed so it will be omega prime.

Obviously, radius of each equilibrium will be achieved (Refer Slide Time: 36:14). It will now operate at this speed there fine or if the speed reduces, then it will definitely come down. Therefore, depending on the speed a governor rotates at a particular configuration and what is that? This is nothing but the censer of speed, depending on the speed you get particular location of the speed and any change in speed can be also sensed by movement of the speed and that can be reduced.

Therefore, governor mechanism is nothing but speed sensor (()) and it is not generating voltage or electric signal; it is simply generating mechanical movement or mechanical configuration, which is on indicated on this (Refer Slide Time: 37:05).

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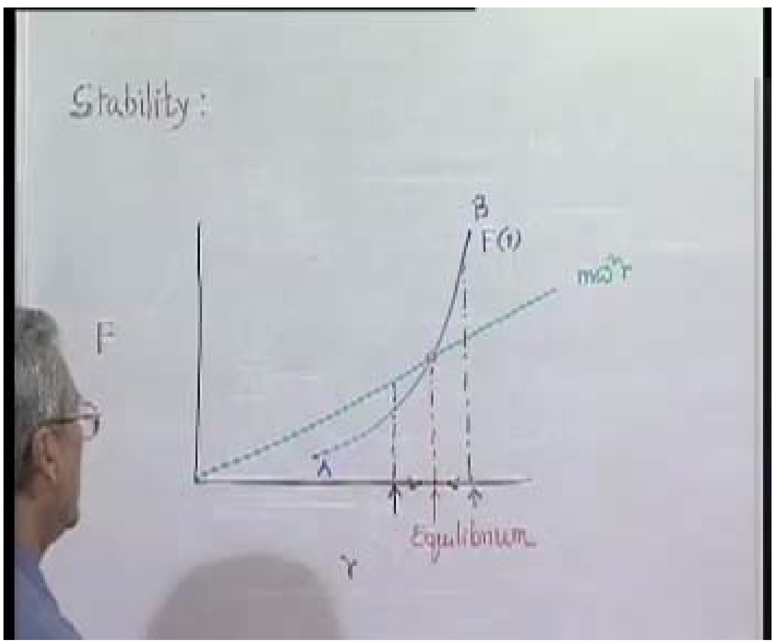

Next important point, we have to keep in mind is stability of operation. What is stability? Stability has it is defined in many other cases. There also stability is defined by the situation what happened if the system is displays from its equilibrium; it displays the configuration little bit from its equilibrium running condition. If it comes back to the original equilibrium position it means governor running stable back.

On the other hand, if it flies away that means, if we display little bit from the equilibrium position and instead of going back its equilibrium position it goes out. So, obviously that have unstable situation. Let us consider the cases when governor runs in a stable manner, and when it is unstable. What we will do? We plot this diagram, as you seen earlier that this is the controlled speed, controlled force diagram and say it is rotating at a particular speed omega and very deflecting centrifugal force and obviously our equilibrium position is as shown (Refer Slide Time: 38:58).

Now, what will happen? If without changing the running speed; the governor is rotating at the same speed omega, but we artificially shift the location form here to here (Refer Slide Time: 39:28). Suppose give a push to the governor or the ball in such a way r goes to the higher value of this, what will happen; you given there? No. You can see that now restoration is the control force is more than the deflecting force and the equilibrium are locked, due to that what will happen? It will come back; since, restoration is more r will reduce.

So, it will again try to come back original equilibrium position. Similarly, if we displace it to this location and give a push to the ball, so that it push ball to inside. What will happen? You can see now, the control force is less than the deflecting force.

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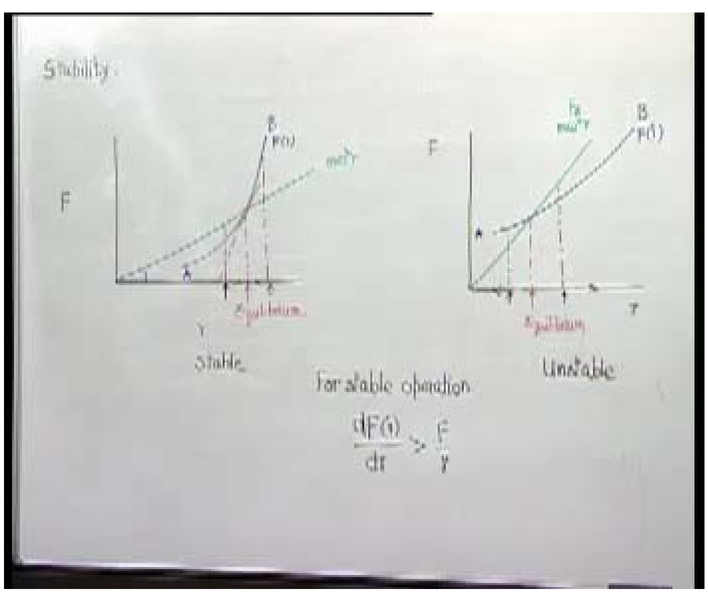

So, this way the balls will try to go out by increasing the radius. That means it is always trying to come back to its original equilibrium position which is for that particular speed. Therefore, this situation is stable operation. On the other hand, this is stable. Here, this is control force diagram and for a particular speed omega, in the reflection force m omega squared r (Refer Slide Time: 40:58). Obviously, the equilibrium positions were the deflecting force and it is running in the equilibrium.

What will happen, if we push it without changing the speed of rotation of a governor to this position; now, you can see that dual deflecting force is still more than the controlling force. So, rather than trying to come back to this position it will further go out. Similarly, if you give a push up governor push the ball so that, which attacks and operates there, what happened, now the control force is more than the deflecting force. So, it goes further away from the original equilibrium position.

Obviously, this kind of equation is unstable and you can perhaps guess by now, mathematically you can describe the situation are defined for stable operation, what is needed is that is find a system; you can see slope of the control force torque should be more than the slope of the deflecting torque; that is m omega squared and then it is stable. So, dF r by dr should be more than this dF r. This is nothing but, tangent of this should be more than the angle; tangent angle of this. That means how much? This is F and this is r, tan of this angle more than tan of this angle and mathematically that is the condition; that is all satisfied so, it will be stable operation (Refer Slide Time: 43:00).

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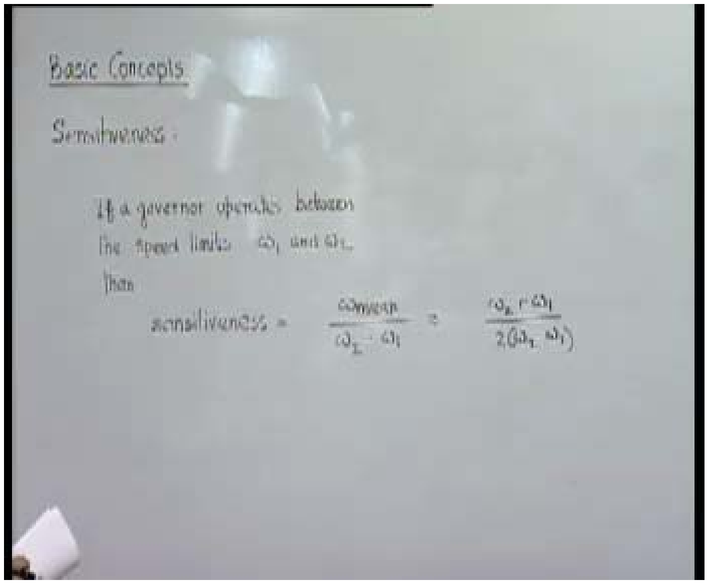

There is another quantity, which we should now look in to call sensitiveness, which indicates that how sensitive governor is to any change. It can be very intensity, we have to provide a lots of changes then only it is response; or it can be very sensitive that slighter disturbance or slighter change in the situation, can (( )) by the governor. As I mention, if a governor operates between two speed limits maximum and minimum, it operates in that range and these two: maximum upper limit is $omega_2$ and lower limit is $omega_1$ (Refer Slide Time: 45:10).

The mean operating speed, which is generally the average of these; omega means, then sensitiveness can be define by this one. You can see, if the governor the limiting speed is very near to each other; that means, it can operate only between say 500 and 501 rpm. Then obviously, 501 will be $omega_2$ and 500 will be $omega_1$ corresponding to each other and you can see it is very sensitive thing.

On the other hand, governor has enough speed that means it operates at 100 rpm at lowest position and 700 rpm at highest position. There is a huge heat gap between the limit or the upper and lower most position of the sleeve, then its sensitivity is very less. These can be of course, omega mean is $omega_2$ plus $omega_1$ by 2 approximately (Refer Slide Time: 47:03). This can be also treated as it continues, if we know the maximum limit enough we can find out.

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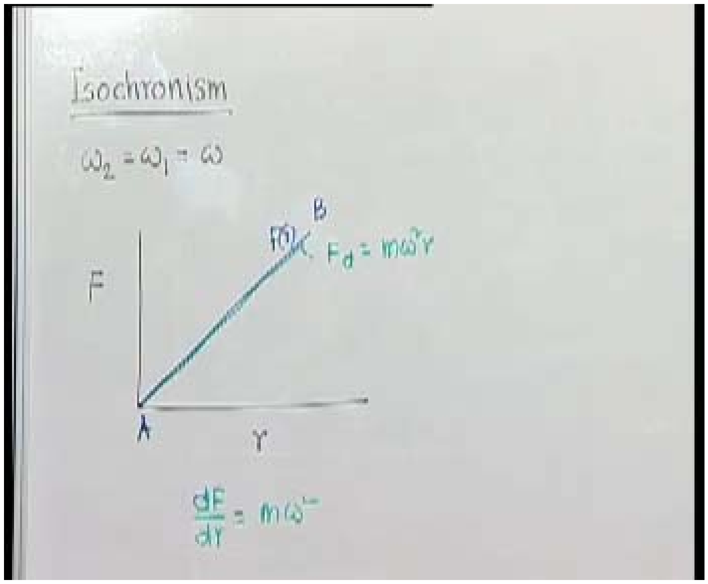

Next, very important concept in governor mechanism is isochronisms. When governor is at equilibrium at only one particular speed, then the system is called isochronisms. Therefore, when it can happen? It happens, when the limiting speed omega$_2$ and omega$_1$ we have seen that is, it cannot have any equilibrium except at one position speed, one particular speed, the governor is called isochronisms. That means what? It will look like that we have plotted r and it is a force, if the control forces curve something like this A B.

Therefore, in such a situation the two will be deflecting force, the centrifugal force can be equal to that only at a particular speed; when the two line front side or you can see the slope of the deflecting force of the m omega squared, slope of the control force that is dF dr, when they are equal and the mark like this; the system is call isochronisms. It is also obvious here, since omega$_2$ equal to omega$_{1,}$ the sensitivity of this particular governor when it is operating as an isochronisms governor will be infinite.

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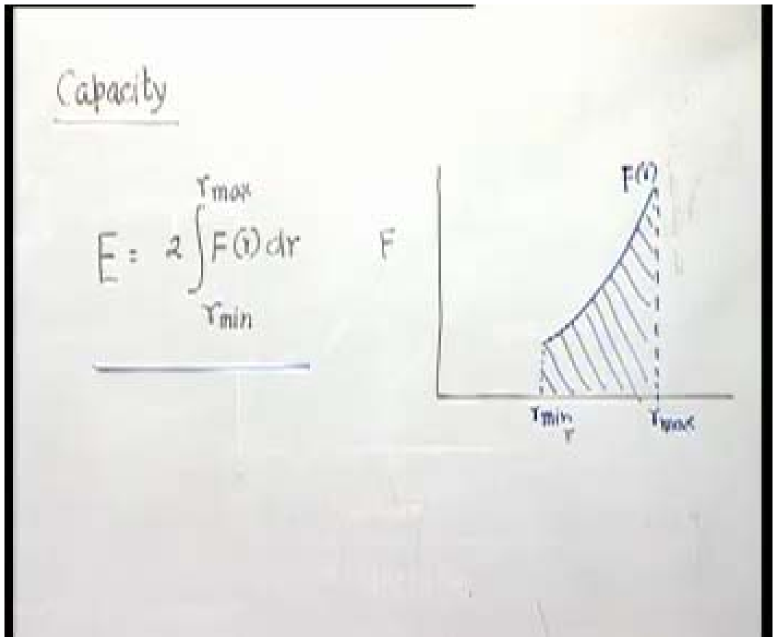

The other term we should be finalizing with other characteristic will be capacity. I already mention that the governor has to do some physical work also by operating the whole ball control mechanism. So, it is important to have enough capacity; what capability of the governor, this is defined as which is nothing but work done, this is the control force curve between the minimum and maximum operating radius.

This is the control force then, how much work is done by the control force when it is falls from the high speed? The possible speed position that r max r means, is nothing but work done by this force; which is the area under the curve and mathematically this is shown (Refer Slide Time: 50:00). This is the energy released by the governor ball when the speed falls from top most to lower most position.

Suppose, you are operating at the higher possible speed that means, at ball r max r; suddenly the load goes so what will happen? Load increases; what will happen? Speed will fall, moment falls, ball should like to come to r minimum, while doing that it will release this much of energy. This energy is available to us for operating the whole governor control or the ball control mechanism. So, we find that there are certain important general characteristics about these governors, which we should be clear about this. I think, it can discuss different types of governors, different types of control arrangements and we will discuss that in next class. So, we take up centrifugal governor first and then gravity control centrifugal force governor, next will take up spring control force.