**Course Name: INTELLIGENT FEEDBACK AND CONTROL**

**Professor Name: Leena Vachhani**

**Department Name: Multi-disciplinary primarily for Mechanical, Electrical, Aerospace and Chemical engineering streams**

**Institute Name: Indian Institute of Technology Bombay**

**Week - 02**

**Lecture - 07**

Hi, in this video we will look into selection of PID controller. Mainly to answer which controller to use in which condition. Controller as in whether we should use proportional, proportional integral, proportional derivative or proportional integral derivative controller, which kind of structure suits better in what situation. So here typically in the control scenario the requirements comes out to be as how well my set point changes should be responded What is the quality of rejection of the load disturbances?

How is my controller able to attenuate the measurement noises? How is the nominal control actions? Because any abrupt changes into the control action is going to eat up the energy of the system finally. And the endurance of the batteries or any power requirements are going to go will be directly related to the nominal control actions that we apply. Whether the controller is insensitive to the process variations because the process is going to undergo various different environmental conditions, various different disturbances would be appearing here.

Process variations because the process is going to undergo various different environmental conditions, various different disturbances would be appearing here. At the same time, there are going to be model parameter changes due to aging as well. These requirements, more or less, we had discussed it earlier. But at the same time, we have also seen that there is a tradeoff when we are designing PID controllers. So what is going to be my priority is to be thought about very carefully when applying the PID controllers.

For the PID control design, we will be requiring process dynamics because this is purely based on the model-based information. What are the levels of the actuators are there? What are the minimum and maximum limits at which the actuators are working? Or actuator saturation information needs to be available to us while designing the PID controller. Or the disturbance characteristics when the controller is designed specifically for rejecting the load disturbance.

So now, in all these scenarios, whether it's a trade-off or whatnot, are we able to do a justice with the PID controller? Can the controller as simple as PID controller work as so well in order to satisfy these control requirements? And fortunately, the answer is yes, because if the PID is applied under suitable conditions, one would be able to do the controller job very easily. And these requirements can be satisfied. What we have to look into is that under what scenario, what kind of structure of the PID is going to work the best.

And that's what these slides are about. When do we use P controller? So for example, my transfer function is given by K upon one plus S tau one and S tau two and S tau three, or maybe many more poles available here. But at the same time, I have a single dominant pole such that my tau one is greater than, and this particular tau one is the dominant, corresponds to the dominant pole. Under such conditions, the proportional control works well.

Tuning is also easy and it of course introduces steady state error because there is no integral action appearing here. At the same time, the control objective is simple regulating type. What is that regulating type that we are talking about? The set point is simple. The regulation, there are two kinds of the control options that we want to look at.

How is the, based on how the input is changing. If the input is such that this stays as a step input in terms of one has to maintain at a particular constant value, then it's a set point regulation problem. But if the input is changing or it's varying with time, then one looks for the control options of tracking type. So the difference between the regulation and the tracking is understood based upon how the input is changing. If the input remains constant for a particular interval of time, it's a regulation problem.

And if this particular regulation problem is to be applied on a system with a dominant pole, the proportional control gives the answer, is what this slide tries to convey. Looking at the I control, only the integral control, We already know that the integral control helps us in getting no steady state error, but at the same time, it is slow responding. So therefore, it is effective for very fast processes or with very high noise levels. Also, it is also effective for process dominant with the dead time because even if there is a dead time, the integral action is taking care of the averaging period of the time and it takes care of the control actions accordingly very efficiently.

At the same time, it is also effective when there are higher order system with all time constants of the same magnitude. As compared to the proportional control where we were looking at the system with the dominant pole, the I control, pure I control works when there is multiple poles at a particular value. Looking at PI control, this particular PI control is adequate for all processes where the dynamics is essentially first order, which means certain examples are the level controls in single tank, stirred tank reactor with perfect mixing, et cetera. or those do not have large number of time constants. So you look at the integral control, we had the higher order terms with multiple poles at a particular value, whereas PI control is very effective when the dynamics is almost same as the first order, or we do not have very large number of poles or large number of time constants associated with those corresponding poles. At the same time, if the step response looks like that of the first order system or so we can assess this by with the help of a step response of the system or using the Nyquist plot where for the Nyquist curve, these first order kind of behavior turns out to be lying in the first and the fourth quadrants only.

So with this kind of assessment, we can say, okay, the system is behaving more like a first-order system, and so PI control is a good candidate for tuning and for getting the control object as satisfied. So if the process has been designed so that its operation does not have tight control, meaning I am looking forward for PI control giving me zero steady state error, perfectly fine, which is coming from the integral action. Some adequate transient response is coming because of the proportional action. But if there is a tight control over getting, saying that I want this much disturbance rejection ratio, I want this exact transient response, we have seen that there are trade-offs. So one cannot get the very tight constraints satisfied with the help of the PI controller, even if with the slight relaxations on these control parameters or control requirements being satisfied, the PI control works even for the processes with higher order terms.

Because we know that integral action is helping us in taking care of the zero steady state and the transient response can be modified with the help of the proportional action. When do we use PD control now? Proportional and derivative control. It is effective for systems with large number of time constants. Now, because compared to the P control,

PD control is giving me more rapid response and less offset. And that's where one can look forward for using the PD control. But it is not at all suitable with very fast dynamics or if the measurement is noisy. For example, it's a flow measurement, so measurement is typically going to be very noisy and one has to resort on either derivative filters applied and these measurements are noisy with high frequency components associated or the dynamics itself is a fast dynamics, So the derivative control is tending to give you more errors rather than giving control performance satisfying the control objectives.

Now looking at the PID control. For example, I have a double integrator that cannot be controlled by PI controller is what we will try to look at it. And why is this particular statement coming up? Because the process with the double integrator where the transfer function is given by G of S is equal to one by S squared. This is already introducing the phase lag of 180 degrees.

With PI controller, it will introduce further phase lag, which means the system is going to be unstable. And so, in such conditions, derivative control is only needed for such processes. Now, with PID control, it will be more suitable when the dominant dynamics is of the second order. Because now with only PI, we see that there are lag getting associated. So the derivative association of the derivative control will add to the phase lead and we will be having a good stability margins turning out to be there.

At times with the dominant dynamics is of second order, then PID is the best solution rather. And you may not get any better gains using any complex controllers. So that's the other reason that the industrial controls are still relying on PID control. Because more or less the PID or any for any such combination of proportional control, integral control and the derivative control is able to give you satisfactory control objectives, which we listed in the beginning of this video. Coming to the idea when to use PID control instead of PI control.

More or less we have said this. When we have these dynamics are characterized by time constants that differ in magnitude. Remember, PI control was beneficial when the system dynamics is more or less dominant by the first order system. But if there are time constants that differ in magnitude, then you will have to consider the dynamics as a second order or higher order dynamics. In that case, the derivative action then be used for the speeding of the response.

At the same time, when tight control of higher order systems is required. We have seen that higher order system can be approximated as first order and second order depending upon the operating frequency range and so on and so forth. So this particular high order dynamics would limit amount of proportional gain for the good controls. All right. But with derivative action, since the derivative action is improving the damping given by it, one can further increase the gain of the system.

So this is why we say that PD control or introduction of the derivative control is is improving the stability of the system because you get more margin to play around with the proportional gain. At the same time, higher proportional gain will speed up the transient response. So both proportional with derivative is more or less is helping us in getting a better transient response, whereas integral control is helping us in satisfying the steady state response of the system. At the same time, when the dynamics is daily dominated, then PID control gives better options as compared to the PI control because the derivative action will give modest performance improvement compared to the PI controller. But at the same time, derivative action gives significant improvement because of the lags dominant of the system.

If you are having a long time delay, then one has to resort to the dead time compensator. But very, very nominally okay lag PID control is still be resorted to instead of making it more complicated by adding dead time compensator and so on. If it's a very long time delay system, we have said that it is difficult to control, because the system's average residence time is smaller as compared to the lag of the system. One has to resort to complex methods like adding the dead time compensator, but with addition of this dead time compensator will provide me the bandwidth to play around with the high loop gain. And with this high loop gain, we will have a better load disturbance rejection ratio.

But at the same time, we can, with dead time and a PID control, give solutions for the systems with long time delays as well. The next category is system with oscillatory modes. So we will, these oscillatory modes are possible when you have flexible robot arms or when we have the disk drives or we have the optical memories, flexible space structures, combustion systems, or we'll take up one example of atomic force microscopes or MEMS systems which are adding the flexibilities into the system and each flexibility can be flexible. For example, it's a flexible arm. One can look forward for a piecewise combination of rigid arms.

And each of the piece is adding one or the other oscillatory mode to the system. So under those conditions, the PID is the answer for applying the control. This particular slide summarizes when to use what. For example, my process dynamics is integrating process, first one. Then it is best to use only proportional control and we should not use I because we know that integrating process is already lag dominant.

And adding the I control is introducing further phase lag into the system, and the system will rather become an unstable system. If it's a truly first-order system, then PI is the answer, and the D controller is not at all required. Essentially first order. What's the difference between true first order and essentially first order? Is that true first order means I have clearly having one dominant pole.

Whereas essentially first order means there is a nearby pole, which is not very far off as compared to the dominant pole. So there's going to be some transient characteristics because of the nearby pole, which is coming up, but we can still consider this as a dominant pole. In such situation, again, one can resort to PI, but very small gain of the derivative control can also be considered here. Dominantly second order, similarly true second order and the dominance. If it's a truly second order system, PID is going to give you the solution.

Rather, this is recommended that use PID because any other complex controller will not give you any better result as compared to the PID. But if it is dominant second-order pole, so again, this is as we said, true first-order and essentially first-order, same, it is true second-order and the dominant second-order. We have a dominant second-order pole, and nearby other poles are also there, but which are not very much affecting the response at the transient stages. So it is okay to use PID. One can give a try with PID first and tune it.

Most likely you will achieve the control objectives that you have set for. Similarly, for higher order also, PID is okay to start with. But if it's a large time delay system, it is a no-no game. No, PID is not going to give you the solution alone. We discussed this.

One has to relate to resort to getting a dead time compensator or some other predictive methodology in order to compensate for the large time delays. With compensation, one can resort to using PID, but alone PID is not at all going to solve the problem. So this way, we can see that when the system is easier to control with the help of, for example, its dynamics is dominant by the first order or second order system, which we can approximate it based on my operating range of the frequencies. These observations will help us decide that okay we can use p, pi, pd, or pid control. That's all for this video and yeah thank you