Chemical Process Control

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Lecture – 35
Heuristics-Based Controller Tuning

Welcome back, we are looking at controller tuning and let us look at how can we use Heuristic tuning methods to tune a controller, and these are very general methods in a way that you do not require a full process model for applying or using these logics. These are mainly developed to assist a practicing engineer such that if you are operating a plant how to tune a particular controller which is already existing, how do you end up tuning it.

There are two types of methodologies which can be used. One is known as an open loop tuning method where you make the controller switch off, take action into your own hands, and that is operating the plant in a manual mode and end up getting the controller parameters that is known as the open loop tuning method.

There are some methodologies where you go about closed loop tuning, where you keep the controller on so that the primary action is still taken by the controller, but you tune down the effect of the controller, so as to get some information about the process. So, whether you use a closed loop tuning method or an open loop tuning methods, the whole idea is to identify what is the underlying process model.

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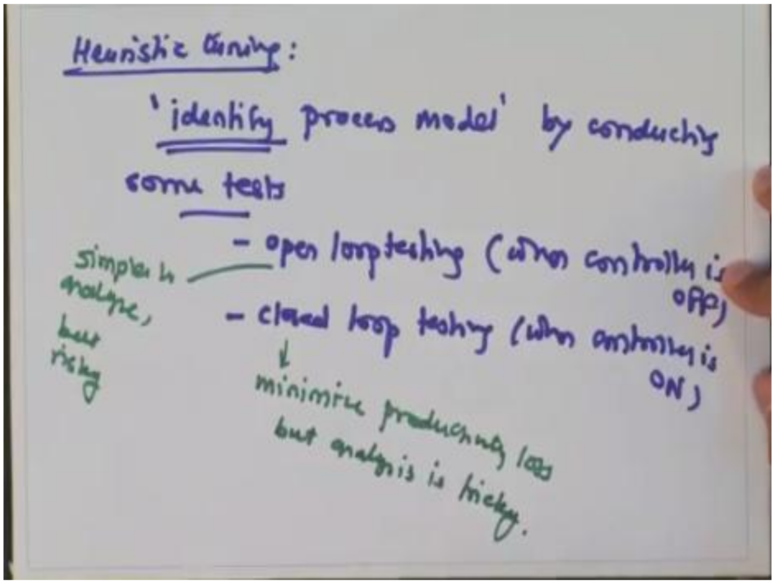

So, in Heuristic tuning, you identify the process model by conducting some tests. If it is done in an open loop, it will be known as open loop testing, when the controller is off, which is a simpler problem to deal with or if the controller is on, it is known as closed loop tuning or closed loop testing. So, these are simpler methods to analyze but risky because you are switching off the controller, so there is no guarantee that the system would remain stable or your product would remain close to your set point value.

So, in that case, you are putting a lot into the hand of the operator, and if the operator is not experienced, he may drive the process towards instability. As against that, they tend to minimize the loss because you are still operating very close to your set point value if the controller is on, but the analysis is tricky. So, depending on which method is comfortable to you either you can do a closed loop testing or open loop.

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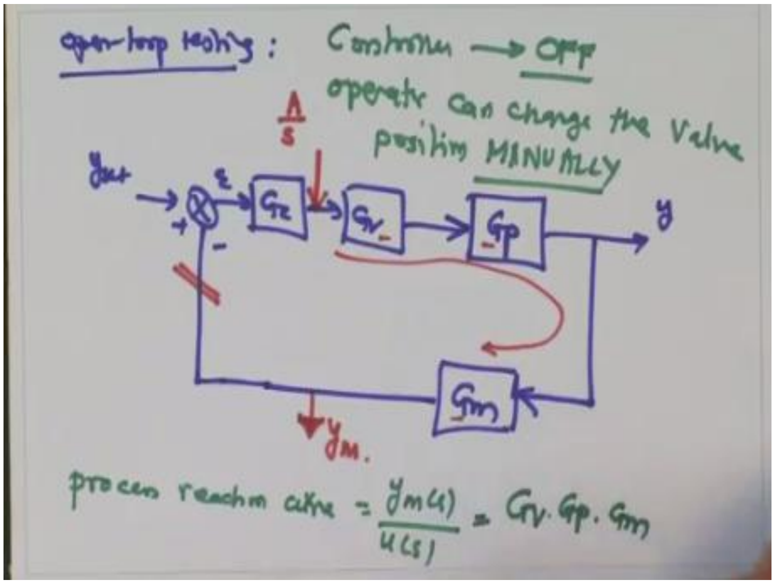

When we talk about open loop testing, let us say this is the process, this is the output, you measure the output then it gets compared with the set point value, the error is generated and the error goes to the controller then it goes to the control valve and that manipulate input goes back to the process.

So, here when you want to do open loop testing, you have to switch off the controller. So if that is the case, the operator can change the valve position manually that is what we know as a manual operation. So, we would be opening this loop, so that is known as an open loop.

So, you no longer pass any feedback, and you give a step change. Let us say a step change of magnitude A into the valve opening. If it is a valve, then the operator would open the valve by a small fraction and then observe what do you get as the measured output. Now the controller does not come into the analysis, all you are analyzing is the effect of the valve transfer function, process transfer function, and measurement and you are seeing if you have a step change into the valve opening, how does your output change? So, essentially what you are interested in is finding this entire transfer function, so this transfer function is known as a process reaction curve.

So, we are interested in how does this measured output change as a function of the valve opening. This is the product of G_v G_p and G_m. If you have these 3 quantities, you can also generate the process reaction curve, even though you do not have an actual plant for which you want to do the open loop testing.

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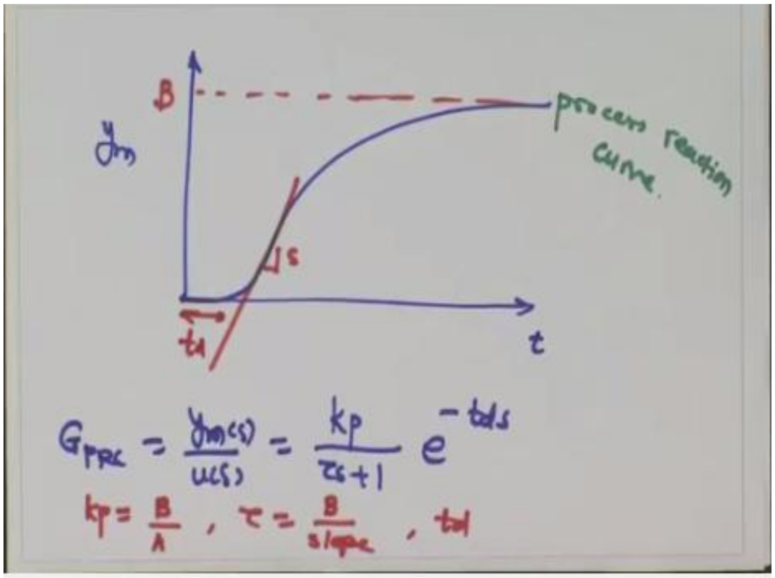

So, let us say this particular response looks like this. The response depends on a very general process will look like this. This response is known as the process reaction curve; this is how the process reacts to the testing. If the final value is B and the slope at the inflection point is S, the process reaction curve is $y_m(s)$ /u(s) = a first order + dead time model.

So, this is an approximation, we want to approximate any process as a first order plus dead time, and you have to use this process reaction curve to represent it in that form and we have already seen how do you convert this kind of a response into a process reaction curve into a first order plus dead time model. In this case, k_p will be = B/A, τ will be B/ slope, and t_d will be = this.

So, from an actual response, you can convert it into a first order + dead time model. So I am saying this as a model because this is not how the process is, this is one way the process response can be represented and then this open loop tuning will give you a guideline about how does your controller parameter like k_c, τ_I, and τ_D depend on the values of k_p, τ and t_d. So, one of those methods is known as a Cohen Coon method.

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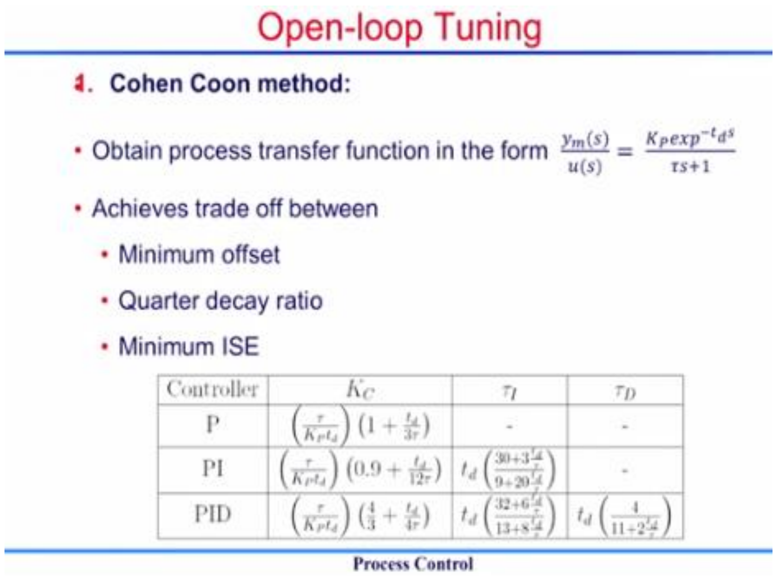
Open-loop Tuning

1. Cohen Coon method:

- Obtain process transfer function in the form $\frac{y_m(s)}{u(s)} = \frac{K_P exp^{-t_d s}}{\tau s+1}$
- Achieves trade off between
  - Minimum offset
  - Quarter decay ratio
  - Minimum ISE

Controller	K_C	τ_I	τ_D
P	$\left(\frac{\tau}{K_p t_d}\right)\left(1+\frac{t_d}{3\tau}\right)$	-	-
PI	$\left(\frac{\tau}{K_p t_d}\right)\left(0.9+\frac{t_d}{12\tau}\right)$	$t_d\left(\frac{30+3\frac{t_d}{\tau}}{9+20\frac{t_d}{\tau}}\right)$	-
PID	$\left(\frac{\tau}{K_p t_d}\right)\left(\frac{4}{3}+\frac{t_d}{4\tau}\right)$	$t_d\left(\frac{32+6\frac{t_d}{\tau}}{13+8\frac{t_d}{\tau}}\right)$	$t_d\left(\frac{4}{11+2\frac{t_d}{\tau}}\right)$

Process Control

So, it says that you obtain the transfer function in the form of this process reaction curve, y_m / u = first order + dead time model and then it tries to achieve a good trade-off between minimum offset, quarter decay ratio and minimum integral of squared errors and based on this, if you want to use a proportional controller then, the best values of the proportional controller according to this method would be given by this formula which is dependent on k_p, τ and t_d.

Once you have these values of first order + dead time model parameters, which is a grey box model, you can obtain the value of the best controller gain for a P controller, if it is a PI controller, then this is how the gain would be calculated, and this is how the integral time constant will be calculated, and for a PID controller, these are the values recommended by the Cohen and Coon method.

Now, one thing I would like to put your attention to is; let us say if you focus only on the controller gain, you would see that the methods says that if I use a certain gain for a P controller, if I go from P to PI controller then I should cut down on the gain and we have seen that when you use an integral action, the tendency of the system is to destabilize and because of that you have to cut down on the value of the gain, for which you can add the derivative action to improve this response.

And that is why whenever you have a PID controller, the gain which you can use is even higher than what you can use for a P controller so that it will give you the fastest response.

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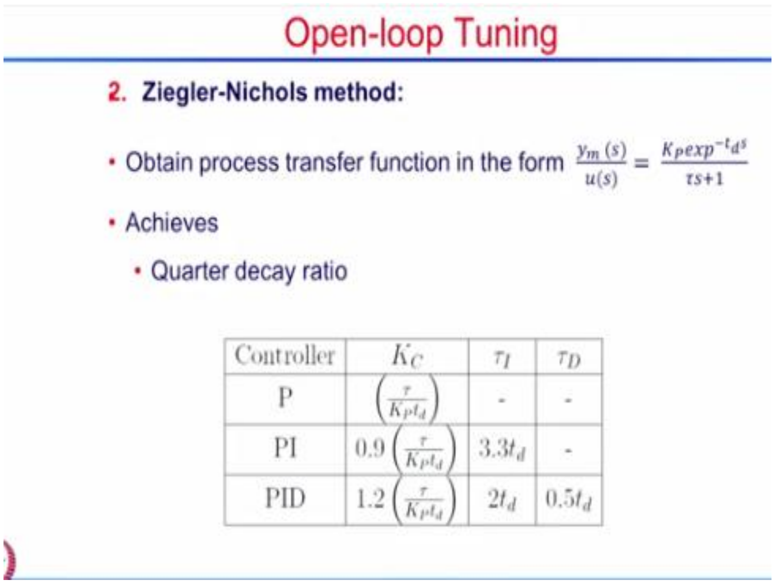

Another method which uses open loop tuning is a Ziegler Nichols open loop tuning method. Let me give you a word of caution that there is a very popular method by the same Ziegler and Nichols which is a closed loop tuning method, so that method is very popular, just for the sake of completeness I am giving you the open loop tuning method which has been proposed by them as well.

This is a simpler method, and it analyses only quarter decay ratio, and you can see that again the same trend is followed that the P controller will have an intermediate gain, PI will have a lower gain than P, and the PID will have a higher gain than the P controller. You can see that all these methodologies they would try to follow this basic analysis which we have done for P, PI and PID controller, the values which you get are based on the criteria which are selected.

So, these are the two commonly used methods for open loop tuning. Now one of the main disadvantage of open loop tuning is that you are putting a lot of emphasis on the operator to maintain the plant operation when he gives the step change into the valve opening. If he gives a much bigger change into the manipulated input, then the system may drive to a new steady state, or it may go into an unstable region.

So, a lot of times, there is a possibility that you would lose production as well as you may destabilize or shut down the plant. That one reason prompted the development of closed loop tuning methodologies, wherein you would want the controller to be on, even when you are doing the tuning. Now, the main challenge here is that as the controller is on whatever the model which you are going to identify from this response is going to be dependent on the controller parameters which are already there, which may not be optimal. Because of that, it becomes very tricky to obtain the true process model when the controller is already on, so that is why the analysis become little tricky here when you talk about closed loop tuning methods. So, I will give you some of the simpler ways in which the closed loop tuning can be done.

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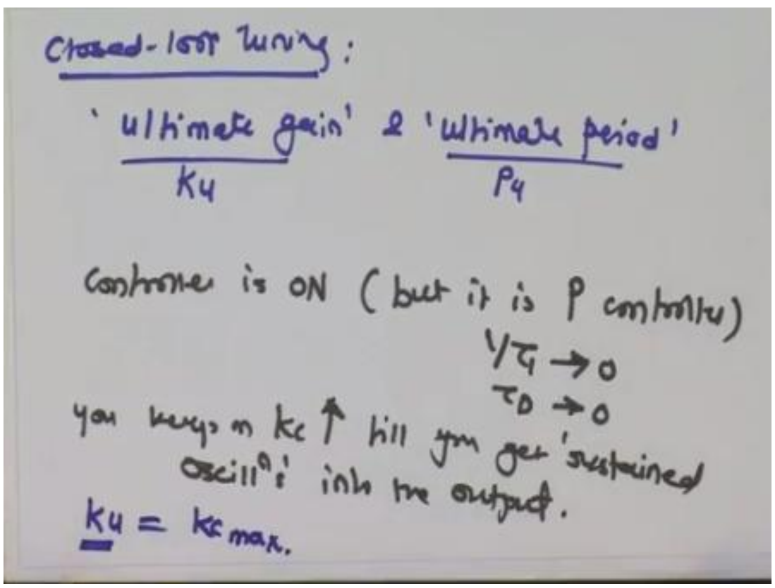

So, closed loop tuning when you want to do, what you are interested in is obtaining ultimate gain and ultimate period. So, for the open loop testing, all you were interested in was to convert your actual response into a first order + dead time model. In closed loop tuning we are interested in obtaining these two values represented as K_u and P_u, so let me explain what do I mean by K_u and P_u.

For this closed loop tuning, what you have the controller on. The controller is on and it is a proportional controller, so τ_I or $1/\tau_I$ is 0 and τ_D is also 0. So only a proportional controller is used, it will ensure that the system will remain stable and you keep on increasing the gain of the controller.

So, you will realize that as you keep on increasing the controller gain, you are eventually going to reach the stability limit after which the response may become unstable. So you are not going to make the system unstable, but you are going to find out at what limit the system reaches the stability limit that means, till you get sustained oscillations into the output. So having sustained oscillations would mark the boundary of stability.

The objective is to find the controller gain or proportional controller gain which will give you sustained oscillations and that gain is known as the ultimate gain, so this will be represented as the ultimate gain.

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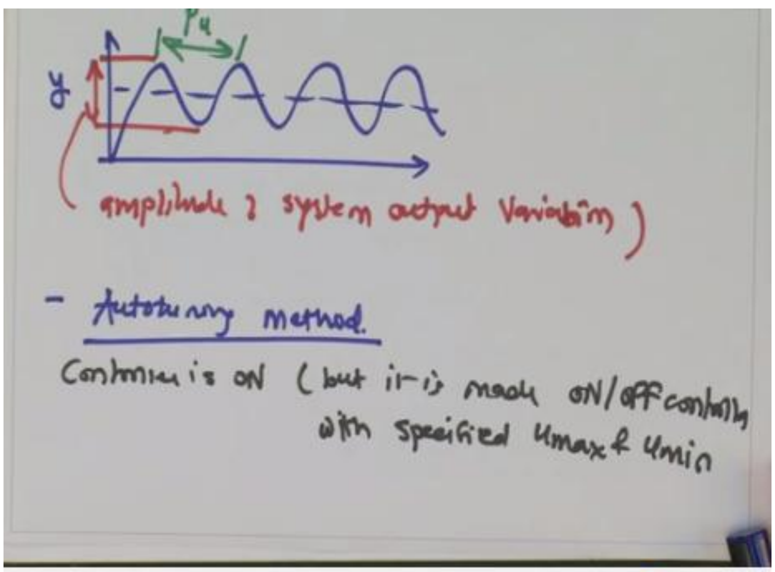

When the response has sustained oscillations, the corresponding time period is known as the ultimate period, so that is how one can obtain the ultimate gain and ultimate period from closed loop tuning experiment and this can be done in a real plant. The only tricky part is, if you do this then you are relying on the process for information about the process, this amplitude of variation, so this represents the amplitude of variation, may be large.

So, because of that when you simply use this P controller based closed loop tuning, you may oscillate the system to a very high magnitude again, something which you may not want to do regularly. To alleviate that there is another method of doing closed loop tuning which is very popular. So, in the auto-tuning method, again the controller is on, but it is made an on-off controller with specified U_{max} and U_{min}.

So, you can say how much your manipulated input is going to change around the steady-state value, and if the amplitude of output variation is too large, you may clamp this U_{max} and U_{min} to be very close to each other, so that the amount of variation in the control variable output would be smaller. So there is a way to tune, how much is going to be the amplitude of this oscillation.

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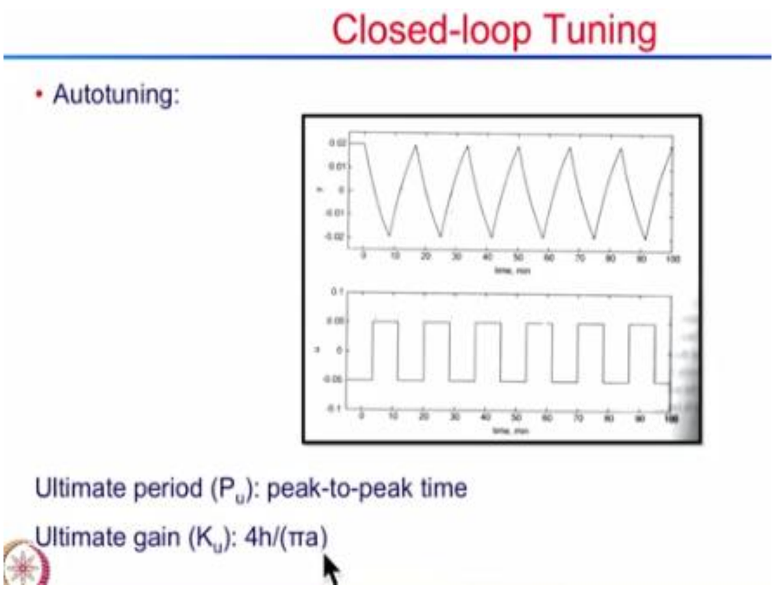

Typically when you do that the response is going to look like this. Your manipulated input would look like a pulse response which is clamped by the maximum and minimum values which you have said, so here the response shows that it is set at ± 0.05 around the steady-state value and correspondingly, the output shows this type of a response. It is not entirely an oscillation like you would see for a typical auto method which you had seen earlier, using proportional controller.

But this type of response also gives you some relationship between the magnitude of input change to the magnitude of output change which will give you the gain for this type of an auto-tuning exercise. Your ultimate period remains similar, that will be the peak to peak distance between the two trough or two crests, and the ultimate gain is slightly different, it is four times the height here, the manipulated input divided by the amplitude of this output.

So, the л comes in here because this is not a completely sinusoidal response, but this is still related to the gain between input and output. So using auto-tuning method also you can get P_u and K_u, and now these are different Heuristic tuning rules which will relate this K_u and P_u to the controller parameters, so very commonly used methodology is Zeigler Nichols closed loop tuning. This is different from the one which we had seen earlier which was Zeigler Nichols open loop tuning.

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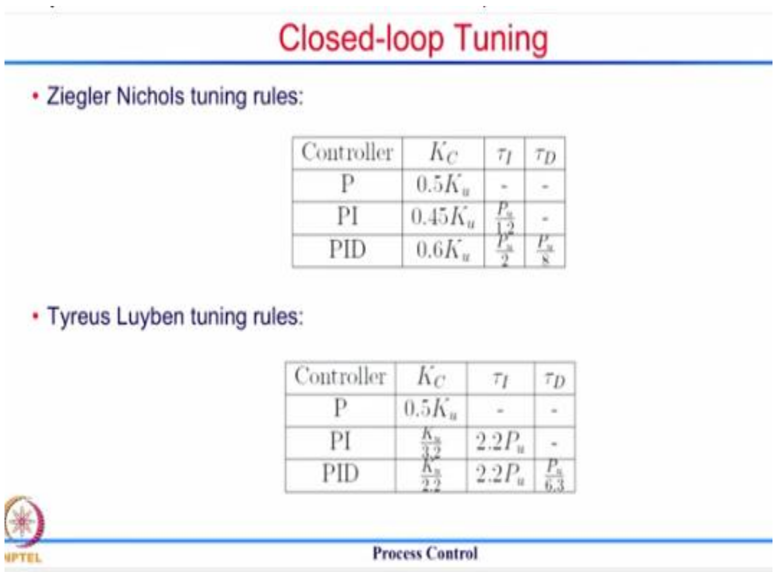

Closed-loop Tuning

- Ziegler Nichols tuning rules:

Controller	K_C	τ_I	τ_D
P	$0.5K_u$	-	-
PI	$0.45K_u$	$\frac{P_u}{1.2}$	-
PID	$0.6K_u$	$\frac{P_u}{2}$	$\frac{P_u}{8}$

- Tyreus Luyben tuning rules:

Controller	K_C	τ_I	τ_D
P	$0.5K_u$	-	-
PI	$\frac{K_u}{3.2}$	$2.2P_u$	-
PID	$\frac{K_u}{2.2}$	$2.2P_u$	$\frac{P_u}{6.3}$

So, here these tuning rules are based on this ultimate gain and ultimate period and you will see that these are the tuning rules. Again they follow a similar nature, this is 0.5 times K_u, K_u represents the stability limit, so you cut down into the half, so your proportional controller is operated halfway from the stability limit. This will ensure that the system would be stable, the PI controller has even slightly lower gain than that, and this is how the integral time constant is related.

Now, what people realize by using Zeigler Nichols tuning rules was that the response tends to be very oscillatory even with a very small value of damping coefficient. If you do not want large oscillations into a system then Tyreus and Luyben detuned these controllers. So the response is little slower than the Zeigler Nichols rule but it is less oscillatory and these are the tuning parameter which is given by Tyreus Luyben method, where the P controller has the same equation.

But all the other controllers are detuned significantly, the gains are much smaller than Zeigler Nichols and integral time constants are larger which in both of these would are going to reduce the speed of response but also they are going to improve in terms of decay ratio, the response will not be very oscillatory. So, by using Heuristic tuning, you can either use open-loop or closed-loop tuning method.

And then here are some of the readymade formulas which you can use. A lot of times these will give you a starting point which you can set your system and then once you have these as a good initial guess, you can still tweak some of these parameters and try to obtain the final best values depending on the process at hand. So these can be used as a guideline, you may not fix, or you may not always operate your plant at Zeigler Nichols tuning rule or at values given by Tyreus Luyben method.
These should be used as an initial guess around which you tweak to see the response of your actual process, and when you are happy with the way the system response, then you lock down those controller parameters. So, we will take a short break here and when we come back, we will look at a more model-based ways to tune PID controller, and those will be direct synthesis based method or frequency response based method. Thank you.