Control Engineering
Prof. S. D. Agashe
Department of Electrical Engineering
Indian Institute of Technology, Bombay
Lecture - 13

Did you calculate the speed it comes out to be about 1400 and 18 RPM and not 1500 RPM as we wanted it. Remember, to have the motor run at 1500 RPM required an armature voltage of 230 volts and that was coming as the output of this box K a for which therefore, the input required was 1.15 volts because K a was 200 which means that the error signal e is to be 1.15 volts whereas, the reference voltage was 20 because of that the tacho generative voltage. We would have add to be 18.85 volts that is 18.85 volts which means that the motor will not running at 1500 RPM.

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In fact, 18.85 volts will be produced by the tacho generator at a speed of about 1413 RPM. So this qualitative argument goes to show that the speed of the motor could not be 1500 RPM but then by making actual calculations with the 3 equations that we wrote down, you will find out that the speed comes out to be about 1418 RPM. So that the error voltage is about 1.09 volts and the tacho generator output voltage is 18.91 volt rather than 18.85 volts.

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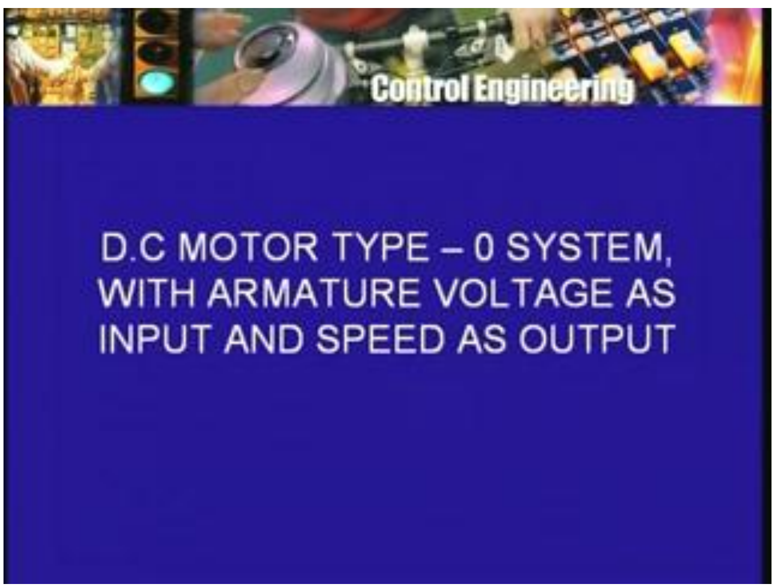

Now the point of the whole argument was that, if we have a feedback control arrangement like this which is said to be the proportional control type in which the error signal is the difference between the reference signal and the feedback signal and the reference signal, it represents the desired quantity and the feedback signal. In this case the tacho generator voltage is proportional to the output quantity. So if we use proportional control scheme in which the error voltage e produces an output in this case or armature voltage which is proportional to the error voltage. Remember, the type of the system was 0 in the sense constant armature voltage would produce constant motor speed current.

So in the motor speed is the output and armature voltage is the input then the DC motor behaves like type 0 system. So we have a type 0 system with proportional control and if you look at most through the textbooks you can look at the formula for the steady state error and it will turn out that, there will be a steady state error and this is what, we actually found out that instead of 1500 RPM. The speed will be 1418 RPM. Now of course one can say that the amplifier gain K a was only 200, you required an error voltage 1.15 volts to produce an output voltage of 230 volts which is going into the armature. So let us increase the gain of the amplifier, so that the error voltage required to produce 230 volts is much less all right.

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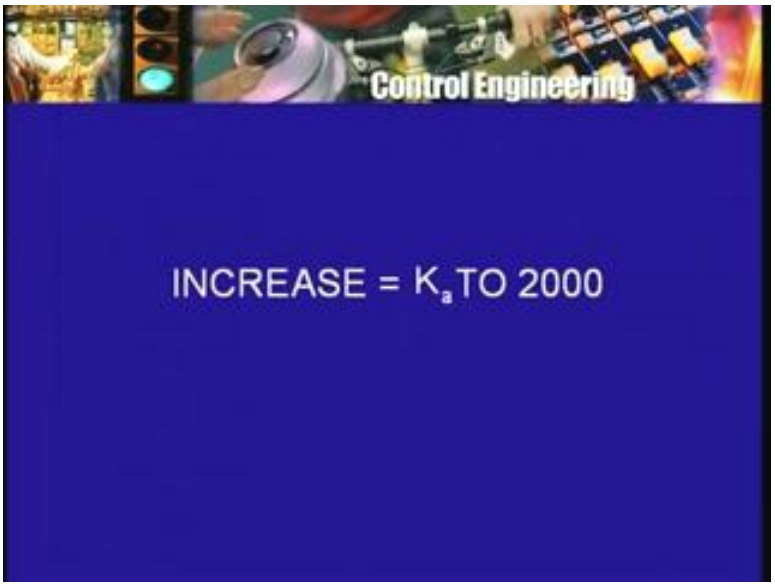

Let us increase the gain by a factor of 10, so make now K a equal to 2000, instead of 200 the error voltage required to produce 230 volts therefore, will not be now 1.15 volts but will be one tenth of that that is .115 volts, the reference voltage is 20. So the tacho generator voltage will still be less than 20 volts, it will be less than 20 volts by the smaller .115. So it will be about 19.885 volts but it will not be 20 volt and so, the motor speed once again cannot be 1500 but will be something less than 1500 and you can redo the calculations with the gain K a equal to 2000 and you will find that the speed will be now much closer to 1500 RPM then the earlier answer of 1418 RPM.

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But still it cannot be exactly 1500 RPM and this is why, the books say that there will be a steady state error which is non-zero. If you increase the gain still further by another factor of 10 then the speed will be still closer to the desired speed but the point is, since you have an actual amplifier some error voltage is required to produce the output voltage of 230 volts and therefore, there will always be a steady state error that is the motor will not run at the desired speed.

Now in a way this is absurd because this means that uh you cannot design a drive. So that it will run at a desired speed using this idea of proportional control at least. So there should be some way of getting over the situations still keeping the idea of proportional control and indeed, it is possible and you will also see where the mistake, we are making is or what is the errors about error that we are committing. We want the motor to run at 1500 RPM. So let us say that we still use the same tacho generator, so its output voltage will be 20 volts, if the motor is to run at 1500 RPM the tacho generator is unchanged the tacho generator output voltage will be 20 volts is nothing we can do about it now.

Similarly, the armature voltage required is 230 volts and therefore, if we keep the same amplifier gain K a, the voltage e a, the so called error voltage or the output of the difference device will still have to be 1.15 volts. But now, instead of keeping the reference voltages are 20, why do not we increase it so that that voltage minus the tacho generative voltage 20 is equal to 1.15 volts and so, all we are to do is you have to change the reference voltage from 20 to 20 plus 1.15 volts or 21.15 volts.

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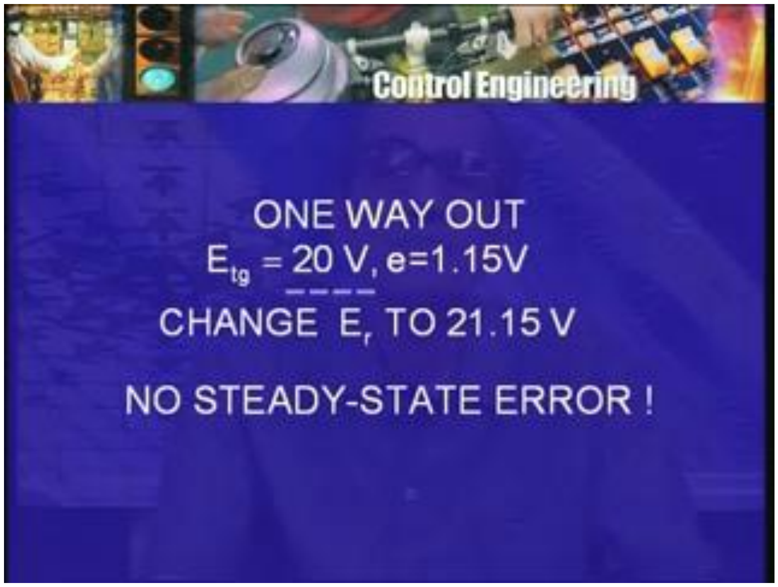

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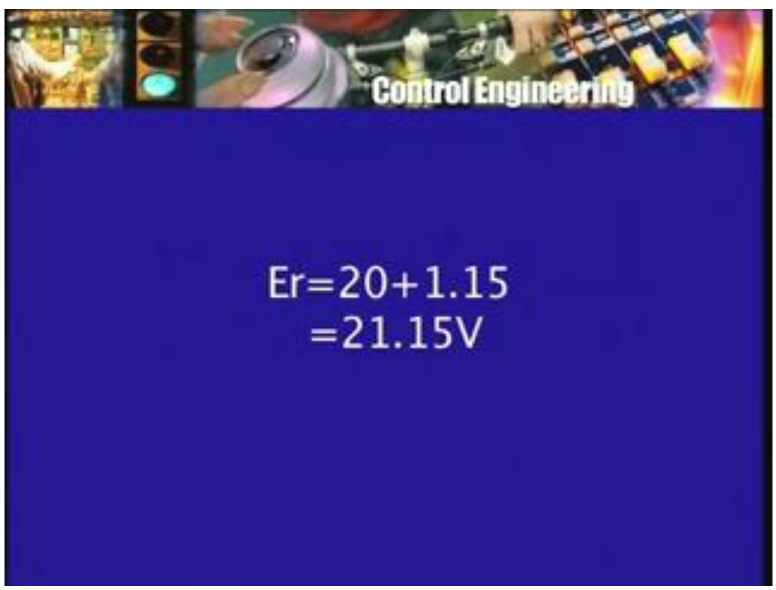

Now you can redo the calculations with a reference voltage of 21.15 K a equal to 200 as before every thing else as before and you will find out that the output speed will come out to be 1500 RPM, as is desired. So the reference voltage instead of 20 volts which corresponds to the tacho generator output voltage of 20 volts and 1500 RPM is to be a little more and how much more exactly the amount that is required to produce the desired armature voltage in this case 1.15.

Now this is why, I have mentioned that perhaps it is not correct to use the word error for this output of the difference device because the motor will be running at 1500 RPM, tacho generator will produce 20 volts, reference voltage is 21.15, the output of this difference device is 1.15 volts which produces 230 volts which is therefore, ensures that the motor runs at 1500 RPM. So the drive has no steady state error the drive is running at 1500 RPM. So this e which is 1.5 volts is not really the errors in the sense, it is difference between the desired speed and the actual speed it is the output of this device to the difference device or the error detector or comparator, which is speaking as 2 input reference voltage, which is to represent the desired value and the feedback signal in this case the tacho generator voltage, which represents the actual value.

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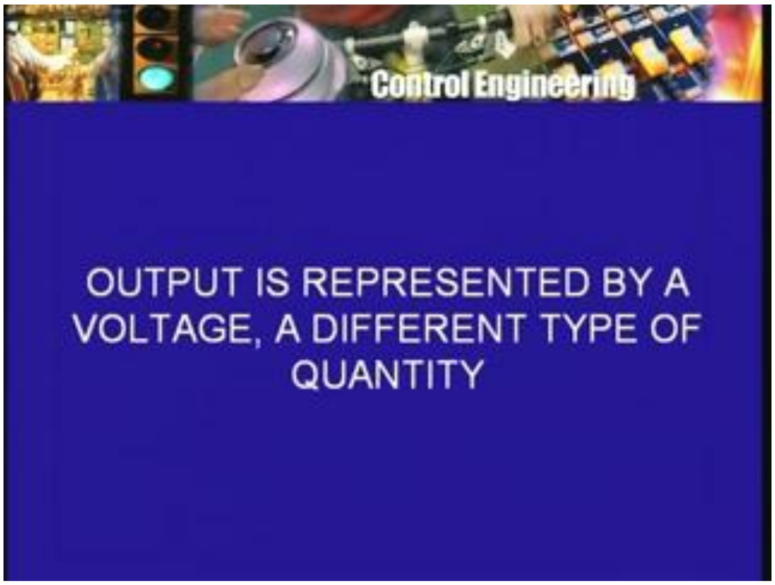

So this e should not really then be called the error in the sense it is not related to the error in speed. Now this is one way of rectifying the situation all that I have done is I kept everything as the same tacho generator unchanged gain K a, unchanged I have simply changed the reference voltage. So that it is not 20 volts but it is 21.15 volts and why did not I think of it earlier because the thinking was that the desired voltage should be 20 volts because the tacho generator output voltage at the desired value is 20 volts and so, let us have reference voltage equal to 20 volt.

Now, what we are doing is the desired speed 1500 RPM is not represented by 20 volts but is represented by 21.15 volts. Now that is okay the desired speed is to be represented by some voltage and in this case, that voltage is such that with a specified feedback arrangement namely the tacho generator and the specified proportional controller arrangement namely, the gain of 200, the reference voltage which represents the desired speed is just the correct value not 20 volts but 21.15 volts.

So that the drive runs at the correct speed this is one way out of the situation. So we have changed the reference voltage and we have changed our way of thinking all that, we are thinking always the reference voltage represents the desired value. The tacho generator output gives you the actual value, the only thing is these two need not be the same when the drive runs at the desired speed. We sort of use one representation for the desired value and we get one representation of the actual value.

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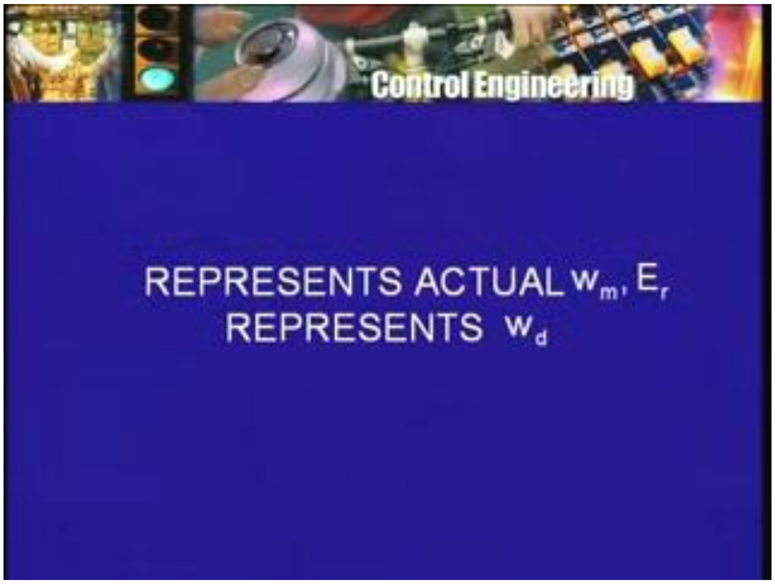

So that there is a non-zero difference between the 2 when the conditions are the desired ones which produce a non-zero voltage which causes the motor to run at the correct speed, what is the second alternative? Suppose, I want to keep the reference voltage is the same 20 volts, say I have got my 20 volts supply or whatever it is, now and I do not want to touch the amplifier, the amplifier gain will be still 200. Then what has to change now 20 reference voltage unchanged the output required is 1.15 volts that is unchanged. So what do I require now I require a tacho generative voltage which is no longer 20 volts but 18.85 volts. Now if my tacho generator is producing an output or 20 volts at 1500 RPM, I have 2 alternatives either I can replace the tacho generator by another which will produce 18.85 volts at 1500 RPM or alternately, I use the same tacho generator but take only a part of its voltage for example, through a resistance divider network or a potentiometer arrangement.

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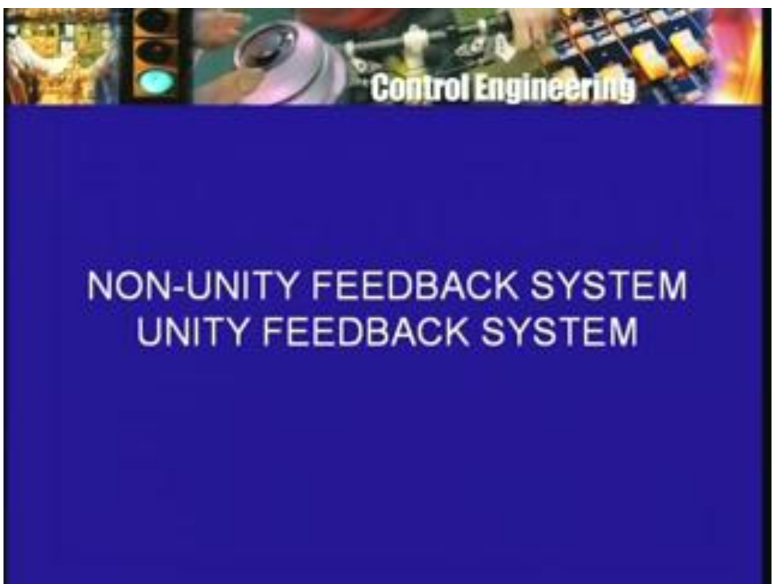

So that from the 20 volts produce by the tacho generator only 18.85 is taken and given to the error detector. With this also then the motor will run at the correct speed 1500 RPM tacho generator output will be 20 volts but not all of it will be fed back, 18.85 will be fed back to the error detector, for which the other encode is a reference voltage which we are kept at 20. So there is a difference of 1.15 and that produces the correct value 230 volts and therefore 1500 RPM.

Now in this second case one some time talks about non-unity feedback and in fact, these are the two terms which are use in the literature and they can also give rise through this confusion or they are another way in which is the same confusion can arise. So, one distinguishes sometimes between unity feedback system and non-unity feedback system. Now what is the difference and what are these 2 in fact, in most cases these 2 terms cannot be applied directly to the actual control system configuration. They can be applied to a block diagram that we can draw and then, we can say all right this signal here should be nearly equal to that signal there or this signal here is .8 times that signal there and things like that.

So, on the block diagram we can certainly indicate signals and say that under ideal conditions these two signals should be equal or one of the signal should be equal to .8 times the other or .9 times the other and so on and there is a good reason for this. Let us get back to our speed control system what was the output quantity 1500 RPM the desired speed.

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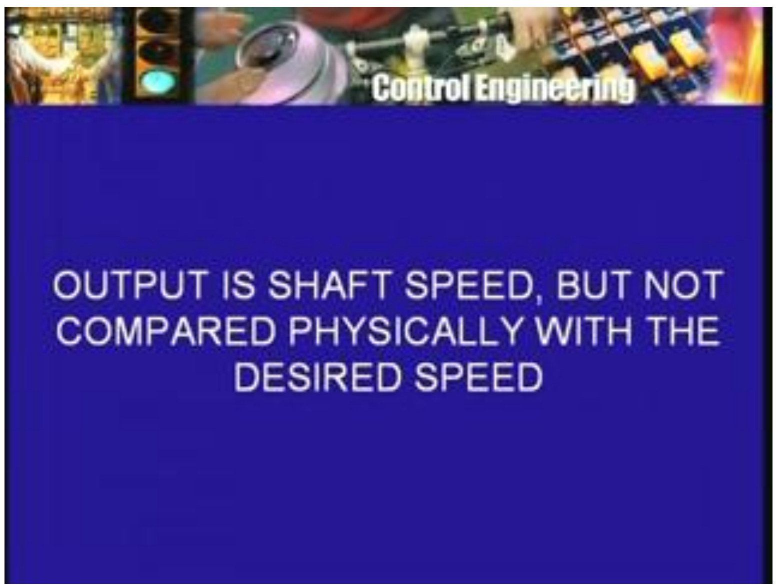

Now we did not want a shaft to run at 1500 RPM, so that we can check whether the actual motor shaft speed is 1500 RPM or not that is, we did not want to compare the shaft speed of the motor under actual operation with some other shaft running and at that constant speed of 1500 RPM because it is inconvenient I have need a synchronous motor, the supply voltage will have to be at 50 hertz frequency and then what do I do, I have to shafts running at two different speeds however, you find out whether the running and the same speed or not and then take some action based on that.

So this is thoroughly impractical as a result therefore, since we already using generator and motor and what not, we decided to use a tacho generator to represent the desired quantity and also the actual not represent the desired quantity actually to represent the actual quantity, the 1500 RPM or whatever RPM, the motor runs at is represented by the tacho generator output voltage. So the feedback device, if it is the tacho generator its output is voltage its input is RPM its output is 20 volts, its input is 1500 RPM certainly voltage is not the same thing as RPM nor is 20 volts or 20 the same thing has 1500.

So am I using unity feedback or non unity feedback in fact that question does not make sense. In this context the input to the whole thing because the feedback signal was voltage because it is a field current, which is to be adjusted or manipulated because the field current will be manipulated because the field current will be manipulated by changing some voltage because a voltage can be produced by an a electronic amplifier. Therefore, we chose the reference input also as a voltage we did not chose the reference signal as a 1500 RPM shaft but it was the voltage similarly, the error signal or the difference on the output of the error detector or comparator is also a voltage.

So they are voltages there RPM we have left behind although the interest finally is in the speed at the input end, we are really working with voltages only and this is what is likely to happen in most control applications. The output variable will be speed, angular position where it will be degrees or radians or whatever, you may want to specify angle or it could be pressure, it could be temperature, it could be velocity of some particle or it could be the rate of flow of some fluid or it could be the concentration of some chemical in a mixture on what have you, it will be a physical quantity of some appropriate kind based on the application. The input quantity on the other hand is not going to be any one of those things in most of the cases the input quantity will be a voltage. Of course the input quantity may not be a voltage as such on the face of it, think of the air conditioner for a moment how do you adjust the temperature. We do not directly fiddle with any voltage as such what you do is there is a knob on the air conditioner panel and you turn the knob.

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So in this case the input is the angular position of the knob what you change the input, we have to turn the knob and this is very often when there is manual element involved this is very often how we control anything. You control the air conditioner temperature by changing that knob or if you have a remote control for it and you will press a button somewhere and then see a number come up which will say the temperature that you want or if you are driving a scooter or a car it is the steering wheel and the accelerator peddle and the break peddle or the grip bar for the breaks that is what you are going to control, what you are going to control? Of course, is the speed of the vehicle, the position of the vehicle whether the vehicle is going to turn or go straight and things like that.

So the input variables or the reference variables are quite different in physical nature from the output variables and so their values are also quite different. So it is extremely rare that the reference signal will of the same type physically as the output that is being controlled. So this is volts that is volts perhaps, now this is degrees that is degrees of the same time not only that they may be of the same level of the same range of values the reference input is of the order of some volts, say 10 volts then the output voltage is also of the order of 10 volts it is only rarely that this happens and just about the only case in which this happens is precisely the case of another kind of system that I mentioned in the beginning, what you are talking about motor speed control is a regulator type system.

The goal is to keep the output quantity constant, in contrast with that is the class of systems called the servomechanisms or follow up systems or tracking systems. In which the system produces an output quantity which is through track the input quantity and in the case of our radar gun control system the output is angular position of the gun and the input would be if the input is not being tracked by means of a radar but let us say the gunner who is sitting on the tank on which the gun is located or if it is not on tank it is stationary wherever it is, he has a line of sight that is he has the telescope which he turns and once the anywhere craft is in the speed of vision then he tries to follow it or track it.

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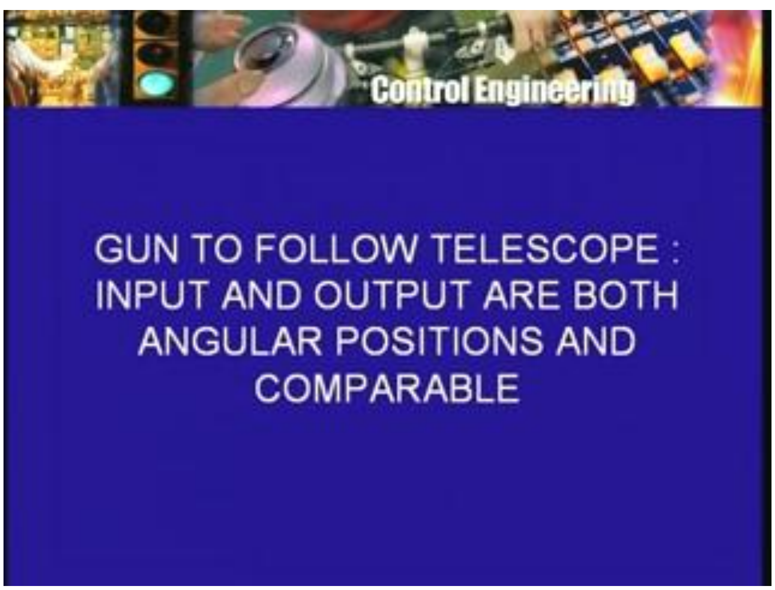

So he moves his telescope, so there is the movement of the telescope as the enemy target is moving and you would like the gun to move correspondingly this is about the only kind of situation where you have an angular position, the angular position of your line or sight or telescope and then you have the angular position of the gun the system being controlled and the two have to be equal the equal not only in there equal in the physical sense that is both are angles and both should be equal in the sense if the telescope is pointing at say 40 degrees elevation and certain azimuth at angle then the gun ideally should also be pointed at almost the same elevation and the same azimuth at angle.

So in this sense only the input value will comparable to the output value both will be of the same kind and I can talk about direct comparison between the input angular position the position of the telescope sight and the output angle of position the position of the gun these may be measured of course not directly the gun may be out there the telescope excite may be at another place. So we are not going to couple them mechanically and compare the 2 positions each angular position will be represented now this is the key idea that is what we want to happen is that this angle signal should be equal to this angle signal as far as possible which would follow but what we measure, what we do is that we convert them if you wish transduce them or sense them and instead of angles we work with voltages or amperes current or whatever convenient quantity. So that both these angles are going to be represented by some other physical quantity perhaps voltages and in fact this is what is actually done.

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I mentioned a device called a synchro and I said that these come in pairs that is you really have two synchros one is connected to the telescope excite and the other synchro is connected to the gun the synchros produce voltage output and it is these 2 voltage outputs which can be then taken compared and any action that is necessary taken by comparing these two taking the difference if you wish because it is not DC, it is AC you may do some rectification or ah you know all these kinds of things or you may use an AC motor instead of a DC motor and what not.

So this unity feedback idea of directly comparing the actual quantity with the desired quantity makes practical or physical sense in only very exceptional situations like this. In most situations the actual quantity of course is actual it is actually the motor running somewhere or some bath having a certain temperature or there being a certain pressure developed under a certain state of bellows or whatever. So the actual quantities of course physical it is speed temperature pressure whatever.

The desired quantity is in your designer's mind or on a piece of paper written as 1500 RPM it is not a shaft running somewhere at 1500 RPM or if the temperature is to be maintained at 27 degree Celsius then it is not some other device in which there is the ambient temperature of 27 degree Celsius. So that you could compare the actual temperature with this temperature and take some action it is almost never like that. So of course one is thinking of the desired quantity the desired value and the actual value and the two should be equal, strictly speaking that is not what we mean what we mean is that the actual speed should be equal to a number which can be specified or which is specified beforehand. The actual speed should be 1500 RPM there is no comparison between or made between the actual signal and the desired signal which is the same kind physically and of the same value numerically as the desired as the actual speed.

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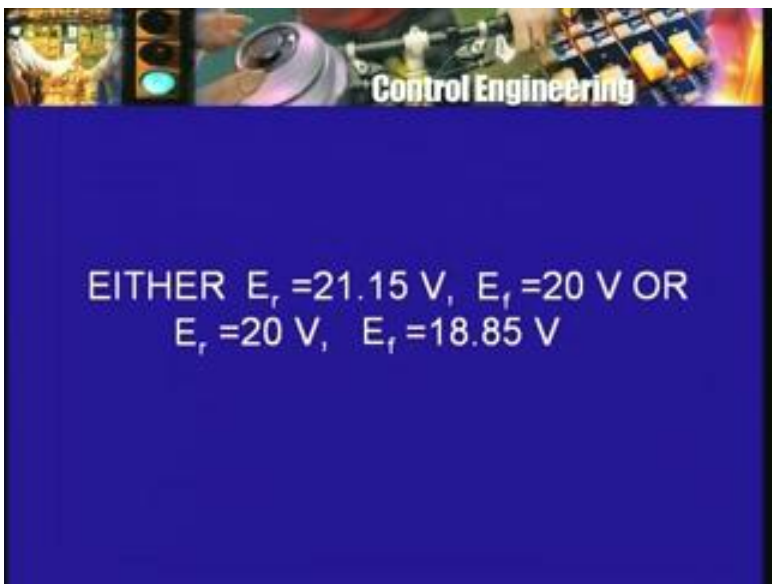

So this unity feedback and a lot of talk is made about it because as I said on a block diagram you can indeed show a number of signals whose values will be comparable. In fact we have it on our example the reference speed is 20 volts, the tacho generated output voltage is also voltage and the two are comparable, the reference speed is 20 volts, the tacho generator voltage may be 19 volts there is not a big difference between the two. So in that sense there is some comparison being made between two quantities which are of the same type and their values are close to one another.

So I could talk about unity or non-unity relationship between them. Of course both the solutions are to be found out are such that there cannot be equality between the two, what was the first solution? The first solution was to change the reference voltage instead of 20 volts increase it to 21.15 volts find, so 21.15 volts is the reference voltage the tacho generator output voltage at the desired speed is 20 volts. If you want the drive to run at the correct speed then it should produce

20 volts reference voltage is 21.15 and other thing is all right but the two are not equal 21.15 is not equal to 20.

Of course you can say that 20 is some fraction of 21.15 volt surely it is but that way any number is a multiple or fraction of some other number there is no great significance. In the first arrangement there was no potentiometer being used the reference voltage was 21.15 the tacho meter voltage, tacho generator voltage was directly connected into this difference device. There was no potentiometer used there was no multiplying coefficient used at all in the second solution we kept the input voltage is the same 20 volts therefore we required a feedback signal which was not 20 but less than that.

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However, the tacho was producing twenty so we put this potentiometer or an attenuator as it is called in amplifier practice to reduce the value from 20 to 18.85 volts. But still 18.85 is the feedback signal finally going in to the comparator 20 volts is the reference signal that were not equal and they should not be equal because if they are equal then the output is 0, the motor will not run think over all of this carefully read the relevant element material from any one of the text books. I find that even very good text books have committed this mistake or this confusion have fallen prey to this confusion this distinction between unity and non-unity feedback about which a lot of fuss is made and this idea that the system is driven by the error on the one hand and that signal e, when the drive is running at the correct speed is an error signal.

This is where the mistake lies when the drive is running at the correct speed that error signal that signal e, the output of the comparator is not zero but that is not the error in the resistive that does not indicate that is a motor is not running at the correct speed. In fact it will if it is of the correct value it indicates that the motor is running at the correct speed so it will not be correct to call it the error detector in this case and in fact in most cases where you have proportional control and you have a type zero system. In such a case that signal is should not be called the error signal if by error we understand that the actual value of the output is not equal to the desired value something has gone wrong somewhere, the system is in error, no that is not the case. This signal does not represent or indicate error at all however it does indicate something and it is required to produce the desired speed. Now suppose you wanted to change the constant speed from 1500 RPM to 1000 RPM and let us say we wanted to keep the same motor we wanted to keep the same amplifier K a with the same gain 200, same tacho generator the motor is to run now at a speed of 1000 RPM, what should be do?

So if you think correctly the answer is, the answer can be found out by going through the actual calculations 1500 was produced by 1.15 volts for the value of e. Now I want 1000, so that will be reduced correspondingly 1500 RPM was producing a tacho generator voltage of 20. Now I want 1000 RPM so the tacho generator voltage will be less so knowing this new tacho generator voltage and the new value of the voltage e I can find out the new value of reference signal E r and all I have to do is I have to generate that value of reference signal somehow and you can think of here a potentiometer a voltage divider arrangement say 30 volts is applied to it.

So that is you can pick of some required voltage so for 1500 RPM I pick of voltage 21.15 so there is a slider and of course that slider is not marked in volts, it is directly marked in RPM. So when you do the set point or and you do the setting you simply move that slider up and down till it is at the against the correct mark which corresponds to the correct to the desired speed which will produce the correct reference voltage and under ideal conditions by that we mean what by that we mean that the torque is at the rated value, the field current of the motor has not changed, the gain of the amplifier has not changed, the generator which is supplying the armature voltage its features have not changed etcetera parameters have not changed given all those conditions under which we made our calculations.

If those conditions apply then the speed will be at the desired value which ever it is whether it is 1500 or 1000 or 500 by simply adjusting the reference voltage E r appropriately the drive will run at that desired speed the system is of type 0, the system is not really driven by error but the voltage input in this case the armature or the field current is derived in a proportional manner from the output of a difference device, the difference device does take the difference of the reference signal and the feedback signal and that difference device is multiplied by some quantity a like this gain K a.

So there is some kind of proportional idea here type 0 system this kind of proportional control but there is no steady state error, the system can operate at any specified speed without any error what so ever. We look into this once again when we come to the section or the material on error in control systems and system types and so forth and so once again I will point out there the mistakes that have taken place in many of the textbooks because of this confusion. Now the reason for using feedback was not really all this because the operator could directly control the or set the field current at the desired value. So, that the motor runs at the 15 RPM speed so why have you bothered to produce all the speed back.

Now any system any control system whether regulated type system whether manual or automatic has to have a set point input. If it is to be capable of running at different constant values of the output quantity I repeat here, if you want to drive that will run at 1500 RPM and only 1500 RPM and at no other speed then you do not need to change any settings anywhere once and for all they will be a fixed all you are to do is turn the motor on there is some starting arrangement if that can also be automatic you will get 1500 RPM. In that case perhaps you will not use a DC motor at all.

You will use a synchronous motor a 4 bolt synchronous motor from a 50 hertz supply if it is sufficiently stable supply will give you 1500 RPM without any of all these round about operation. In fact one usually has different requirements at different times you would like the drive to run at 1500 RPM on one application may be at a different speed at another time in other words there will be this set point business or a setting business, air conditioner think of it once again.

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You do not want an air conditioner that will only produce a temperature of 27 degree Celsius no matter what whether you are comfortable or not, you live with it no we have the set point adjustment and so depending on the desired quantity the set point is appropriately selected and this will have to be done manually because I can think of a futuristic if I am not such a very futuristic system where you may feel that the thing is not being done manually is being done automatically, imagine a air conditioner remote unit which is controlled not by pushing a knob somewhere and setting some digit somewhere but my speaking into that remote unit.

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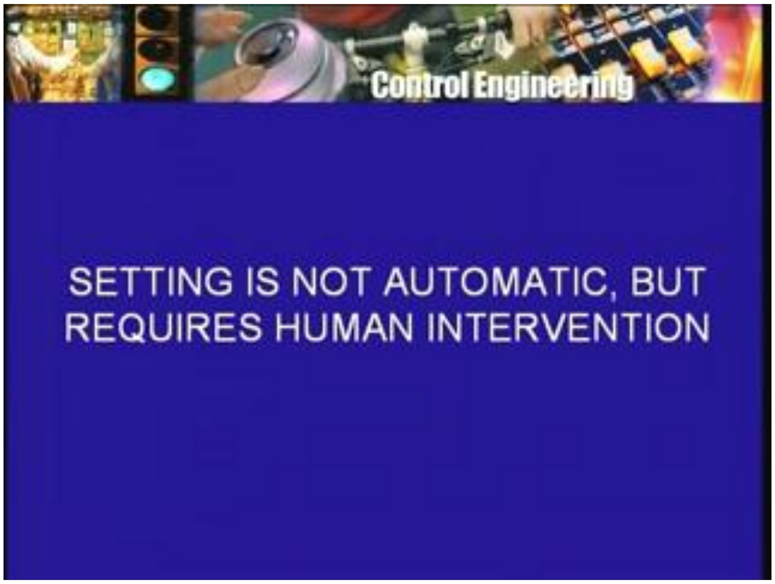

So I say 25 degree Celsius and that device side smart enough it listens to what I am saying interprets it as 25 and then does some setting somewhere, some setting and resetting it will have to be there there is no way out. Now is this automatic, the answer is no because I have spoken and said set it to 25 degree Celsius I have given the input the air conditioner did not automatically change it to 25 degree Celsius. Of course one can go to some further futuristic scenario where as I do not know about this temperature, Celsius, air conditioner and so on. I am too lazy to even speak out and say 25 degree Celsius.

So I have something connected the my body say to some part of my skin and that thing sort of senses whether I am comfortable or not and so as things happen I do not do a thing that sensor there checks for my comfort in some way and says okay change it to 25 no, no, no change it to 26 this guy is not comfortable is too cold or no, no, no change it to 26 from 27 because this guy is not comfortable he is feeling too hot, may be you can measure the amount of sweating that is taking place, of course all this is futuristic nonsense I hope we never reach that stage when it will be so lazy and we will have all these devices so that we do not have to do a thing and we are comfortable all the time.

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So given that fact that at the moment at least we do not have any such thing setting resetting set point adjustments are there are there as a part of any control system any practical control system. Therefore, for different desired speeds change the reference voltages not a big issue it has to be changed of course that setting can be marked already some body has done all that work therefore I do not adjust any voltage with a voltmeter. I simply put the slider in the appropriate mark somewhere it says 1500 RPM, I put the slider there or if it says 1200 I will bring it down or up put it against that 1200 mark and that is what actually will happen now it is going to measure any voltages and speeds and what not.

So this is how typically the control works there is some knob which is to be turned and that results in some other change of course we have the on off situation available to us all the time that is the most preliminary or simplest kind of control that I mentioned namely on off control and which is not too bad after all but it requires a lot of attention and action. Even then you have to change it from on to off and off to on, so there has to be a change of setting but to comeback to what I was talking about we do not really need feedback, I did not really need that tacho generator output and so on because directly 1500 RPM requires 230 volts, 230 volts is produced by say one ampere of field current and that one ampere of field current is obtained by some voltage of 20 volts somewhere.

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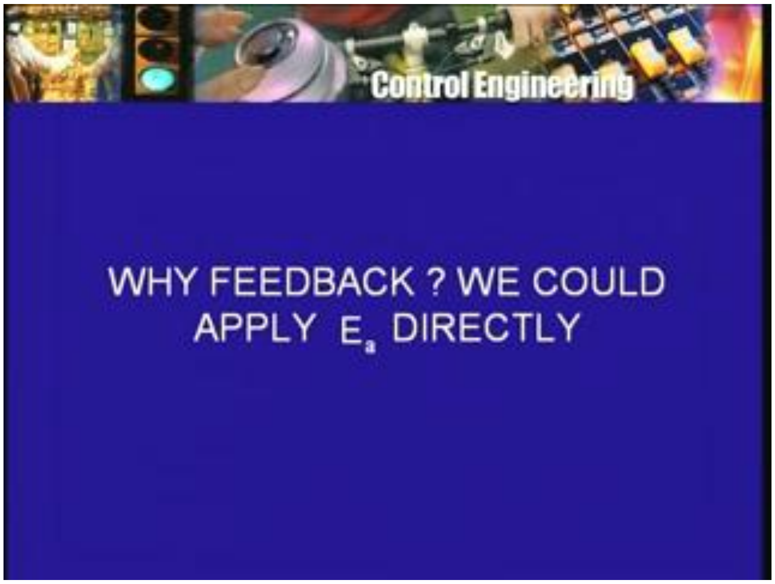

So 20 volts produces 1500 RPM, I want a different speed, in different armature voltage, different field current therefore a different voltage somewhere else why do I need feedback, why do I need tacho generator, in fact I do not so then why are we introducing feedback and to repeat and I think this point is worth repeating because one tends to forget why feedback is used not just because it is some fancy idea but because we want to take care of or we want to get over these things that are going to happen when the system is in operation, two kinds once again disturbances, the load torque is not going to remain at the design value. In fact you may want the speed to remain constant in spite of changes in the desired ah in the torque value and you want the speed to remain constant without somebody making adjustment of the input voltage all the time certainly with human operator it is possible to make the motor run at the desired speed even when the torque changes.

If we want to make it automatic and if you want to make it automatic you have to see what is actually going on that seeing motors actually going on is feedback and then you have to make an adjustment which is based on that feedback the speed is not correct, it is less I have to increase it or it is more I have to decrease it. So I have to make some adjustments somewhere this adjustment we want to be done automatically and that is what the whole purpose of the feedback idea is that is even when there is a disturbance we would like these adjustments to be made automatically so that after some time delay the speed remains at the old value.

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Remember, there will be a transient error, there will be a short period during which the speed will deviate from the desired value but hopefully this adjustment will be made. So that the speed is back at the desired value even if the armature field, the field current of the motor changes we had assumed that it will remain constant, even if the field current of the motor changes by small amount. We would like this speed of the motor to remain unchanged and many other disturbance signals one can think of in the Lenard system, the motor is fed from a generator the generator is run by another motor or by an IC engine what about its speed, its speed may not remain constant and so on and so forth.

So disturbances disturbance variables they are always there one of the purposes of feedback is to see whether the effect of the disturbances can be reduced or even cancelled out completely whether adjustments could be made and remember not manually, manually things can always be done within limits of course, automatically. So, that the error is reduced or made 0 if possible adjustments to be made so that the error is 0 or as small as possible. The second is parameter values, changes in parameter values or uncertainty about parameter values the design value is not exactly the same as the actual value perhaps and therefore the pre-programmed control will not work necessarily, it may work in very few cases by chance. But generally things will go wrong little bit and so some adjustments will be required anyway. Now if the parameters change I do not want to keep on measuring them making recalculations and making readjustments I would like automatically something to take place.

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So that the effect of the parameter variations can also be countered in the word used here, in a more technical sense later on, is that which changes compensated. The load torque is increased yes but I will compensate it that is I will make some other adjustment. So that that load torque increase does not change the speed some parameter value is not the same as the design value yes but the deviation or the difference can be compensated by an adjustment somewhere else. Now if you go back to our control system arrangement where we had the tacho generator output the reference input the comparative device and that signal amplified going into the motor which drives the load with that kind of arrangement, can it handle.

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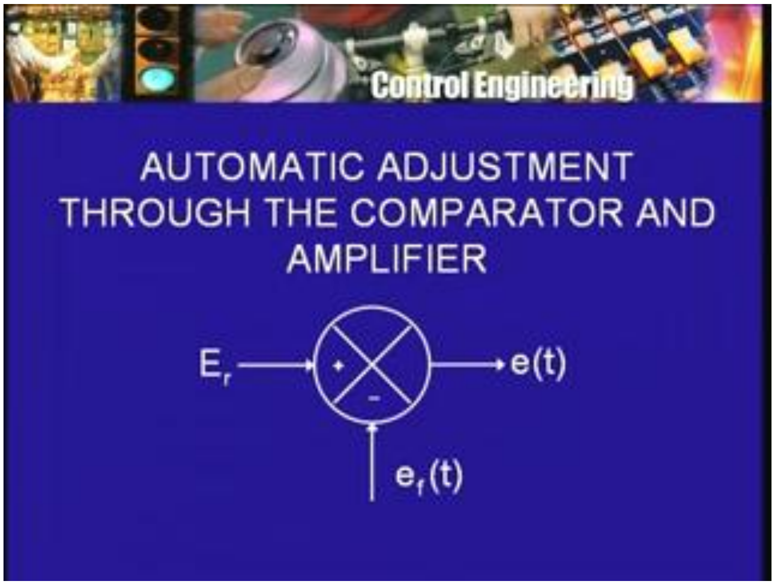

So no other changes to be made the where is the automatic adjustment in that system the automatic adjustment is through the mechanism of that comparator device remember this symbol for it circle with plus and minus, the reference signal r of t or in our case DC voltage E r going in the other one the tacho generator voltage getting subtracted from it and the third quadrant comes out, the output E t, this E t is the signal that is then driving the system and this E_t is sometimes called the actuating signal or it can also be called the manipulating signal that is things are changing through this E t things change because this E t changes. So, one talks about it as the actuating signal or the manipulating signal.

Now the arrangement that we have although it has speed back, we will see that it cannot take care of the 2 reasons for which feed back was introduced or is to be introduced namely disturbance and change in parameter value. So what I am saying is now if the load torque changes of course I am not going to measure the load torque that is an assumption that I making if the load torque changes and I am not going to measure anything else other than the speed and my arrangement is as before the comparator et amplified through K a etcetera no change.

So my reference voltage of 21.15 volts produces 1500 RPM for a load torque of say 30 Newton meters, no problem there or it could be 20 volts because the tacho generator we have taken only of a part of its voltage. If the load torque changes then with the same reference input I am not going to change the reference input because the reference input corresponds to the desired speed and I do not want to step in to this thing, I want it to happen automatically. So I am not going to make any adjustment what will happen if the load torque changes, we had earlier worked out the design calculation under steady state conditions by saying that the armature voltage will be so much, the back emf will be so much etcetera, etcetera.

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So that take example now and assume that the load torque changes from 30 Newton meters to 0 from 30 Newton meters it changes to 0 in other words. there is no load there is of course still the frictional torque required for the motor to run because you may want still the motor to run and not simply switched off. We may be changing from one job to another. So the load torque is changed only momentarily perhaps from 30 Newton meters to 0 of course, one can say if 30 is changed to 20 that is another calculation that you can make.

So suppose the load torque is changed from 30 Newton meters the original value for which the reference voltage will produce the desired speed, no error nothing once the reference the torque changes the speed is going to change and we went through that argument as to why the speed will change and what as that argument very quickly, if the load torque changes the total torque produced by the motor is no longer the same therefore the armature current of the motor is not the same we are assuming that the field current is kept constant, if the armature current is not the same, the armature voltage drop is not the same the applied voltage is not being changed, if it is not being changed then the back emf will not be the same and therefore the speed will not be the same.

So the speed will change but that was for the so called open loop arrangement in which 230 volts was being applied as input to the motor and we have some equations with result resulted in 1500 RPM under the rated conditions. But under 0 load, the no load speed of the drive would be greater than 1500 RPM. But now the situation is different we are not applying 230 volts to the armature we are applying a voltage which is produced by this arrangement of the comparator and the gain K a and so on. So in fact the voltage rate is produced will not be 230 volts, what will it be?

Well, we need to calculate, we need to make fresh calculations to find out what will be this new voltage which will be generated at the output of the amplifier. But you can do the calculations find out what the speed is and you will find that it will not be 1500 RPM and I can in fact you should also see the reason why the speed cannot be 1500 RPM, if the speed were to remain the same that tacho generator output voltage will remain the same, reference voltage is the same, the output e therefore is the same, if the output e is the same that means the armature voltage is the same load torque has changed the speed cannot remains the same. So the assumption that the speed remains constant leads you to the conclusion that the speed is not the same therefore the assumption is wrong, the speed will change.

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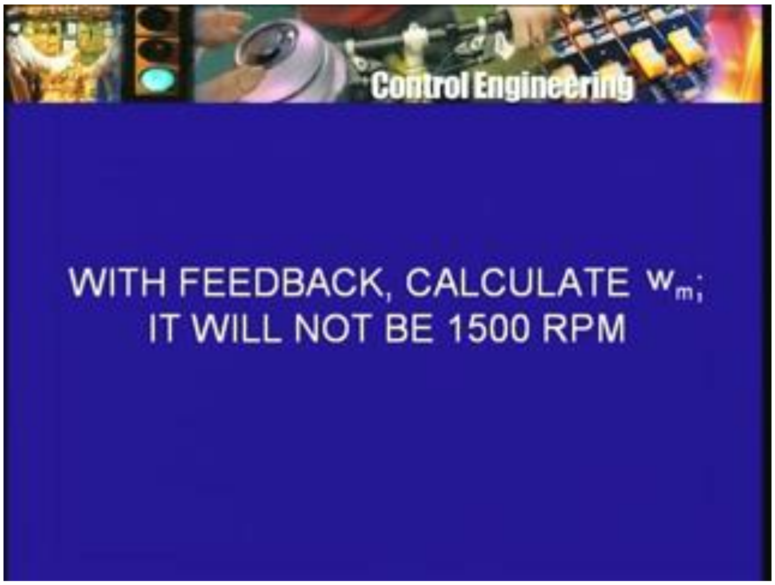

Now one can find out by how much the speed will change and compare the 2 situations the very preliminary crude open loop situation in which just apply 230 volts to the armature did nothing about it. Let the load torque vary, the motor speed will vary by a small amount because after all the DC shunt motor is a good one for constant speed operation and if that change of speed was tolerable well and good. So there was nothing being manipulated, there was nothing being adjusted, there was nothing no actuation of any kind 230 volts fixed applied with load torque changes the speed was would change.

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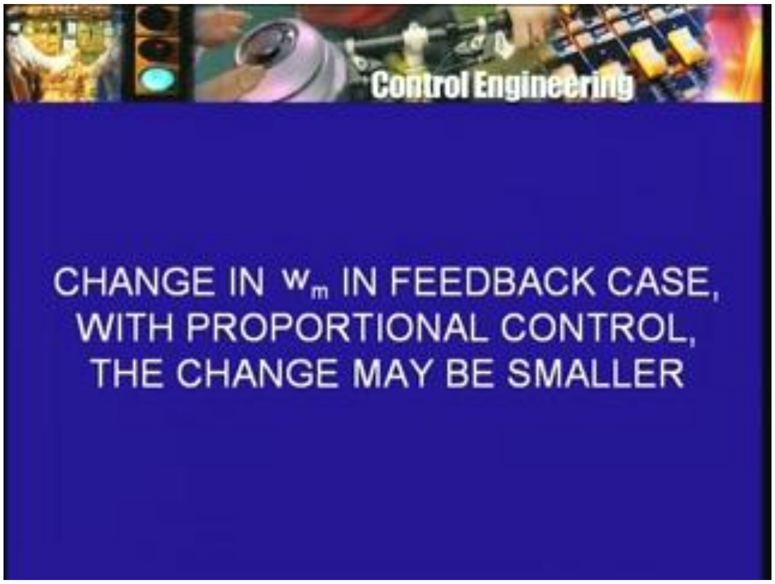

Now we have changed the system we are using this kind of a proportional control idea therefore the reference voltage is kept constant, the reference voltage is not going to be changed because we are not intervening manually, the reference voltage is kept the same but because of this feedback arrangement the speed will no longer remain the same of course that is also clear but the speed will not be at the same value as it would be if we have not use feedback. So you can compare the 2 situation one of it can be called open loop though strictly speaking it is not open loop but what we can mean is something like this.

Suppose we took this system as it were and got rid of this error detector and taco generator and reference signal etcetera and just gave a constant input at that E t point, say we kept E t constant at 1.15 volts. So that the armature voltage was 230 volts, so in the sense the loop has been broken, so in this sense open loop, so under open loop conditions when the load torque changes from 30 Newton meters to 0 Newton meter say from rated load to no load what is the change in speed there will be increase in speed, what is the change in speed and secondly with the closed loop arrangement that is the arrangement that we have been talking about where feedback is used.

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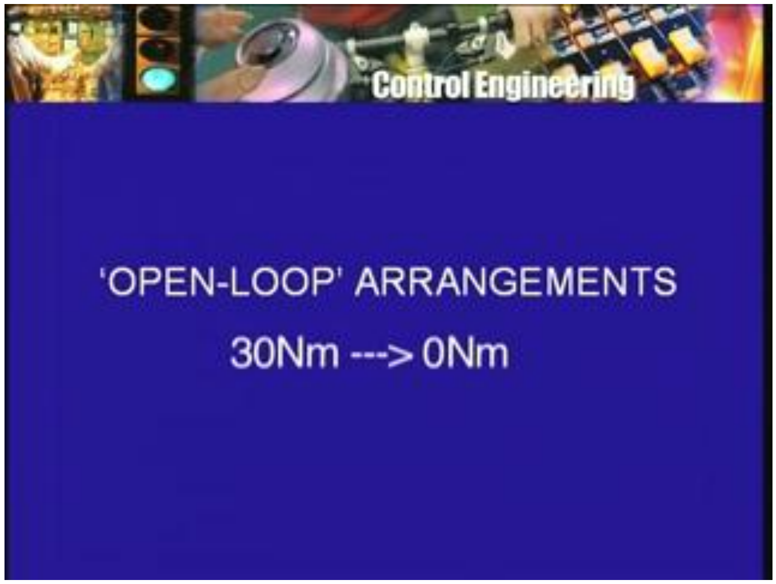

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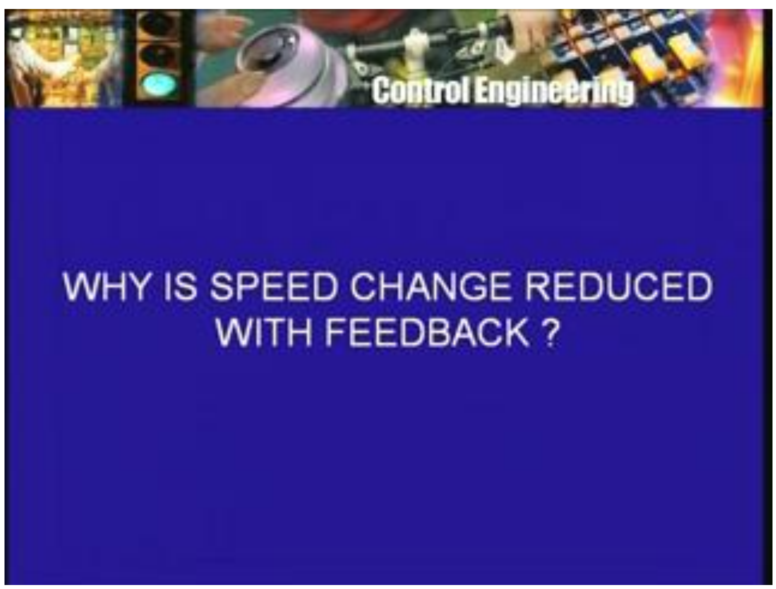

You have the tacho generator the reference voltage the error detector the amplifier K a and all that stuff the additional and at all thing is the controller now plus of course the IC engine and the generator which is driven by it and so on this whole thing is now my controller plant is still the same the same old DC motor diving the grinding wheel or whatever it is. So with this feedback controller using proportional control idea for a type 0 system with the change of torque what will be the change in speed. Do these calculations, I will go through them to check whether your calculations are correct. We will find that the speed change will be less with feedback than it was without feedback. With 230 volts constant armature voltage if there is certain change in speed with this feedback arrangement for the same change in the load torque the speed change will be reduced.

Now one can speculate or get mystified as to what how is it happening that the speed change is now less than it was earlier in the open loop case and that to it is happening automatically but of course one can get mystified but a part of the answer is that the arrangement that we have provided the tacho generator, the amplifier is such that the voltage E a is no longer necessarily remaining going to remain constant at 230 volts. We have provided for a possibility of its being manipulated or adjusted we have provided the possibility of its adjustment and so we should not be surprised if the adjustment is working. The only thing is fortunately the adjustment is working in the correct direction, the speed change is less with feed back then it is without feed back but if the set point is not going to be adjusted then there will be a speed change.

So with type zero system with proportional control with a disturbance signal of this kind there will be a steady state error when the disturbance signal acts. However, this steady state error can be made smaller then what it would have been if we have not used feedback and if we had not used any adjustment. So, feedback does provide us with the advantage or the possibility of reducing the steady state error. With the present arrangement the proportional control arrangement, the steady state error when the disturbance signal change or disturbance takes place the steady state error cannot be made exactly 0 and we can see how because if there error is 0 of the speed the motor will run at the correct speed et will not change but if E t is not changing armature voltage is not changing in the presence of disturbance, the speed cannot remain unchanged.

So that simple argument shows that with this kind of a disturbance that is the disturbance is also of the type 0 type that is disturbance directly effects the speed load torque increases speed will decrease load torque decreases speed will increase just as armature voltage increases speed will increase armature voltage decreases speed will decrease. So the relationship between the disturbance variable in this case load torque and the speed is also of the type 0 kind then we cannot avoid steady state error in the presence of disturbances.

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You can go back and use our formula that we have derived under steady state conditions and play around substituting different values of load torque or substituting different values for the parameter. Let us say K b or K t's change and so on we had done this calculation again you can do it again and then do the same thing with feed back that is with the feed back arrangement what will be the error and see for yourself that this steady state error will be reduced how much reduced. Well, it turns out that it depends on that gain K a and that too one can see why the error the speed not being the correct value it changes the output E t by a small amount.

Now if the E t is the itself is of a much smaller amount because of the gain K a being large then the change in the speed must be of a still smaller amount. So you can work out the problem with the gain K which is K a which is ten times 2000 closed loop system with a gain in the forward path of 2000 and then work out the speed change when the torque changes from thirty to 0. You will find that the speed change is even less so by increasing the gain K a, I can reduce this steady state error and so of course I can become ambitious but careless and say that all right let me increase it by another factor of 10. My steady state error will be still reduced well the answer is yes, but what about the transient error we have not looked at the transient error at all we are only looking at the steady state case, what about the transient error?

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We will see later that if you increase the gain too much the transient error can be increased in fact with K a not very large the speed may simply change from one value to another increase from 1500 to say 1510 RPM slowly but steadily, but if K a is too large then the speed will change from 1500 to 1510 perhaps not steadily but in an oscillatory manner. So that during the transient period the speed may go beyond 1510 RPM may go to even say 1600 RPM then may go below 1500 RPM and go on oscillating like that till finally it reaches the value after sufficient number of time constants of the new value 1510 RPM. This of course is you know in a qualitative way referred to as some kind of instability although the system is not unstable but there were no oscillations but now there are oscillations the transient behavior is not satisfactory now.

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So the steady state errors was reduced but the transient behavior is not any longer satisfactory so there are limits up to which you can go and of course we will be looking at this in greater detail. When the concentrate on the role of this parameter K a the gain in the forward path, how it effects steady state performance and how it effects the transient performance of the control system. This is one way of reducing the steady state error namely increase K a but there are different ways I had mentioned earlier integral control and derivative control what we have used is proportional control essentially what we are doing is we have to make some adjustments, when there is a error, when the actual speed is different from the desired speed, how that adjustment is made that is where we have to exercise our intelligence. The proportional idea is the simplest one and we will redraw the block diagram to see very clearly that the kind of mistake that is there in the text books is not made by showing that adjustment things separately.

So it will become clear that in that sense the adjustment is proportional to the error but not e proportional to the error or the difference between the actual speed and the desired speed. But by changing the mechanism of this adjustment by introducing the possibility of some kind of integration over a period of time, we will see that the steady state error can be make 0. Although the transient error will not be 0 and once again the transient error may have some unwanted futures. So for a type 0 control system with proportional control with disturbance we may have non-zero steady state error but with integral control we may be able to reduce or make the steady state error 0 but we will have to look at the transient performance.