Control Engineering

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Lecture - 11

We want to replace the operator who will who can, who could make the adjustment in case the speed changed from the desired value. We want to replace the operator by an automatic mechanism the system which is called a controller and because just as the operator had to look at the system in operation see what the actual speed was similarly, this controller will have to use the information available about the actual operation of the system in particular the speed of the motor. This is call feedback as we saw earlier and therefore the controller is sometimes called feedback controller, how to design this feedback controller? What are the things that can be done are there somethings which cannot be done these are the questions which we will take a look at or start taking a look at because in a way the whole course is concerned with this the design of feedback controller for a given problem.

Now firstly, I mentioned earlier and I repeat that there is something which one cannot avoid no matter how clever we may be in designing a feedback controller and this thing is transient error. Now why is that we cannot avoid transient error there are two reasons one of them I mentioned already one of the reasons is that there are inertia kind of type of elements in the system, there is the inertia associated with the motor armature winding what one could think of as electrical inertia, inductance in the motor winding it is, it is not zero and therefore it does play a role and effect the performance of the system. The second is the inertia in the mechanical part of the system, this is actually called the moment of inertia of a for rotation of the shaft with the masses on it.

Now this is something which cannot be made zero and there could be delays in other parts of the circuit in the cases human operator there was the human delay of the reaction time but measurement of the speed through the tacho generator, this could also contribute one more inertia element and therefore a delay. So in other words when the speed changes the information that the speed has changed will be available only after certain amount of delay as a result during that period at least one will have to tolerate error, the speed will have deviated from the desired value. In fact in a way it is the deviation of the speed from the desired value that causes some action to be taken that causes the adjustment to be started.

So the inertia elements, this is unavoidable and we will have to look at it later on will look at differential equations which describe the system behavior and we see that these delay elements result in what are called various time constants of the system, these time constants in a way are related to the delay that I am talking about. Of course one would try to reduce this time constants as much as possible so that the system response is as quick as possible but the second thing is that the changes are usually unanticipated or unknown beforehand. The load changes now if there is enough time for the person who is operating the machine perhaps or the lathe to tell the operator of the motor that look now I am going to change from this particular application to this other application which will require maybe different speed and a different torque.

So why do not you reset the thing in other words if you can allow for sometime to elapse before the speed of the drive and the torque. These are the two basic requirements change and these would be known beforehand then perhaps one could make those adjustments. For example, you can imagine that the operator has before him a chart or the slider of the potential meter or the rheostat that I talked about is marked in terms of perhaps load and torque requirement that is if there is so much load and there is so much torque then make these changes perhaps in the field, a circuit resistance and in the armature circuit resistance.

So that once these changes are made the desired torque will be produced at the desired speed but very often such changes are unanticipated unknown beforehand and so far at least we are not been able to take anticipatory action about these changes. No matter how clever we have been or we are power supply changes are also something which it is difficult to anticipate, things may be going on all right here but certainly there is a load thrown on or off somewhere else as a result of which the power supply voltage changes suddenly. So we are refer to these changes as disturbances implying that well they are not in our hands they do disturb our system and they are unanticipated and therefore it requires a time, sometime before the system can be reset one can take care of these disturbances by making appropriate changes.

So this is the second reason and both these reasons time delays and lack of previous knowledge of the sudden changes or changes in the load in the supply voltage and so on. These are two major reasons why there will be period a transient period during which there will be error this is something which we will have to live with of course as I said one will try to make the controller or to have the design in such a way that not only the transient error is reduced, it cannot be made zero that is all right but it can be reduced perhaps and perhaps the resetting can be done as quickly as possible that is the error is made 0 as quickly as possible and so in fact one can think of these two as contributing to some kind of a specification for the controller design, you may say that the controller should put the error or make the error back to 0 within a certain time.

Similarly, the controller will restrict the error that arises in the transient period because of sudden changes to a certain amount. For example, to take our running example with 10 percent load change if you do not make any adjustment there will be a change in the speed by perhaps ten percent or little less and that will be a steady state error but we can make readjustment. So that this error can be made 0. Now perhaps one could have a controller so that when that load torque changes suddenly by 10 percent the speed does not drop down by say 9 or 10 percent but drops down by a smaller amount if it is possible to do this then that will be better of course the controller also should make the error zero as quickly as possible. I had earlier talked about performance specification such as rise time settling time oscillations tolerated or not and if there are oscillations maximum percentage overshoot or undershoot and so on.

So all of these do make sense in this case so when designing the controller, some of the specifications or requirements they have to be taken care of. So that is one thing the second is I talked about the speed control system that we are discussing named or suggested by Leonard which is actually a variable speed drive, DC motor drive, the variable speed in principal ranging all the way from 0 almost to the full speed no load speed under a given maximum supply voltage condition.

So apart from these sudden short duration changes that may take place in things such as the load and the applied voltage and one is trying to keep the speed constant at one particular value it may also be required to change this value at a later time for another application. Let us say the motor runs on a particular job at 1500 rpm for sometime then that job is finished and now you would like to reset things, so that the motor will now run on a new job produce a different amount of torque at a different speed such a thing is referred to as resetting and therefore there has to be a provision for what is called a set point change and there should be a provision so that the desired constant value can be changed as and when required. Sometimes one also puts the condition that and in some applications this may be the case that the desired value because of the application at hand is required to be changed as quickly as possible in other words somebody is doing a machining job which runs at 1500 rpm and then there is a slightly different machining to be done on the same job perhaps and the speed has to be changed brought down by us let us say to 1000 rpm.

Now you would like this speed change also to take place as quickly as possible the motor is running at the constant speed of 1500 rpm. Now you would like the speed to change this new value 1000 rpm as quickly as possible and stay at this value so long as it is required. So in addition to previously unknown or disturbance kind of changes in load torque and supply voltage one would like to provide for a deliberate change in the set point. The system controller design should be such that this is possible.

So there may be some applications where there is no change of speed required you have to run the motor constantly at a particular speed and therefore set point change is not involved but this flexibility of set point change would be very useful unless one was making a very special purpose drive for a very special application where there was no change in speed, desired speed and no set point change and therefore the machine operates at one speed and that is it, you have no choice think of an air conditioner which would keep we had only one setting of temperature and so you have to live with it whether you liked it or not, one would like to have flexibility therefore of set point change.

So a sudden change in set point can also cause an error 1500 is changed to 1000 just as on the air conditioner the switch or the knob is changed or a button is pushed and the temperature setting is changed but the desired new temperature will not be attained immediately. So there will be an error, a transient error because of set point change. So there are several changes that one has to consider changes or changes which are we should have called disturbances like load, load torque and applied voltage in our formula in our two formulas and formula for the speed then E a and T l these are the 2 variables which might change suddenly and the third is a set point change itself that is a variable omega m itself may be desired to be changed.

Now how shall we go about designing the controller what should be there and so on? We will make a beginning first of all by drawing a block diagram and we will be drawing them of and on now. Block diagrams are simply a pictorial or a diagrammatic way of conveying some ideas and conveying some information. I had talked about schematic diagrams earlier, these are diagrams which give you some idea of what the system consist of like the motor armature connected by shaft to a load and the field winding and the supply voltage and so on and so forth. Block diagram is a little different from the schematic diagram in the sense the block diagram highlights not the actual physical or mechanical connections such as the wiring or the shaft and the gears or pulleys or what have you. The block diagram looks only at the variables that are involved and it may not show all the variables in fact it will only show some of the variables which are of relevance or of importance.

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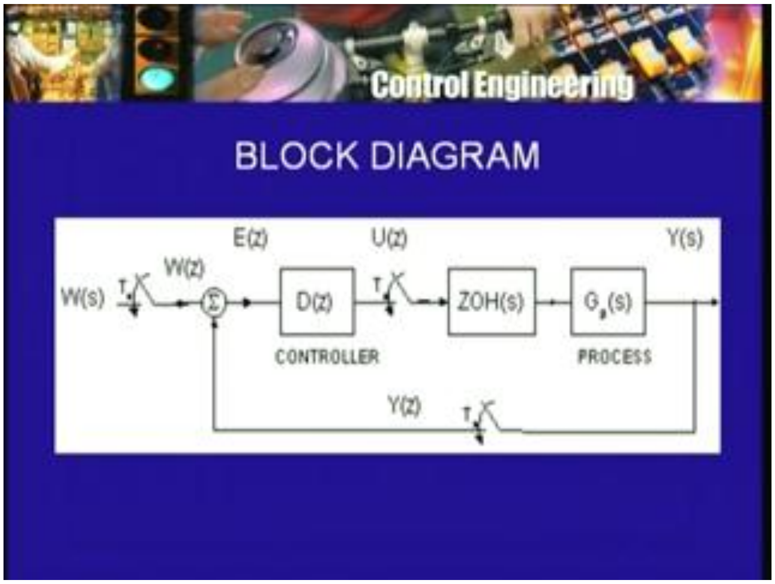

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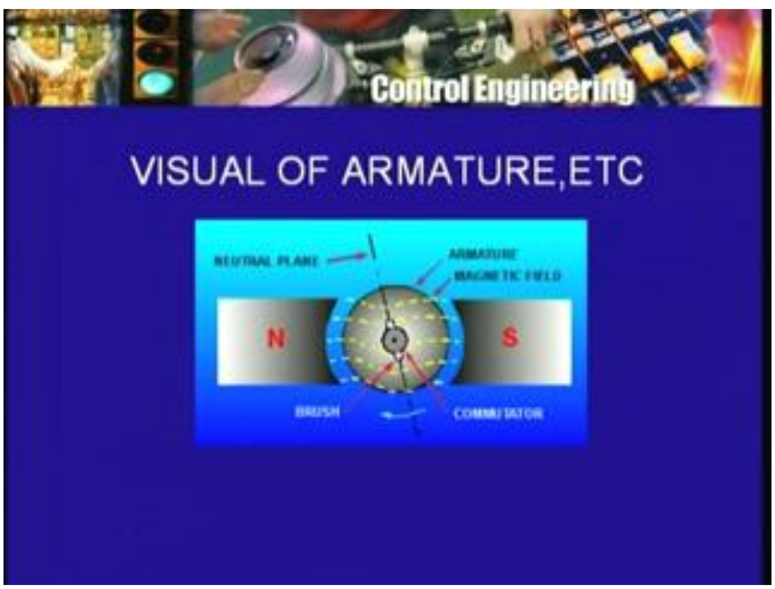

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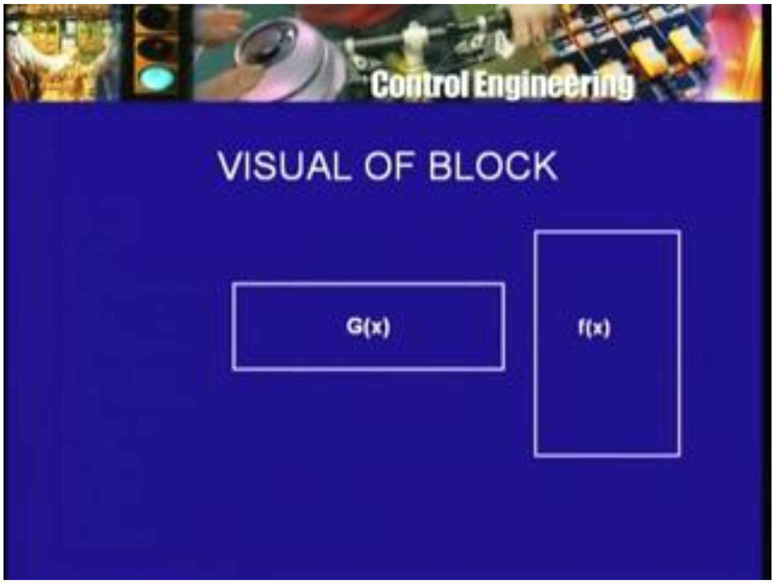

So in the case of our motor driving a load that is our control system a system to be controlled we can draw one block. Now as I said these are to convey some information and to enable some thinking to be done a little quickly and so on so there are lot of conventions that are used here. They have been developed over a large number of years and so one follows certain conventions for example the very concept of a block something in a shape of a rectangle, I did not say rectangular block but usually it is understood that you have a rectangular block like this and this rectangular block is usually wide across the page and not so wide from top to bottom.

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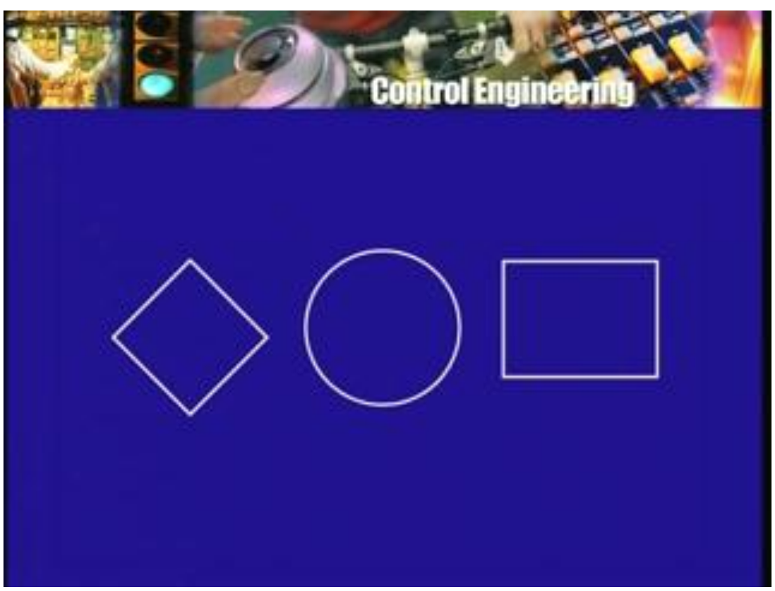

So it will be very rarely that you will see a block like this in a block diagram, the block that you are liking to see in block diagram is of this sort. You must have seen diagrams in other situations for example when thinking of computer programs one draws flow charts or at least when I learnt it I used draw flow charts and there are various kinds of symbols that appear there. For example, something that looks like a diamond or a circle or sometimes of course a block which square or rectangular or whatever. So we have these other symbols that are used on flow charts but in block diagram the only symbol not only because I will have to introduce a few more symbols but the most important symbol is this rectangular block, this rectangular block will stand for some the system may be in this case we can have the motor and load being treated as a single system which of course is connected to the external world in the sense the motor is connected to the power supply and the load interacts with the say the grinding wheel, rubs against the job or surface which is to finished.

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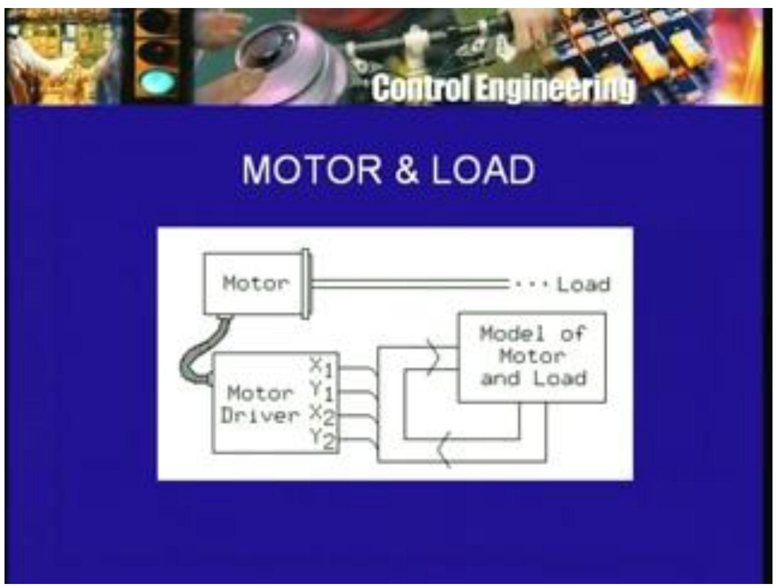

So, not everything is shown on the block diagram. So if I am looking at the motor and the load combination that is the motor armature shaft and the grinding wheel as one single thing, one important part of the whole thing. So that there is one block devoted to it then on the block diagram as I said we will not show the actual physical arrangement symbolically as was done earlier the motor, armature, the motor field then the shaft that joins the motor, armature to the load perhaps the load in the shape of a pulley or a gear train and things like that these will not appear in the block diagram what appear on the block diagram along with the blocks of course are the symbols commonly used for the various variables or things that change the time associated with the system.

So in this case given the motor and the load what are the variables by variables one means things that can be expected to change with time sometimes rather quickly? So the variables in our case would be 3 and we have talked about them earlier the applied voltage E a, it is not variable because although in principal or ideally you would like it to the remain absolutely constant in practice it is not going to remain constant while the motor is running.

So that is why it is called a variable although it is desired to be constant. So E_a of t this is one the second is the load torque, once again it would be nice if the load torque going to remain constant the application was such that the load torque remain constant in addition to the applied voltage remaining constant. But that is not going to happen all the time. So it is also a variable T_l of t the third variable which is of immediate interested is of course the motor speed omega m of t and once more it is desirable that the motor speed remains constant and really does not vary but then as applied voltage torque change suddenly, the motor speed will change even for a even if it is for a transient period.

So it is also a variable any away these are the E_a and T_l the supply voltage and the load torque are the two disturbances and omega m is the quantity which is being controlled in fact which is a quantity being regulated, what we are talking about is what I referred to earlier as a regulated time system where something is to be maintained constant. In this particular case the speed of the motor is to be kept constant that is the main purpose and goal of the control system are there any other variables associated with our system yes, if we go back and look at the equations one more variable is the armature current I a of t because when these changes take place the armature current is also going to change. However, it is not our primary purpose to make the armature current either remain absolutely constant or to make it behave in a particular way armature current is only the intermediate agent through which torque is generated and the load is driven we are not interested in i a itself we are interested mainly in omega m.

So omega m is usually referred to as the output quantity but there is this armature current which can change ideally it should be at the designed value but in practice when these E a and T l are changing I a also will be changing and in fact there is a reason for trying to include I a in our list of variables associated with the drive because it is easy to measure the armature current whereas it is a little harder to measure the speed to measure the speed we have to mount a tacho generator on the shaft and then measure the D C voltage or the output voltage coming from the tacho generator. To measure the armature current all that one needs to do is to connect an ammeter in series with the armature and this is something very easy to do and not very expensive.

So we might also think of i a as we go along that is there is this information which is available to us in addition to the angular speed omega m what about this two disturbances themselves E a T l can they be measured. Well, if we look at the supply voltage or applied voltage E a certainly it could be measured all you have to do is connect a voltmeter across the supply. So that you can keep on looking at the supply voltage so E a also can be measured and therefore measurement of E a can be made use of in our controller scheme, what about the load torque can the load torque be measured I told you earlier that if not the load torque the torque that is being transmitted at any section of the shaft can also be measured but again it is not measurable so easily you will have to put some strain gauge network or as connect a number of strain gauges in a particular way and then of course you get an electrical output from the strain gauges you will have to amplify and so are and so forth.

So it is going to be more involved to measure if not the load torque that is the torque at the grinding wheel end itself but may be the torque that is being transmitted at a any particular section of the shaft it can be close to the motor or it can be close to the load, it is possible to measure the load torque but at a slight inconvenience and cost but if measurement of the load torque will help improve our performance of our drive then that can also be included.

So as you can see the design will depend on what and how much you would like to know about the operation or actual operation of a system am I just going look at the speed omega m and not bothered to look at anything else or do I have available also the armature current information in addition perhaps I can look at the supplied voltage and finally I could even look at the load torque. So I have with me almost all the information that I need about the drive any other variables they hardly any other variables in our equation I talked about the torque produced by the motor as K t into I a but that is not a torque which can be easily measured because it is a torque produced by the forces acting on the conductors but the motor shaft itself in the motor bearings has friction and there may be a fan mounted on the motor shaft.

So it is not going to be easy to measure the torque produced by the motor although theoretically it is just proportional to the armature current and therefore if we measure the armature current we can calculate or we could have effectively measured the torque produced by the motor T m. Now these are the variables that are associated with the the drive and therefore with the block and one or more of them may be shown along side the block that has been drawn. So that the block has now some variables and one way of showing these variables is to put some lines attached to the various sides of the block. They denote variables at the moment I can just put them down I can put them down at the moment in any order in any way I like. They can be and if there is there is there are more than four variables then of course I will have to put more lines and in fact that is sometimes that has to be done but in our case let us say there are only these 4 variables the applied voltage the output that is the current and the armature current and the load torque these are the 4 variables and therefore I could use these 4 lines to indicate these 4 variables.

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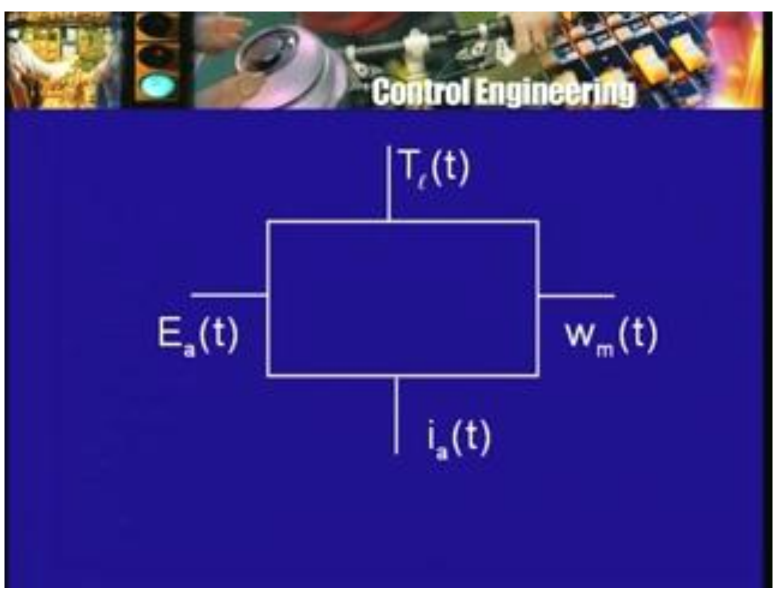

Now once again there is a convention about how we go about doing it if since it is a convention if you do not know what it is then it does not have any meaning for you. So what is the convention I already mentioned that the speed angular speed is in a sense what is called an output of the system or the drive. We do not mean it literally that it is something that is actually coming out of some box you know like some quantity of matter crude oil or you know what ever coal coming out from somewhere. So it is not an output in that sense but it is the outcome of the control system, it is the major item of interest and since therefore it is not of a some kind of an output the arrow, the line associated with it is put in the form of an arrow that seems to come out of the box or the block. So this block has this arrow coming out of it as it where and I have called it omega m.

Since we are talking about an input we can also talk about an an output rather, we can also talk about what could be an input. Now once again in this case one is not putting in something some matter some stuff into a box or into a conveyor or a into a container or a hopper or what have you like iron ore being put into a hopper and then steel in that or steel, molten steel coming out at some end. So it is not input and output in that sense but in one sense at least the whole thing is dependent on the electrical power supply. The mechanical job requires power and requires energy power in time is energy that is appearing as heat at the job perhaps and this can come only from the electrical sources which in turn of course consist of some turbine or some boiler and so on.

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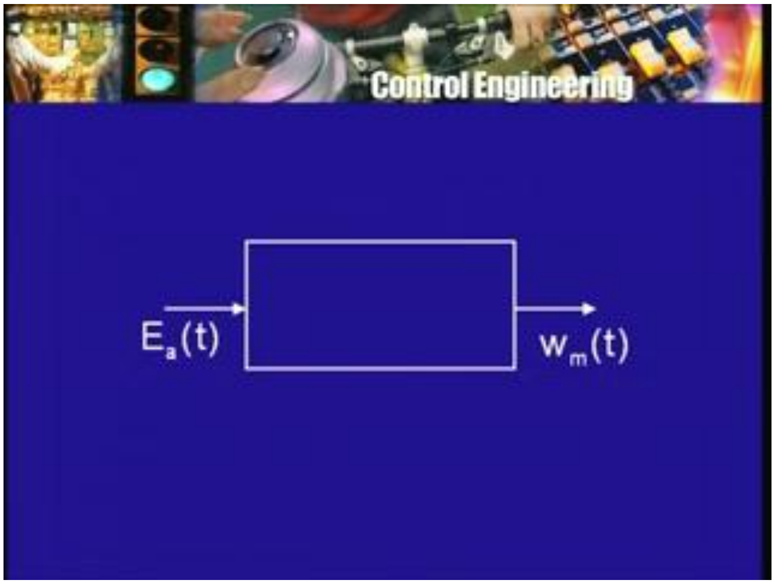

So in this sense we can think of E a as an input and therefore this variable is shown attached to an in going arrow. So I have shown here E a as input and omega m as output and of course as I said the whole purpose of a block diagram and conventions about it is that you do not have to really tell everything by just looking at the diagram it becomes sort of immediately clear what is going on so if I look at the block diagram and find out the conventions then I know that omega m is the output and E a is the input. So perhaps omega n is the variable or quantity of interest and importance to me I want something to happen to it and this I am going to to achieve this I need this E a and may be I can do it by doing something to E a what about the other 2 variables, the load torque and the armature current.

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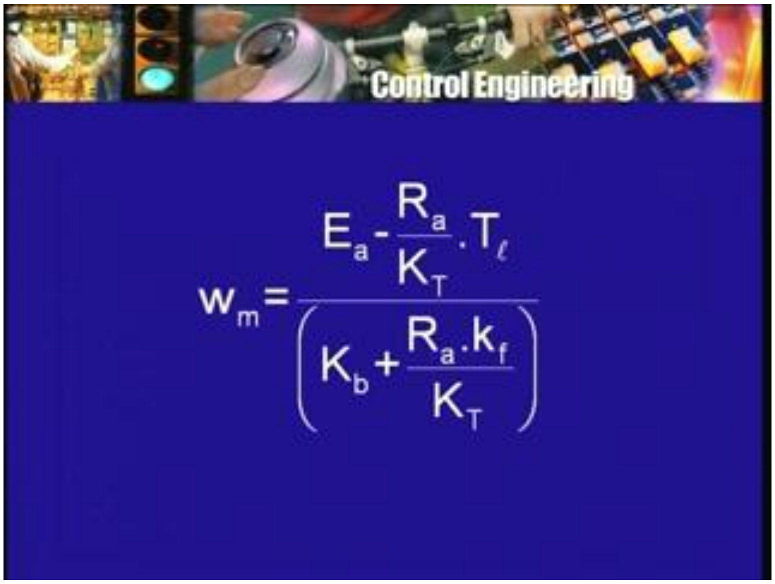

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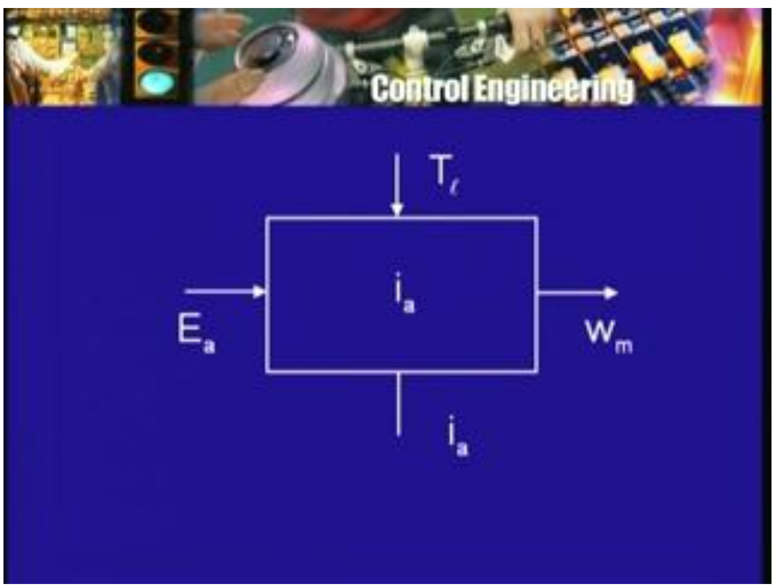

Now the load torque is it an output variable or an input variable. From the mechanical point of view of course the load torque is the output of the motor in fact one would say that the motor does not produce so rotation only but it produces rotation while overcoming a certain torque that is it produces torque which causes rotation. So I should show the load torque also as an output variable therefore I should have an arrow coming out of this block or box with the label T l however because of the way the equations are because of some of the manipulations that we have done earlier what we have, what we did was we obtained the formula for the angular speed omega m in terms of these 2 variables E a and T l the variable I a the armature current was eliminated and we had a formula for omega m in terms of E a, T l and the parameters of the system.

So looking at it from the point of view the equation perhaps T l and E a are on the same footing and therefore we will show T l also as an input and if you think of not T l but changes in T l as disturbance then you can think of T l as an input which is therefore called a disturbance input that of course sounds very odd that you are deliberating putting an input in into the system which is called a disturbance but that is not what is meant here. It is an input in the sense the output quantity omega m is going to be related to the input quantities in a rather simple way and T l is one of the variables or quantities that appears in that equation but this T l also has a disturbance aspect about it that T l can change suddenly without previous knowledge therefore it is called a disturbance input

In fact E a also should be thought of as a disturbance input because E a also can change without previous knowledge although we may be able to ensure that E a remains fairly constant by arranging for a constant voltage power supply whereas T l it is going to be difficult to be sure about it is remaining constant because of the nature of the job itself, what about the fourth variable armature current, is it an input variable or is it an output variable. Well, it is really neither the supply voltage guarantees only the supply voltage E a it does not tell you how much current is going to be drawn from the supply.

So there is nothing like putting although sometimes figuratively one talks about putting 5 amperes in or taking out. So many milli ampere out of an amplifier sourcing and sinking current this is what one talks about in amplifier situations one is not really saying that I can arrange for two amperes to go in or 5 ampere to come out or whatever I can only arrange for 230 volts to be produced at the terminals no matter what the load is but the current base will be determined by what is going on in the system. so in that sense I a is not an input I a is not an output either because our interest is not in I a as such our interest is not to produce current in the armature our interest is to produced torque and speed. So this variable I a perhaps can be left out of the block diagram all together or we can show it may be by this line with no arrow on it sometimes one may show it inside the box as a variable which could be perhaps measured but which is neither an input nor an output variable.

So this is a very simple block diagram that represents some aspect of our control system it shows the important variables associated with the system and some indication about the nature and what is happening is given by the arrows, there are input variables there are output variables, there are some which may be neither like the armature current here. So the block diagram is the first step and if one knows the convention it already tells you a few things for example it may be arrows are this tells you that probably I can expect an equation expressing omega m in terms of E a and T l and indeed we had derived that expression earlier.

So we can accept that there will be omega m, there will be an equation or there will be a formula which one can write say in a general way as omega m as some function f of the applied voltage and the load torque T l. So along with the block diagram then some such equation or formula or relation would be available. Later on we will look at block diagrams which are more advanced than this one where we will used the concept of transfer function or a set of transfer functions and so the formula that is associated will not be like this one omega m is equal to E a minus something divided by something. But it will be a little different one involving what are called transforms, Laplace transforms of the various functions and so, one can talk of transfer functions associated with a block, the transfer function is simply a way of giving a relationship between the various variables associated with the system namely the output variables, the input variables and the other variables which are neither regarded as input nor as output.

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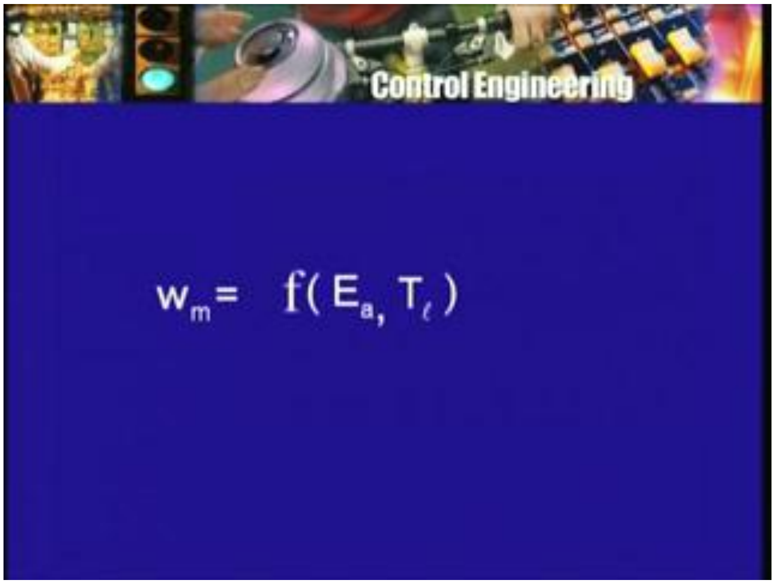

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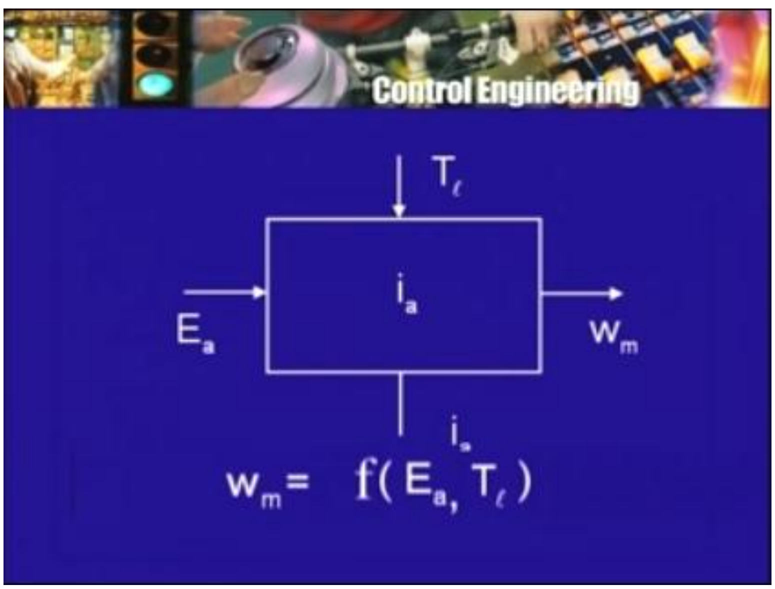

So a block diagram may have transfer functions associated with it and in fact here it self-inside that block I could write perhaps this formula itself and then one talks about a transfer function then inside that box usually one writes down the transfer function. So the block diagram does tell you not only that there are these variables this is input, this is output but is also gives you equations or relations between the various functions that are associated with the device. So the block diagram is a very useful tool and we will be using more and more we will be using it more and more as we go along.

Now what about the other things that appeared in our equations besides these the 4 variables what appeared in the equations were the parameters. Now these are different from these variables in the sense once again in ideally we do not expect them to change armature resistance, coefficient of friction, motor torque constant, motor back emf constant, motor inductance, moment of inertia, we do not accept them to change while the system is running during a particular application.

So in that sense they are going to remain much more constant then these variables like supply voltage or load torque of course over a very long period of time these parameters may change and this is one of the problems that I talked about or during operations sometimes the parameters can change, the armature gets overheated as a result of which the armature resistance no longer can be treated as absolute constant or the field current for some reason changes and therefore the back emf constant or the torque constant cannot be regarded as constant any more but will be changing but there is a difference between the variables and the parameters and that is an important difference and therefore associated with the block diagram you do not show the parameters although the parameters may appear in the relationship. For example, in a relationship that relates the motor speed to the load torque and the applied voltage all the parameters make their appearance.

Similarly, if I have a transfer function inside the block which gives a different kind of relationship then this transfer function will also have this parameters appearing there. So they are not to be neglected or to be ignored there are very important and they are to be kept in sight and there will therefore be there associated with the block diagram but they are not the same kind of thing as these variables in which we are interested. Now to get back to our problem for the moment let us say we only look at the disturbance aspect and not the parameter change aspect then we do not worry about what if R a is no longer what it was thought to be etcetera but we ask what if T l changes suddenly if T l increases or E a supply voltages decreases or this both things happen together what will happen that equation we have looked at it earlier that if T l increases E a remaining constant then omega m will go down, on the other hand T l remains constant but E a decreases then also omega m will go down.

Now we are thinking of a controlled scheme where the adjustment that is to be made to put omega m back to it is desired value T l was increased if I do nothing about E a omega m will decrease there will be a steady state error I do not want that to happen therefore I need an adjustment somewhere and the only thing that I can adjust here I will assume that I am not going to change the parameters I am not using armature resistance, resistance in series in the armature circuit or a resistance in series with the field winding for making the adjustment that was the crude scheme with an operator it could do very well but I am thinking of the Leonard speed of control scheme of control were now this adjustment is the adjustment of the variable E a that is I am going to provide for the possibility of this E a being changed.

So T l has increased if E a was not changed omega m would have remained at a different value but I make this provision. Now this means that I have to put something more into the system if I just connect the motor to the power supply then there is nothing I can do about it I am at the mercy of the power supply. So here I have to make a decision I have to make a choice that I will install a separate motor generator set or some prime over driving a generator whose output is then going to be connected to the armature of the motor which is going drive my load.

So this is involves more equipment therefore involves cost but it provides the possibility of the making this adjustment and perhaps all this is to be done because the performance will be better and indeed this is what was shown by Leonard more than 100 years ago that you could get a very good performance of the drive if you wanted to vary the speed we could vary the speed, very smoothly and you could do it also very quickly. If you wanted the speed to remain constant then you could do that also of course that is not what he showed because at that time he had not made use of the idea of feedback but if you wanted to do it manually it could be done, the generator as you remember has field winding. So all you have to do is in fact that is what is involved manual adjustment of the field current of the generator that provides for adjustment of the drive. So that the speed can be changed if you wanted it the speed can be maintain to constant if you wanted it but Leonard system required an operator to do it and we are now thinking of doing it automatically and the question is then how are we going to do it.

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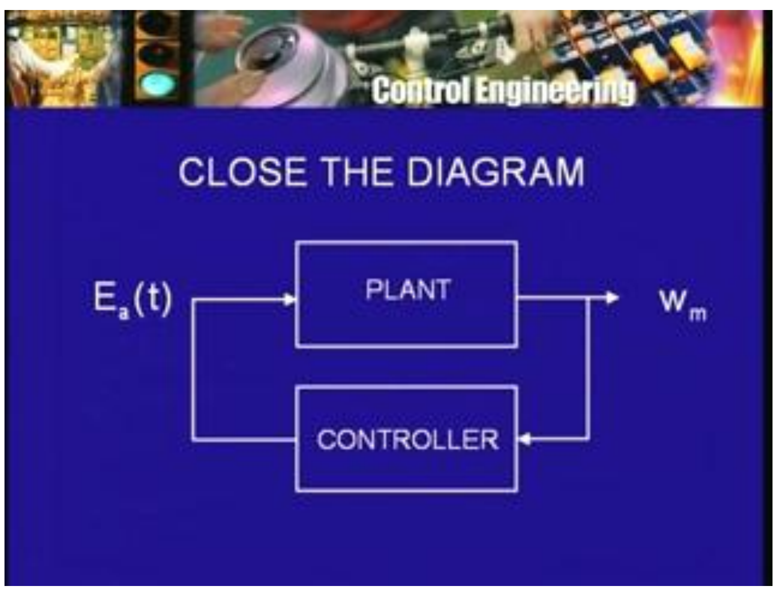

Now we have to replace the operator, the operator would have look at the speed. So we need a method of measuring the speed and this block I can call it a block now because it is going to be a system which I have to now add on to what I already have. So here is the motor and the load already what you seeing an output omega m is an input E a and also affected by the load torque T l with some relationship between these things I am going to be measuring omega m and this measurement will effect my adjustment of E a. So in that sense now I am thinking of a additional system this means of course in today's language additional hardware which will be influenced by omega m and therefore I can think of this omega m as serving as an input to this controller and one way of showing this is simply to do this business show another block this is my controller, the first block was the system to be controlled chemical engineering people use the word plant.

So this word is sometimes used so you talk about the plant which has the output omega m which is controlled by changing the input E a. Now if there is no feedback that is it a human being may be required to change E a so you have manual control now with feedback we have an additional block called the controller for which the speed will serve as an input in other words the controller action will depend on what this omega m is and therefore I will have to measure omega m. Now I have shown this by means of this line coming out from that omega m arrow and going in to the controller. So this is again a convention this is not an electrical connection, this is not a mechanical connection, this is not meant so say that the controller has a shaft which is connected to the motor shaft.

In fact, it will not, what is shown is that this variable omega m will affect the controller performs and that is shown in this way so this is conventional and it is important to remain remember that this is convention this is not an electrical or mechanical connection. One of course in this case talks about signals and it is fashionable to use that word signal. Nowadays so you can say that E a T l omega m these are all signals although this word is signal really was used in connection with communication applications some information had to be communicated from one place to another and this was done with electrical or electromagnetic means in that situation then the electrical thing voltage current or the electromagnetic thing field quantity was called a signal that language can be extended to what we are doing. So in that sense E a is an input signal omega m is an output signal T l is a disturbance signal for the plant which is our electromechanical drive.

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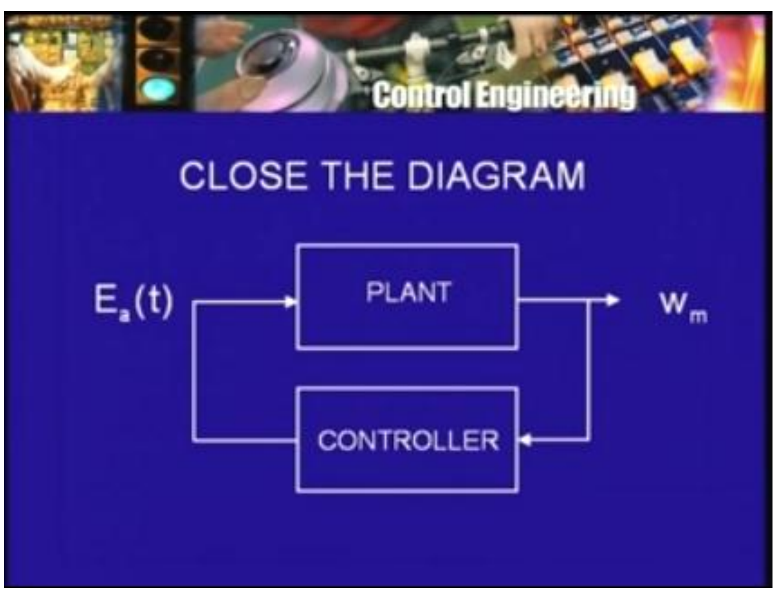

Now we have a controller block for which omega m will serve as an input signal in the sense just as we can think of omega m depending on E a in a particular way we can now think of the controller doing something was depends on what omega m is and in fact I can in a very simple way close this diagram by showing the controller output as the E a itself that is the controller produces an output voltage which is affected by the signal the output of the system omega m and this output voltage of the controller is given to the plant.

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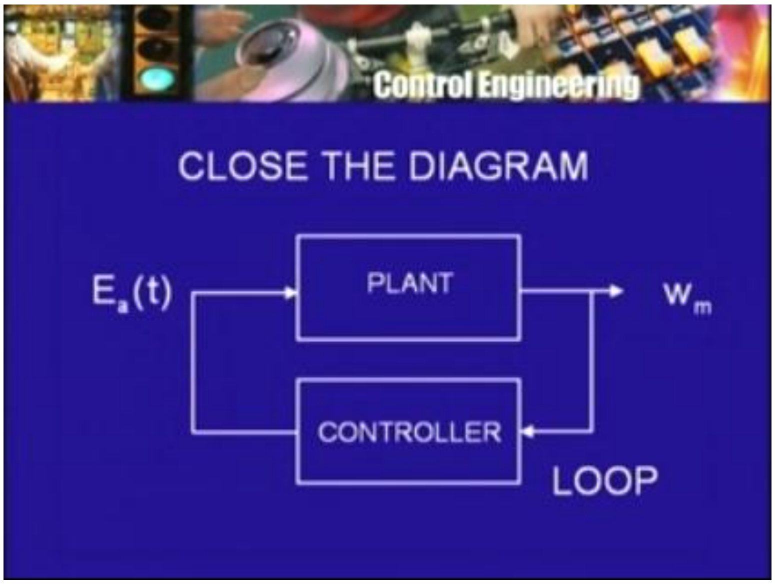

Now this is were one beings to see the loop or the closed loop that one talks about very often and so what we now have is what is called a closed loop control system or a feedback control system the line going from the output to the controller input is referred to as the feedback and this feedback causes the controller to produce or to take appropriate action at the input end of the plant. Now of course this is not really the whole story because the controller if it has to produce the supply voltage then the controller in our control system will involve the whole thing it will involve the generator which is essentially supply and producing E a which is getting connected to the motor but also whatever is driving that generator if it is another motor then that motor if it is an IC engine then that IC engine, if it is a motor which is driving that generator than that motor is getting it is power supply from some were else. So I will have to include that as my controller.

So if I do that then my controller becomes really a huge thing that is the whole thing it is the generator it is the IC engine which is driving the generator the field winding of the generator and whatever adjustments are to me made there or it is generator and it is the motor which is driving the generator and the power supply which is in turn giving electrical power to the motor. So that is a this is very simple way of looking at the plant and the control situation but it does show that there is on the diagram at least what looks like a loop this is referred to as the loop and since there is an this arrow going in and there is the arrow coming out both plant and controller have an arrow going in and an arrow coming out, one can almost think of in a moving around a loop in a particular way input to the plant produces output to the plant which is the input to the controller produces the output of the controller which is to the input to the plant and so one can ask the question which is what is the plant driving the controller or is the controller driving the plant which is first the chick or the egg.

Of course we know what is first what is first is a plant with some primary arrangement of power supply to the plant what you are now going to add is this controller, the way in which the supply voltage can be adjusted depending on the changes taking place. So that the speed is restored to it is old value or speed is set to it is new value. Now this link from output speed through the controller can sometimes get actually broken. In our case for example the output speed is measured not mechanically but electromechanically or mechano electrically through a tacho generator so as a signal really once being transmitted to the transmitter to the controller will be the tacho generator output voltage in a say DC voltage rather than a shaft or some bearing being connected between the motor shaft or the load shaft and some other shaft.

So in fact we will modify this diagram very soon and we will show the tacho generator voltage also a signal and therefore the tacho generator can be shown as one more block on the diagram. Now it could happen that that connection gets broken actually some wire comes out suddenly, so this feed back link is broken what happens in that case. Well, in that case things can go bad and that is where as I said the human operator is always expected to be around the scene if the feedback link is broken then the system is not going to operate as it is expected to get feedback because this link is no longer there. Of course fortunately for us the IC engine will still running or then power supply will still be available and therefore the NG set or the I C engine generally the set will still continue to operate but this is link the controller which was doing the adjustment is broken.

So now an adjustment in the supply voltage will not take place automatically as it was expected with the controller and so a human being may have to intervene and make that adjustment. One can of course think of some kind of manual override that is the automatic can always be replaced by a manual you have a choice either you have something automatically taking place or you go back to a manual mode. So that provision is almost always there in all systems as I said one does not really one does not reach the situation where there is nobody available there is nobody around and so let anything happen. Even in the case of space missions where on the surface of Mars of course there is no human being moving that over or whatever vehicle is there still there are human beings back here who are causing things to happen there.

So but one does sometimes have to think about what happens if the loop gets broken and in that sense then this becomes what was a closed loop system becomes an open loop system unwantedly it was not expected or desired but because of the loop getting broken it as become an open loop system in a simple situation like we are taking about this is not a very big problem because there is only one tacho generator I had make sure that the connection is good the wire will not come out easily and the connection may be very short. So I do not have to transmit anything over long distances it may be quite easy to ensure that that connection will remain one can also provide for redundancy that is one several wires in parallel let us say etcetera but there are systems were there are large number of output quantities or there are large number of quantities which can be measured usefully to improve the performance of the system and therefore there are large number of these cables or wires carrying these signals from various places to the controller, the controller itself may be distributed. So signals coming in signals going out and there is quite a strong likelihood of a connection getting broken in connection with the probe on Mars or even satellite launches and so forth one is aware of this connection getting broken for some time then connection is restored and so on.

So in the case of feedback control systems were there are a large number of feedback paths large number of feedback signals one has to look at this possibility of certain feedback connections getting broken in that case how bad the operation of the system would be before a human operator comes on to the scene and tries to restore things. From a practical point of view this is very important although we will not be able to spend much time on this because the stay example itself will become fairly complex as referred to systems which have more than one loop or multiple loop feedback control systems and they are quite common in chemical engineering practice were the plants are large and distributed there are several things happening and so you have multi loop control systems and this problem is extremely important.

So reliability by providing for redundancy if necessary and also what if a feedback link one or more gets broken, one can provide for some automatic action in that case. For example, one can sense that something has happened to the tacho generator link and therefore provide for this in a whole system. In the end of course the human being may have to intervene and stop the whole thing switch it off as happens in the case of nuclear reactors sometimes and if does not happen then we have a disaster. So, once tries to make things as automatic as possible and therefore one has to think of all these possibilities.

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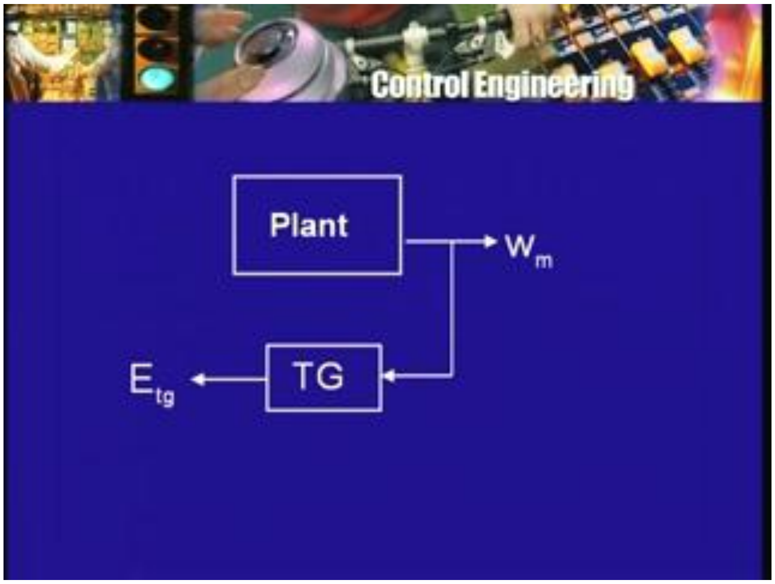

Now this is not quite the block diagram that we are going to carry on, I am going to modify it and one of the modification I told you is that will show the tacho generator voltage as a variable on the block diagram and therefore I can do that very simply by adding the tacho generator as one more block. So I will have the plant the motors and the load then I have this omega m sticking out and then I have a small block which are called TG let us say, the tacho generator to which I showed the omega m as the input and the tacho generator output voltage let us E tacho generator as the output.

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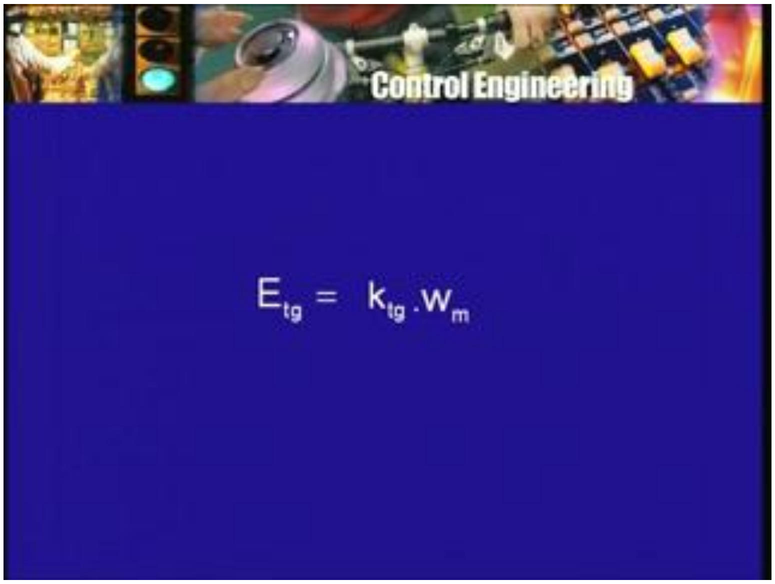

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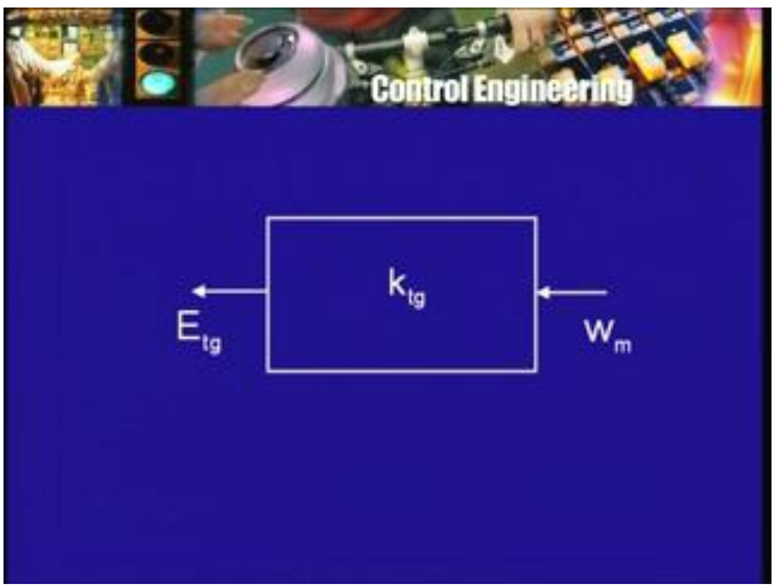

So why E t g as output because there is a certain cause an effect kind of idea that is the voltage of the tacho generator is produced because of rotation of the shaft and not the other way round. The shaft has to be driven by something in this case the motor and it produces the output voltage E tacho generator not only that there is a relationship between the tacho generator voltage and the speed and so that also could have written, I could have written inside those block as E tacho generator equal to K tacho generator into omega m or if the understanding is very clear then in place of writing this equation inside I could have simple put K t g inside the block and I have omega m as the input E t g as the output and so I have the tacho generator equation, tacho generator voltage is this coefficient into omega m appearing on the block diagram itself. I have not here put down anything inside the plant box although we have an equation earlier, later on we will put transfer functions inside or by the side of these boxes right now I just left it as blank.

Okay now omega m was to be kept at a particular value as a result E tacho generator is to remain at a particular value. We are not watching omega m now directly we are watching E tacho generator and when this E tacho generator is not at the expected value then some adjustment has to be done, some action has to be taken as to what is actually going on. In the case of our system I am going to show this very qualitatively this E a, which is being produced is going to be determined by the field current of the generator winding.

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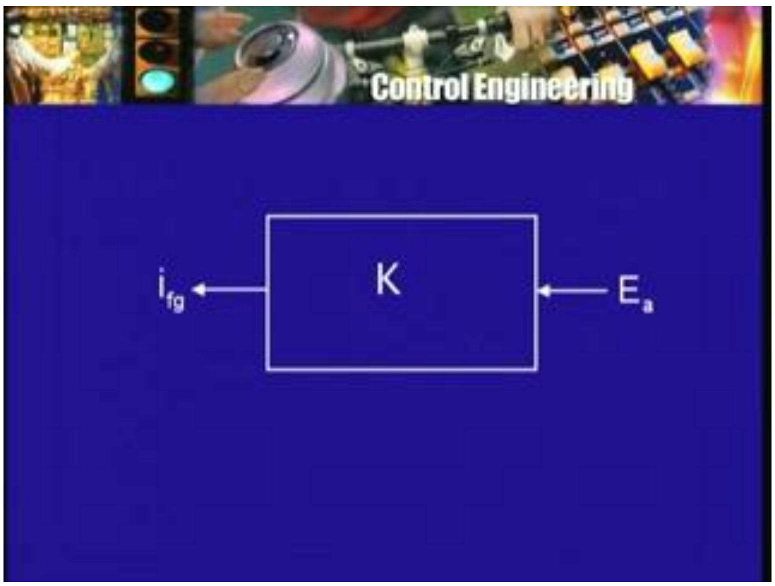

So I am showing this here at this moment as just aligned with an arrow on it a signal I f so it is the field current of the generator which is going to determine the output voltage of the generator which is being applied to the motor. In fact, I could do a little better I could show a small block here for which I f the field current of the generator is the input and I a is the output when I do that of course and this is something which is very important to remember here is E a as the output of this block and I f is the input of this block, what is not implied is that these are the only 2things of interest it the field current goes in the field winding of the generators. So there is a generator this generator armature is producing E a.

So that is all right the generator is being driven by a motor or an IC engine if it is a motor that motor itself is taking power from a power supply none of this is appearing in this. So we have sort of ignored the other things that are associated with this we are only concentrating on the 2 variables the filed current of the generator and the voltage produced by the generator which I could have called E g but it is connected to the armature circuit of the motor. So it is the same as E a.

So with this understanding then it is not that the field current produces the voltage what produces the voltage is the field current the rotation of the generator everything electromechanical interaction and what have you but it would be good to show the relationship between E a and I f again ideally it may simply happen that the voltage of the generator is only some coefficient some constant K into I f because if the generator is being driven at a constant speed then the generator equation which is what we look at earlier the emf produced is proportional to the speed through a constant coefficient which depends on the field current. The speed of the generator shaft to been kept constant so the generator voltage is only dependent on the field current and if I assume that the field current is not going to be very large. So that saturation effects do not come into play then I simply have E g equal to a constant K a coefficient K into I f as a good description of this part of the system and so I have shown it by simple block K field current of the generator may be I can put here I f g to emphasize that it is a field current of the generator and not the field current of the motor, the field current of the motor is somehow being kept constant, it is not a part of our adjustment scheme.

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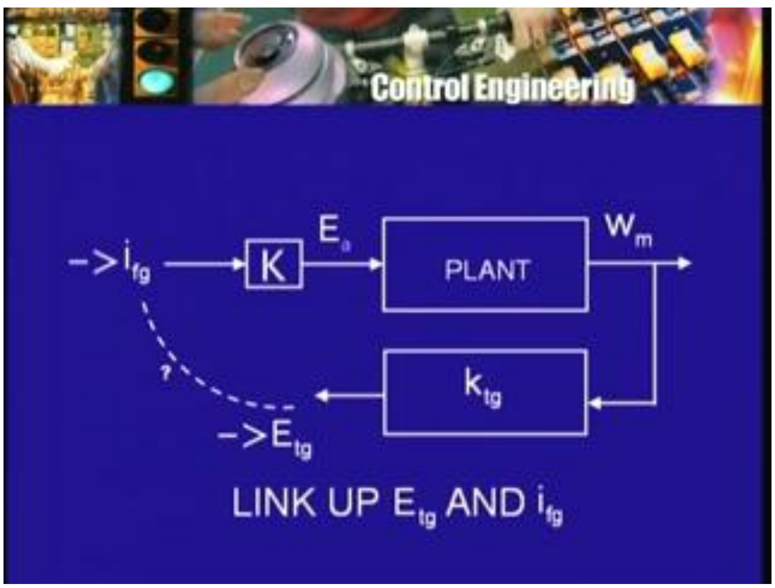

So there I have E a coming out from this box K this going into my plant producing omega m the motor speed that going in into the tacho generator which produces an output voltage E tacho generator and now all I have to do is to link up these two variables. The tacho generator voltage and the field current of the generator which is going to feed the motor, this is the possibility of adjustment looking at omega m therefore looking at E t g if I were an operator I would make changes in I f g if the speed was going down may be based on previous experience or I have instructed will increase this which will simply mean move the slider up or down or left or right.

When you see omega m or when you see tacho generator voltage going on this side of the mark indicating lower speed do this to the slider which is a effectively changes the field current of the generator in a particular sense whereas if the speed is going in the other direction going up then I should do this to the slider I should do change the field current in this way or that way as an operator of course I do not need to know any equations essentially all I need to know is if this goes this way what should I do with this norm or slider is that is what we do when we operate an air conditioner, we do not bother about equations and so on, so forth.

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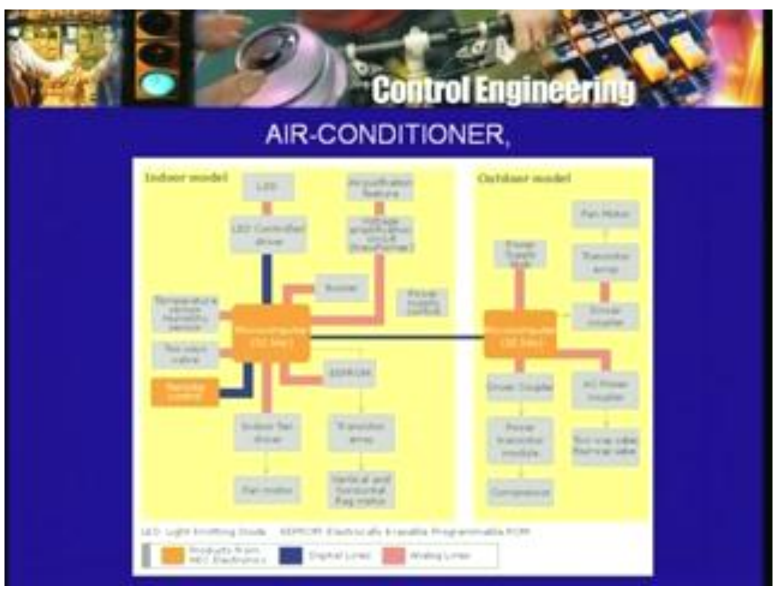

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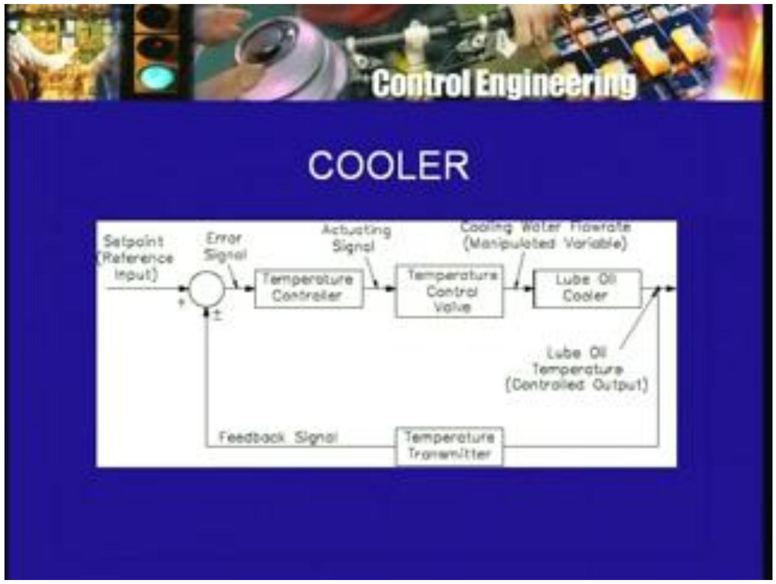

There is a dial the temperature is not cool enough. So I will change the position on the dial this is the adjustment that now we have to talk about. So what kind of adjustment what kind of link we have to provide between the field current of the generator and the tacho generator voltage. The tacho generator voltage is other means of knowing about the speed and the goal is to keep the speed constant that is one thing I mentioned earlier which we will show on this diagram very soon. The tacho generator voltage tells me what the actual speed is at any moment of time, what about the desired speed, I want the speed to be 1500 rpm and as I said if I am operator it may be a mark on a dial. So the operator does not have to know that mark is 1500 rpm that mark is a desired speed similarly, if the whole thing is going to be done by a human operator I can have an voltmeter dial on which there is a mark which tells you that that is the mark corresponding to the rated speed. I do not even have to know how many volts and so on. But we are going to replace the operator by something else and therefore it cannot be done that way.

So in this sense we need something which will stand for the desired thing, the desired speed to be kept constant omega m because I am not going to have a dial on which there is a mark. So I know that the quantity has deviated from the desired one. So in this sense we have to have some physical thing which will represent this desired quantity omega m. Now the omega m is a mechanical thing it is a rotating shaft may be rotating not at 1500 rpm but at 1475 rpm, the desired thing is a speed of course. So I could think of another shaft may be rotating at 1500 rpm no matter what happens it is possible we have motors which are called synchronous motors, A C motors whose speed is guaranteed to remain constant when one will says guaranteed one means normally because it depends on the supplied frequency.

So if the supply frequency remains constant at let us say 50 hertz then I can have a synchronous motor a small synchronous motor whose shaft will run at 1500 rpm. As I mentioned earlier there is a certain relationship between the number of poles or pole pairs of the motors or generator and the frequency of the supply or the frequency of the AC voltage that is produced so at 50 hertz to produce 1500 rpm you will require 2 pole pairs or a 4 pole machine or another hand if you ran a 4 pole machine at 1500 rpm the supplied voltage that it will produce will be 50 hertz.

So in principle I can think of a small synchronous motor which is connected to a 50 hertz supply available so that it is shaft runs at 1500 rpm and now I have this motor shaft which is not running perhaps at the same speed. So I want mechanical variable the motor shaft and another mechanical variable the synchronous motor shaft and the difference that whether the motor is running at the desired speed or not can be found out by looking at the speeds of these two shafts of course looking means not by a human being but by a some mechanical or electromechanical system. Now this can be done but it will be quite clumsy it is much better to represents this desired speed on the diagram.

So now in additional to omega m which is the actual motor speed and in fact I may put omega m as a function of d because it may actually be changing especially during the transient period, I will now put talk about one more thing which I called the desired speed omega d omega for speed d for desired or sometimes omega r, r for reference and we will see the reason why the word reference is used here. So this desired thing fifteen hundred rpm is made available not as a mechanical thing a shaft rotating at 1500 rpm but in some other way and what simple way other than what we already have on our diagram. The motor speed is made available electrically through a tacho generator. So why not think of this omega d as represented by a voltage there is no need to actually produce omega d of 1500 rpm then have an tacho generator which will produce this voltage represent this desired quantity omega d by a voltage and in this transient pole we will have a reference voltage depending on what is convenient we could use the symbol E or V and r for reference or sometimes more explicitly E reference.

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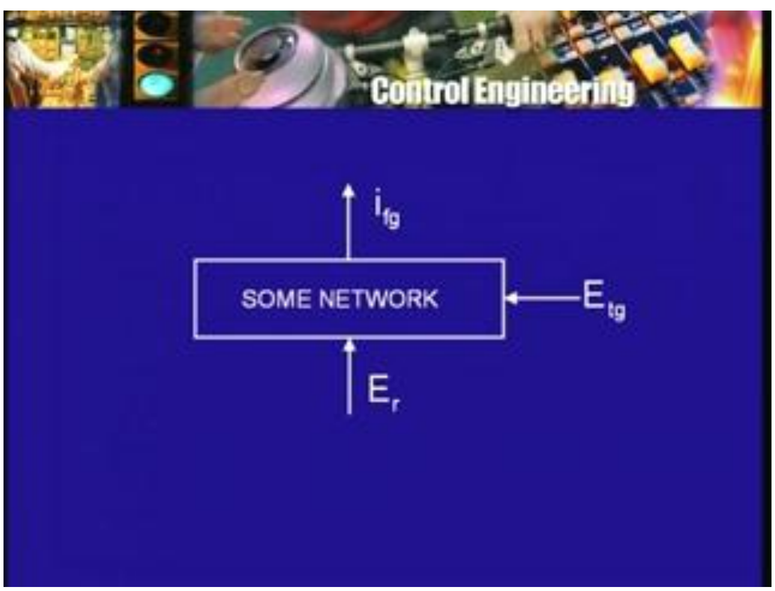

So somewhere in the control I have to have this physical entity E reference, a reference voltage. Somehow I have to produce this reference voltage, this reference voltage will be the reference mark against which the actual voltage will be compared to make adjustments or to take action. If

E reference was 1.5 volts then it will very easy to provide for this reference voltage, a dry cell, a fresh dry cell would do quite well and if you wanted something better than that you could take a standard cell which is supposed to keep it is voltage constant much better than a dry cell although any time you operate that cell, you take some current out of it then the voltage is not going to remain constant forever.

So in electrical measurement instrumentation practice one does talk about voltage references current references and in fact standard resistors, standard capacitors and so on, so forth. So in this things, we can actually have a physical thing something as simple as a cell which provides this reference voltage but if this reference voltage is not of that order 1.5 volts in my example I took it to be simply 20 volts. So that I would immediately think of a cell then I have to produce this 20 volts somewhere and use it as a part of the controller. So then what we have available now is this signal E reference which could be connected to whatever of course not anything may be to some simple electrical circuit or network.

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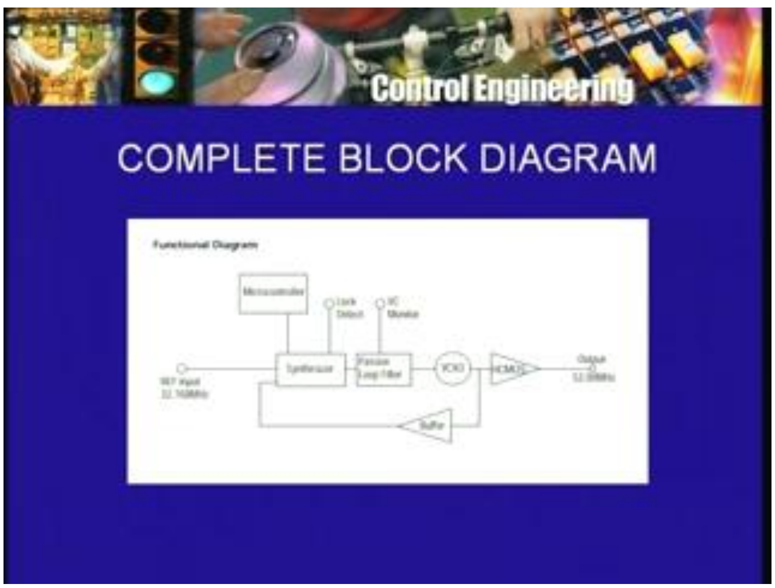

So we have E reference available, we have E tacho generator also available and these 2 are combined in that circuit or network to produce the field current of the generator and the loop is then closed and then we have to see how this adjustment can take place and whether the system with feedback will perform better than the system without feedback, thank you.