Control Engineering
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Lecture - 17

Let us have a look at the modified signal flow graph for the feedback control system once again. We have 2 input nodes the reference voltage node E R and the load torque T L. We have 2 output nodes or non-input nodes omega M. Of course the signal of interest to us and the armature current I A and now, you can see that there are 2 loops in this signal flow graph whereas the earlier one had only one loop, the one without the feedback path had only one loop.

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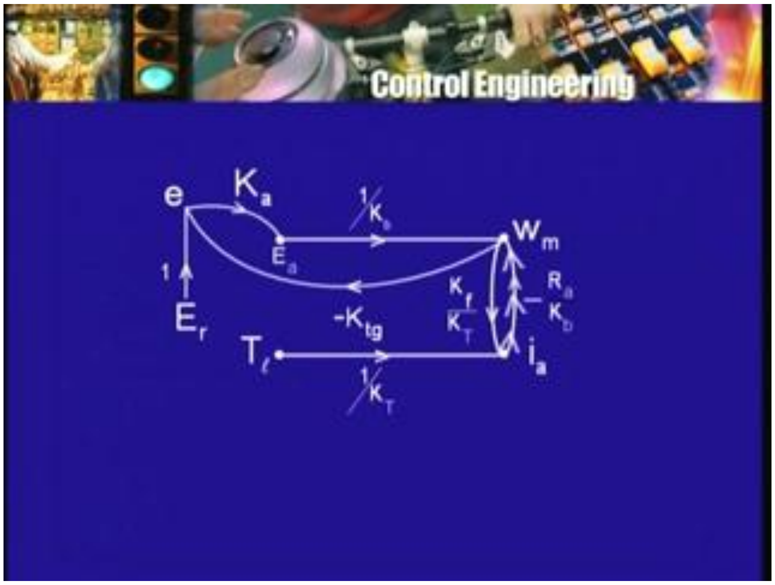

Now we have 2 loops and so the calculation of the gain coefficients etcetera is going to involve a little more work and there will be a few more terms that we will have. So what was the first step in applying Mason's rule to identify all the loops of the graph and then to calculate or write the expression for the common denominator, determinant, delta. So that we can do here we have 2 loops the loop gains will be L 1 will be given by there is a loop consisting of K A from E to E A then 1 by K B from E A to omega M and then the tacho generator feedback path from omega M back to E. So that is the loop and for which the gain will be given by minus K A, K TG divided by K B minus K A, K TG divided by K B. There is the other loop from omega M to I A and what is the purpose or the why does that loop occur why does that path occur because it is multiplied by the coefficient of friction.

So this is the torque required to work on friction divided K T and therefore this is the part of the armature current that is required to overcome friction. One should interpret terms or coefficients that appear on the graph and the various signals it is not good enough to just do things mechanically because then only one can understand what is going on and also notice if one has made any mistakes. So this path through omega M to I A through K F by K T, once again it is because K F omega M is the frictional torque that divided by K T is a part of armature current that is required. The other part of the armature current is required to produce the load torque and therefore T L divided by K T and that is the summation at I A, what about the path from I A to omega M, why does it occur that is because of the armature resistance drop.

Now that is a voltage which is in addition to the back EMF and therefore the applied voltage is sum of the 2 or the back EMF is the applied voltage minus this voltage. So that divided by K B is sort of a part of the speed you you can say which is used up for the armature drop, if the armature drop was not there then back EMF would be higher therefore the speed would be higher and so what is the gain of the other this other loop L 2 is given by minus K F by K T multiplied by R A by K B. I have not here equating K T by K B although as I told you earlier K T and K B are equal the back EMF constant and the torque constant for an ideal motor at least are equal.

Let us keep them as 2 separate symbol, so that we know what is the what in one place it place the role of EMF generation in the other place it plays role of torque generation therefore it is good to keep separate. So we have the 2 these loops L 1 and L 2 and therefore we can start writing delta so delta will be equal to 1 minus L 1 plus L 2 just make sure that these are the only 2 loops that you have on your signal flow graph that is easy for this graph plus is there a plus term now, are there loop pairs which do not touch each other, no because there are only 2 loops L 1 and L 2 and L 1 and L 2 actually touch each other at the node omega M.

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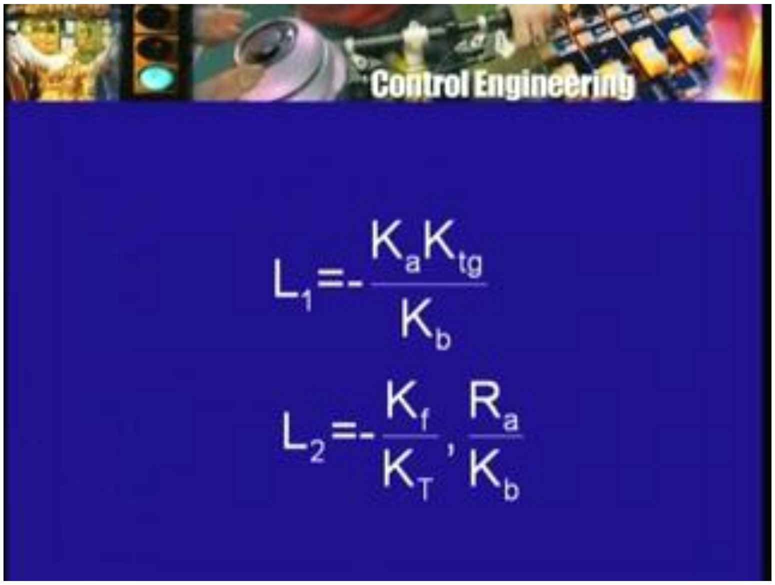

$$L_1=-\frac{K_a K_{tg}}{K_b}$$

$$L_2=-\frac{K_f}{K_T},\frac{R_a}{K_b}$$

So there is not additional term and so this is all that you for delta namely delta equal to 1 minus L 1 plus L 2 and therefore delta is equal to1 plus K A, K tacho generator divided by K B plus K F by K T multiplied by R A by K B. So this is our expression for the common denominator delta or the determinant of the signal flow graph, what is the next step? We want to obtain an expression for omega M in terms of the 2 input signals one of them is the reference voltage. So an expression which multiplies E R plus an expression which is going to multiply the load torque now here also one can anticipate few things if the reference voltage is increased then we expect that the speed will increase.

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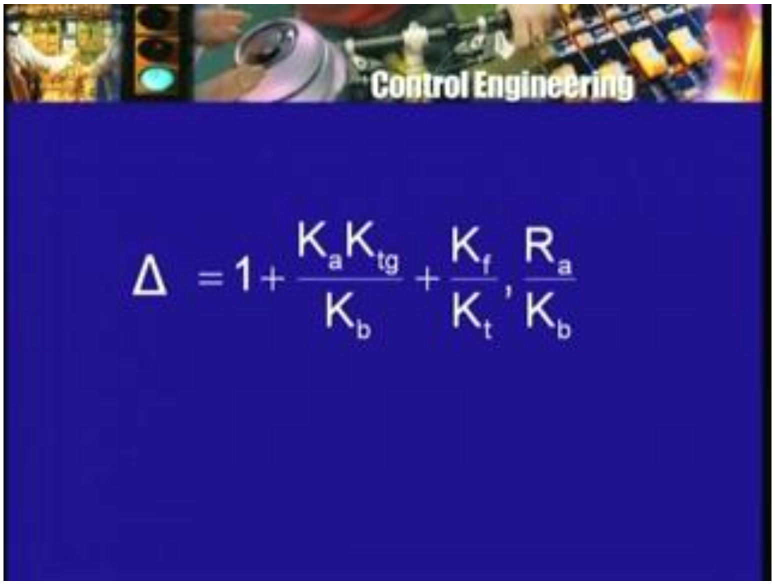

$$\Delta = 1 + \frac{K_a K_{tg}}{K_b} + \frac{K_f}{K_t}, \frac{R_a}{K_b}$$

So the coefficient that multiplies E R should turn out to be normal positive which increase reference voltage, the speed will be increase or you can look at it the other way. Now if you want to change speed of the motor if you want to increase it then we will have to increase the reference voltage or you want to run the motor at a lower speed we will have to decrease the reference voltage, what about the coefficient of T L, I have put a plus sign between the 2. Now here we expect that if the load torque is increased the speed will be decreased therefore with this plus sign this coefficient will turn out to be negative or alternately then we can write a negative sign there between the 2 terms then the coefficient will be positive and let us as we go ahead, let us check whether we do get a these expectations.

Okay, so the coefficient of E R for that what do we have to do we are writing an expression for omega M, E R is the input node so identify the forward path from E R to the input node. So E R from the input node omega M, E R to the output node or the node whose signal we are interested in namely omega M. So what is the forward path well it goes from E R to E and then from E to omega M is there only one forward path yes, there is only one forward path as you can check from the signal flow graph.

Now what is the gain of this forward path then it has only 2 terms K A the error voltage is amplified to produce the armature voltage capital E A and then it gets divided by K B because that is because of the back EMF effect and if there was nothing else then E A divided by K B would have been omega M. So the gain of the forward path is therefore K A divided by K B. So now we are ready to write the expression that multiplies E R we take the gain of this forward path and then multiplied by the terms in delta that remain when we remove the touching loops. Now what about the 2 loops both of them pass through or touch have the node omega M, our forward path ends at omega M therefore the forward path touches both the loops as a result what will survive from delta you have to remove the loops which touch the forward path. So L 1 will go L 2 will go and what will survive will be only one do not forget that one. If the paths are named P 1, P 2, P 3 etcetera then what survives in the numerator is often called delta 1, delta 2 etcetera.

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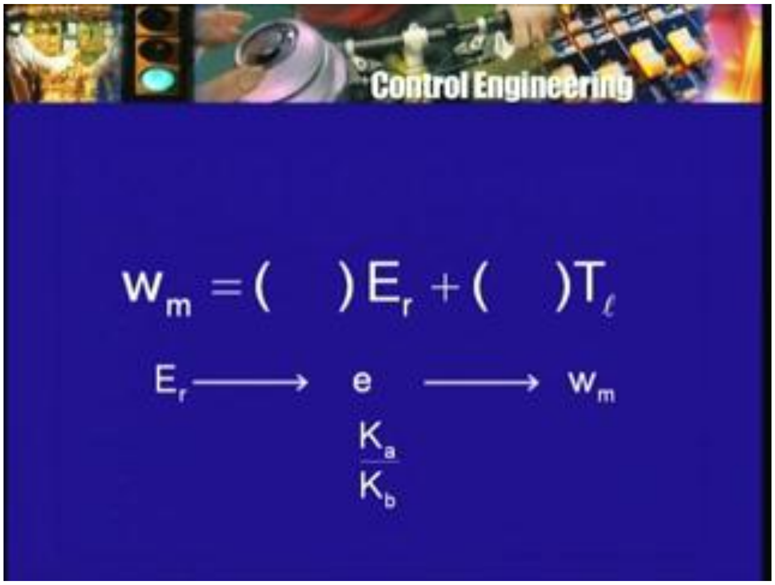

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$$w_m = (\quad)E_r + (\quad)T_\ell$$

$$E_r \longrightarrow \underset{\frac{K_a}{K_b}}{e} \longrightarrow w_m$$

So if I have to write a general expression for a gain from a particular input node to another node it will look like sigma P I delta I divided by delta. There is no particular advantage in the writing this kind of a notation if you do not understand it I very often find students write this thing but when they you want to apply or when they applied it they fail to understand what is going on, what does the sigma mean this sigma means that if there is more than one forward path then there is more than one term in the numerator, if there is only one forward path then there is only one term in the numerator, is it possible that there may not be a forward path from a given node input node to another non input node, it is possible. In that case what would you put nothing or therefore 0 then each forward path gain is multiplied by delta I, now what does delta I stand for delta I stands for what remains from delta if we remove those loop gain which touch the path P I whose gain is being multiplied by delta I. So choose a forward path a corresponding what remains from delta multiply them together then go to another forward path find out what remains of delta for that forward path multiply those together add up and so on.

So understand this sigma P I, delta I divided by delta properly. So that you do not go wrong it is not enough to write an expression one must know what it means and one should be able to use it properly. So in our case then what will be the a numerator numerator is only the forward path gain what remains of delta is only one and so that expression which multiplies E R is ready. I have write again, so omega M equal to something into E R and that expression the numerator will be simply the forward path K A divided by K B and in the denominator I will have that expression for delta1 plus K A, K tacho generator divided by K B plus K F by K T into R A by K B.

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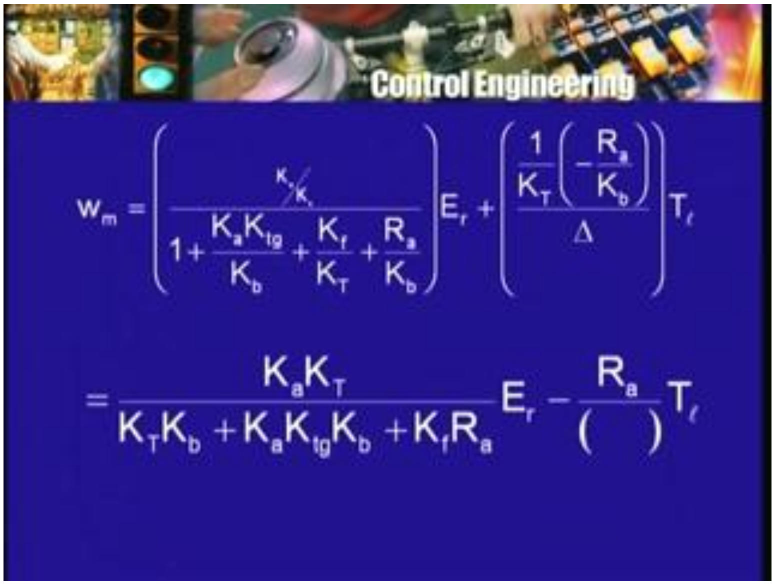

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$$w_m = \left(\frac{K_a/K_b}{1 + \frac{K_a K_{tg}}{K_b} + \frac{K_f}{K_T} + \frac{R_a}{K_b}} \right) E_r + \left(\frac{\frac{1}{K_T}\left(-\frac{R_a}{K_b}\right)}{\Delta} \right) T_\ell$$

$$= \frac{K_a K_T}{K_T K_b + K_a K_{tg} K_b + K_f R_a} E_r - \frac{R_a}{(\quad)} T_\ell$$

So that is the expression that multiplies the reference voltage what about the expression that multiplies the load torque now what is the forward path from the load torque node to the speed node, T L to omega M. Once again there is only one forward path T L to I A and I A to omega M and as I had anticipated earlier. In this path there is a negative sign which I told you we expect because of the load torque increases we expect the speed to decrease. So can I then write down and this forward path does it touch a both the loops yes, because it ends at the node omega M therefore it touches both the loops L 1 and L 2 therefore what will be in the numerator multiplying the forward path gain only one that is why I can now do that very quickly and I can write this as therefore this is the minus sign normally there side a plus sign here.

Okay, let me write here plus sing because this is the normal rule plus when the bracketed expression may have a minus sign which it does so bracketed expression is now as we found out one by K T let me write it down one by K T multiplied by minus R A by K B divided by the same expression delta. So this is the complete formula now giving the speed of the motor in terms of the reference voltage and the load torque. If we know the parameters of the system such as the gain K A, the back EMF and the torque coefficients K B, K T, the armature resistance R A, the frictional coefficient K F. The specified load torque the rated load torque and the reference voltage that is applied we will be able to calculate the speed of the motor omega M and if E R changes or is change or T L changes then we can find out the new omega M or we can find out the change in omega M caused by a change in the load torque and that is the quantity in which we were interested.

We were trying to reduce the change in speed when there is change load torque. The whole idea of trying to or introducing feedback was to see whether the change in omega for a given change in T L will be reduced than it could have been done earlier, when the armature voltage was kept fixed. We will see that a very soon. Now when you have an expression like this complex expression like this the next step to do normally would be to simplified by getting rid for the various fractions that you have and then look at the new expression of course when you get rid of the fractions the expression look simple but then it is very difficult to interpret what each term a means.

So one should be very careful in simplifying this expression because a wrong calculation somewhere will upset your whole a calculation. So if I now get read of the fractions here in this coefficient that multiplies E R then what will I get I will have to multiply numerator and denominator by K T into K B to get rid of the fractions. So if I do that then I will have in the numerator K A into K T and in the denominator I will have K T, K B plus K A, K tacho generator K B plus K F into R A. So I get products of several coefficients and added up as I told you this now does not immediately have significance, this whole thing multiplies E R and then now will bring that minus sign which was inside I will bring it outside.

So minus the coefficient that multiplies in the numerator will be R A that is all because K T, K B is what we are going to multiply numerator and denominator and the denominator will be the same expression that appears in the coefficient multiplying E R. So this is the expression for the speed in terms of the reference voltage and the load torque. The coefficients are all positive and the expressions that multiply E R and T L are both positive of course there is a negative sign that multiplies the whole thing a that multiplies T L and so now we see immediately that if P L increases omega M will decrease, if P L decreases omega M will increase, if E R increases omega M will increase, if E R decreases omega M will decrease. But now from this expression we will see something which as I told you earlier is normally interpreted as steady state error.

Now let us look at that once again in the normal discussions in many textbooks, it is asserted that the reference voltage value should be equal to the feedback voltage that will result when the output as is at the desired value. So omega T is the desired speed K tacho generator omega D is therefore the tacho generator voltage when the motor is running at the desired speed this is compared with E R and if the difference is 0 there is not error therefore E R is put equal to tacho generator into omega D. Now we see immediately on putting or making use of this relationship in the expression that we have derived that if this is the case if we set E R equal to K TG omega D, where omega D is the derived speed then the speed omega M will not be omega D but will be less than omega D that is the drive will not run at the desired speed even though the tacho generator output corresponding to the desired speed is equal to the reference voltage or the reference voltage divided by the tacho generator a coefficient is the desired speed.

Now why is this so E R equal to K tacho generator into omega D. Now you look at this part omega M involves E R and also involves T L. So this T L the load torque actually reduces the speed if the load torque is zero then this term is absent if there is some load torque then omega M is even going to decrease. So let us assume that T L 0 is no load torque even then the motor will not run at the desired speed if E R is equal to K tacho generator into omega D. Can you see why so for E R now substitute K tacho generator into omega D. So in the numerator I will have K A, K T into K TG into omega D and in the denominator I will have this sum. Now can you see why omega M turn out to be less than omega D that is because what multiplies omega D in the numerator is K A, K T into K tacho generator that term appears in the denominator also but to that are added 2 more terms which are both positive. So we have omega M equal to K A, K T, K tacho generator divided by the same thing K A, K T, K tacho generator plus some positive quantities multiplying omega D.

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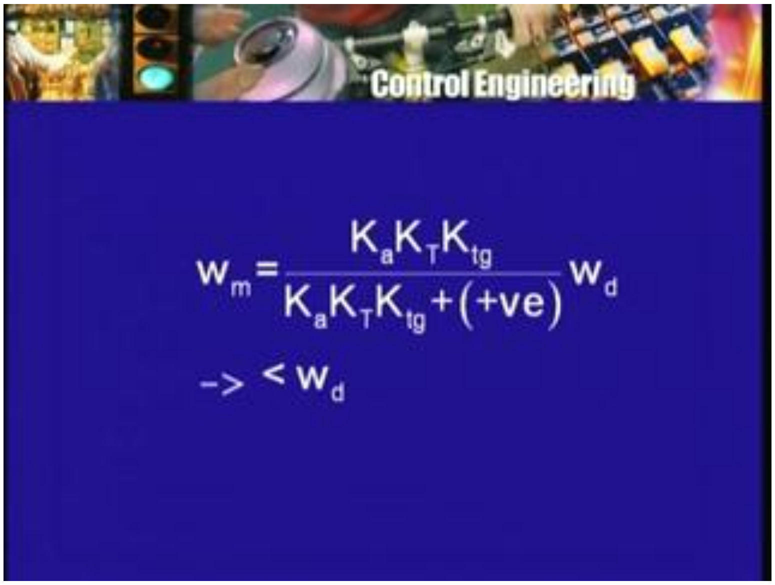

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$$w_m = \frac{K_a K_T K_{tg}}{K_a K_T K_{tg} + (+ve)} w_d$$

-> $< w_d$

So because the numerator is less than the denominator therefore omega M must be less than omega D. So this sort of the proves that if you choose reference voltage equal to the tacho generator voltage produced at the desired speed then the drive will not work properly in the sense it will not even run at the desired speed and I told that this is absurd because we can certainly make the drive run at the desired speed under the rated or the nominal conditions. So if we know the load torque full load torque. Let us say if we know all the coefficients etcetera then we can certainly make the driven run at the desired speed and so what is the mistake that we are committing here.

We are not committing any mistake in the calculations a calculations are all correct the mistake was the assumption that the reference voltage equals K GT omega D and so what is the solution to this problem, well increase E R do not put it equal to K tacho generator into omega D the desired speed choose it sufficiently higher. So that omega M equal to omega D under the rated or nominal conditions or alternately the tacho generator is such that the tacho generator voltage, K tacho generator omega D at the desired speed will be sufficiently smaller than E R the reference voltage that you have already chosen.

Now the mistake was that the E R reference voltage which a supposed to represent the desired speed K tacho generator omega M on the other hand represents the actual speed and so the difference between the desired speed and the actual speed is the error for control people that is the error, for instrumentation people it just the opposite and so the argument is this error should be 0 ideally. You should have zero steady state error because you want the drive to run at the desired speed therefore this error should be 0 and therefore E R should be equal to K TG omega D but what is not realized is that we have type zero system, the motor with the load is a type 0 system if you apply 0 armature voltage to it the motor will run at 0 speed to run it at some nonzero speed require some non-zero voltage if that voltage is obtained by the output of the generator and that generator therefore its field current is being adjusted then that generator voltage cannot be zero the field current cannot be 0.

So whatever produces or adjusts that field current namely our error signal E cannot be zero but this E is not the error signal, E is just to signal that is the difference between the reference voltage which represents omega D and the feedback voltage which represents omega M. The only thing is the proportionalities are different the reference voltage represents omega D with a certain proportional coefficient whereas the feedback voltage the tacho generator output voltage represents omega M with a different proportional coefficient. So that the difference between the 2 even when there is no error even when omega M is equal to omega D the difference between the 2 is nonzero that is amplified results in an armature voltage which therefore makes the motor run etcetera, etcetera.

So there will be no steady state error but the reference voltage will not be K tacho generator omega D or if you insist on using the tacho generator and the same reference voltage then you must not apply the whole of the tacho generator voltage to the input of the difference device. You should take only a suitable part of it now at this point I would you to go back and redo some of the calculations that we had looked at earlier. So that you will get some numbers and you will get some figures and see actually what is going to happen but1 can also see what can be done to make even when E R is chosen as K tacho generator omega D and I repeat it, it should not be there is no reason to choose it equal to that but even when it is chosen that way can we omega M come closer to omega D.

Now look at this expression, we have this term in the numerator which also appears in the denominator but in the denominator to it are added 2 terms namely K T, K B and K F, R A. Now if we can make those 2 terms insignificant compared with this term or to put it the other way if we can make K A, K tacho generator K B large compared with K T, K B and K F, R A. Then, the numerator and the denominator will be nearly equal they cannot be equal ever but they will be closer to equality and one way doing that will be to increase K A, if we increase K A then K A, K TG, K B will be increased the other 2 terms K T, K B, K F, R A remaining the same therefore the numerator and the denominator will become more nearly equal than they were earlier and so the motor will run at speed which is still not equal to the desired speed but closer to the desired speed than it was earlier when K A was smaller. But then I said that you cannot increase K A by any amount that you like because this is only for steady state error consideration.

We are not looked at transient error at all and we will see very soon that increasing K A will cause some trouble for the transient performance. But we do not really have to do that, we just have to choose an appropriate E reference E R or alternately choose an appropriate { tacho generator or take an appropriate part of the tacho generator voltage for feedback and the drive will operate at the correct speed however because of this term which is present in the expression omega M the load torque term, the load torque changes will affect the change in speed and if we look at the load torque term what multiplies it, in the numerator we have armature resistance and the presumably armature resistance will not change by a significant amount.

The motor for example I said that motor armature can get heated but then usually there is a fan on the shaft, so that the motor does not get heated too much or therefore there is some cooling therefore R A is going to remain more or less what it is. In the denominator we have again the sum of those 3 terms. Now if you want to reduce the effect of changes in T L then what can we do about that sum well K T and K B we are assuming we are not going to touch them the field current of the motor is not being change therefore that is not going to be change frictional coefficient certainly we do not want to add to it and we cannot reduce it either hopefully it has already been taken care of before starting the motor that the bearings are well oiled and what not.

So the only thing that we can do is the with the middle term here K A, K tacho generator K B and therefore one solution is to increase K A. Now what will happen is that when the load torque changes the drive speed will change and therefore there will be a steady state error produced when the load torque changes that is the in spite of the feedback that we have used load torque changes will result in speed change and therefore will result in steady state error. But you can compare this with the expression that we had earlier when there was not such arrangement of feedback and you can see that the load torque change with the feedback, the speed change rather because of load torque change with feedback will be less than the speed change cause by load torque change without feedback. So this K A increasing K A in fact will reduce the effect of the load torque changes or will reduce effect of disturbance on the drive.

So our type zero system with a proportional control will give you a situation in which there will be no steady state error under rated conditions when the load torque is at the rated value however with change in load torque that is with the disturbance or with a disturbance signal there will be a steady state error. So proportional control in this sense gives rise to steady state error because of the disturbance that is present and there is no steady state error because the drive is error actuated or error driven or whatever all those statements are not correct and to repeat once again that signal E does not represent the difference between omega M and omega D, it is only the difference between reference voltage which is proportional to omega D and the feedback voltage which is proportional to omega M but the 2 proportionality coefficients are different, they are not the same. Therefore E does not represent error although for convenience and most textbooks will call it the error signal but that is not correct.

Now the next thing that we can do is to see what other kind of feedback can be used, so that we can get over this difficulty that load torque changes that is disturbance signals produce steady state error how to do that and I have mentioned other schemes of control such as integral control and derivative control. But before we do that we will look at the same situations from the block diagram point of view because I do not want you to get the impression that you have draw a signal flow graph then only you are able to do something you can do things with the block diagram also in fact we will see that for the block diagram that will draw which will be so simple that we will with sort of use the signal flow graph rule as it where with the block diagram itself.

So the block diagram itself can be read as a kind of signal flow graph if one is careful so we do not have draw to signal flow graph although one could and one should it draw it, if it helps. So that is the next thing that we would like to do and but as I told you you should go back to our original design data and workout some numbers. So that one get some idea of what is going on what about the set point changes as the expression shows omega M is directly dependent on E R. So if you want to increase the speed at which the motor is to run increase E R to a suitable value if you want it to decrease decrease E R to a suitable value.

So our drive is capable of operating at any desired steady states speed and it can be set by setting the reference voltage. So this reference voltage setting of course as I told you is not done by watching a voltage or reading with the help of volt meter and so on. You will have some slider or you will have some knob on a surface on which the speed will be marked and so what a person has to do is just as we set an air conditioner, you turn that knob and make it point in at the appropriate place. So that the set speed the desired speed is set that way, so our drive with feedback then provides for setting of the speed that part is not automatic somebody will have to set the speed manually somebody will have to select the position of the knob or the reference voltage manually. But then our drive reduces the effect of torque changes on the speed.

So in this sense use of feedback as the improved the performance of the drive under rated conditions the drive will operate at the rated speed . So the drive will work perfectly under rated or nominal or the conditions which were used at the time of the pre calculations or the pre-programing. Now let us do it with the help of block diagrams let us see what is the difference and what things are similar. Earlier, I had drawn only one single block like this with 2 inputs E A and T L and with 2 inputs omega M and armature current I drawn only a single block I did not anything inside the block but I said that you write down the 2 equations that govern the behavior of the system.

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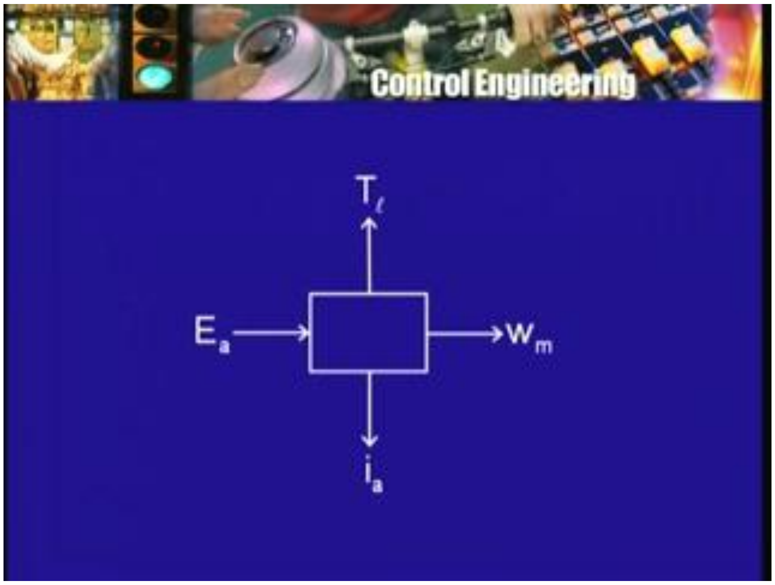

Now we can improve a little bit on that by drawing a somewhat different block diagram and we can make use of some of the ideas from signal flow graph analysis that we have studied and as I said earlier it is almost like drawing a signal flow graph except that I am going to show blocks.
So the voltage equation armature voltage equals back EMF plus the armature voltage drop I will rewrite it or after thinking of rewriting it I will draw a different or I will draw a block or you see if there is one block or there is more than one block on the block diagram also as you have seen earlier the various signals appear E A omega M, T L, I A as input signals output signals are the various blocks okay.

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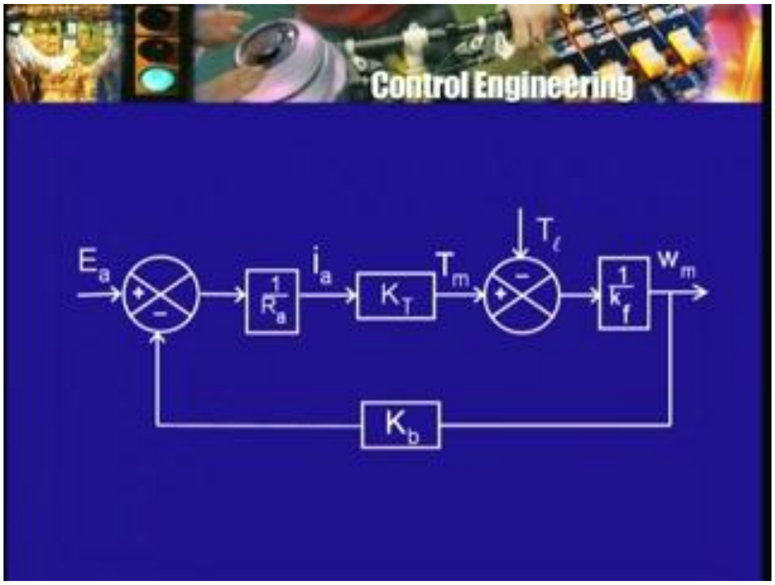

So let us make a beginning so I will show a block which is going to be like our difference device. So the symbol for the is not really a rectangle but its circle with the 4 quadrants shown in the traditional way, to one of the quadrants I will mark with the plus I give E A as the input to the other quadrant and I will mark it with the minus I will give an output coming from omega M. I am just showing that signal omega M as an arrow coming out I have not attached it to a block right now. But suppose signal omega M is available then from omega M through a block now here a block is appearing although it could be regarded as a coefficient or a gain I have K B. So this block has omega M going into it and therefore coming out of it will be what will be a signal or value K B into omega M.

I told you that this is not really physical signal when the motor is running it is extremely difficult to measure this K B into omega M although one can measure omega M easily but as voltage the back EMF cannot be measured while the motor is in operation it is something which according to Faraday's law of induction produced while the motor runs, K B omega M therefore is not a physically measurable signal but it is a term which appears in the equation. So this goes into this circle with a minus sign E A is the other term the input signal to the circle with a plus sign of course this circle is nothing but our difference device. So you see it a if we use it here again then the output of this will be what will be E A minus K B omega M.

Now that is related to the armature current, so I will put here a block whose coefficient will be 1 by R A and that will give rise to the armature current. So I have represented the equation E A equals K B omega M plus I A, R A in this peculiar fashion it is a obvious but its work mentioning that these blocks do not represent some actual physical systems which are connected in some particular way as shown on the diagram here. But they are way representing the equation which we wrote for the armature circuit E A equal to K B omega M plus I A, R A if you understand these blocks correctly then from I have drawn so for what follows is only equation and nothing else.

Now it is time look at the second equations and the second equation has the load torque the frictional torque and the torque generated by the motor. Now you can expect how I am going to add to this block diagram that I have already drawn some more blocks. So that equation also will be represented and therefore I will have both the equations represented on a single block diagram. So what what is it that we should do on this block diagram I have already have armature current I A, so multiplying it by K T will give me the motor torque. So I just have to put one more block there and I will do it soon and I will have the motor torque that motor torque is equal to the load torque plus the frictional torque.

So I can think of the load torque being subtracted from the motor torque to produce the torque that is left for overcoming friction. Now this is very funny because the purpose of the drive is not to work in friction the purpose of the drive mainly is to work on the load the friction is the unwanted part of the load but for drawing the block diagram this seems to be a convenient way of doing it. So if were only to look at that part of the block diagram then assuming I A, I have got somehow I have put this block K T. So that produces what I had called earlier T M, the motor torque from this motor torque now once again this difference device will make its appearance the circle will its appearance from T M, I will subtract T L and so the difference will be K F omega M and therefore the output will be K F omega M. Once again K F omega M is not easily measurable physically the torque require to overcome friction is not easy to measure physically while the drive is running but as signal its meaningful thing and essentially therefore what we are writing is terms in the equation T M or K T, I A equal to T L plus K F omega M what we are done is we are transpose the term K F omega M to the other side.

So it looks like K F omega M equal to T M minus T L but I am not interested in KF omega M, I am interested in omega M. So put a block one by K F and that will produce omega M, so this block diagram by itself will show or will represent the second equation and now it is just a question of putting the 2 blocks together to produce a single block, it is something somewhat like what we did earlier with signal flow graph. With signal flow graph we had one signal flow graph representing the EMF or the voltage equation, we could think of another signal flow graph representing torque equation and then we combined 2 signal flow graphs together to have a signal flow graph in which all the signals appeared but not as 2 separate diagrams but as single diagram and the equations where correctly represented.

In the case of the signal flow graph each node other than the input node represents an equation or a summation. Here this circle device which in this we are interpreting as the difference device represents an equation and there are 2 of them one for the armature circuit equation and the other for the torque circuit equation. So putting these 2 equations or the 2 blocks together I will draw the composite diagram and you should try to draw it by yourself now without looking at a what I am drawing by going through the thinking once again. So how do we start we start with armature voltage so here is armature voltage then from that I am going to subtract back EMF to produce a voltage which divided by R A gives me the armature current that multiplied by K T gives me the motor torque from that subtracting the load torque leaves the frictional torque. So that divided by K F produces the motor speed omega M but I should not forget about those 2 subtractions that took place.

So one of them took place here and that is the a thing that I have drawn line from omega M to E A and I should of course for the K B there not a direct line but K B. So let us check at this difference device E A minus K B omega M is something which divided by R A is equal to I A that is correct at the other coming in is K T into I A minus T L that divided by K F omega M that is also correct. So we have we now have single block diagram which represents the 2 equations instead of a single block which had 2 input signals and 2 output signals. Now I have an block diagram which is different and what has several sub blocks.

Now this particular difference device is it feedback and is it negative feedback because the minus sign would make one say that it is negative feedback but is it negative feedback or is it feedback. Now the answer would be yes and no, no in one sense that it is not something which has been introduced by us after thinking of open loop, close loop and all that step. It is a part of the operation of the motor current in a conductor in a magnetic field in the presence of the magnetic field experiences of force that produces the torque of the motor unfortunately the moment you have motion and you have current that produces this back EMF and therefore we have this term K B omega M.

So in this sense you can say its feedback that is the fact that the conductors are moving does change things electrically the armature voltage gets opposed by this back EMF and therefore a much smaller current flow in the armature than would have flown if you had applied the armature voltage and the motor was not running or the motor was at stands still and of course that is something while should never do you should not turn on a DC motor with full armature voltage on you have to have a starting resistance as we had mentioned earlier. So this block does and does not represent feedback it is not introduced by us as a part of the control system it is a part of the behavior of the motor itself what about the second difference device that is certainly not anything like feedback . The load torque cannot by any stretch of imagination be looked upon as a feedback signal or whatever now that thing also could be changed around the little bit at this point I do not want to do it and we can make another loop appear in this diagram although right now only one loop appears in this diagram that loop is from the output of this difference device in fact there is none, there is no actual difference device the signal at this point is also not a signal which is physically measurable.

So I should not even call it E but whatever that signal is from that signal through the block 1 by R A to the a armature current through the block K T to the motor torque through this again second difference device through the block one by K F to omega M and then through the block K B back to the other the first difference device. So we have a big loop and therefore I can now convert this block diagram into a signal flow graph if I wish. In fact it will be very easy to convert it into signal flow graph why do not you try I will do it and you also try to convert the block diagram into signal flow graph, we have to put nodes corresponding to the various a positions and then just put transmittances on edges that joint these nodes.

So if I start with the node EA then there will be a transmittance of one to the next node for which there will be this K B omega M coming, so here is the output node omega M of course K B omega M with the minus sign. So I will put minus K B, so this one and minus K B takes care of that difference device so that is the output here but that is multiplied by one by R A. So that is the next signal which is identifiable as the armature current multiplied by K T is the next signal that can be identified as the motor torque then we have the load torque as another node.

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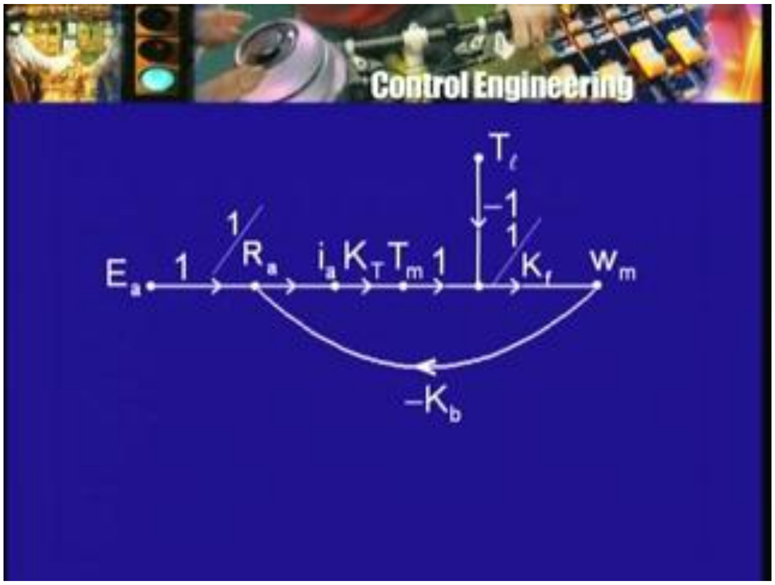

So coming from T L with a gain of minus 1 and from T M with a gain of plus 1 is the next node and the node signal here can be identified as the torque require to overcome friction. So from that then I will have 1 by K F and that is the back to the output signal omega M. So this will be a signal flow graph that results from starting with the block diagram and then transforming into the signal flow graph you can compare this signal flow graph with the signal flow graph that we are drawn earlier and find out whether 2 signal flow graphs are really the same except for redrawing the arrangement of the nodes is a little different but the signal flow graphs are the same or they are not the same. Of course the nodes E A and T L appear in both the diagrams the nodes omega M and I A appear in both the diagrams.

Now I can apply Mason's rule to this signal flow graph which is also correct and I have obtained it from the block diagram to get an expression for omega M in terms of E A and T L and of course I should get the same expression. what is the delta for this signal flow graph? This time how many loops are there is only one loop right there is only one loop. So what is the loop gain simply take the product of these terms 1 by R A into K T into by K F into minus K B that is the loop gain since there is only loop the denominator delta is very is easy to write it simply 1 minus the loop gain.

So delta will be equal to 1 minus but there is this minus sign on this transmittance. So I will get plus and I will have K T, K T into K B divided by R A into K F. So that will be the delta, what is the forward path from say E A to omega M forward path from say E A to omega M is the straight path that is only one forward path the loop touches that forward path therefore the numerator will be only the forward path gain which is 1 by R A into K T into 1 by K F and so with this we are ready to write down the coefficient that multiplies E A in the expression for omega M similarly, the expression that multiplies T L and you can do this and check that it agrees with the result that we had got earlier. It should not be different if it is different then we have made a mistake somewhere and therefore one should go back and check each and every step of our argument.

Now this is for the system without feedback now what if I have feedback then what is going to happen. If I have feedback now the armature voltage is not being directly applied but is produced as a result of that motor generator set and therefore we are represent it by the represented by the gain K A the signal that is input to that block K A. We called E and that E was difference between a reference voltage E R and the feedback voltage K tacho generator omega M. So what I will have to do is then on top of this signal flow graph I will have to add the whatever that is required to the represent what additional thing we are doing or if I go back to the block diagram I will have to add the blocks the represent this feedback action.

So if I do with the block then what is the feedback action well E R is the reference signal then there this difference device plus minus as usual the input to that comes through K tacho generator block from omega M. So that is taken care of that way so here is the difference E R minus K tacho generator omega M and we have called the signal E is amplified by K A to produce the voltage E A. So this additional thing I will put on top of the original diagram to get the complete block diagram for the system which proportional feedback arrangement. Similarly, I can draw a signal flow graph that stands for all this block diagram representation and add that to the signal flow graph and I will get the signal flow graph for the system which proportional feedback.

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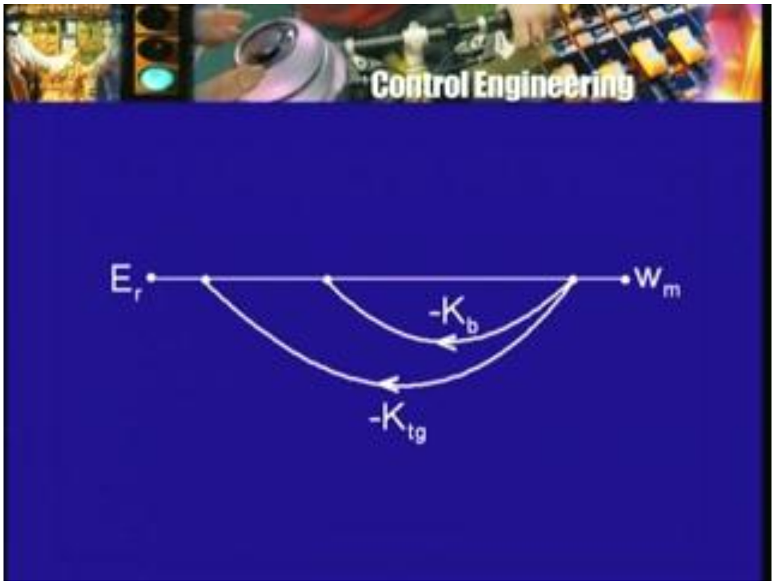

So do that and then apply Mason’s gain formula or Mason’s rule and check whether you get the same result that we had got earlier let us only note one thing that is when you draw the total block diagram or the total signal flow graph then as happened earlier 2 loops will appear. The block diagram or the new signal flow graph that we will obtain we will have 2 loops so I will just show them very schematically like this there is one loop and then there is one more loop, one of the loops goes from omega M through a transmittance minus KB and that is the back EMF loop so to speak the other goes from omega M through minus K TG that is the explicit actual physical feedback signal, the tacho generator voltage output and so we have a block diagram or we have signal flow graph in which we have 2 loops. I told you earlier that in many cases the control system arrangement will result not in just one loop but 2 loops. But in this case this loop that appears to come because of this K B is not a physical loop, there is no physical signal being picked up as K B omega M and connected to some difference device at all.

So this loop is not something physical, it is something only conceptual or in terms of signals or equations or transfer functions eventually the other loop is a physical loop in the sense there is the tacho generator mounted on the motor shaft and you connect the output of the armature of that tacho generator to this difference device. There is an actual physical connection K tacho generator omega M is an actual physical signal K B omega M is not an actual physical signal, K B omega M is not an actual physical signal that is measured and then connected to some device whatsoever so our system still has only one real feedback loop although on the block diagram or on the signal flow graph 2 loops do appear. Therefore you might think of feedback being used in 2 places but of these one place is just the action of the motor itself that is the way the DC motor runs the moment it runs because of torque it also produces back EMF.

So in fact as I said long time ago and all of you should know as electrical engineers that the motor action and the generator action go on simultaneously. A conductor moving in a magnetic field produces voltage a conductor in a magnetic field produces force and therefore can result in motion and so motor is also generator simultaneously or generator is also simultaneously a motor and therefore we have to always think of these 2 equations together the voltage equation that looks at the voltage or the EMF aspect and the torque equation that looks at the mechanical aspect of the electromechanical system that a DC motor is.