Experimental Methods in Fluid Mechanics

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Transient response of thermal system, Thermocouple compensation, high speed flow Contd

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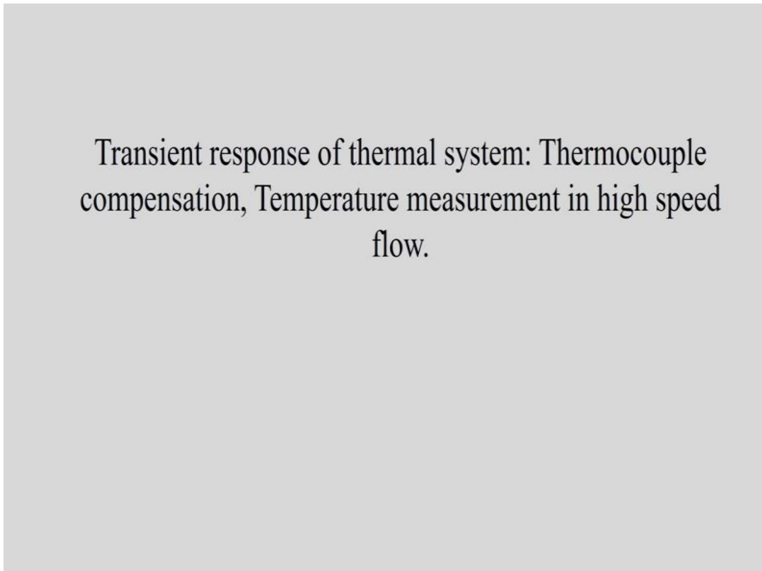

Good afternoon, we will continue our discussion on experimental methods in fluid mechanics and today we will try to discuss about the thermocouple compensation. In fact, if you try to recall that we have started our discussion on the transient response of the thermal systems and we have tried to model we have tried to, you know, you know, represent the response characteristics of a thermal system, taking an example and in continuation of that we will see today, what is thermocouple compensation?

Why do we need to study the thermocouple compensation? And what are the different you know, methods available for the compensation of the thermocouple?

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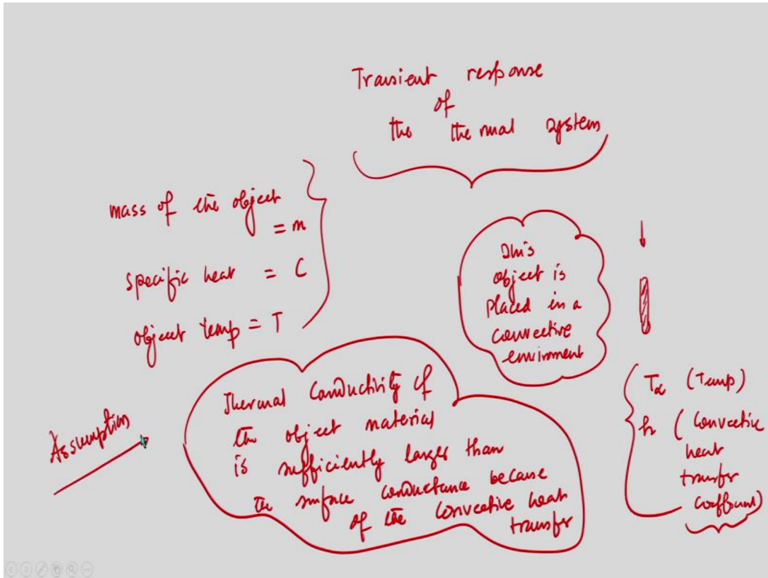

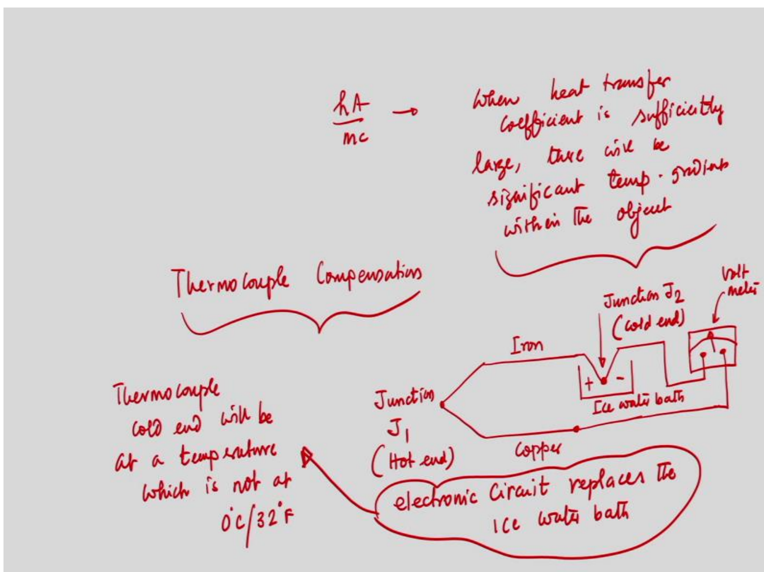

So, you know, if we try to recall that transient response of the thermal system what is that? In fact, we have seen that say we have one object and the object is placed in a convective environment So, this object is placed. So, this object is placed in convective environment. Then if we have placed this.

Say mass of the object is m, then specific heat is C, and this object is placed suddenly in R convective environment, environment and t infinity is the temperature of the convective, convective environment and h is the convective heat transfer coefficient. So, these are the object specification that is mass of the object is given by m specifically heat is given by C and the object is placed in a convective environment, where temperature is t infinity and heat capacity are in specific capacities sorry convective heat transfer coefficient is h and temperatures t infinity.

So, this is temperature and this is convective heat transfer coefficient. If we can, if we can rather our objective would be to cast now that to model this system mathematically, so that we can study the transient response that means, if we place the object in the convective environment where temperatures is t infinity, and object temperature is T. So, these are the environment characteristics and these are the object features.

Now, we can assume that the, you know thermal conductivity of the object material is sufficiently larger than the larger than the surface conduction. Surface conduction because of the surface conduction, because of the convective heat transfer. So, if we consider this assumption. So, this is one assumption, then we can now model this system that means, in a convective environment 1 object is suddenly placed, then we can write the equation that is hA T minus T infinity or T infinity minus T that is mc, that is m into C into dT by d small t.

So, this is that means, if we place the object in that environment, the temperature will be transferred from the environment into the object and this is the equation. So, what is, what will be the time required for which you know objective temperature of the object and temperature of the environment will be in equilibrium.

So, these equation in fact, this equation we have studied in the last, you know, class and we have tried to obtain the solution of this equation and the solution of this equation is T minus T infinity divided by T naught minus T infinity that equal to e power minus hA you know by m C into small t, where t naught is the temperature of the object at time t equal to 0.

So, this is the initial condition and we have obtained this expression. If we try to recall that this hA by m into C this we have tried to, you know express this quantity by another term say this is k. Now, what we can see from this expression that for a particular material C is constant conductive heat transfer will be constant mass if we fix the shape of the object then it will be constant.

So, what we can do, we can increase the area or decrease the area and that is what we have established in the last class, the effect of area the temperature you know, if the object size is reduced, then we can that is good for the system that is what we have drive in the last lecture.

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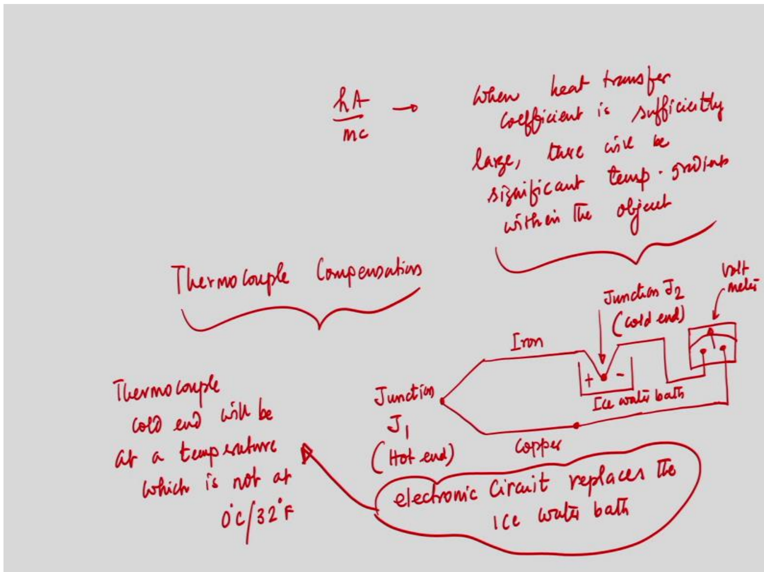

Now, so what we can see from this expression that you know that means, when so if I go to the next slide, that means hA by mC So, that means when heat transfer coefficient is you know sufficiently large there will be you know, you know significant temperature gradient within the object.

So, this also has an important effect. So, what you can see from this expression is that the transient response characteristics of a particular system if the object is now thermometers, so if we now go back to my previous slide, if this object is thermometer and we are placing we are inserting this thermometer in our fluidic environment and there is a flow of fluid. So, we can measure the temperature.

Now, depending upon the conductivity mass, conductivity heat transfer coefficient and also the other things that means the transient response characteristics will depend upon many you know parameters and that is what we have, you know established in the last lecture. So, today in continuation of that would like to see the thermocouple compensation.

So, that means they have understood we have tried to, you know, in fact today I have tried to you know, recapitulate what we have established in the last lecture and we have understood that there are a few factors which influence the transient response characteristics of a particular system.

Now, question is that what is thermocouple compensation. So, this is an important that before we go to discuss about the thermocouple compensation, it is important to know why these thermocouple compensation is important? And what is that? Why need to compensate? And what do we need to compensate?

That means, when you talk about thermocouple compensation, what factors need to compensate? And why you need to compensate? So, these two important questions to try to address in this class and then we will try to see if we need to compensate our thermocouple when thermocouple is measuring temperature in an environment, where there is a step change in temperature input.

So, to address these 2 questions, if we try to recall, rather we will try, we will try now to refresh in the schematic of a thermocouple and we will see differently that we will see that the role of thermocouple and then from there, we will try to understand what, what is that important aspect? What is that important feature of a thermocouple you need to compensate. So, if you try to, you know, draw the schematic.

So, this is one junction, junction say J2, this is voltmeter, this is ice water bath and this is junction J1 and this is hot end and this is cold end. So, this is you know we have discussed in 1 of my previous lectures that the, you know there are 3 important effects and these effects can be exploited, exploited to develop the temperature measured measuring instruments.

So, now this thermocouple if you know now, look at the schematic there are 2 ends, there is you know there are 2 different that is iron and copper and we have we know that, you know there are 2 different junctions, that is junction 1 that is hot end another junction that is J2 that is cool end and that junction is in the ice water bath.

And so, what is the you know basic you know principle of the thermocouple in this context, I would like to give you an example, if we had to blow air through a straw, then we, we can we can understand that, there will be a flow of fluid flow of air from high pressure end to the low pressure end.

Now, the similar concept can be used to explain the principle of the thermocouple when it measures temperature, so there is 2 different ends 1 is hot end and another is the cold end, now hot end the temperature is high where and because of this higher temperature, electrons will be excited and there will be you know I can say you know, you know speedy movement of the electrons. So, the movement that is another is another end is the cool end, where electron movements are very low.

So, the electrons will now move from hot end to the cold end and there will be a flow of current. So, that is now connected to the voltmeter. So, we can measure the EMF that is the, I mean electromotive force. Now, that means that is a civet effect. So, that means, when electrons are excited at the hot end, and because of this excitation higher energy electrons will now move towards the cool end.

Because at the cold end, the electrons movement is very slow. They are you know, closely, I mean, in space. Now, question is we can measure there so because of this movement of the electron there will be flow of current and we can measure the voltage. Now, knowing the voltage from the voltmeter we can correlate the temperature at the hot end and that is the basic principle of the thermocouple.

Now, do we really get the absolute temperature at the hot end during the thermocouple? My answer is no, because when we use thermocouple, we essentially measure the difference in temperature that means, we measure the temperature between the hot and cold end and that is why it is mandatory that if we somehow can place the cold end at the ice water bath, and if we can maintain the temperature of the cold end at 0 degrees Celsius temperature or 32 degrees Fahrenheit, then by knowing the voltage we can correlate the temperature of the hot end.

So, that means to know the temperature at the hot end we need to know the voltage as well as the temperature on the cool end and cold end temperature is known since it is placed that is that junction J2 is placed in a in an ice water bath. So, what will happen, this is the you know, laboratical set up, but thermocouples are most, most of the time rather I can say thermocouples are used in many real life applications in that case, the thermocouple will be taken from the lab and it will be you know, placed in defined temperature sensor.

In that case, it is very difficult to have a cold water I mean ice water bath and to maintain the cold end temperature at 0 degrees Celsius. So, what I would like to say that this schematic which I have drawn here, that is you know, I mean what is done in the laboratory, laboratory scale experiment, but when you take this thermocouple from the laboratory to defined temperature sensor for measuring temperature in different real life applications then it is very difficult to maintain the temperature of the cold end will remain at 0 degrees Celsius.

Now, if that temperature I mean we will not be able to maintain the temperature at 0 degrees Celsius temperature. Instead, we need to include another electronic circuit to, to replace this cold water, cold end and when we are including another electronic circuit that means, we are introducing an error that means, the voltage we are measuring between these 2 ends cold, hot end and cold end that measurement in voltage you will essentially give us the temperature and that correlation is available in table.

But, in any case if we remove this ice water bath and if we try to mimic this end using another electronic circuit, we will be able to maintain the temperature at 0 degree Celsius that is true. On the other hand, the voters that we will now measure that will lead to an error in the thermocouple voltage So, we need to now compensate that compensate because of this replacement of this ice water bath, we need to compensate and that is what is known as cold junction, you know compensation of the thermocouple.

So, that is that means thermocouple you know cold end will be at a temperature which is not at 0 degrees Celsius or 32 degrees Fahrenheit. If that is the case, then what will happen that means, we need to, that is very true for the real life applications. We cannot maintain, we cannot ensure the temperature of the cold end will be at 0 degrees Celsius temperature.

If that is the case then electronic circuit that means, I can say that electronic circuit replaces the ice water bath and because of that, it is very difficult to maintain that the temperature thermocouple cold end temperature will be at a temperature which is not at 0 degree Celsius temperature. So, now we have understood at least that why we need to go for compensation and what is an important aspect what is an important you know, I can say factor that should be compensated.

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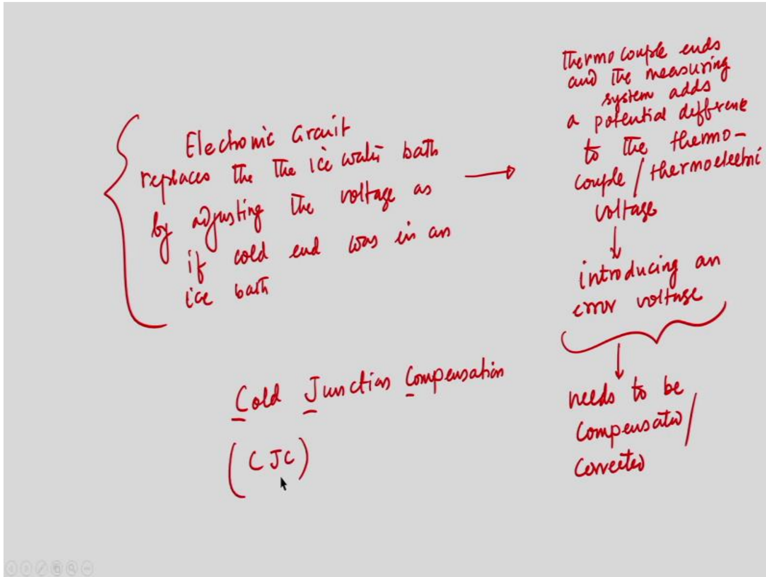

So, you know that electronic circuit as I wrote in the previous slide, electronic circuit replaces the ice water bath by adjusting, by how? By adjusting the voltage as if cold end was in an ice bath. So, this is the case that means, since it is not possible to maintain to keep the ice water bath in real life applications, we should have an electronic circuit and that will replace the cold ice water bath by adjusting the voltage and as if the cold, cold end was in the ice bath.

When we are doing so, this you know in this aspect that means, when you are you know including when you are including on electronic circuit in the thermocouple that that means when the thermocouple is now integrated with this electronic circuit is essentially to replace the cold water bath, what we are doing, we are introducing, introducing a potential difference.

Rather I can say we are introducing we are, I mean, the thermocouple ends and the measuring system adds a, you know, potential difference, difference to the potential difference to the thermocouple voltage or thermal electrical thermoelectric voltage, and this issue this aspect introducing an error voltage and this error voltage needs to be compensated needs to be compensated corrected.

So, I hope you have understood that what is an important factor that should be corrected or compensated and now we will go, we will, you know, go to see another move to see what are the different methods available to compensate that error voltage.

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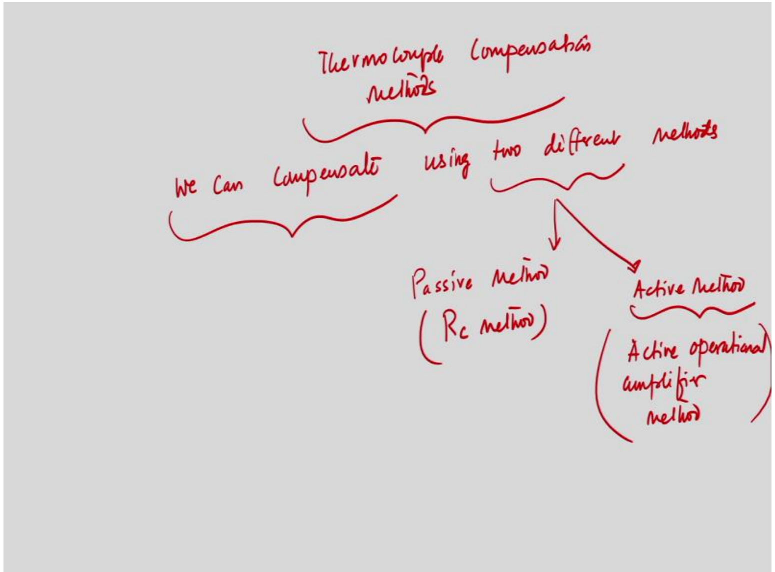

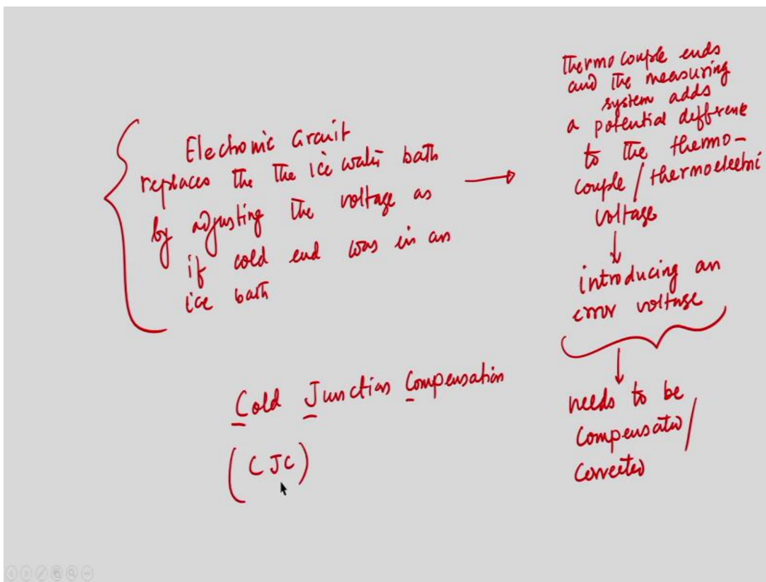

So, now, we will move to see the thermocouple compensation methods and this is sometimes known as cold junction compensation. That is CJC, that is CJC what is known as Cold Junction Compensation. So, next we will discuss about the different methods which are available for the thermocouple compensation.

So, I mean, we will discuss, I mean 1 important method which is used to compensate this, you know that error, which is introduced, and we will discuss this method taking an example where we have seen where we will see that thermocouple is used to measure temperature, rather is to measure or you know temperature where there is a step change.

That means, what I would like to see, we will discuss an important method, which is used for the compensation and we will discuss this method taking an example where thermocouple is considered to measure temperature in an in environment where there is a step change effect so we will discuss now. So, if we now discuss that thermocouple compensation using step change in with we know step change environment step change temperature environment.

So, as I said that we can compensate this using 2 important methods using 2 different methods. One is you known as passive method and other is known as active method. Passive method or Rc method. That is, essentially need to introduce an electronic circuit and we will see how we can really compensate that and that is nothing but resistance capacitance method. So, Rc method Rc circuit we should include an active operational amplifier method which is active method active operational amplifier method.

So, these 2 methods are typically used to compensate that error, but today we will you know, focus our attention rather we will, you know, restrict our discussion on the passive method. So, that means today we will discuss this compensation thermocouple compensation issue with the passive method and of course, taking an example where thermocouple is placed to measure temperature in an environment where there is a step change, you know, temperature effect.

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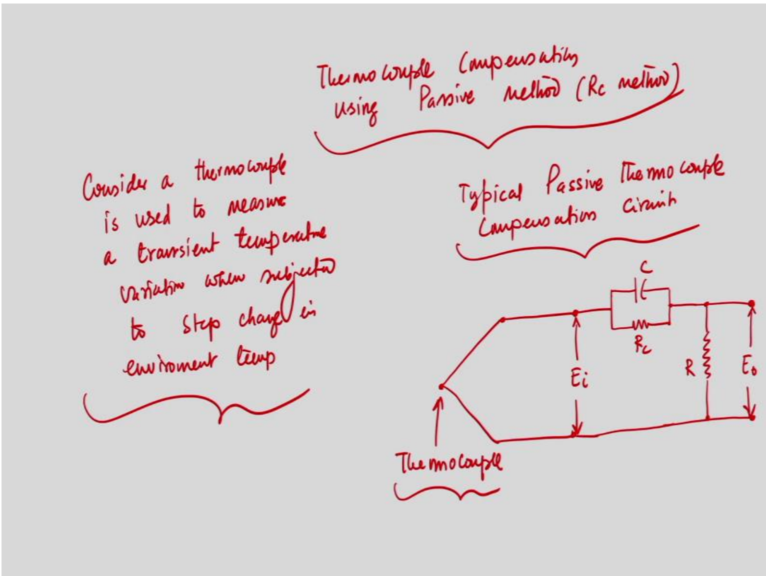

So, we will discuss this you know, the schematic depiction, but you know that thermocouple compensation using passive method that is Rc method, and further we will discuss suppose thermocouple then we considered a thermocouple you know is used to measure you know, our transient temperature variation when subjected to step change in environment temperature. That is what we will do today.

So, but of course, our towards this, you know towards the end of this exercise we will try to you know, discuss about the advantages of using this method and of course, what are the disadvantages of course, these methods will be discussed and we also will try to discuss the advantage of the active method. So, now we will discuss these taking an example. So, we need to know what does you know we will discuss using a schematic depiction.

So, this active method that is what I was telling this active method you know thermocouple compensation, this that is Rc method and you know we will show the typical you know, passive thermocouple compensation circuit. So, if we try to draw the schematic in fact we have drawn the schematic in the previous slides now. So, this is the input voltage, say Ei and then this is the output voltage E naught and this is on resistance R and this is Rc and this is capacitance C and this is the thermocouple. So, the typical passive thermocouple competition circuit is shown here. This Ei now I am writing what is the Ei? What is E naught? And what is R?

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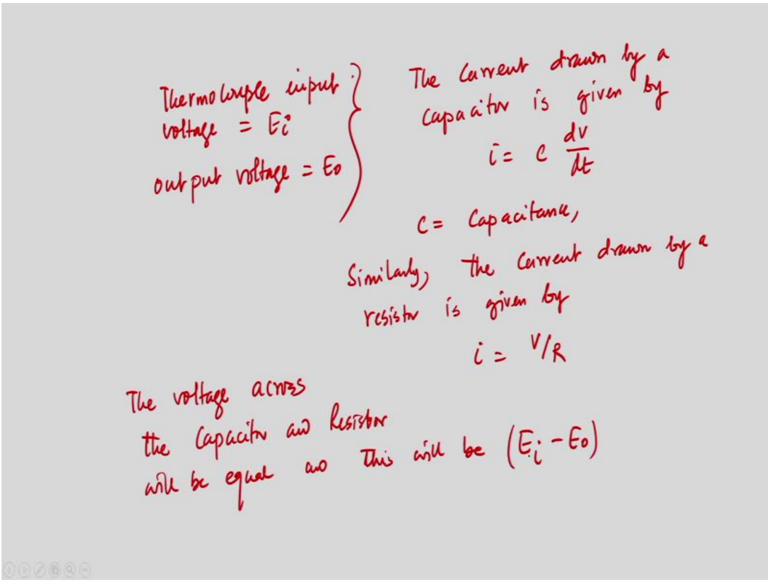

So, if I write this, you know, thermocouple input, thermocouple input voltage is Ei, output voltage is E naught. So, now if I so, that means, the thermocouple input voltages Ei and output voltages E naught. If we now do the you know, exercise then you can write that you know, from the schematic the current drawn by the by capacitor.

That is shown in the circuit is given by, you know i equal to C into dV by dt, where C is the capacitance of the circuit. Similarly, we can write the current drawn by resistor is given by i equal to V by R. Now, if we go to the previous slide, so what you can see the voltage across the you know register Rc and capacitors will be equal. So, the voltage across the resistance Rc and capacitor will be equal. So, if I write this the voltage across the capacitor and resistor, you know will be equal and will be equal and this will be Ei minus E naught that is input minus output voltage.

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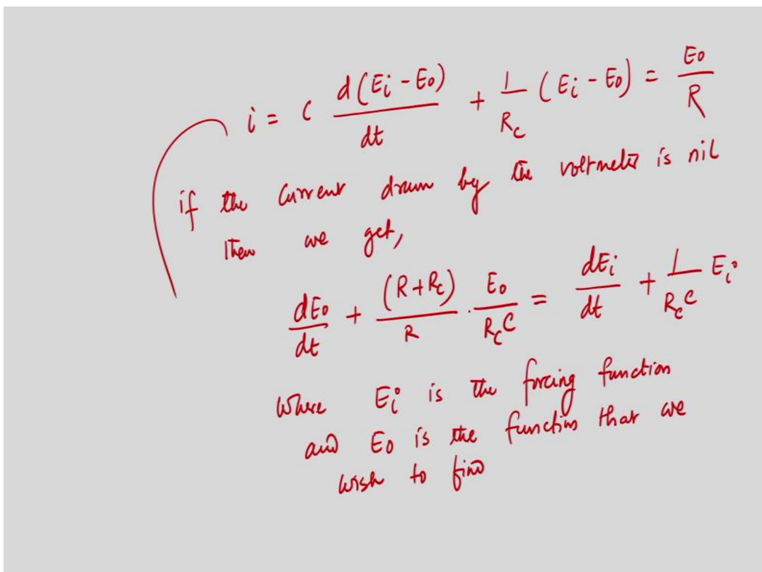

So, we can write that I equal to C into d Ei minus E naught divided by dt plus 1 upon Rc into Ei minus E naught will be equal to E naught upon R. Now, if the current drawn by the voltmeter is nil, then we get another equation and that equation if I right we will get d E naught dt plus R plus Rc into you know, I can say R into E naught divided by Rc into C equal to dEi by dt plus 1 upon Rc into C into Ei, where Ei is the forcing function and E naught is the function that we wish to find.

So, we have now model the system, we have you know, arrived at the you know situation where we need to solve this equation where Ei is the forcing function and E naught is the function that is to find. So, that means as I said that I mean that, that error you know voltage. So, this output voltage that we need to find out and, and that is that will be obtained using this equation.

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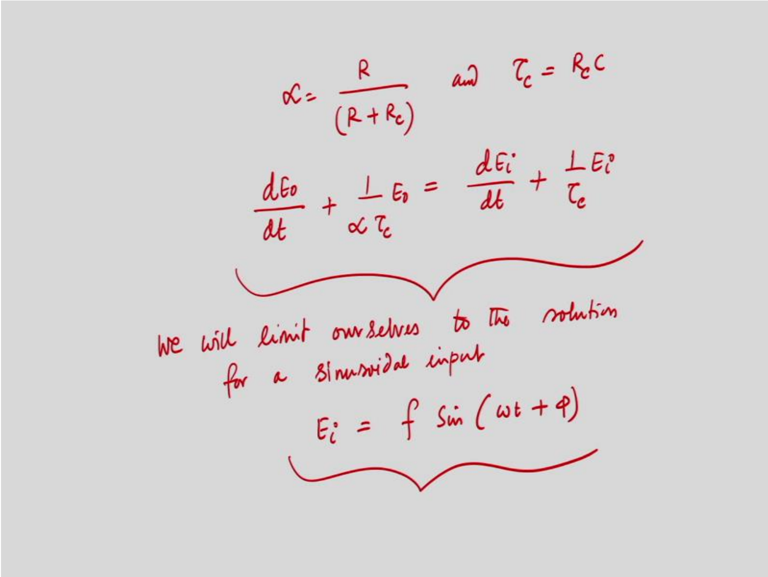

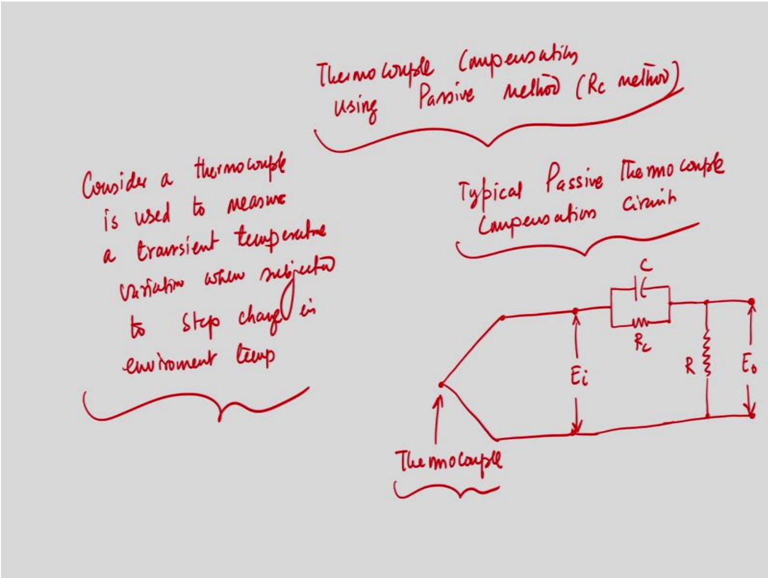

Now, we can simplify this equation, we can simplify we, we can simplify this equation if we now consider that alpha equal to R upon R plus Rc and tau C equal to Rc into C, then we are doing this for the sake of simplicity in the analysis, then we can write the equation will be dE naught dt plus 1 upon alpha tau C into E naught will be equal to dEi by dt plus 1 upon tau C into Ei.

So, this is the equation we need to solve where Ei is the forcing function and E naught is the function that we wish to measure. Now, we limit ourselves to the solution I am writing we will limit ourselves to the solution for a sinusoidal input, if we can recall that in the beginning of this exercise, we have assume that we are interested in modeling the thermal response, you know of the thermocouple, where thermocouple is placed in an environment which is subjected to stem change environment temperature that is means the forcing function is sinusoidal that is step change.

So, now, if we consider that a sinusoidal input that is, you know, Ei that is f sine omega t plus phi if we consider this step change input that thermocouple would be in a position to measure the temperature, we would like to see the thermal response characteristics of the thermocouple where input is sinusoidal.

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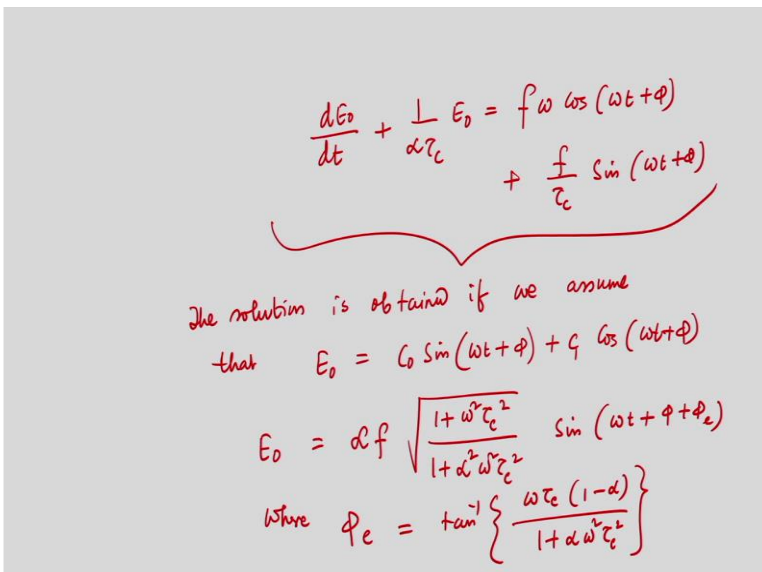

Now, considering Ei we can you know write the equation again that to be dE naught dt, E naught we wish to measure is to find that is our final objective now, plus 1 upon alpha tau C into E naught that will be equal to f omega cos omega cos omega t plus phi. If we write plus f by tau C into sine omega t plus phi.

So, this equation we have to solve and the solution is obtained, the solution is obtained if we assume that is E naught is equal to C naught sine omega t plus phi plus C1 cos omega t plus phi, and I am not going to write the intermediate step. In fact, if we go ahead with some algebraic manipulations and rearrangement, then ultimately we will get the final solution E naught that will be equal to, you know, we need to find out C1 and C naught and then ultimately we will get alpha f root of 1 plus omega square tau C square divided by 1 plus alpha square omega square tau C square into sine omega t plus phi plus phi E where phi e will be equal to tan inverse omega into tau C 1 minus alpha divided by 1 plus alpha omega square tau C square.

So, this is the solution and that is what we wanted to find out. So, we got this expression. Now, that is the output voltage and that is very important to know and that because knowing this parameter we can, I mean compensate. So, now, question is we will see the characteristics and that is what we have started that means, we have started our discussion that means, we need to know the thermal response characteristics of the thermocouple after compensating this air voltage using electronic circuit and what will be the characteristics and then what, what will be the you know important features, you know, that means after you know, having adapter.

So, you know it will we will try to you know, graphically show the variation of a few important parameters and from there we will try to draw a few important conclusions.

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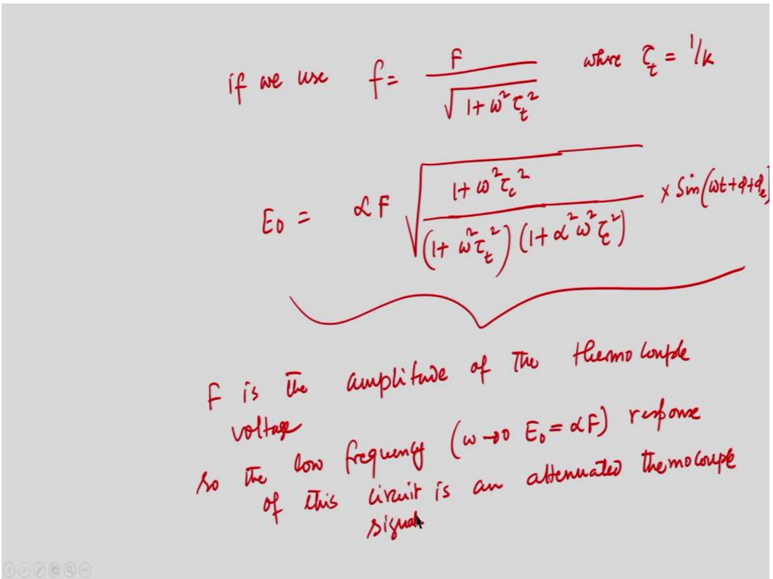

So, now what we can say that I mean, if we use, if we use f equal to capital F divided by root of 1 plus omega square into tau t square, where tau t equal to 1 upon k. That is with response of the thermocouple we obtain if we use this then we can obtain E naught equal to alpha into capital F root of 1 plus omega square tau C square divided by in fact, if I go to the previous slide, omega square plus tau C square divided by 1 plus omega square into tau t square into 1 plus alpha square on omega square into tau C square into sine omega t plus phi, plus phi.

So, this is, you know the final solution, we can write where we have a represented small f by these quantities. I mean f by this where tau t is equal to 1 by k the thermocouple the response of a thermocouple of a thermocouple. So, that means, this we have done essentially for the simplicity and analysis. Now, f is the amplitude, this f is the amplitude, if you try to recall of the thermocouple voltage and that means, so the low frequency that is omega tends to 0, E naught will be equal to alpha into f response, low frequency response of the circuit is an attenuated thermocouple signal.

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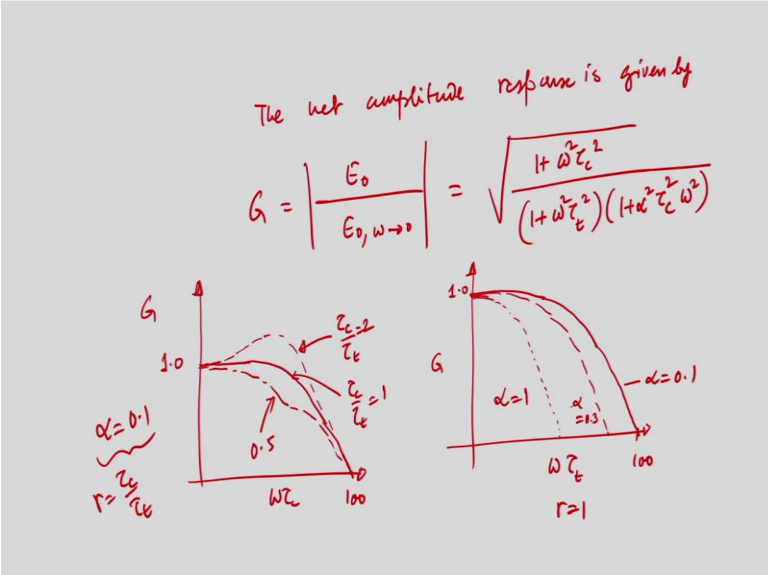

Not only that, the net amplitude response is given by G equal to E naught by E naught when omega tends to 0 then we can write that is nothing but 1 plus omega square tau C square divided by 1 plus omega square tau t square into 1 plus alpha square tau C square into omega square. So, this is the net amplitude. Now, if I try to you know draw a few I mean the variation that is what you need to know.

Now I will try to draw the G versus omega into tau t, this is omega into tau t. Now, G will be equal to 1, of course when this is near about 100 and this is 100, this is 1 this is 1.0, this is 1.0 and this is G, this is G, then we will get you know, profile like this. So, if we now consider tau C by tau t and that is, if we try to recall that tau C by tau t, if we consider now tau C by tau t we will get different kind of profile.

So, this is tau C by tau t that equal to 2. This is for tau C by tau t equal to 1 and this is for 0.5. Similarly, if we try to draw, we will get you know profile like this, this is for the 1 this is alpha, this is for the alpha that alpha. So, this is for you know alpha equal to 0 point typical behavior I am trying to show, the effect of R that is R equal to tau C by tau t and this is for R equal to 1, but for different values of alpha that is alpha equal to you know 1 if we.

So, alpha this is alpha equal to 1. Now, this is alpha equal to 0.1, again this is the, you know graphical plot. So, this is alpha equal to 1 and this is alpha equal to 0.3. So, what we can see from the figure is that, I will try to draw conclusion. So, this is the figure what you can see what you can see that is very important ultimately to draw conclusion.

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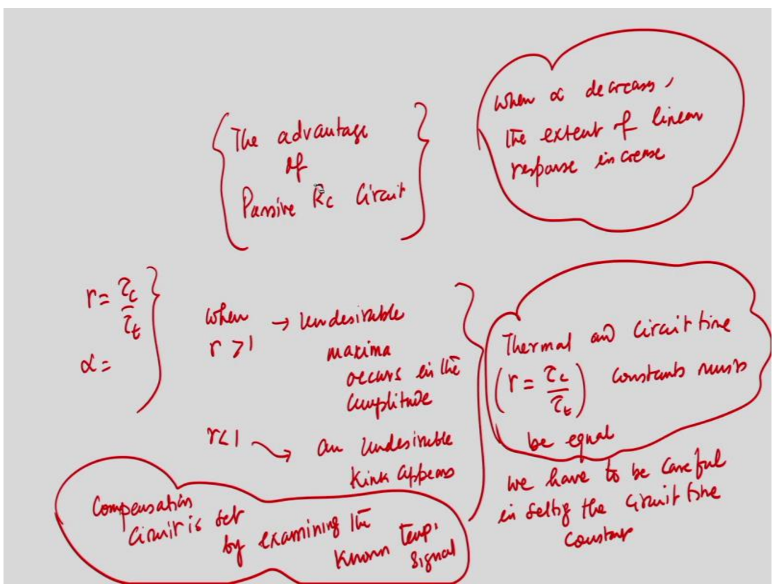

So, the advantage of the passive Rc circuit what are the advantages you can see from the circuit is that it is very important that at least what we have, you know, drawn from the schematic is that if we try to look at these schematic, schematic that for R equal to tau C by tau t and alpha, these 2 parameter we have changed and what we can see that when R is greater than 1, then undesirable maxima occurs in the amplitude.

When r less than 1 then an undesirable, an undesirable kink appears. So, if we go to the previous slide, we can see when, when r less than 1.5 and undesirable kink is appearing and when greater than 1 and undesirable maxima occurs. That, that means, what it is true that the thermal and this observations you know, suggest that thermal and circuit time that is r tau C by tau t thermal and circuit time constants must be equal, this is important that are very important and we have seen that when alpha decreases and finally you can write that when alpha decreases the extent of linear response increases.

So, this is 1 important point from the figure itself, when alpha increases, when alpha, alpha decreases the response of the extent of linear response will increase. So, that means, from this 2 variation I can say the we have to be careful. So, this is another important point, we have to be careful in setting the circuit time constant. That means, we need we are trying to compensate for that we should be careful, this circuit time constant that means, compensation circuit is set that means compensation circuit is set by examining by examining the non temperature signal.

So, this is last and important conclusion of this analysis is that when we are planning to design a circuit, compensation circuit, circuit will be designed will be set by examining the known temperature signal that is very important. Finally, in this context we can you know discuss that advantage of the passive Rc circuit is that, what are the different advantage?

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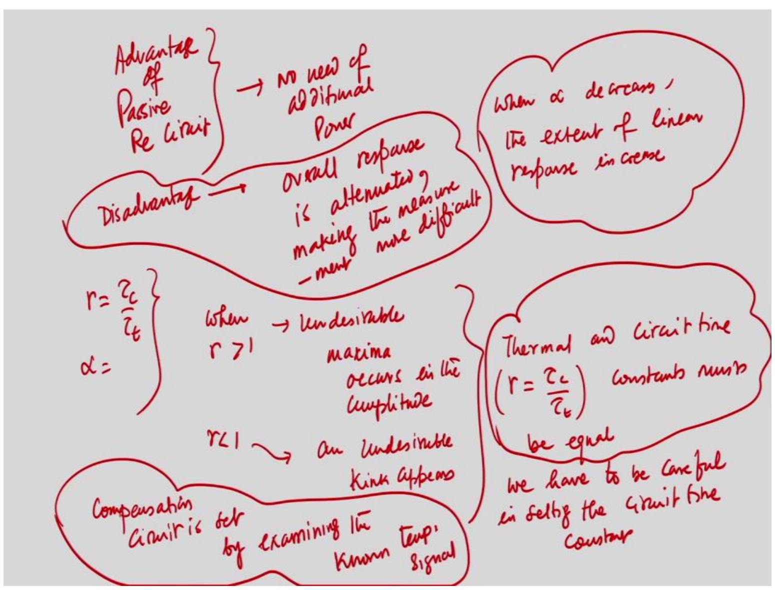

I am writing. In fact, I am writing over here that advantage of the passive Rc circuit. So, advantage of passive Rc circuit. What is this? That no need of additional power. However, there is an important disadvantage, what is the disadvantage? That overall response is attenuated and which making the measurement difficult, more difficult. So, this is the disadvantage that of the passive Rc circuit and advantage is that no additional power is required or to be supplied.

So, to summarize today's discussion, we have recapitulated the thermal response characteristics modeling equation from there we have try to understand there are several factors issues, which are important to consider to what the thermal response characteristics that that thermal response of a system will depends upon so many factors and that is what we have identified.

Then, we have tried to understand what you know a thermocouple, you know, when we when we use a thermocouple then what is an important factor which is which we need to compensate and in fact, we have identified the factor need to compensate and if you would like to compensate that factor, what are the different methods available?

Finally, by identifying the basic of the operation of the thermocouple we have understood that we have identified the factor which you need to compensate and then have discussed there are discussed that there are 2 important methods available to for the compensation one is the passive Rc circuit which is included in the thermocouple you know, circuit and another is the active method we have focused our discussion today by taking an example hired thermocouple is placed in an environment where there is a you know step change temperature input.

That is we have you know discussed the passive method considering an example, where the forcing function is sinusoidal that means thermocouple is allowed to measure temperature in an environment where there is steps in input and from the mathematical exercise we have understood what are the different issues we need to consider while designing the circuit to be integrated the thermocouple and finally, you have seen what are the what is the advantage and disadvantage of using this you know Rc circuit. So, with this, I stopped my discussion today and we will continue our discussion in the next class. Thank you.