Modelling and Simulation of Dynamic Systems
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Lecture - 9
Methods of drawing bond models Mechanical Systems

Good Morning, I welcome you all in today's lecture of the course modeling and simulation of the dynamic system. Today, we are going to see how we can draw the bond graph model of any mechanical system.

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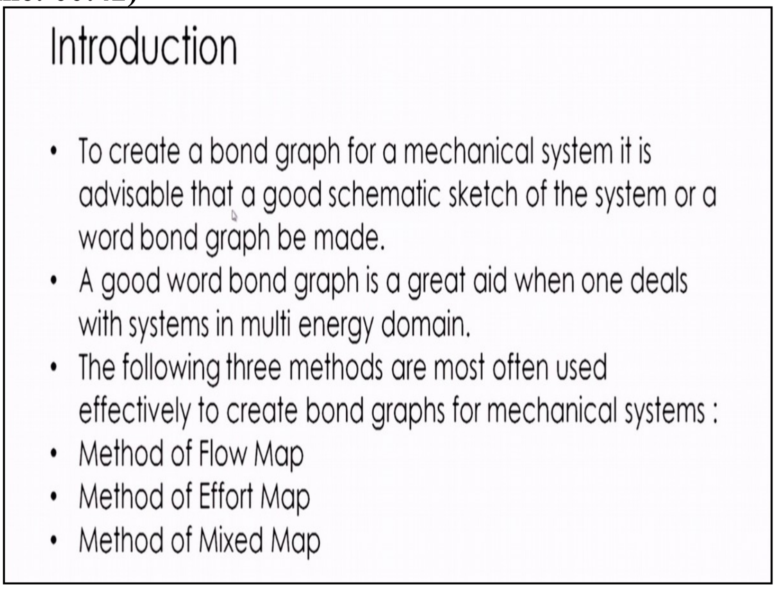

So, to create a bond graph model of a mechanical system it is advisable to have a good schematic diagram of the mechanical system, or we can have the word bond graph of mechanical system. Word bond graph basically is a way of representing the various system sub components and how the power flows from one component to and another component.

So, if you are able to draw the word bond graph of the system then also, it helps us in creating the bond graph of the system. A good word bond graph is great aid when we deal with system which is there in the multi energy domain. Now, there are three methods which can be used to create bond graph for mechanical system.

This method of flow map, method of effort map and method of mixed map. In the first method that is, method of flow map we basically track the flows and with the help of that tracking of the flows we are able to draw the bond graph. Likewise, in the method of effort map we keep track the efforts and with the help of that, we are able to draw the bond graph and incase of method of mixed map we combine both the effort map and flow map approaches to draw the bond graph of the system. We will see one by one. Let us have a method of flow map. Now, in this method of flow map, the single port Mechanical c or r element may be attached to a 1 junction where the relative velocity of the ends of these elements is available.

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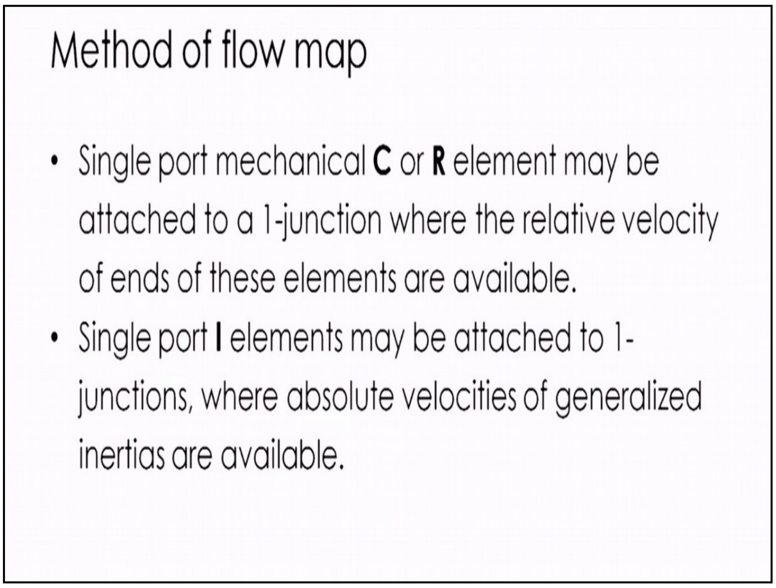

So, for example if, I say a spring and these are the two ends of the spring then I can make one junction, where the relative velocity between this end and this end is available and there I can attach a c element. Likewise, I can do with the r element, so the single port mechanical c or r elements may be attached to a1 junction where the relative velocity of the ends of these elements are available so say if this is your x1 dot and this is say ax2 dot.

Then basically here this will be x1dot-x2dot. So, this is how we can do that, then the single port I element may be attached to 1 junction where absolute velocities of generalized inertia are available. So, as you know that Newton's law is applicable only with respect to the inertial frame. So, we attached the I element to only that port were the absolutely velocity is available. So lets look at the general methodology for creating a bond graph model using the flow map method.

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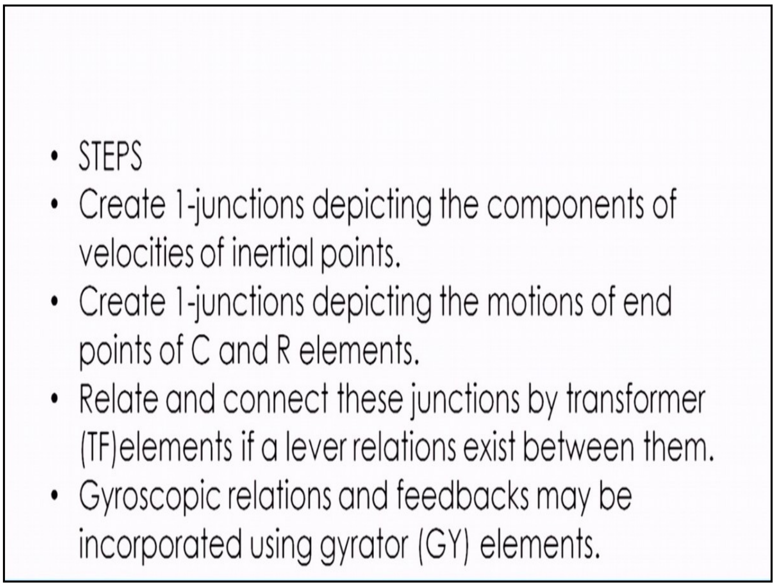

So, first of all what we do is that, we create one junction depicting the components of velocities of inertial point. So, first 1 junction is created which depicts the velocity components of velocities of the inertial point, and next we create the 1 junction depicting the motions of end points of c and r elements other than this one 1junction basically depicts the motions of end points of these c and r elements and then we can find out the difference of those end point motion and then we can attach the c and r elements there.

Now, relate and connect these one junctions by transformer element if a lever relation exists between them and if a gyroscope relation and the feedback is there then, we can use a gyrator element. So this is how we can proceed for a drawing of the bond graph model.

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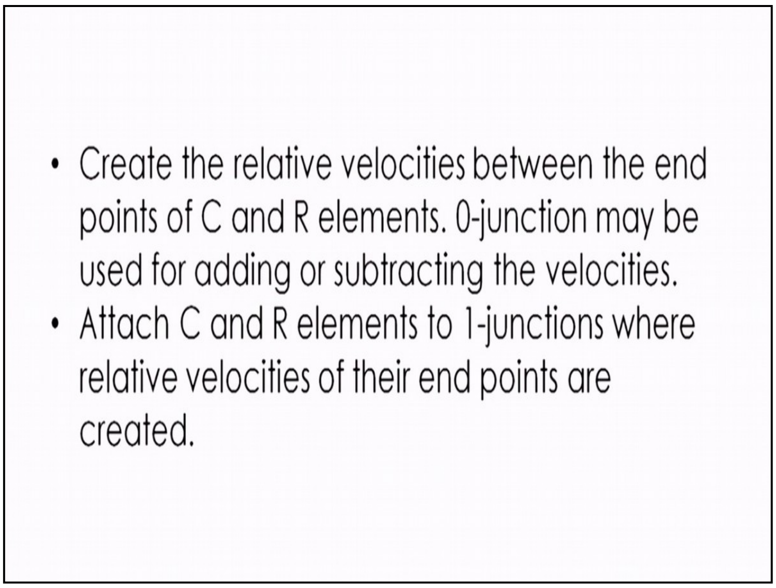

Now, create the relative velocity as I said between the end points of c and r elements by using a 0 junction as you know that the 0 junction is a constant effort junction or at the 0 junction we have the some essentials of the velocity. So depending on direction of power, we can have the addition or subtraction of velocities so that is how we create relative velocity port with the help of the 0 junction so 0 junctions may be used for adding and subtracting of the velocities.

Then attached c and r element to 1 junction where relative velocity is of their end points are created so this is how we can do it. So, we can follow this procedure to draw the bond graph or give the model the of the given mechanical system,

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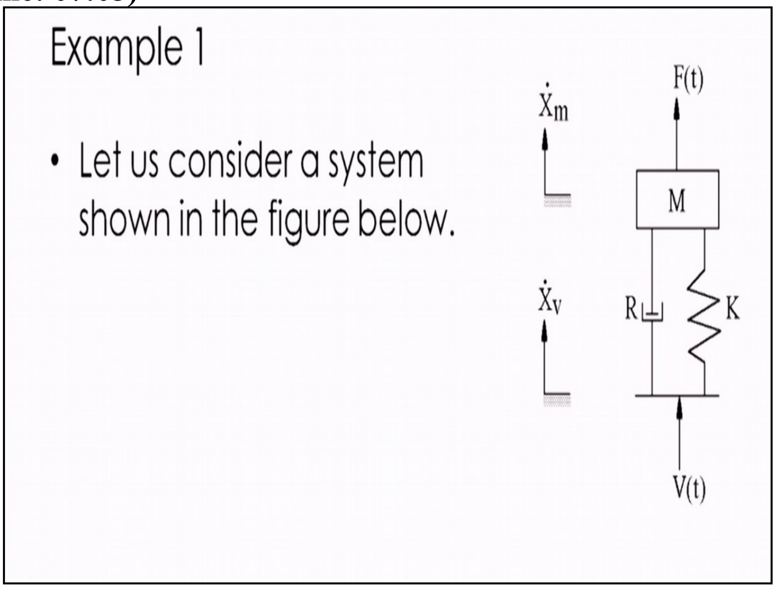

Let us explain this concept with help of say some examples. So, first I am going to take an example of spring mass system with the base subject to certain ground excitation. This may be just considered of a simple model of a car with the wheel subjected to certain excitation from the ground. so this my mechanical system and this mechanical system as I said consists of a mass a damper a spring and this mass is subjected here to say excitation ft and the ground velocity coming to this vt.

Now, here we identify the 2 coordinates here you can see that here it represents the velocity of the mass here and this velocity excitation which is coming from then the ground. So this the description of this example. Now if, I want to the draw the bond graph model for this system so what we do essentially is that,

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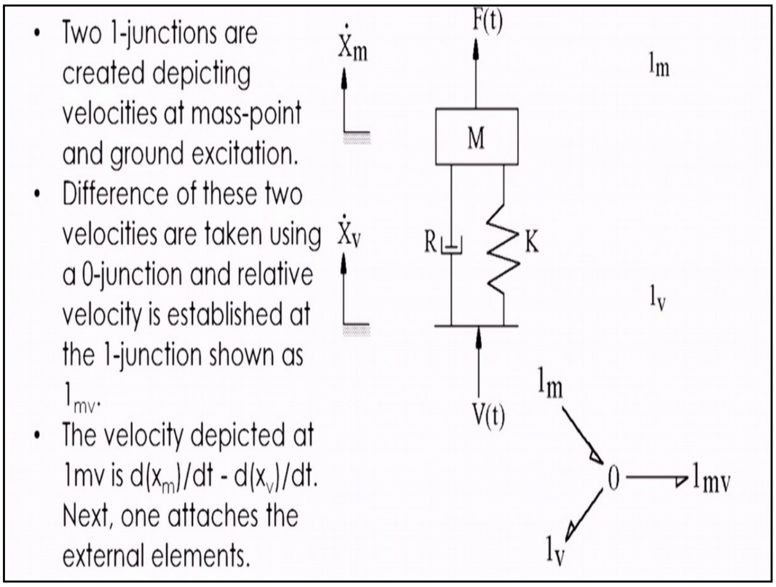

We create the two 1 junction here and these two 1 junction basically represent velocities this xm dot and this velocity xv. So, these are the two 1 junctions created depicting the velocity of the mass point and ground excitation so this actually represent the velocity of mass point and this represents the velocity of ground excitation.

Now then what do we take the different of this velocity using the 0 junction so here you can see that I establish a 0 junction here and I take a velocity different here how does this velocity difference comes basically so you can see that here this power is in power and this power is out so here if I take our law of conservation then here this velocity basically is going to equal to this velocity plus this velocity or velocity will be this velocity minus this velocity. So this is how I get this velocity and then as I said the velocity

I depicting at 1 mv basically is this velocity difference and once we get this velocity difference we can attach the spring and damper at this velocity port.

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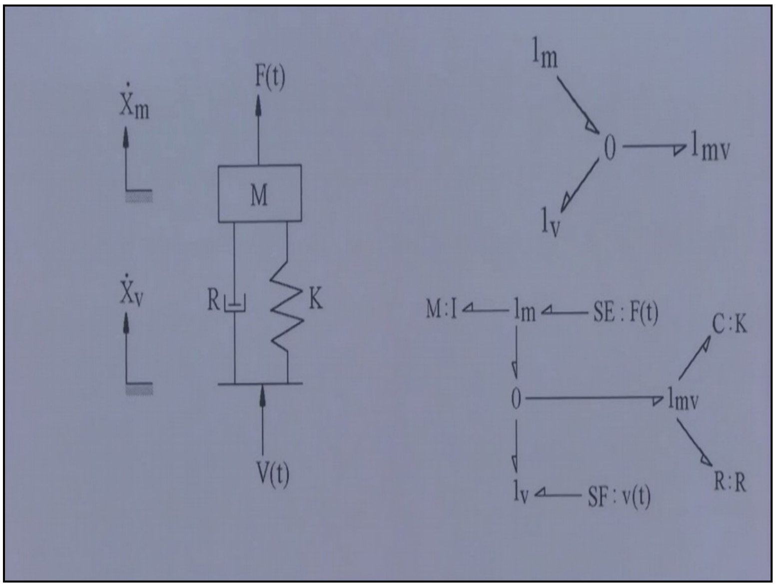

So let see how it is done here so this was the mechanical system and I have taken these two Velocity differences here and now at this 1 mv port I attach a c element and a r element so this way I do it so this is done .now you see that we had this absolute velocity port for this mass so I attach a mass here and at this port there is a force acting here.

So I attach a bond here representing the force with the help of a s c element and again here you see that at this the velocity of this port is decided by basically the ground excitation which is coming here and so I attach sf is equal to say vt the velocity here.

This way this figure represents the bond graph model of the mechanical system and of course with our usual procedure we can causal this bond graph as per the causality assignment procedure which we have seen. So I can quickly just tell you how can we causal it say this is my i this is my se i have 0 junction here then I have 1 mv port here I have 1 v port and here i have as sf vt and I attach c and r element here this represent spring and this represents a damper and this our represents mass and this is my ft.

Now, what I do first of all we a casual the sources. So, this sc this will always be giving effort and this sf and this will always be giving flow now after causaling sources let us causal the storage elements. So the i elements take efforts return flow and c elements take flow returns effort so this is how this done and now let us see the rest of the causality so here this is my 1 junction so and this i is giving flow here so here this has to return the effort so this effort here will flow here.

Now, let us come for here this flow a here so this has to be effort .so the flow and flow here this 0 junction has to be determined by someone and only this bond can determine that so let us put the effort stroke here and this is a returning flow and giving flow here and . This is 1junction so is only one bond can flow so this going to be causal like this so this way we can casual this bond graph.

Once we have the causal bond graph we can derive the system equation i which I have discussed in our previous lectures. There could be alternative ways of drawing the bond graph also and here n this alternate way we can create relative velocity in junction for individual c and r element.

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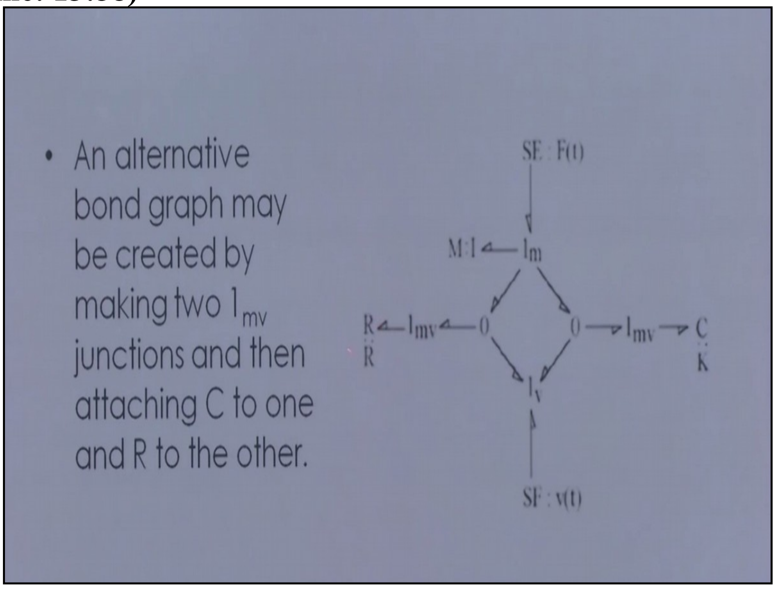

So, here you see that I create relative velocity junction for r element this is my inertial port and this is my ground excitation and i take relative velocity here and this velocity can be given to this r Similarly I create relative velocity port c here so this minus this will be going to this here I attach c elements and rest of the things. I have already explained it in my previous slide.

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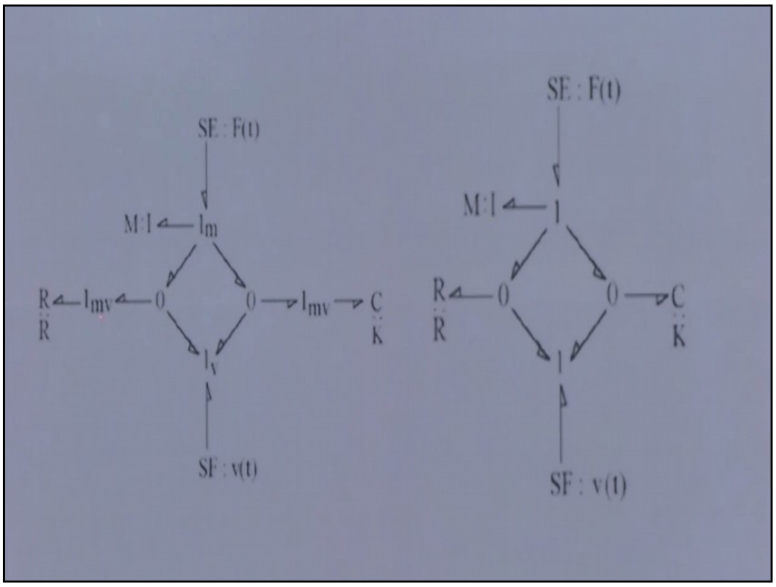

We can further simplify this bond graph here I just see that whatever power is coming the same is going to this 1 junction is redundant. So I can remove this 1junction and make it straight. So, this r element can be directly connect to this 0 junction likewise this element can be directly connected to this 0 junction this is how we do it. Now, suppose our spring damper system at the bottom end is fixed. So make we can used same bond graph in fact and reduced the same bond graph.

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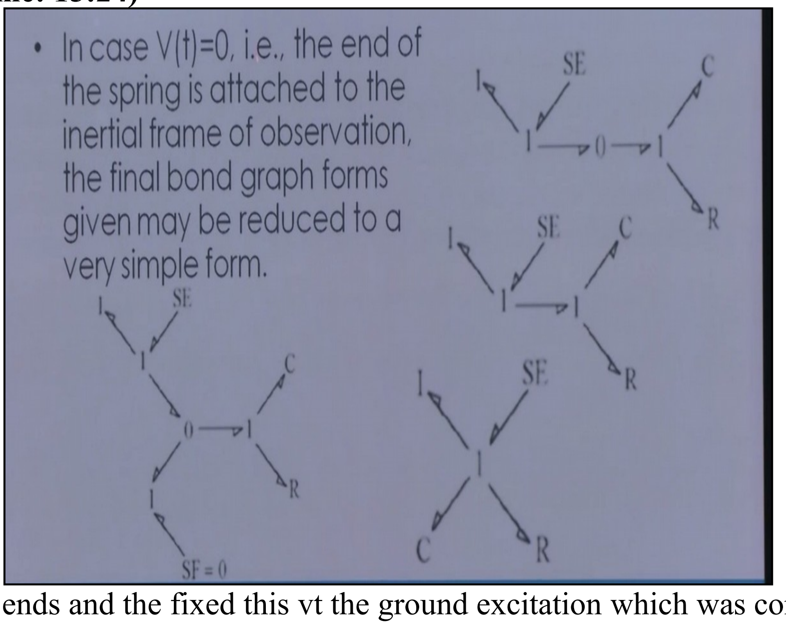

So if the bottom ends and the fixed this vt the ground excitation which was come that going is to equal to 0. So, here you can see that we can put sf equal to 0 now if i put sf equal to 0 here is his power is 0 this power in bond also going to 0.

So all together we can remove this portion here when i remove when this portion this is what i get. So se i0 1 here c and r and again you see that in this 0 junction what where power is going same is going to this retender and so we can remove the this is what is also no as the reduction of bond graph .so I remove this 0 and this is how it's come and again if there are 2 adjacent same junction then you can merge those junction this one and one can be must together and we have one the junction.

Like this and A and R. So you can see that at the bond graph has be reduced the previous bond graph has be refused to bond graph of that of simple mass damper system where all the components where got the same velocity one and here this subject to certain force represented by the c elements Let us take another example.

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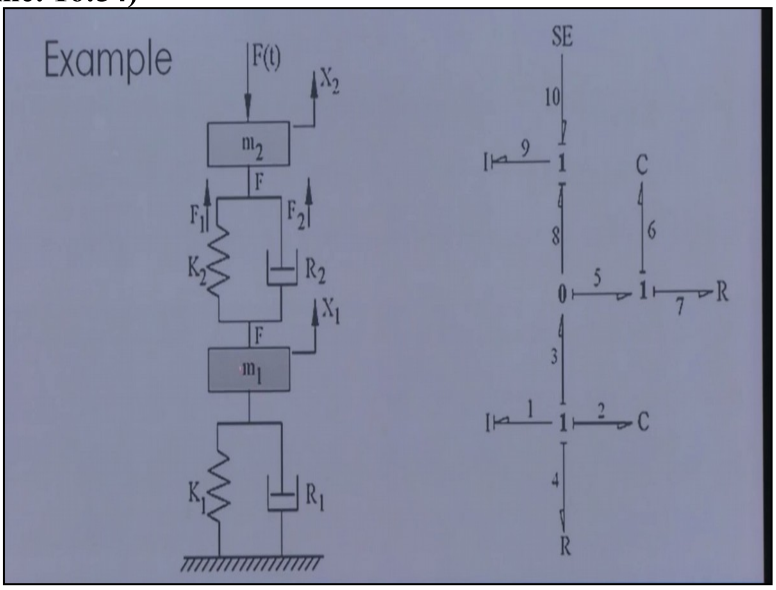

Now, here in this example you can see that there is mass a the m1 and this mass ends is attached with spring and damper see coefficient k1 and aiming coefficient r1 other end is fixed. So this portion is a that is what of simple spring mass damper system which we have seen and if lo at this portion then we have the mass and we can spring damper alright this another example what we have seen in the previous example.

Now, the different is the here instead of v t the velocity is now deciding by this mass this system subject to that different of velocity .so to draw of bond graph model it simply here a we create 1 junction corresponding to this velocity port of m1 I attached I and c and r corresponding to this so I have c and r complete the this portion complete the my this portion and for here I have this m2 here. So I attached i here and this spring damper this system will be subjected to velocity difference of between this and this x2 and x1.

So, just find out the velocity difference this is x1velocity and x2 velocity ay so i find out difference here and here I attached c and r. So this c and r attached again this one junction i attached these element to represent the ft. So this way I draw the bond graph model for the hole system we can casual it I explain you in my previous slides that way we can causal bond graph let take another example here a we have spring of mass damper of system and there is another mass hung from the spring and end of these are attached to the liver and you known that leaver we can model using the a transformer element. So that is what we can do.

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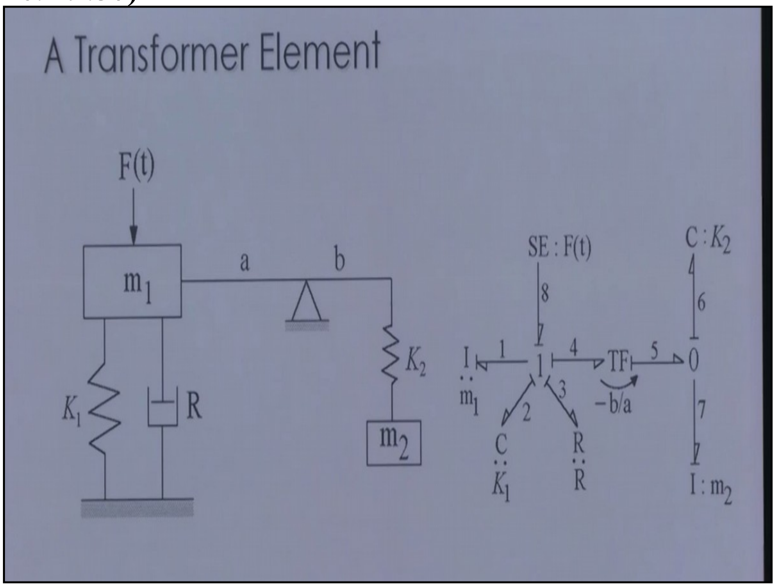

So here I can simply create a 1 junction corresponding to the velocity of this m1 her i attached and I attached c and r here and the ft is here this way this portion tells gives me the bond graph model for this portion and then suppose get the velocity of this point. Now you can see for here you can form here that this is spring and this mass will be subjected to the same force. So if this spring and mass are subjected to the same focus then I can attach them 0.

Junction and here i can attached spring and i can attached mass are we can rather say that it this spring and damper are this spring will be subjected to velocity different that is velocity of this point minus the velocity of this mass and then form i can take the velocity difference of this 2 point and i can attached spring over they and of course then I will be get in the velocity and this port basically and this velocity and this velocity are related by the transformer modules minus b by y minus a because the direction of portion of this end and this end are going to be opposite that is taken care by put in the minus in this alright .

Here this way draw the bond graph model for this system all the here of just stop little about how we can model form the effort respective which i will be talking next method but you can always set you can always do it from the velocity perspective if you want i can just explaining how and other end we can do it this.

Velocity perspective we can find out actually this velocity here at the end of the lever b and i have the velocity of this i equal to M2 and i can take velocity different basically here in 0 junction like this and whatever difference comes here i. Can attached a spring this is my k2 basically alright and then i can reduced bond graph so reduced means a a here say this can be just return the as ground at like this is 0 junction and here whatever this there same is there. So c k2 and here whatever power comers same goes so we have i equal to m2.

This is what a is been shown over here. So we can lo at it from the I either perspective alright fine. Now let the another example suppose i want to model this car so how can I do that first all.

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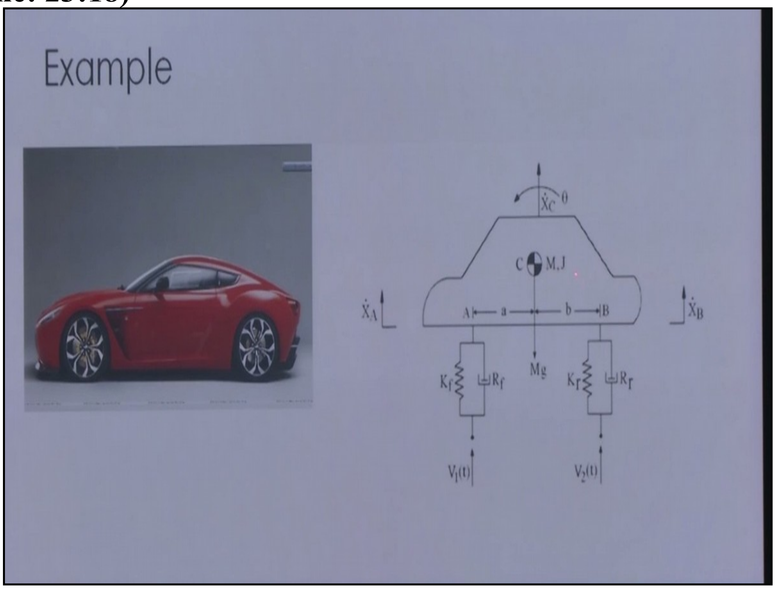

We draw is schematic of the car here you can say I am representing say by c the centered the car here this car of the same got say the mass m the polar moment of the inertia j and here using the two co ordinates one theta for the angular motion for them and say one the vertical motion al right there are the say front suspension is that point the back point the b here or rear point b and here the front say the suspension what is stiffness kf rf likewise the rear is kr and rr and they are subject to the ground excitation v1 t and v2t and say the z and this distance a form c g and distant b form the cg and am mg the weight of the vehicle.

So now i want to model for the vertical dynamic of this car lets how can we do it using the velocity method of flow map a

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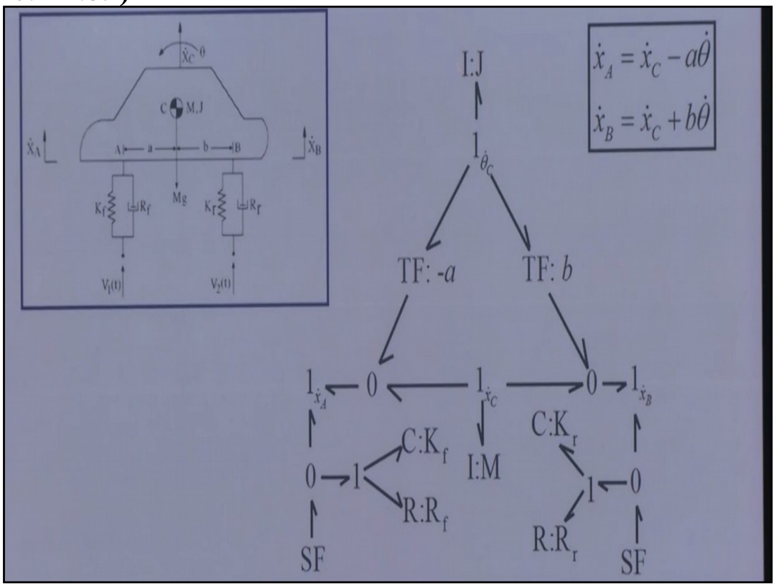

Here a we can see that this my 1 junction are corresponding to the rotation of the car. So i attached a polar I element representing polar moment of inertia here a and i have 1 junction representing vertical motion of the car. So i attached i element the representing the motion i. Now can see that here the x a motion will be x motion this vertical motion at a will be this political emotion minus this motion so xc dot minus a theta dot similarly b will then be this

Vertical motion and because of the theta velocity of going to up again velocity this is xc dot plus b data dot using these equations i can draw the bond graph. So we see here say this is x c dot here. So i can subtract velocity at zero junctions. So xc dot minus a three theta dot i have theta dot use a transformer with models minus is so here i get minus theta dot .so here xc dot minus theta dot will be here and the here i get the velocity of point a now i have the ground excitation.

V one and t in a zero junction i can take the difference of the i get it in the velocity i attach c and r element here representing k f and rf al right likewise I can draw the bond graph model for rear suspension system here in this case this relationship implemented and xb dot and xc dot plus b dete dot those this is exit of and this is deta dot velocity if for the models b the velocity here will be b deta plus and xc dot.

whatever is a and this velocity minus v two t will be here and I take a different that is kr and rr element here further we can she that this relationship that is we are drawing this bond graph model using velocity relationship .and we can see that this relationship can be usually derive using this relationship.

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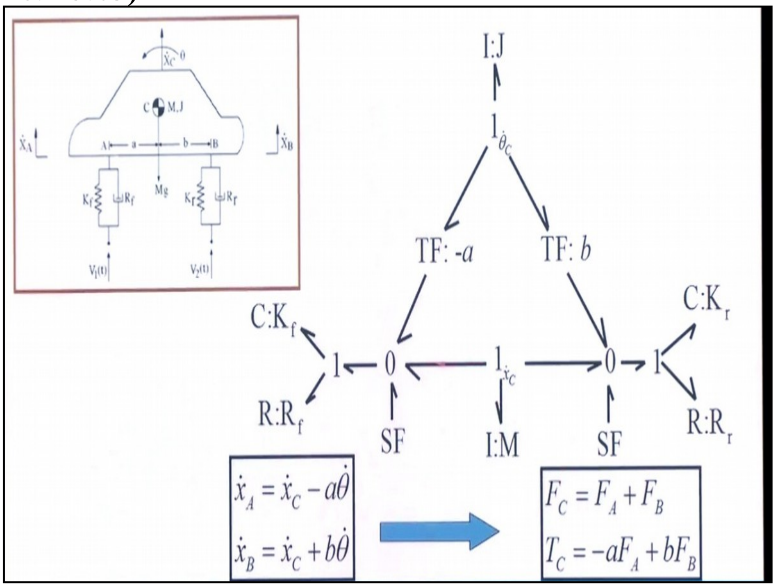

The force and torque relationship can be establish over here that fc equal to fa and fb here .so that fa plus fb like wise tc here will be minus a times fa and b times fb plus b times fb that is how this is done then we can use the method of effort also to draw the bond graph model of the system.

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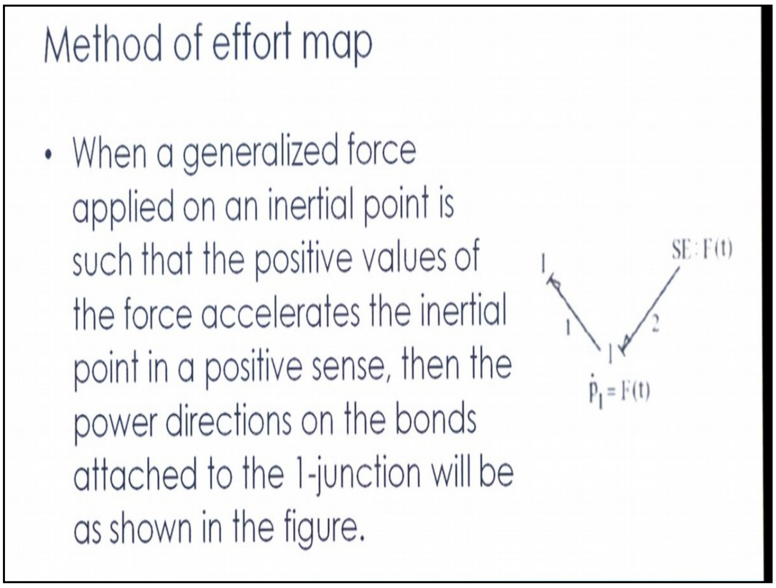

Now in the effort map the wet track the efforts when generalized force applied on an inertial point is such that the positive values of the force accelerates the inertial point in a positive sense this is how the power direction represented that is ft and here this i alright But, if the reverse is the case that it is when a force shown.

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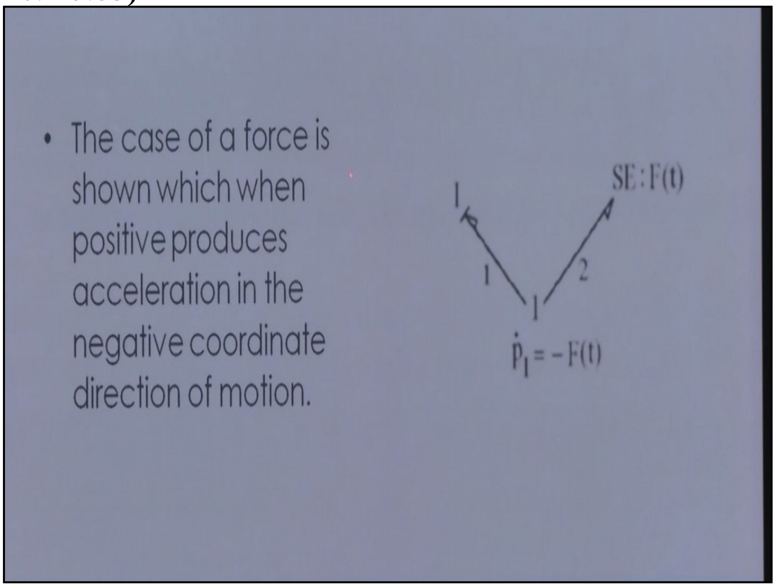

Which when positive produces acceleration in the negative coordinate direction of motion this is how shown i is it presented here and this direction is reversed.

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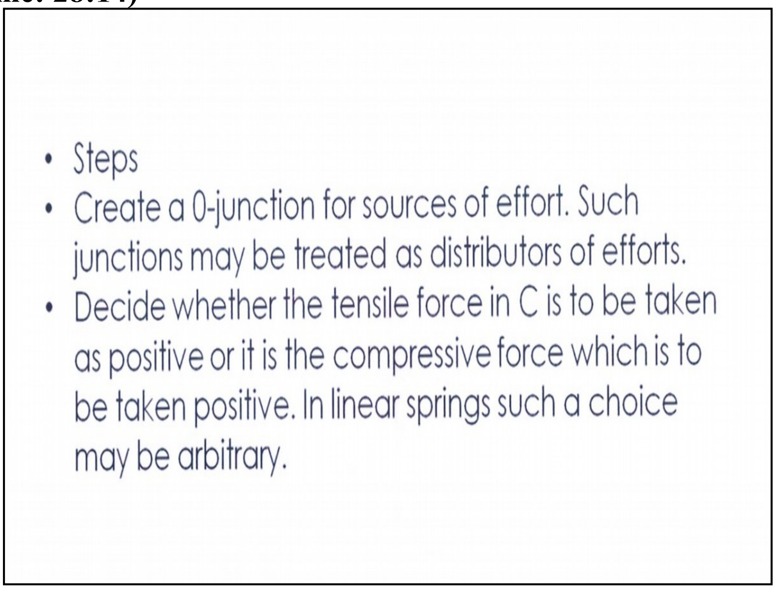

Now for creation of bond graph model using effort map we do is the we create a zero junction for source of effort and these this 0 junction may be treated the distributor of the effort then we decide that whether the tensile force c is to be taken as positive r it is a compressive force.

Which is to be take positive in linear is such a choice may be arbitrary and for r element decide what kind of relative velocity is to be taken as positive again in linear spring this choice may be arbitrary and addition of forces be done using you one junction which is a constant flow junction or effort summation junction and linear force may be converted it to couple using the TF elements and similarly angular velocities may be converted gyroscope forces using the gyrator element and then reduce the bond graph using the method.

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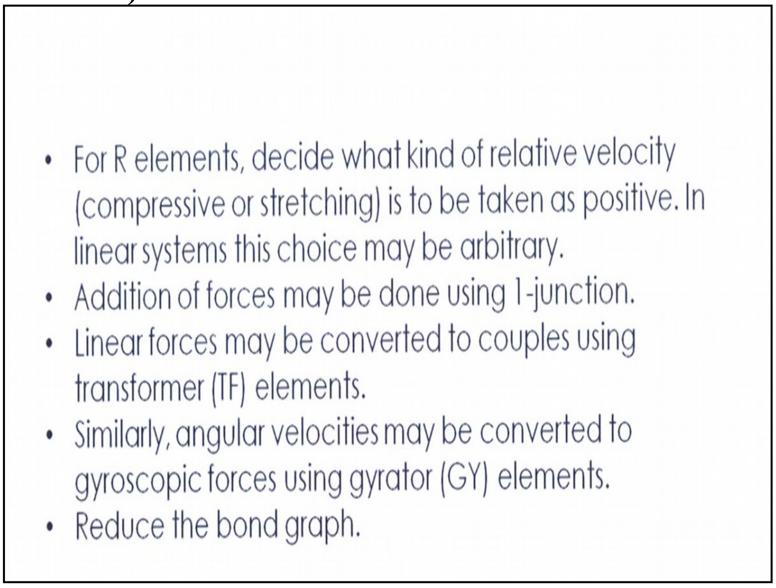

Which we discussed find i take up the same example which have seen in method of flow map so here i have the damper system which is subjected to excitation from the ground vt now you see that I separate this mass then ft acting in this direction .

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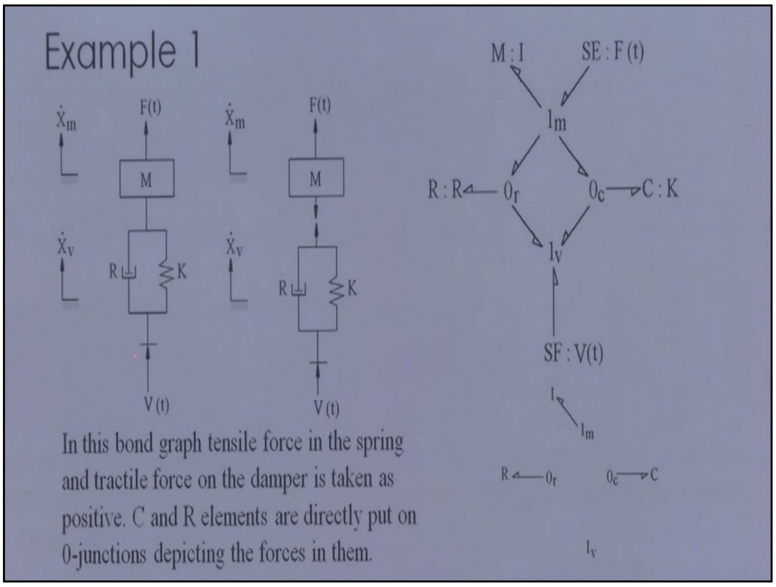

So here the direction of the force going to be the opposite and likewise direction of force going to be such that this direction now opposes this direction t let us see this one. Now here i say is ft going to accelerate this mass so.

We have sc and this mb put like this all right or here what we see that in zore junction in this two zero junction we can attached r and c over here .so this way as I said for this model for the position compiled now see that find draw models for this positions here the power direction in this going to in this which is an opposite of this one here and the power direction here is going to opposition because of here the direction of opposite going to and rest of the thing is same.

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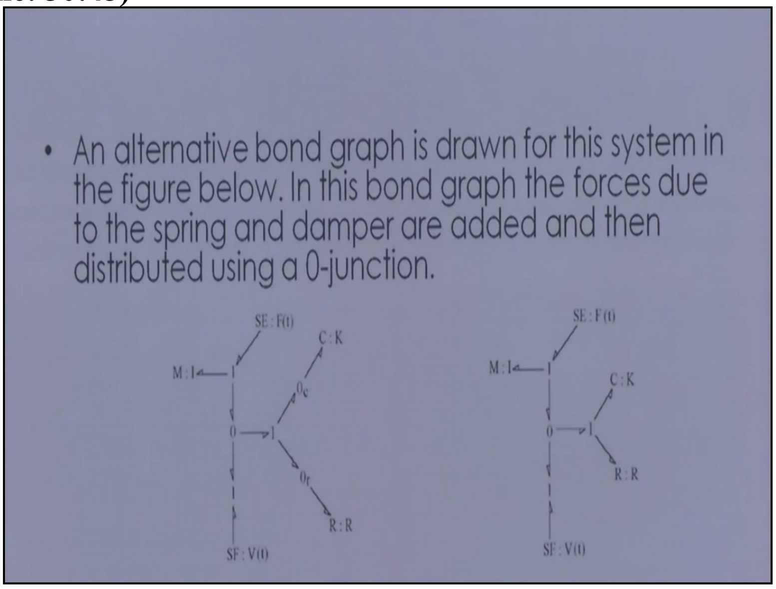

We can to it other way also that is forces spring damper or and then distributor. So here comes the force of the spring and the of the damper we can add this one junction can be distributor here and here this we can to it and this bond graph modeling can be simplified by the eliminating the 0c and 0r of junction .

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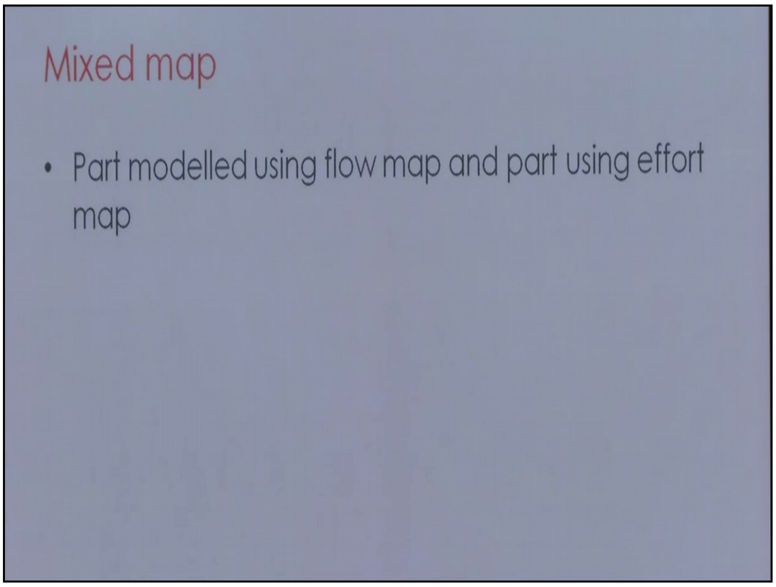

So this way we can do that next method is mixed map and i am not going to talk about here because its a combination both flow map and the effort map .so part of bond graph draw using method of the flow map and part of bond graph drawn using the method of effort map.

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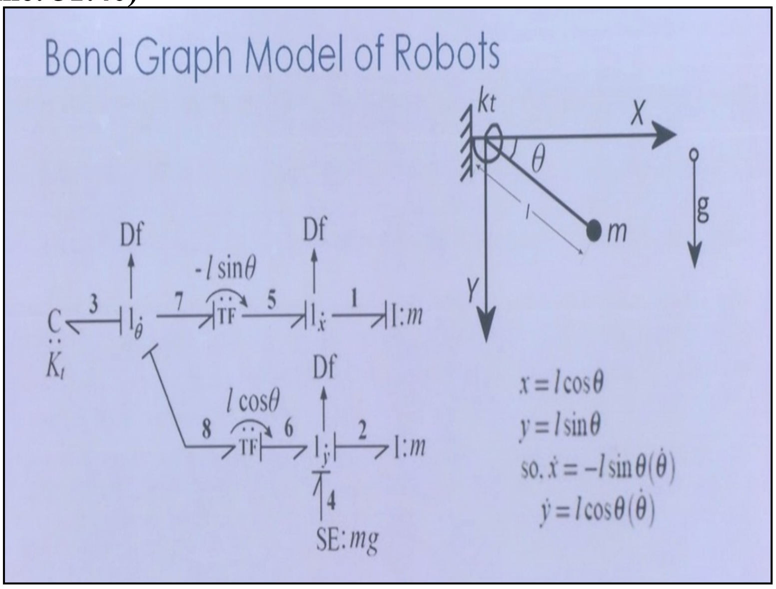

Next the last example which I just wanted to take you the bond graph modeling of the robot its say it again very good mechanical system .so lets take a very simple example say there is a one link arm and here end of this there is a mass m and here this end is spring of kt is there alright so what we do essentially over quadrant system xy this the direction of the system g.

Let of this arm is the l what to essentially find out the velocity so to find out the velocity we write the displacement equation way and l cos theta and y is l sin theta then we differentiate this relationship so the x dot minus l sin theta dot y dot is l cost theta dot now what we do it that suppose one this one theta dot is the port which represent here the velocity one end of the spring other end of spring is fixed.

So I have the velocity of the one in of the spring I attached an c elementary a then and say I x dot end of the mass I is the velocity of the mass this x dot velocity is related here by minus l sing theta dot in to theta so here is the theta dot so I uses the transformer with model finder l sine theta so here it theta dot I use this is velocity dot attached the mass alright the poss.

like wise using there cos theta a as the transformer model like here I cannot get the velocity of y dot forces I attach the mass see here and the y direction I attached, So I see this element with a this weight as mg and I attached the sensors of velocity here to measure the to say r see are to x dot velocity y dot velocity at and theta dot velocity and then I can causal the bond graph here you can see that this I element is subjected to differential causality and we can remove the differential causality artificial compliances which we call as the pad the bond graph language. Thank you.