**Robotics**
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**Lecture – 43**
**Biped Walking (Contd.)**

Now we are going to discuss how to tackle the scenario for the double support phase.

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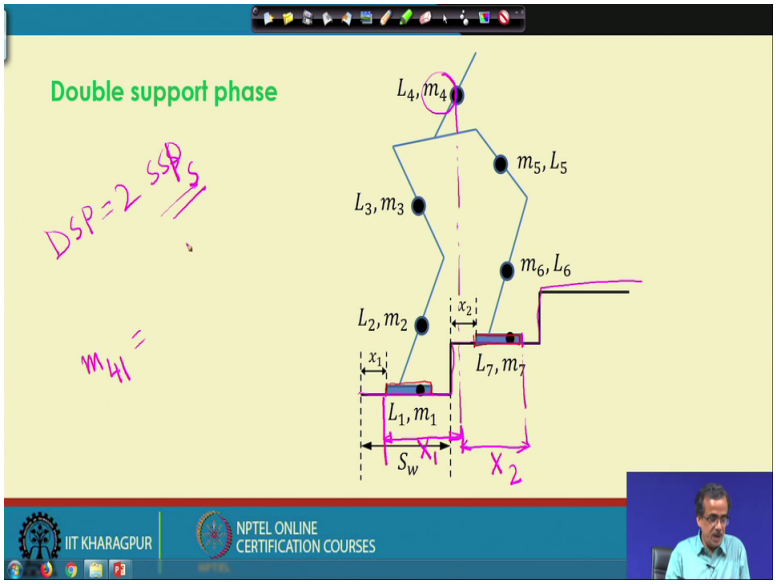


Now during the double support phase actually both the feet are on the ground. Now here let us see how to take care and how to carry out this particular the analysis during the double support phase. Now during the double support phase; so this particular foot is on the ground. Similarly this particular foot is also on the ground and this is nothing, but the staircase.

So, this staircase is denoted by, so this is this is nothing, but your the staircase; so this is the staircase. Now here the way I discuss so, L 1, m 1 are the length and mass of the first link that is the foot. Similarly we have got L 2, m 2 length and mass for the second L 3 and m 3 for the third, L 4 and m 4 that is length and mass for the fourth, link m 5 and L 5 for fifth, m 6 and L 6 for the sixth one and L 7 and m 7 are the length and mass for the foot.

Now, here to tackle this your dynamic support phase it is bit difficult and actually what we do is now here the trunk mass this particular m 4 has got significant influence on your the dynamic balance margin. Now what you will have to do is, the moment this particular biped robot is walking on the plain surface. So, what you can do is; so this particular m 4 we can distribute or divide into 2 equal parts. And the moment it is negotiating so, this type of staircase so this particular m 4 I can divided into 2 parts, but the 2 parts will not become equal.

Now, why do you need it? For the purpose of analysis of this double support phase, we will have to assume that that this is consisting of 2 single support phases. And we have already seen how to carry out the analysis for this particular the single support phase. So, what I do is; so this particular DSP is actually assumed to be consisting of 2 single support phases SSPs and for each of these particular SSP so we try to carry out your the dynamic analysis, we try to find out what should be that particular the ZMP point.

Now, let us see how to carry out this particular the analysis, now as I told that this particular trunk mass that is m 4 has got significant influence on the balance. So, what I do is; so we take the projection of this on the ground for this trunk mass and what I do is we try to find out what is the distance between say this particular point that is your the edge of the leg to this particular point.

And similarly we try to find out edge of this particular leg or the foot from this particular projected point of the your the trunk mass. And supposing that this is denoted by capital X 1 and this is denoted by capital X 2. Now, if I know this capital X 1 and X 2 now I can distribute this particular m 4 into 2 parts. Now supposing that X 1 is equals to X 2; that means, your the biped robot is walking on the plain surface. Now in that case we can find out that is m 41 is nothing, but what m 41 will be equal to Your.

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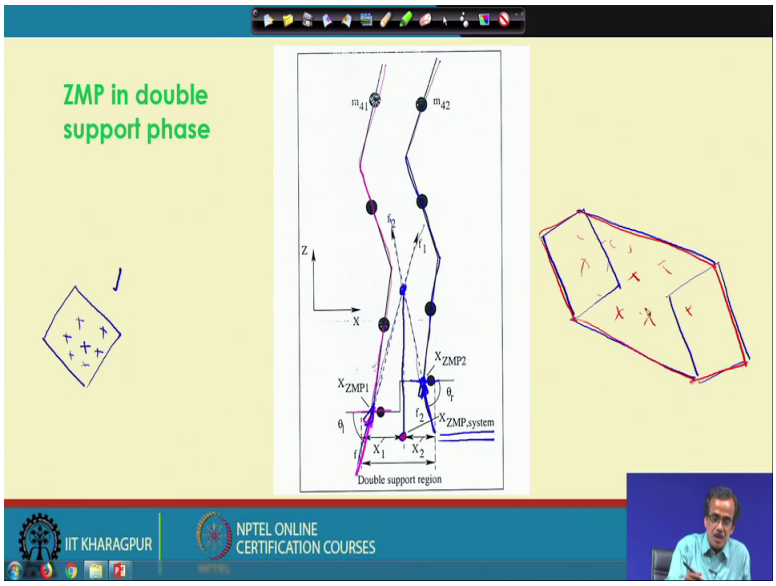


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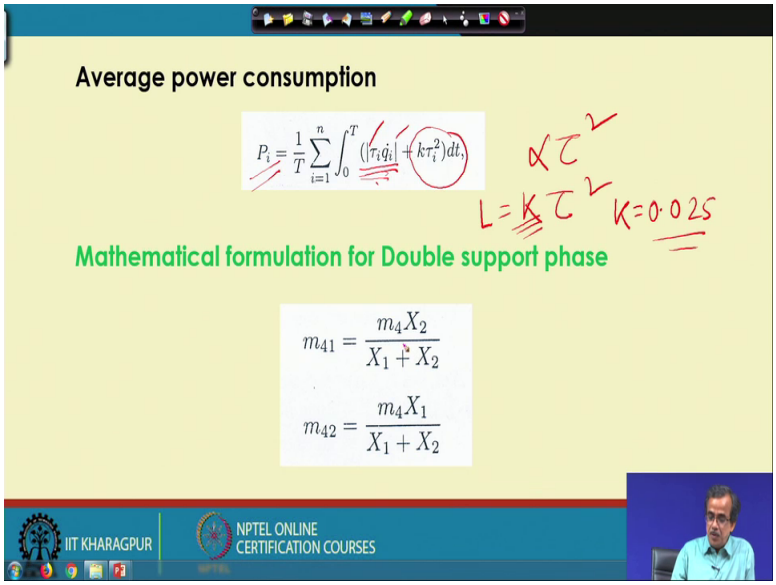


So, m 41 will be equal to this particular expression that is m 4, m 4 X 2 divided by X 1 plus X 2 and similarly m 42 is nothing, but m 4 X 1 divided by X 1 plus X 2.

Now, if I get X 1 equals to X 2; so definitely m 41 will become equal to m 42; that means, whenever it is walking on the plain surface, so m 41 will become equal to m 42. But the moment it is negotiating the staircase or it is crossing the ditch or some uneven terrain.

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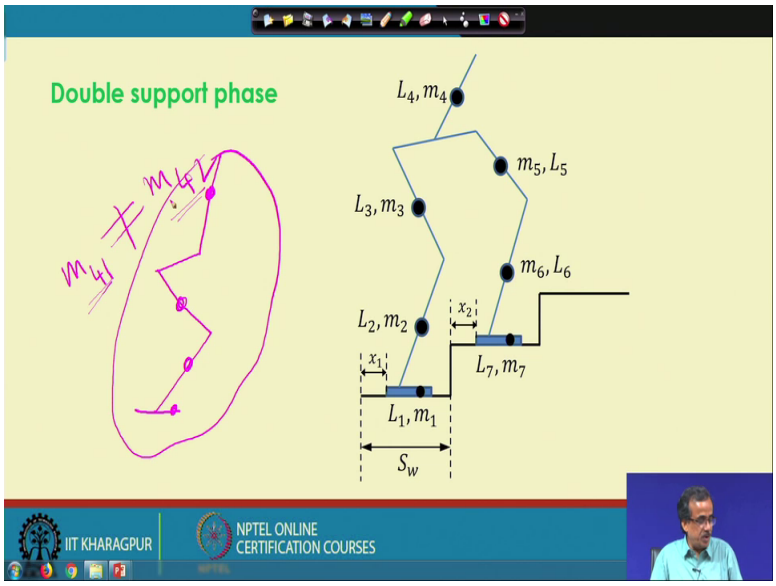


So in that case; so this particular m 41 and m 42 are not equal and your so this particular m 41, m 41 becomes not equal to your m 42. And supposing that it is negotiating the staircase now in that case m 41 and m 42 could be say 40 percent 60 percent of m 4 or they could be 30 percent, 70 percent of these particular the m 4.

Now, once I have got this particular the numerical value for this m 4 and m 1. So, very easily what we can do is we can consider so this particular double support phase is nothing, but a combination of 2 single support phases. For example, say one phase will be something like this so this is one single support phase. So, this will be something like this and this is one mass, similarly I have got one mass here, I have got one mass here, I have got one mass here. So, this is nothing but a single support phase; similarly on the right hand side, so I can consider another single support phase. And once I have got this particular single support phase; so by following the same principle so what I can do is I can carry out; so this particular I can find out what should be the ZMP point.

Now, for example say if I concentrate on; so this particular your the single support phase. So, this is one single support phase; so for these particular single support phase. So, I can find out the ZMP and these particular ZMP is denoted by this, so this is the ZMP. Similarly for these particular doubles another single support phase which is nothing, but this, this is one link, this is another link, another link, another link so this is nothing, but is your the ZMP point and this is your X ZMP.

Now, remember so this particular X ZMP is nothing, but a vector and I can also find out what should be the magnitude, what should be the direction. And we assume that; so this particular your the reaction force, the ground reaction force whenever the biped robot is walking on a ground or it is negotiating some staircase; there should be some reaction force. And this particular ground reaction force is going to act through this particular ZMP.

Now, and due to this ground reaction force only we are able to walk. So, this is the point through which the ground reaction force will walk and as I told that this is nothing, but a vector. So, this indicates the ground reaction force and it is passing through the ZMP. Now if I extend, so this particular your this particular straight line so I will be getting something like this and this vector if I extend so I will be getting something like this and these 2 straight lines are going to intersect at this particular the point.

And we take the projection of these particular intersection point on the ground and that indicates actually so this particular point indicates the system ZMP that is X ZMP comma system. Now, once again I am just going to concentrate on the single support phase and the double support phase and how to maintain the balance. Now during the single support phase; supposing that so this is the ground foot ok; now if the X ZMP point or the ZMP point if it is lying within this particular the ground foot ground region then only the dynamic balance is maintained, but if it goes outside the balance is going to be lost.

Now, if I consider one double support phase something like this. So, this is one ground foot and this is say another ground foot. Now here; so the safe region is denoted by this so this is nothing, but the safe region. So the safe region if I just draw so the safe region is nothing, but is nothing but this; so this is nothing, but the safe region. Now this particular system ZMP; so this system ZMP should fall within this particular safe region; then only the dynamic balance will be maintained otherwise it is going to lose the balance and it is going to fall.

Now, in a particular walking cycle whether it is in single support phase or in double support phase; the balance has to be maintained at the same time during the transition of single support phase and the double support phase. So, that particular balance has to be

maintained then only it will be able to maintain its balance in a particular the walking cycle. So, this is the way actually the biped robot maintains balance during the walking.

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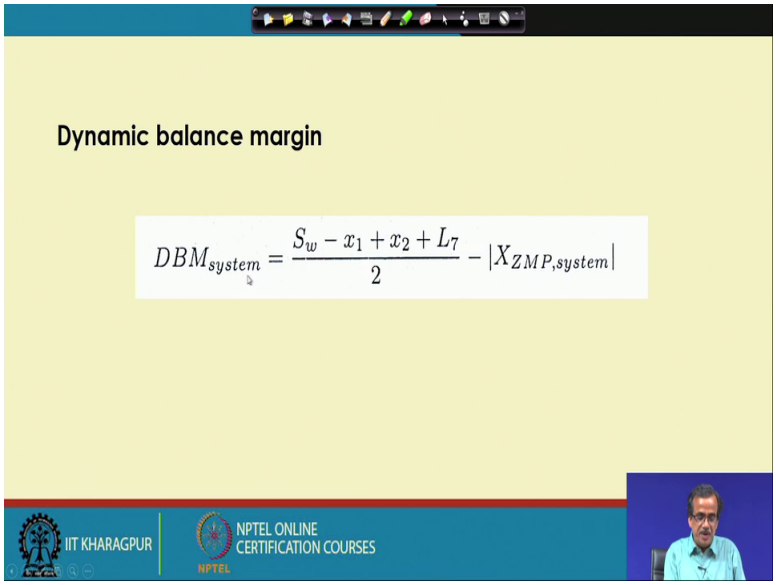


And this is how to determine the ZMP during the double support phase, this I have already discussed little bit.

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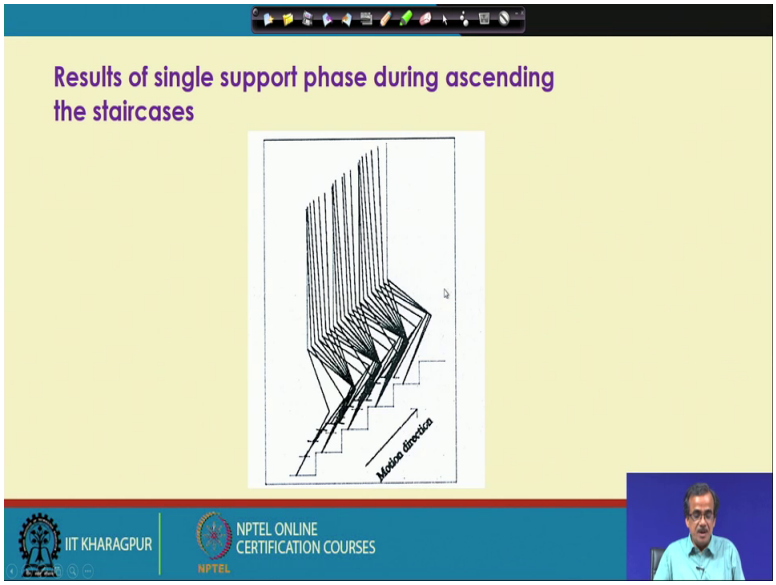


Now, here I am just going to show you some stick diagram that a biped robot having 7 degrees of freedom is negotiating the staircase during the single support phase. So, one foot is on the ground and the other foot is in air.

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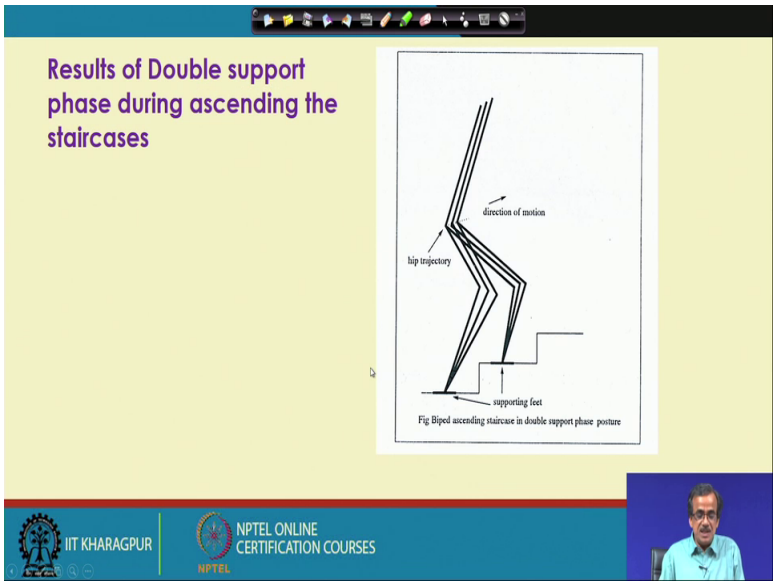


This is another stick diagram where the same 7 degrees of freedom biped robot is negotiating the staircase and here both the feet are on the ground.

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Now, I am just going to, we are going to show you one real experiment on a very simple biped model. Now I am just going to discuss the different components of the biped robots which we have in our lab.

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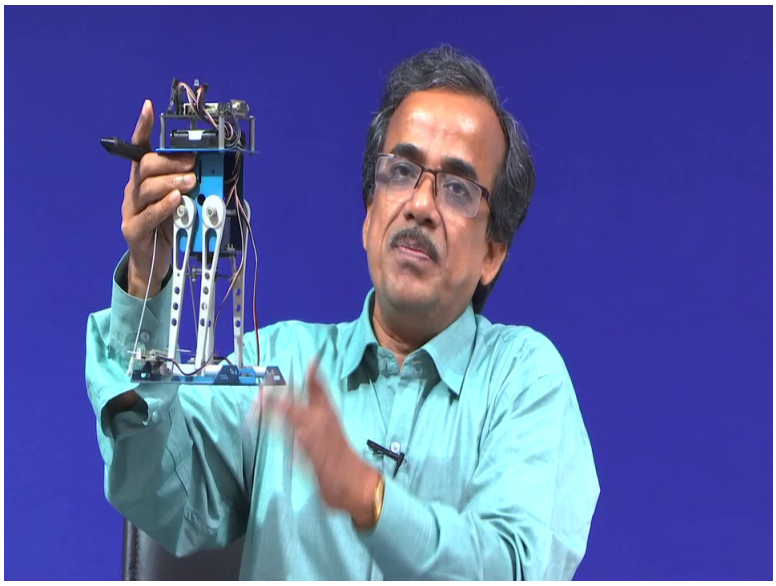

And actually this is nothing, but the very simple biped robot and we can see that so, here we have got 2 servo motors. So, the servo motors we can see so this is one servo motor this is another servo motor, it is a very simple model.

Now with the help of this particular servo motor; so we can control the movement in the forward and the backward direction. Similarly, with the help of this particular servo motor and with the help of this these 2 tilt rod; so, we can actually go for we can lift and we can place the foot of this particular the biped robot. And here we have got actually one micro controller so with the help of that; so we can control the preprogrammed motion, actually we can control we can run.

Now, here if you see the area of this particular foot is much larger compared to the overall dimension of this very simple setup. Now the purpose is actually which I have already discussed so that we can get more safer region to maintain its dynamic balance. So, that we can get during the double support phase or the single support phase, we can get the larger area for the safe region and that is why the, your the dimension of this particular put has been kept somewhat larger even compared to the overall dimension of this particular the setup.

Now with the help of this particular very simple biped model so, we are going to show you like how to generate the forward and the backward movement. Or how to how can it

walk on the plain surface in the forward direction and in the backward direction. So, now, we are going to show you that particular experiment.

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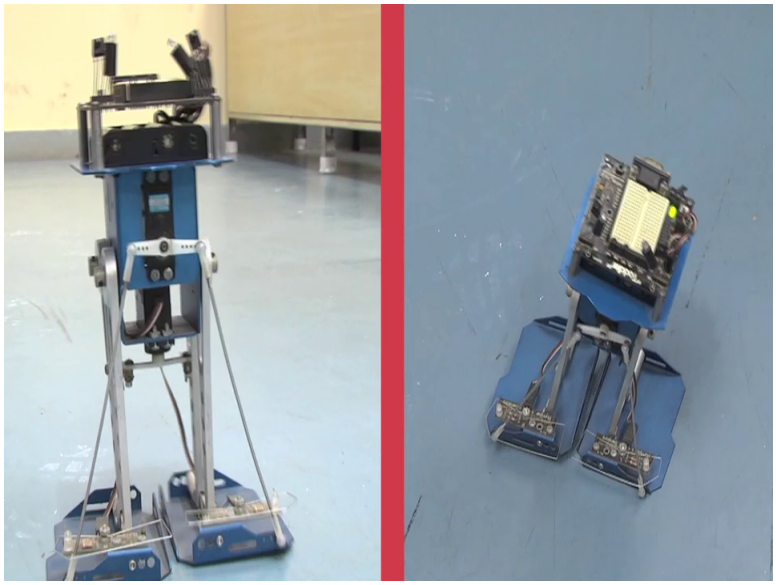

Now it is showing the forward movement of the biped robot and now it is moving in the backward direction.

Thank you.