Manufacturing Automation
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Lecture – 06
Vibratory Bowl Feeder

Welcome back to the lecture series of Manufacturing Automation. Let me remind you that in the last class we have discussed about the production and the throughput time.

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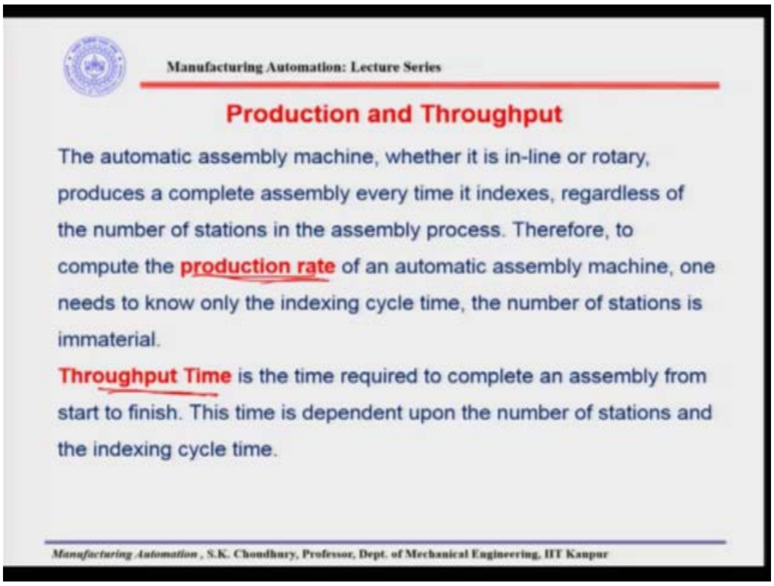

We have seen that the throughput is the time taken for an assembly to be completed. And also one fact that I would like to once again repeat that in an assembly line whether it is in-line or the rotary one, each time it indexes we will get one complete assembly, this you have to keep in mind.

So, to compute the production rate one has to know only the indexing cycle time. If you know the indexing cycle time we will be knowing what is the production rate, because each time it indexes we know that we get one complete assembly, whereas, we said that the throughput time is the time taken for making a complete assembly.

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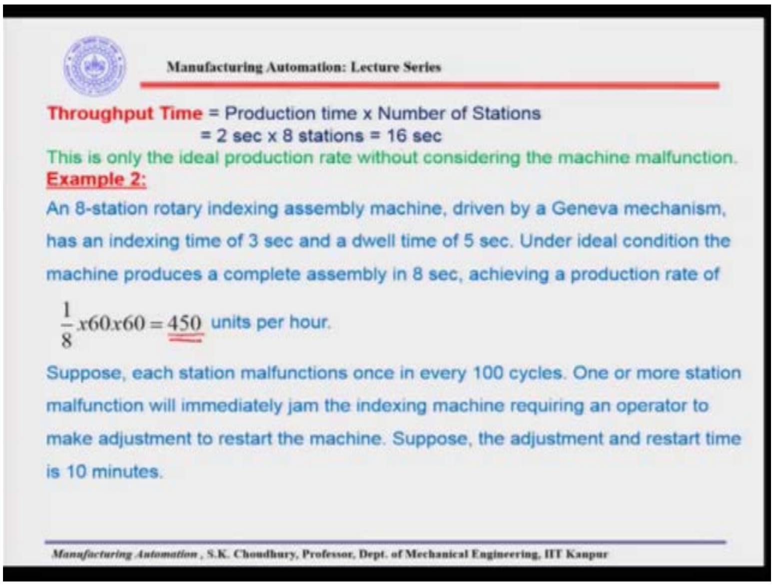

Therefore, the throughput time will be equal to the production time into the number of stations. So, number of stations will be immaterial while considering the production rate. Whereas, in considering the throughput time we have to have the production rate into the number of machines/ number of stations.

In an example we have seen that if we want to consider the actual average production rate, it will be very high if we do not consider the line breakage in case of automated assembly in the production flow line. We have also seen in that example that if we have 450 units per hour ideally,

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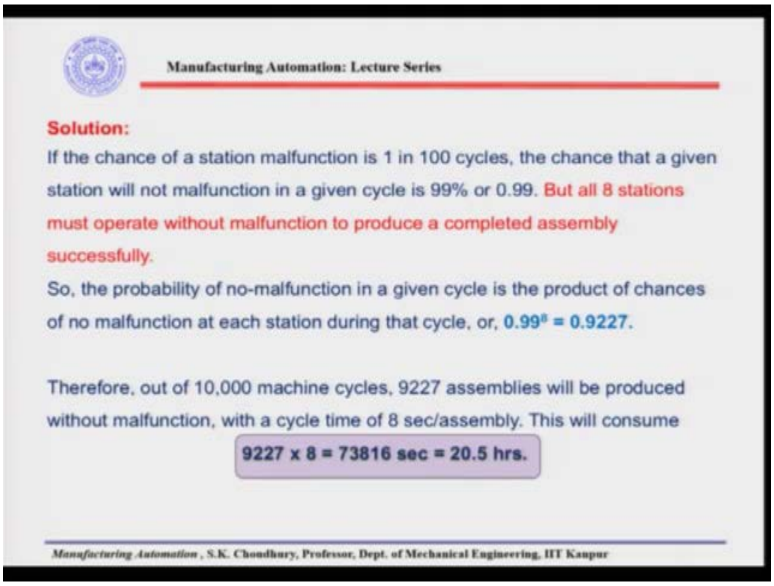

then for one malfunction in 100 cycles, we are actually getting the percentage down time as 86.3% which is very high.

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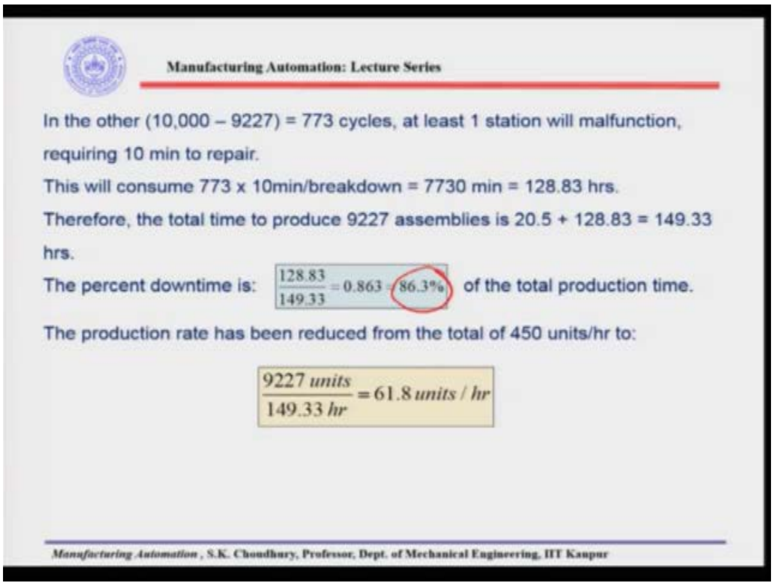

In that example we also said that the station breakdown basically happens because of the improper tolerances or improper parts which go into the assembly and it stops the machine, so the subsequent and the adjacent machines also get suffered.

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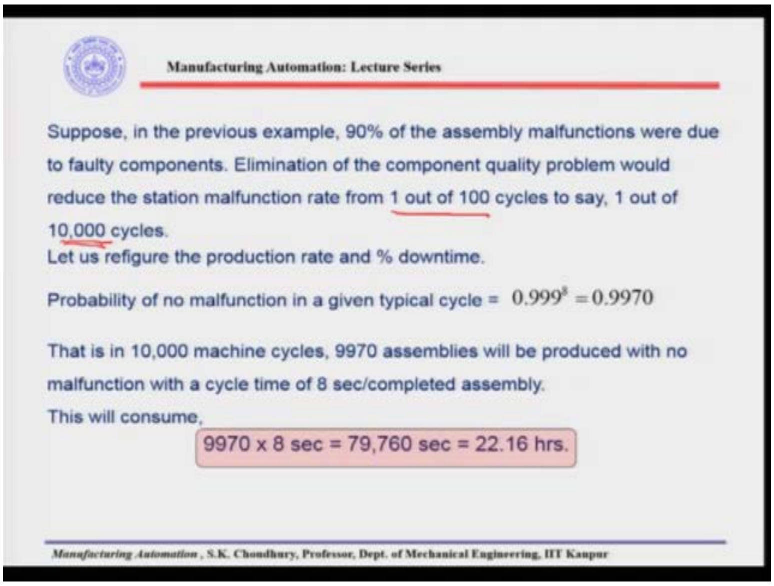

So, if we can improve the product quality, in that case, as we have taken in that example, that suppose we have instead of 1 out of 100 we have 1 out of 1,000 cycle malfunctioning. Then it is improving drastically again and the percentage downtime reduces to 18.4 from 86.3%. I am just reminding you, the production efficiency goes up to 81.6%.

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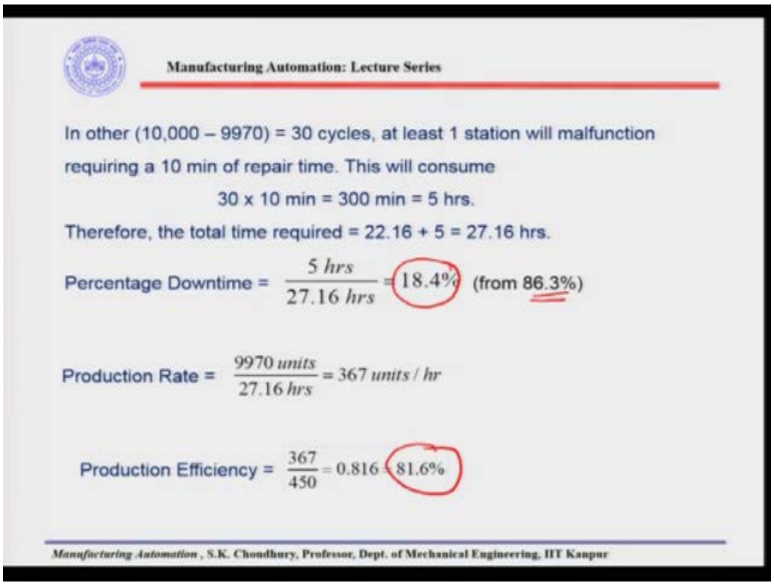

So, through this example I wanted to show that the machine breakdown has to be considered while discussing or while taking care of the production flow line for the assembly.

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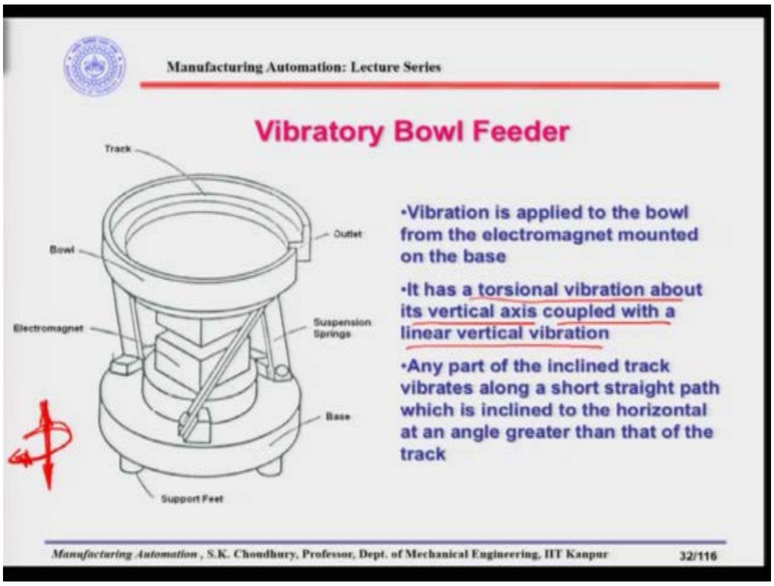

Next we started discussing the vibratory bowl feeder and we said that for small engineering parts, which are majority in the assembly process, feeding the parts to the machine is a very important aspect, very important phenomena. Therefore, the feeders which actually do that have to be considered, those have to be designed in a proper way. Here there is one minor point that I would like to mention right here, that parts have to be not only fed to the machine, but the parts have to be fed in a right orientation.

What I mean to say is that suppose we have a part which has to go in a particular orientation. If the part is coming with a different orientation, it has to be reoriented, because if it goes like this and comes to the machine, the machine jams, it cannot go in this orientation to the machine, it's desired orientation is only this for example. So, if the part is coming with a different orientation, either it has to be rejected from the track and let it be re-circulated again till it comes in the right orientation or it has to be reoriented.

So, the responsibility of the bowl feeder is very serious in the sense that it will not only feed the parts, it has to also feed them in the right orientation. Vibratory bowl feeder is one of the most important and one of the most versatile bowl feeders for small engineering parts. I told you already in the last class that this consists of a bowl and a base, the bowl is connected to the base with the leaf springs.

At the base of the bowl, there is an electromagnet, that imparts the vibration to the bowl, and inside the bowl there is a track which is inclined to the horizontal, which is spirally going from the base of the bowl to the outlet. So, when the vibration is imparted to the bowl, each part located on the track will be moving in a short, straight, almost straight direction which will be inclined to the track with an angle more than the angle of inclination of the track. What is it I will explain it to you.

Now, first of all let us see why these parts have to ride on the track of the vibratory bowl feeder. When the electromagnet imparts the vibration, it will impart two types of vibrations; one is the vibration like this; that is about its vertical axis and this is a linear vertical vibration, and there is another vibration which will be torsional vibration like this. So, as a result of these two, what happens is, that as the part is going up and down, it is also getting a torsion. So it will be moving in a semi-circular motion ahead. That means, the vertical vibration will allow the part to leave the track and as soon as it is leaving the track, torsional vibration will help the part to move ahead.

So, overall there will be a small straight line motion of the part, for each part which is located and on the track of the vibratory bowl feeder and this straight line will be inclined to the track at an angle more than the angle of inclination of the track.

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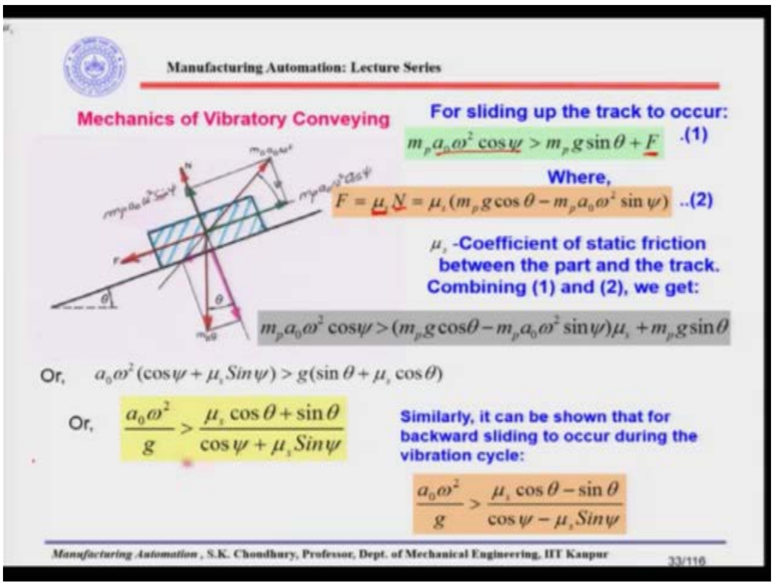

Now let us see what is the mechanics of vibratory conveying. Let us take an example of a small part which is located on the track of the vibratory bowl feeder. This is the track which is inclined to the horizontal at an angle of θ. Now, when it is moving, the m_p which is the part weight/mass of the part and this is the vibration, overall resulting vibration, which is $m_p a_0 \omega^2$, m_p is the mass of the part, a_0 is the acceleration and the ω is the angular velocity.

So, for sliding up the track to occur, this $m_p a_0 \omega^2$ will have the $m_p a_0 \omega^2 \cos\Psi$ in the direction along the frictional force, F, N is the normal force, because of this there is a friction force of F and μ_s is the static coefficient of friction between the part and the track. So, in the direction of the normal force $m_p a_0 \omega^2$ has a component of $m_p a_0 \omega^2 \sin\Psi$. This in the 'n' direction, that is the normal direction, the component which will be coming here, is the $m_p a_0 \omega^2 \sin\Psi$ and, in the perpendicular direction it is the cos Ψ.

We have the $m_p g$ here. So, $m_p g$ will have two components; one is in the direction of N and another is in the F. In the direction of F, it will be $m_p g \sin\theta$ and in the direction of N, will be $m_p g \cos\theta$. Now, for sliding up the track in the direction opposite to F, $m_p a_0 \omega^2 \cos\Psi > m_p g \sin\theta + F$. F is the friction force, because of the normal force acting here.

So, for sliding up the track we have to have this condition satisfied, where this F is the friction force which is μ_s, static coefficient of friction between the part and the track as I said into the normal force. So, the friction force here is the F = $N\mu_s$, N we can find out as: $N = m_p g \cos\theta - m_p a_0 \omega^2 \sin\Psi$.

So, we are putting this value of N here and $N\mu_s$ will give you the F which is the friction force. That means, here if you put in the equation 1, if you put the value of F which is this, in the equation 2, you will get the equation as: $m_p a_0 \omega^2 \cos\Psi > (m_p g \cos\theta - m_p a_0 \omega^2 \sin\Psi)\mu_s + m_p g \sin\theta$

Now, this can be simplified as : $a_0\omega^2(\cos\Psi + \mu_s \sin\Psi) > g(\sin\theta + \mu_s \cos\theta)$ and overall what we are getting is: $\frac{a_0\omega^2}{g} > \frac{\sin\theta + \mu_s \cos\theta}{\cos\Psi + \mu_s \sin\Psi}$; meaning that this is the condition that has to be satisfied for the part to slide up the track.

Similarly, it can be shown that for backward sliding; that means, whether the part is going up or going down. For going up this is the condition that has to be satisfied and you can show that when the part is going down what will be the condition of these forces, it will be reverse and you can show that: $\frac{a_0\omega^2}{g} > \frac{\mu_s \cos\theta - \sin\theta}{\cos\Psi - \mu_s \sin\Psi}$. So, these are the two conditions which are coming here. These conditions have to be satisfied either for the part to go up the track or for the part to slide down the track.

It is important because, if you have the first equation satisfied in that case you can make sure that the part will go up. Because sometimes the vibration may not be of sufficient, amplitude or of the frequency of the vibration may not be enough for the part to go up. So, you have to always see that these conditions are satisfied, particularly the first condition because we want the part to go up and in case the other condition is satisfying, that means, you know that the part will not go up, it will go down.

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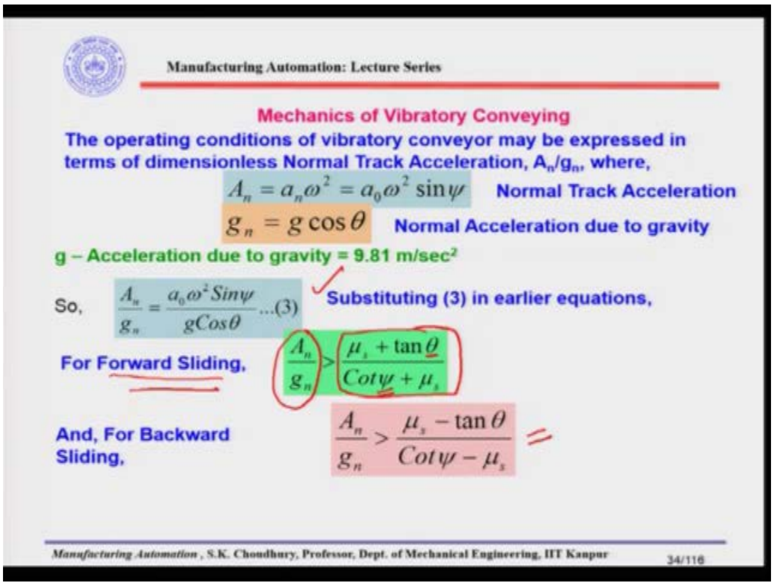

The operating condition of vibratory conveyor including the bowl feeder may be expressed in terms of dimensionless normal track acceleration; this is normal track acceleration which is a convenient way of expressing the operating condition and let us say the normal track acceleration is $\frac{A_n}{g_n}$. Now this can be found out, because the A_n is the normal track acceleration. This is given by $a_n\omega^2$ and this is equal to $a_0\omega^2 \sin\Psi$, and the g_n which is the normal acceleration due to gravity. This is equal to $g\cos\theta$, g is the acceleration due to gravity.

This a_0 is the acceleration of the of the part on the track, i.e., linear acceleration and the g is the acceleration due to gravity, which we know as 9.81 $m/\sec^2$. Therefore, if we are substituting this value of $\frac{A_n}{g_n}$, that will be getting here in the equation 3, then we will be getting $\frac{A_n}{g_n} = \frac{a_0\omega^2 \sin\Psi}{g\cos\theta}$.

Now, from here you can find out that the dimensionless normal track acceleration this $\frac{A_n}{g_n}$, has to be more than $\frac{\mu_s + \tan\theta}{\cot\Psi + \mu_s}$. So, where you are getting this from? You can see the earlier equation and if we equalize this equation, with this then you will get the one for sliding up forward. Similarly, if we are taking this equation and substituting with the equation when the part goes backward then we will be getting the equation or the condition for the backward sliding.

So, this is more convenient to use, because this is the component which actually dictates the operating condition of the vibratory bowl feeder. This is the normal track acceleration and this is dimensionless; therefore, it is more convenient. So, this is important for us that for forward sliding we have to have this condition satisfied, in that case we know that the parts are properly going up the track. Now here one condition you can see that apart from the μ_s,which is the static coefficient of friction between the track and the part, we have two more angles which are important; one is the track inclination angle, which is θ , and another is the vibration angle.

Now, if we go back to the vibration angle, where this $m_p a_0 \omega^2$, the total inertia force, this will be making an angle of Ψ with the parallel to the track which we are calling as the vibration angle, and the track inclination angle is θ that the track is making with the horizontal. So, initially when I said that, because of the two vibrations, that is the linear vibration and the torsional vibration, the part will move in a short straight line at an angle more than the angle of inclination of the track, this is the angle which is apart from the θ. So, this angle is more than the track inclination angle.

So, apart from the μ_s, which is the static coefficient of friction, we have the track inclination angle and the vibration angle which are important to find out whether the normal track acceleration is proper. How these angles are determined or how these angles are defined that also depends on us. Because, we can incline the track as per our requirement, there is a design and the Ψ, which is the vibration angle depends on the electromagnet which we have here plus the suspension springs.

In the suspension spring, the spring constant and the angle, these two factors that will define how the vibration will be imparted and these vibrations are actually the torsional vibration about its vertical axis, coupled with a linear vertical vibration. This is the linear vertical vibration and this is a torsional vibration. So, this will depend on, once again, the suspension springs and the electromagnet.

Therefore, we can actually decide what will be the angle Ψ, which is the vibration angle and this angle is the track inclination angle, once again, we can decide. So, by deciding the μ_s, track inclination angle and the vibration angle, we can actually satisfy that the normal track inclination is more than this equation, then only the parts will go up along the track, that is at the outlet of the vibratory bowl feeder.

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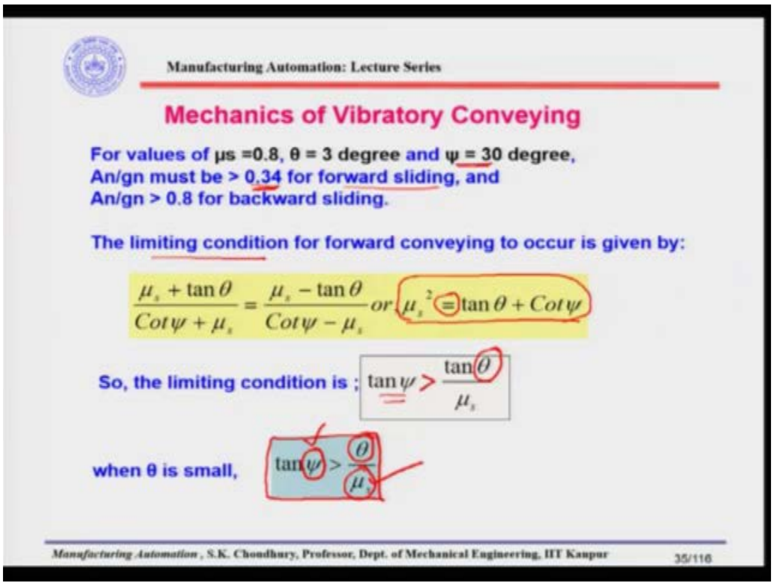

Now, for values of, for example, μ_s is equal to 0.8, let us take a practical value suppose it is 0.8 and we have the track inclination angle as 3^0 and the vibration angle has 30^0. In that case $\frac{A_n}{g_n}$, which is a normal track acceleration, must be more than 0.34 for forward sliding, we are getting it from here as you understand.

So, we put the value of μ_s equal to 0.8, θ is equal to 3^0 and Ψ is equal to 30^0, you will get that the $\frac{A_n}{g_n}$ should be more than 0.34 for the forward sliding, and $\frac{A_n}{g_n}$ more than 0.8 according to that equation for the backward sliding. This is just an example that if it is $\mu_s = 0.8$ and with $\theta = 3^0$ inclination. So, then it has to be more than 0.34. This I am mentioning, because while designing the vibratory bowl feeder you have to take into consideration these factors.

Now, we have these two, that means, $\frac{\mu_s + \tan\theta}{\cot\Psi + \mu_s}$, this is for the forward movement and $\frac{\mu_s - \tan\theta}{\cot\Psi - \mu_s}$ for the backward movement. If we equalize them, this will be the limiting condition, limiting condition for forward conveying to occur. What does it mean? That this is the condition at which the part will just start going forward, it is in the limiting position. So, from here we can find out that if we solve this equation you will get $\mu_s^2 = \tan\theta.\cot\Psi$. So, this is the condition that you are getting.

So, from here the limiting condition is the $\tan\Psi = \frac{\tan\theta}{\mu_s^2}$. As I said that this is 'equal to' because this is the limiting condition. That means, at this condition the part is neither moving forward nor moving backward, it is in the initial position, in the position just ready to move. So, if it is more than that; that means, the part will start moving forward. Now, this can be simplified by assuming that the track inclination angle is small. So, we can consider the $\tan\theta = \theta$ and then we can say in a simplified way that $\tan\Psi > \frac{\theta}{\mu_s^2}$.

So, this is the condition that has to be satisfied, once again, for parts to move forward. So, this is much more simplified, because you can see that here we have the θ and we have the μ_s, which are in our hands. In the sense that how much track inclination angle we are giving that is the design criteria and what kind of smoothness we are giving to the track and what kind of parts we are having, depending on that we will be getting the static coefficient of friction.

So, once we have the θ and the μ_s, we can take the ratio and we can find out that what is the value of the vibration angle. Depending on that we can select the suspension springs, the angle of the suspension springs and the spring constant. These are the suspension springs at which angle you are actually attaching the bowl with the base and what is the spring constant, that is material. And, what is the electromagnet of course, that will depend, that will actually be selected based on the Ψ that you would like to have for the forward movement.

Now, you mind one thing that the parts are of different materials. For example, there are aluminum parts, there could be steel parts, there could be parts with a rougher surface or with smooth surface. So, that will actually determine your μ_s which will be the static coefficient of friction between the parts and the track. So, depending on that you will actually get the Ψ which is the vibration angle and you can design accordingly the electromagnet, select the electromagnet and design the suspension springs and the angle of the suspension springs.

Once again, here it is the design aspects that we are considering. In the design aspect the basic thing that you have to take into consideration are that the parts should be moving along the inclined track which is inside the bowl and the parts have to come out of the of the bowl. Because, these parts from here will actually go to the machine for assembly, which are small engineering parts.

So, if you see actually a bowl feeder in practice you will see as if the whole bowl is moving, whole tract is moving, it seems that as if the track is moving. It is actually not the case. On the track the parts are moving and the track is stationary.

So, now you know that for parts to move along the track, ultimately what we need is this condition to satisfy. That means, accordingly you have to design your track inclination angle, accordingly you have to design the springs, accordingly you have to select the electromagnet. Rest of it I will discuss in my next class.

Thank you very much.