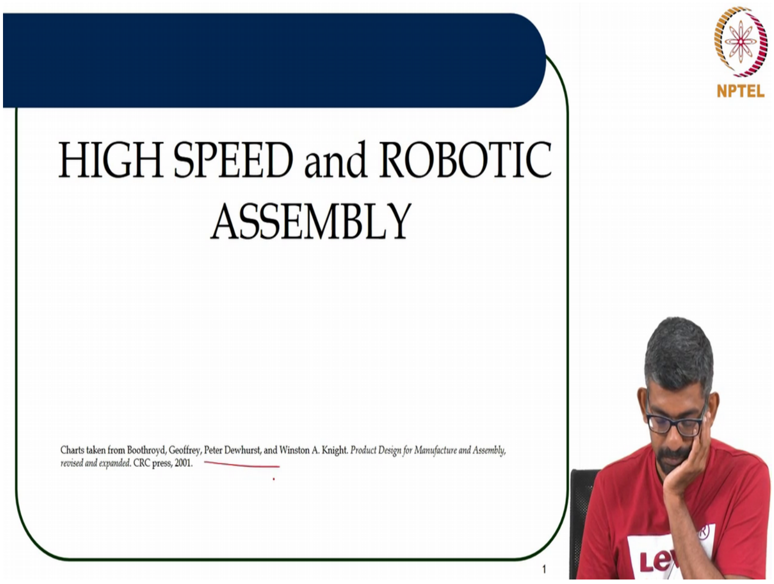
Design for Quality, Manufacturing And Assembly

Prof. Palaniappan Ramu
Department of Engineering Design
Indian Institute of Technology, Madras

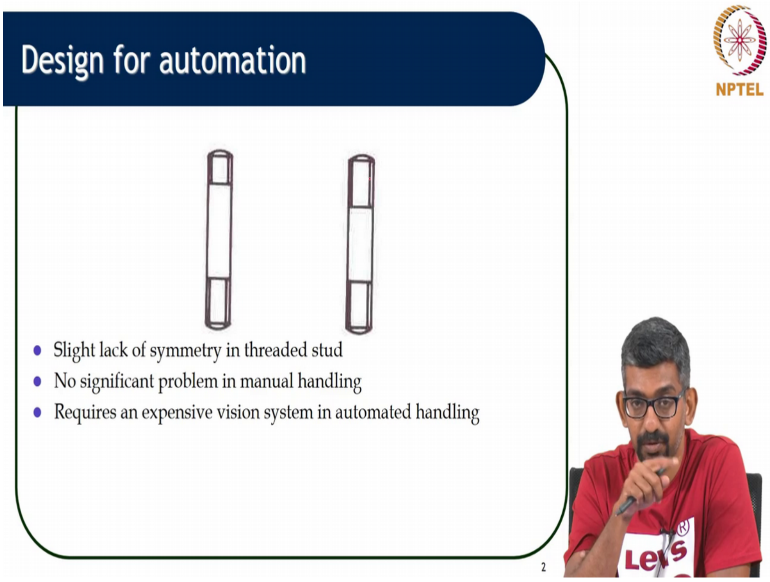
Lecture-37
High Speed and Robotic Assembly

(Refer Slide Time: 00:16)



Welcome back. Today's agenda is to talk about High Speed and Robotic Assembly. In the past, we have spoken about design for assembly mostly from the manual assembly perspective. Today, we will see how those concepts differ or are adjusted for high speeder robotic assembly. Often times, robotic assembly becomes important in today's case especially in mass manufacturing. So, it becomes imperative to discuss about the concepts that leads to analysing and assessing robotic assembly and its efficiency. There are number of charts, and examples that will be shared in the rest of this particular presentation, which are picked from our text book by Dewhurst.

(Refer Slide Time: 01:24)

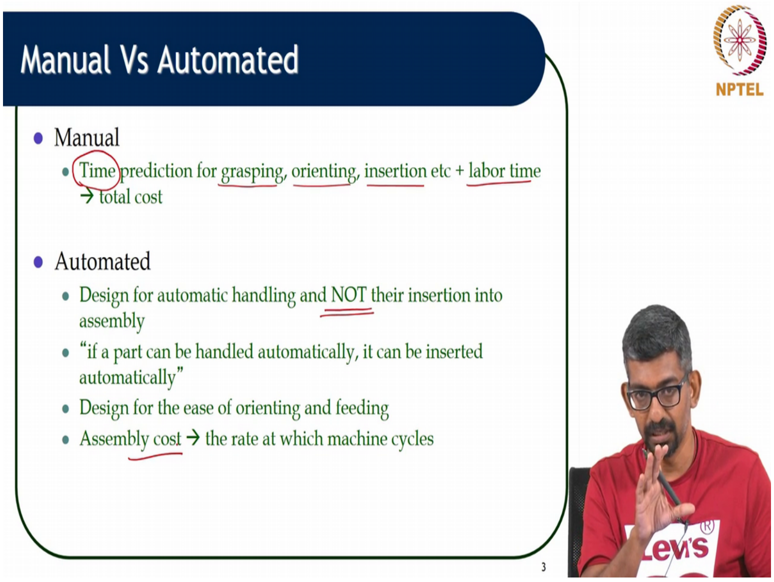


So very similar to the design for manual assembly where we spoke about symmetry, size, weight, thickness and some guidelines. I am going to present you few cases here, where I will try to compare and contrast what is the difference between manual assembly and robotic assembly from a component perspective. So, if you look at this two threaded stud here, you can see that there is a lack of symmetry in this stud compare to this stud ok. These are basically the threads here ok.

And this is a symmetric thread and this is a asymmetric thread. There is a slight lack of symmetry. In terms of handling from the handling perspective there is no big difference in handling, these two from a manual handling perspective. However, if you are going to use a robot and the robot has to distinguish between this, and this. Let us say, this was thread I mean sorry this is a stud a and this is stud b or family a and family b.

And the robot has to or the automatic assembly system has to distinguish this from this, it requires an expensive vision system or an equivalent system that will have to find out that this thread is asymmetric from this ok. So, in such cases you cannot use the same rule that was used for the manual assembly that is why, the difference between manual assembly and robotic assembly comes into pictures. This is just one case.

(Refer Slide Time: 03:23)



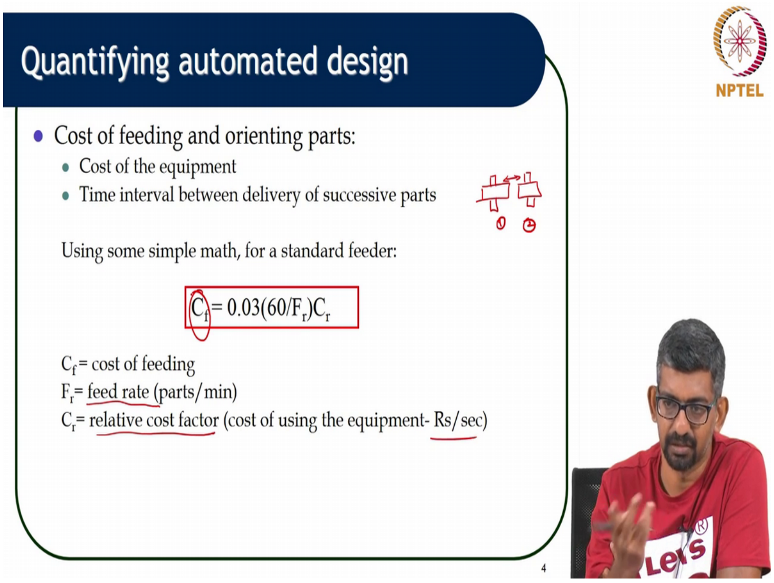
If you recall in the manual assembly, we were predominantly interested in the time perspective. Here also we will be interested only in the time, because that is exactly what the advantage of mass manufacturing where in the robotic assembly comes into picture. But, the time was influenced in the manual assembly by factors such as grasping, orienting, and inserting. We used two quantities if you remember, one is handling and the other one is insertion.

Handling is basically grasping and orienting, and insertion again is orienting and insertion plus of course we have a labour time there, know the labour cost basically that will govern the total cost. However, in the automated design the basic assumption is if a component can be handled, you can safely assume that it can also be inserted, so that is what is pointed out here.

So, automatic handling, and we really do not consider the insertion into the assembly, it is only the handling part of it ok. So, part can be handled automatically, it can be inserted automatically that is all. So, there is no distinct distinguish, we are not distinguishing handling and insertion. So, the design for the ease of orienting and feeding is the other thing ok, because the feeding basically there is a feeder rate and all that which we will discuss next ok.

So, basically what is the assembly cost is the rate at which the machine cycles. How many assemblies can the machine produce over a period of time that is what is your assembly cost essentially from an assembly perspective ok. I mean, we are not talking about the material cost and all that the assembly cost.

(Refer Slide Time: 05:22)



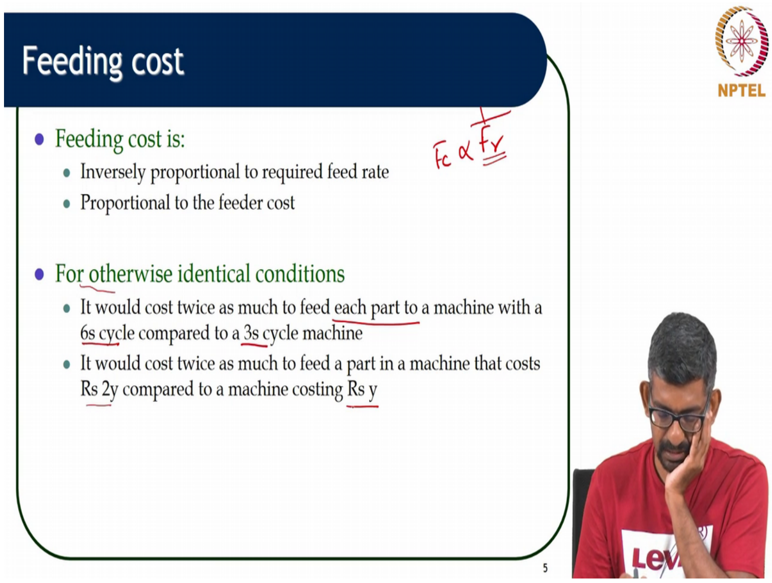
So, how do we quantify this robotic assembly or an automated design, I hope you recall, how we did this in the manual assembly by using the Boothroyd chart ok. It was all in terms of finally it will all boil down to the time. And there will be a labour cost that is associated. So, you multiply the labour cost with the total time you know for the assembly, and then that will give you the total cost that is involved from an assembly perspective and excluding the material cost.

So, here how do are we going to look at the cost of feeding and orienting the parts. Obviously, the first one is the cost of the equipment. And when it after the equipment cost is taken care of from a productivity perspective, what matters is the time interval between the delivery of the successive parts. So, I assemble one part, I assemble two parts irrespective of whatever the assembly procedure is the time between the part one and part two ok. The time interval between the delivery of successive parts. So, 1, 2, 3 successively and of course, it should be the finished assembly ok.

So, in order to come up with the number or formula that relates this using some simple math. There is a relationship that is provided that is this is the cost of feeding, C f stands for cost of feeding. It is some point o 3 times 60 is basically the parts the second minute conversion, F r is your feed rate parts per minute times, C r which is a relative cost factor. Basically, it is the cost that is incurred for using the equipment.

See often times when people want to do tests in many of the institutions the cost is only for the equipment usage. So, if my equipment is being used for 20 minutes, this is what the cost is. If the equipment is being used for n minutes, this is the cost ok. So, basically the cost of using the equipment rupees per second ok so, this is the cost of feeding that we are looking at, it is a product of two things. One is relative cost factor and the other one is the feed rate.

(Refer Slide Time: 07:51)



So, basically there is a relationship between the feeding cost and the feed rate. So, the feeding cost ok, so the feeding cost is inversely proportional to the feeding rate. Let me make sure this is the same thing yes, feed rate is that and the cost of feeding is I have used F c, but C f is the one that I have used in the cost of feeding ok. So, the feeding cost is inversely proportional to the feed rate. And often time, the feed rate is also governed by the capacity of the machine?

Student: Sir inversely

Sorry, so it is inversely proportional inversely proportional sorry the feeding cost was inversely proportional to the feed rate. The feed rate is often time governed by the capacity of the machine, and how many components you want to make in a given time ok. Sometimes the machine capacity is higher, but we do not want those many components. So, we try to reduce the feed rate. And of course, it is proportional to the feeder cost ok, the rate at which you feed is what the feeder cost is.

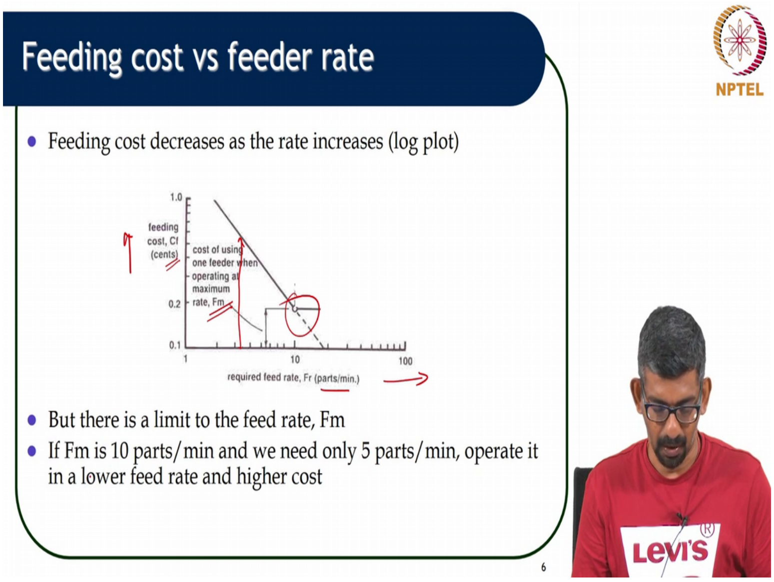
For otherwise identical conditions, may know what I mean by for otherwise identical conditions means this is for the comparative purpose. So, the complexity or the simplicity of the design part, you know the geometry everything remaining the same. What to do what it means is it would cost twice as much to feed each part to a machine with the 6 second cycle compared to a 3 second cycle machine.

So, 3 second cycle means what, let us say that it takes about 3 seconds to feed do the assembly and eject one component. And there is another machine that takes about 6 seconds. So, in 6 seconds this machine will do two assemblies, whereas this machine will do only one assembly. So, it will cost twice as much to feed each part in a 6s compared to a 3s cycle. Obviously, there are other you know this cycle sorry this machine is supposed to be expensive than this machine, but your productivity rate is much higher.

So, in that sense, the cost is twice in this machine compared to this machine. Hence, your machine specification will obviously be in terms of what would be the cycle time. And it would cost twice as much to feed a part, so this is interesting ok. To feed a part in a machine that costs rupees 2y compared to a machine that costs y that is kind of you can see that as a machine cost as well. So, it would cost twice as much to feed a part in a machine that costs 2y compared to a machine that costs y.

So, if there is machine for 100 rupees and there is a machine for 200 rupees, it takes 2 rupees to feed a part in the machine that cost 200 rupees as against 1 rupee for a machine that cost 100 rupees. And of course that that will have an impact on the cycle time hence your total productivity, hence your total cost ok. This is what we spoke about right. So, inversely proportional to the required feed rate that is what we saw here as a first one, and proportional to the feeder cost. So, if your feeder cost, you know is less than the cost is going to be less, if and else the other way round.

(Refer Slide Time: 11:30)

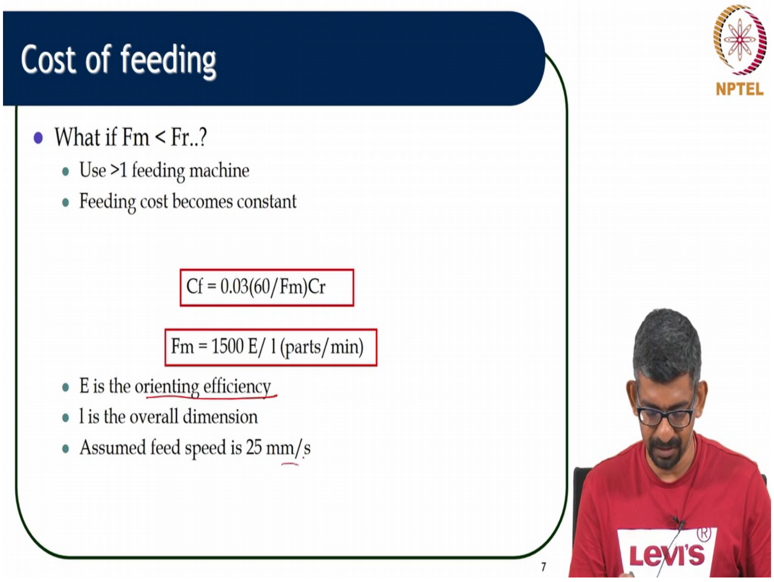


So, to understand the relationship I mean it is a linear in this case, feeding cost versus feeding rate, we have used this particular chart here or figure here. So, the x axis is your required feeding rate, which means parts per minutes, how many parts can you supply in a minute in that machine. And your y axis is your feeding cost, since it taken from a North-American text books, it is in terms of sense. May be you can converted to rupees or any currency that we are talking of ok.

So, this is what the relationship is right. So, this is the inverse relationship that we are talking about meaning if you can increase the feed rate, your feeding cost will go down. Meaning within a given minute if you are able to feed more components, then your feeding cost is coming down that is what it mean the assembly is happening quickly that is what it happen that is what it means. But, does it mean that I can just keep on increasing my feeding rate, and the cost will no there is some kind of a saturation point here there is a limit to the feed rate right.

So, you cannot again you can put the robot to keep on doing it, but there is a limit to that. If you are F m is 10 parts per minute, and if you want to do like 5 parts, which is at this level ok, you do not want that the machine can operate at this capacity, but for whatever reason you do not want to operate at that capacity, then what you do is you operate it at half. Then what happens is there is a lower feed means, there is a higher cost that is associated, because whatever you know for whatever reason the cost is higher in that sense from a productivity perspective.

(Refer Slide Time: 13:15)

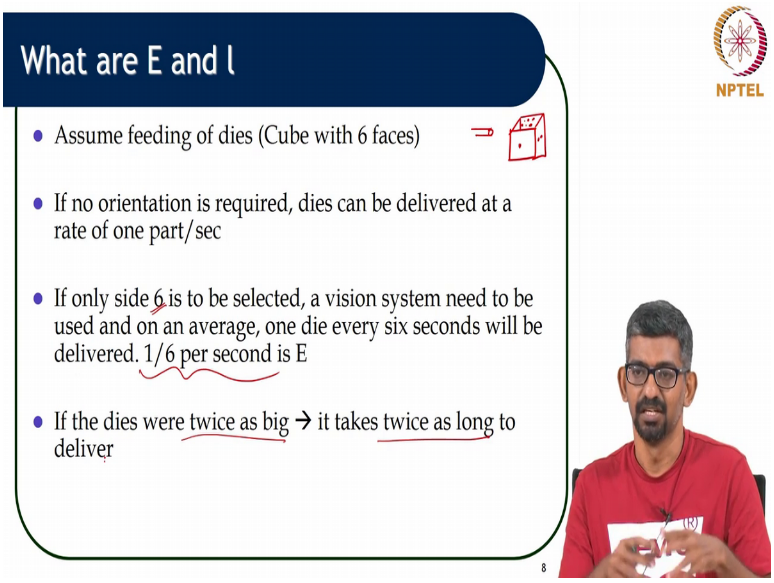


But, what is the cost of feeding this is what we said like 100 rupees, 200 rupees, 1 rupee, 2 rupees so, what is that cost of feeding. So, just in case your F m was less than your F r. What is this F m, F m is this saturating whatever you can call it as operating at the maximum that is what your F m is right. So if you are talking what if this F m was less than your F r, what is your F r? F r is nothing but your feed rate, then use greater than 1 feeding machine that is what it says.

So, what it says is imagine that this is the other way round. So, your F m is 10 parts and wait a second your sorry your F m is 5 and you want 10. Obviously, the only way that you can do this, you use greater than 1 feeding machine ok. The feeding in that sense the feeding cost becomes a constant per machine ok. So, we can kind of write this in this sense is basically point o 3 the same constant 60 times. Instead of instead of F r here, you are going to put F m, and then accordingly the C r is there.

So, instead of a F r, we are replacing it as F m. And F m is primarily the 1500 times this is nothing but your conversion from minutes to seconds that conversion. Times E over l, where E is the orienting efficiency, can I just take it and put it or will have to orient it somewhere, we will discuss what that orienting efficiency is. And l is your overall dimension that you are talking about ok. And in this particular case, we are assuming a feed speed is about 25 metre mm per second.

(Refer Slide Time: 14:56)

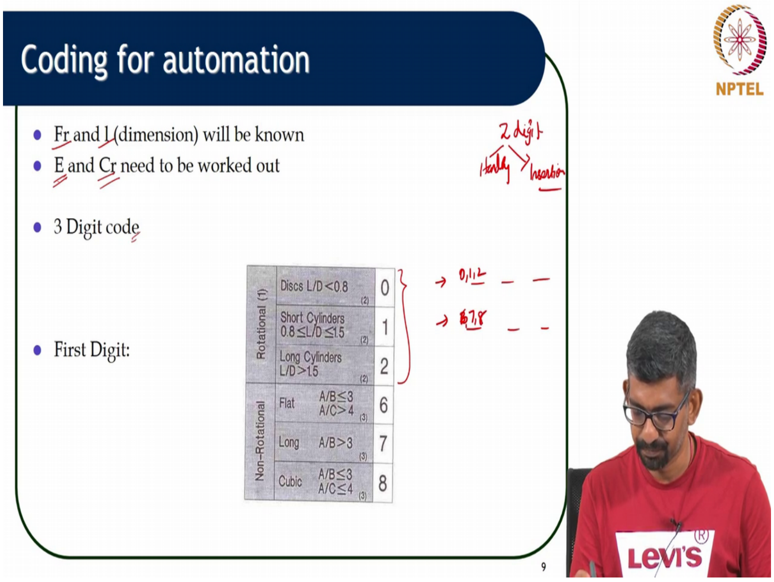


So, what is E and l, how do you get this E and l ok. So, you assume a die that we are talking about ok. Let us say, so if you can, obviously it has 6 faces and let say I do not care, which face you are supplying to the assembly ok, then there is no orienting part toward ok. However, let us say that I have these you know marks on the die, and then ok, so I have these marks in the die.

And for whatever reason, the assembly requires a particular face to be supplied for the assembly part. Then what happens is if you are just going to use the die probably, it will take about one second let us say. But, if I have to use some kind of a vision system to understand whether there was 1 dot or 6 dot or 2 dots, then I have to orient the die in 6 different directions to understand how many dots are there. And then supply that face of it for the assembly part of it. So, it will take about 6 seconds for (Refer Time: 16:21) identify the face, and then oriented.

So, it is going to be only side 6 is to be selected or it can be any side ok. A vision system need to be used, and then you can only do you know 1 over 6 per second that's all you can do or it will takes 6 seconds primarily that is what it means. So, if they if the dies were twice as big, it takes twice as long to deliver ok. So, smaller the better it is if it is larger, then how much ever geometrically it is larger that might longer, it will take for the same machine capacity ok.

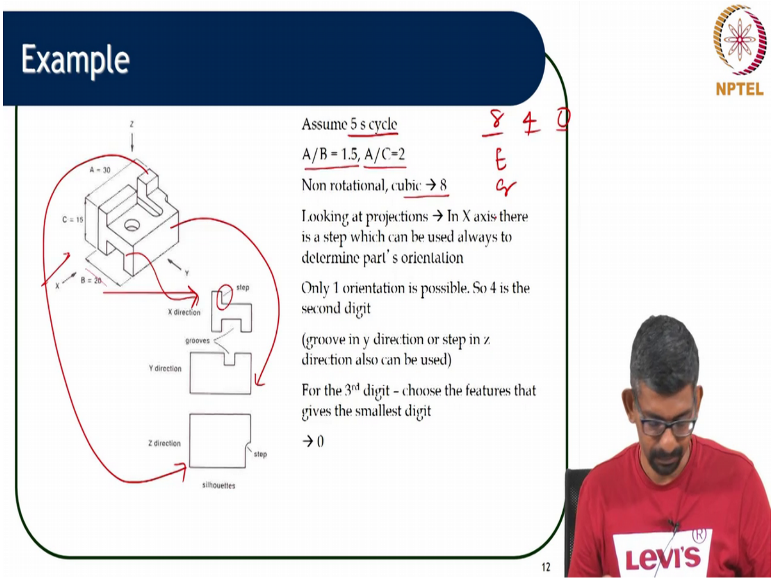
(Refer Slide Time: 16:56)



Now, is the very similar to the Boothroyd approach, where we used it 2 digit code if you remember, and then the first digit was for handling, and the second digit was for insertion. In a similar fashion, we are going to develop some kind of a coding technique here from which we will get some time that is associated with the assembly procedure. So, basically we are going to look at the feeding rate and the l will be known right.

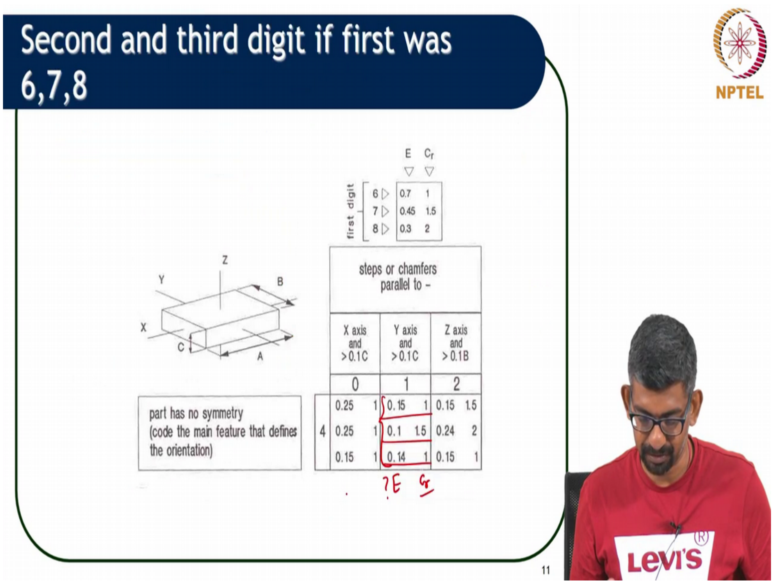
So, we know what the feeding rate is and we know what the dimension of the component that we are trying to assemble here. What we need to figure out, we need to figure out E and C r let us see ok. So, we are looking at here primarily we need to we need to figure out, this E and the C r, l is known ok and Fr or Fm this also known. So, it is basically a 3 digit code. So, there are 3 digits what is the first digit, it is dependent on whether your component is rotational or non-rotational. And if it is non-rotational, the question is whether it is flat longer cubic. So, basically what happens is you do this A over B, I will I will just quickly tell you what your A or B is ok.

(Refer Slide Time: 18:23)



So, we will discuss this example, however I am just showing you ok. So, this dimensions ok, you can only have 3 dimensions right meaning like if you are going to put a subscribe super scribing cuboid around it, then A, B, and C right so based and then it will be clearly given here.

(Refer Slide Time: 18:41)

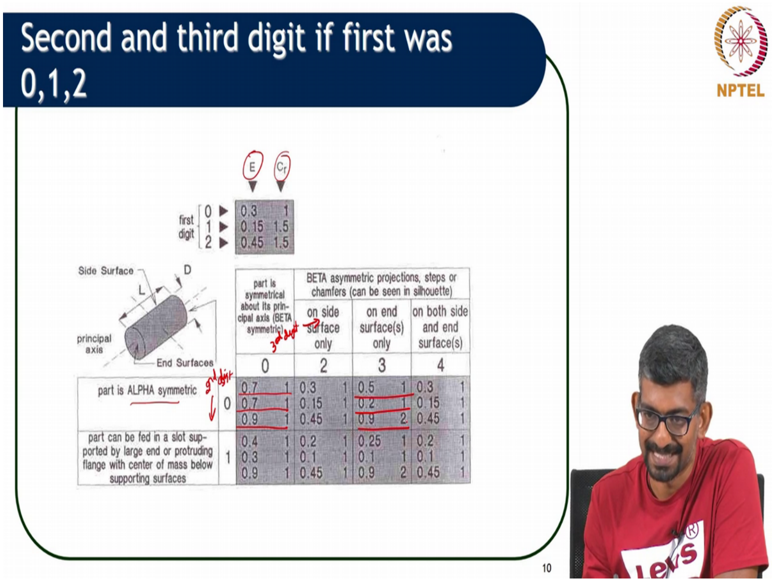


See if you go if your if your component was like this, what is A, what is B, what is C is given. So, it is usually the length, width, and your thickness that is a way. And if it is like this, then it will be kind of an L by D ratio ok, if it is a cylindrical stuff. So, if it is cylindrical or disk, you are going to look at your L by D ratio.

If it is greater than 0.8, then your digit is 0. If its short cylinder, it is 1, if it is a long cylinder, it is 2. Similarly, if it is non-rotational and it is flat, then what is A by B, what is A by C. Long means it is just A by B, C is the third dimension is negligible. And if it is cubic, then A over B and A over C, these are the conditions right. So, depending on it you will get.

So, now the next two digits are going to be divided into two. The first one will be based on, if your first digits 0, 1, 2. And the second case is so your first digit if it is 0, 1, 2 there is one case. And if your first digit was sorry 6, 7 and 8 there is a second case. Now, we will see what happens. The second and third digit, if the first one was 0, 1, 2. What was your first one? It meant that it is rotational that is what it means.

(Refer Slide Time: 19:55)



So, this is what, so the cylinder is a rotational ok. And this is a non-rotational just for clarification purpose. So, if your first digit was 0, 1, 2, this is how to read the chart ok. The chart is available like this, how do you read there are two columns as against what we saw in the manual assembly chart, because there is only one column would have been there right. So, in this your second digit and your third digit there were only 2 digits, in this we have 3 digits. Obviously, the first column belongs to the E, and second column belongs to C r. These are the two things that we wanted to capture.

For instance, you know the alpha symmetry and the beta symmetry, the idea is the same from the manual assembly concept. So, the question is so if your first digit can be 0, 1 or 2. I have just correct here it can be 2 here also. What you are going to see is the part is symmetrical about it is principal axis beta symmetric. Then these are your second and your third digit 0 comma 0 right. So, if your first digit 0 then you take this if you take if your first digit was 1, you take this row. And if your first digit was 2, you take this ratio.

So, I will repeat this again, this chart is for your 2nd digit and your 3rd digit ok. This is your 2nd digit, and this is your 3rd digit. So, let us say that you chose for whatever reason you chose 0 and 3. Your second digit was 0, the part is alpha symmetric, it is 0. And beta symmetric projections, we will see what those projections are on n surfaces only if it is on the nth surface you are only choosing 3. But, there are three options here, which one would you choose that depends on whether your what was the value of your first digit. If the value of the first digit was 0, then you choose this guy. If the value of your first digit was 1, you select this guy. If it was 3, you choose this guy.

What are these two guys? The first one is E and the second one is C r. Once you have this, you can go back and estimate what your cost is. So, is a case here again same story. So, the 2nd and 3rd digit, if the first was 6, 7 and 8 ok. So, let us say your 2nd digit was 4, and your 3rd digit was 1, then which of these three would you choose, it depends on whether my first digit was 1, 2 or 3 that is all and again what are these this is E and this is C r that's all right ok.

So, there is a quick example that we will look at. So, first thing is you know your feed rate, you assume 5 second cycle. And the component is given in this particular case, what is that A over B. A is 30 meaning your length, B is your width, and C is your thickness. So, A over B in this case is 30 over 20, which is 1.5. A over C is 2, 30 over 15. Why do I need this, because I need to understand what my so the component that I showed you is a non-rotational component.

So, non-rotational component you need to figure out, whether it is a flat or longer cubic. So, in this case it was cubic is that right. A over B was less than or equal to 4 yes, and A over C was less than or equal to 3 sorry 3 and 4 respectively that was a case. So, it is a cuboid. So, cube, so my first thing is 6, 7 and 8 right. So, it should be 8 that is what we are choosing, it is 8. So, your first digit was 8. So, what did we see, if 8 there is one particular chart in which you go and see, but in order to do that you have to take projections ok.

So, what is the projection in the three different directions, you look at it. What are the projections in the x direction. So, this is your x, you are seeing from this is what the projection is. And you see from the y direction, this is what your projection is. And you see from this z direction, this kind of top view right. So, this is what your projection is.

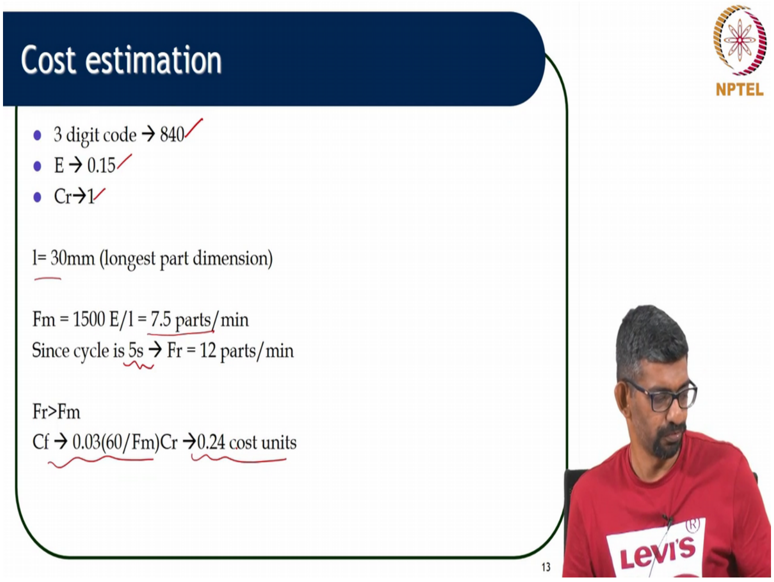
Now, how are we going to use all these things if you go back to the chart, it asks all these questions, what can be fed in a slot supported by large end protruding flange all that. And what is this, beta asymmetric projection step. Now, I am just giving this as an example, but the same thing will be here also ok. So, the steps or chamfers parallel to what axes and all that we need to use, so that is the reason we do this.

So, now you will have to look at the projections. Looking at the projection in the x axis, the first one I am talking about, there is a step there is a step here which can always be used to determine the parts orientation because, we will have some kind of a holding and an orientation scheme for the robot to or the automated thing to work. So, in that case you can use this step as the criteria and sometimes the groove also.

And in this case only 1 orientation is possible ok. So, 4 is the 2nd digit. In this case, part has no symmetry there was no symmetry as we code the main feature defines the orientation. So, my second thing was 4 then I need to figure out, what is my third thing ok, whether it is 0, 1 or 2 how is steps or chamfers parallel to x axis, y axis, z axis so, will see what it says. Groove in the y direction or step in the z direction also can be used. So, there is a groove in the y direction or there is a step in your z direction, whichever you want to use.

So, in that case what happens is your 3rd digit choose a feature that gives a smallest digit. If you have two things, then obviously you will choose the one with the lowest, because that translates into lesser time ok. So, we will choose 0 in this case, now I have three, which one would I choose, it depends on my first digit. What was my first digit in this case 8 it, so 6, 7 and 8. So, I will take this guy. So, it is 0.15 for my E and 1 for my C r that is all. So, 0 and from this you can get what your E and C r are ok.

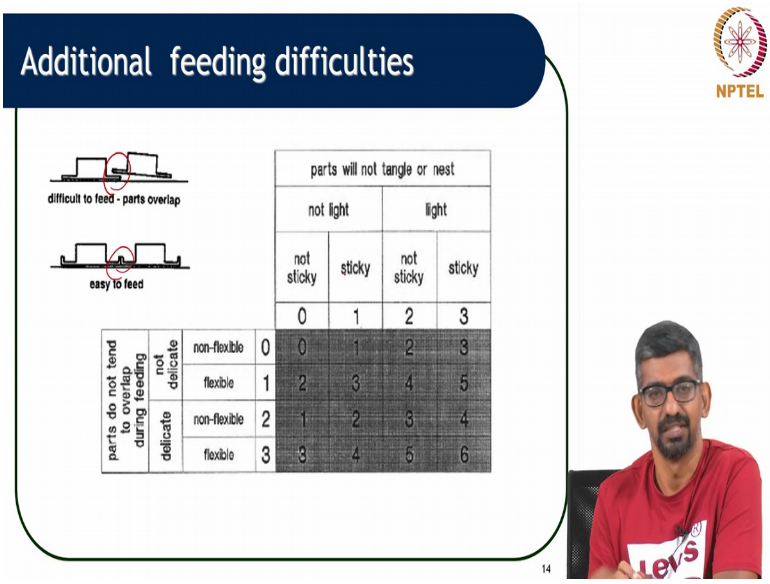
(Refer Slide Time: 26:56)



So, 840 is your 3 digit code, E is 0.15, and C r is 1, E is point 1.5 and C r is 1. So, l 30 mm longest path dimension, this is again from a projection perspective 30 mm was the longest dimension. So, how do I compute F m? 1500 times E over l so, E is 0.15 divided by 30 mm times 1500 you will end up with 7.5 parts per m minute.

Since, a cycle is 5s that is a initial assumption that we made, it means that 12 parts per minute is what you can do. So, F r is greater than F m, hence you use this you use with the F m part C f is point o 3 60 times Fm times C r, you will get about roughly 0.24 units cost units. So, I am not saying is cents or dollars are, so we are just using some cost units. So, 0.24 cost units is what you are looking at.

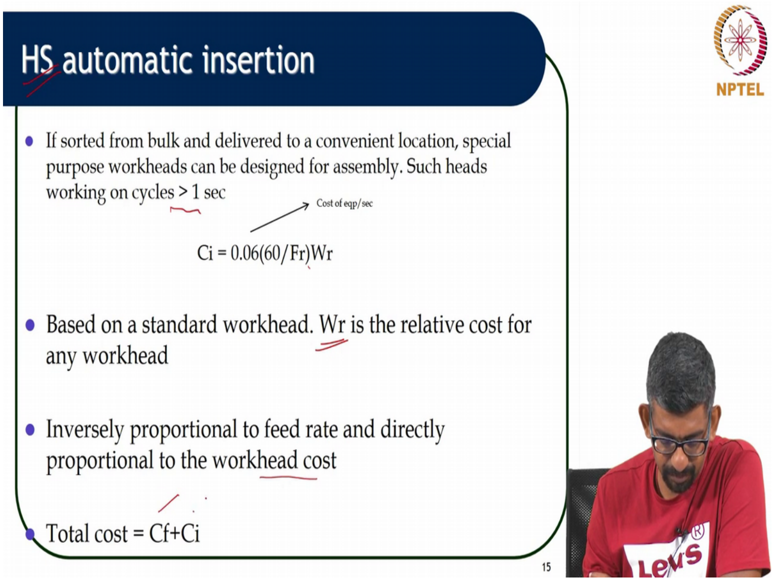
(Refer Slide Time: 27:59)



So, but digit is not this is just to give you an idea, how to deal with robotic assembly, how you can use similar concepts from manual assembly in the robotic assembly case also, but there could be additional feeding difficulties. For instance, the part can overlap in robotic assembly this can happen, manual assembly you will find and you can stop it. This is easy to feed in such a case.

So, you will have to come up with such things meaning such solutions avoid overlapping, but that is kind of taken care in the for instance parts do not tend to overlap during feeding. Then it is a good one, not delicate, it is delicate. Under which does not flexible, and flexible, non-sticky, sticky. Just like very similar to what we did for manual assembly, similarly you can come up with these numbers.

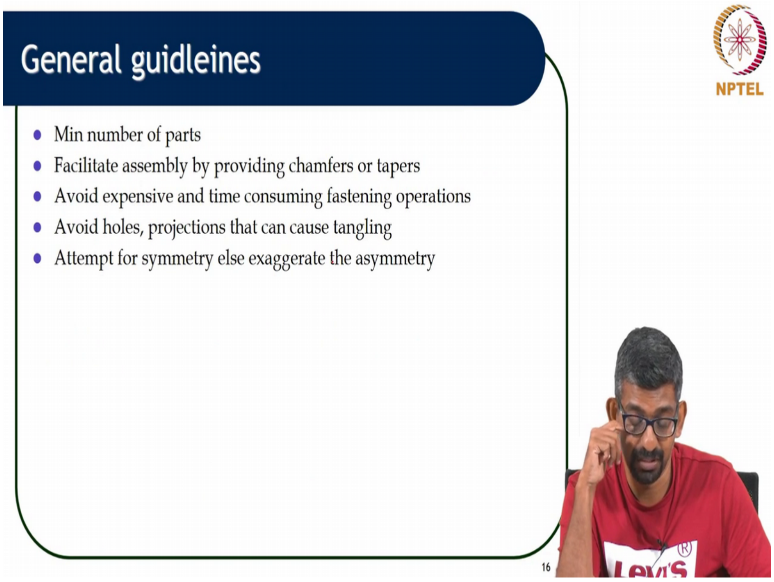
(Refer Slide Time: 28:50)



So, HS stands for High Speed automatic insertion ok. So, the question is we might not end up standing there and giving one component after the other. If it is a robotic assembly, it is an entire robotic assembly, it will pick the part, it will oriented it will inserted, it will fasten it, the whole thing is automated right. So, if the component is sorted from bulk and deliver to a convenient location, special purpose work heads can be designed for the assembly parts such heads working on cycle that are greater than 1 second.

Your C i the cost is point o 6 times 60, it is again the cost of the equipment per second C i times W r ok. So, what is W r, W r is a relative cost of any work head, work head means one head for a work that is a work head. And it is inversely proportional to the feed rate very similar to the other one that we, and directly proportional to the work head cost. So, your total cost now will be your C f plus C i. C f is something that we saw C i is given here, it is in terms of your work head.

(Refer Slide Time: 29:53)



So, the general guidelines; you want to minimize the number of parts that you want assemble, as usual no points were guessing. Facilitate the assembly by providing chamfers or tapers. So, it is easier for the robot to deal with from a projection perspective, they know what is x, what is y, what is z. Avoid expensive and time consuming fastening operations, we might want to avoid any kind of holes projection that can cause tangling that was seen here also, parts that will not tangle on nest. And attempt for symmetry else exaggerate this asymmetric, so that you do not have to have a expensive vision system or detection system to identify the symmetry ok; so with that I kind of wrap up the discussion for high speed robotic assembly.