Manufacturing System Technology - II
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Lecture – 29

Hello and welcome to this manufacturing systems technology; part 2, module 30. We were discussing about the various joint configurations and how you represent them in terms of notations.

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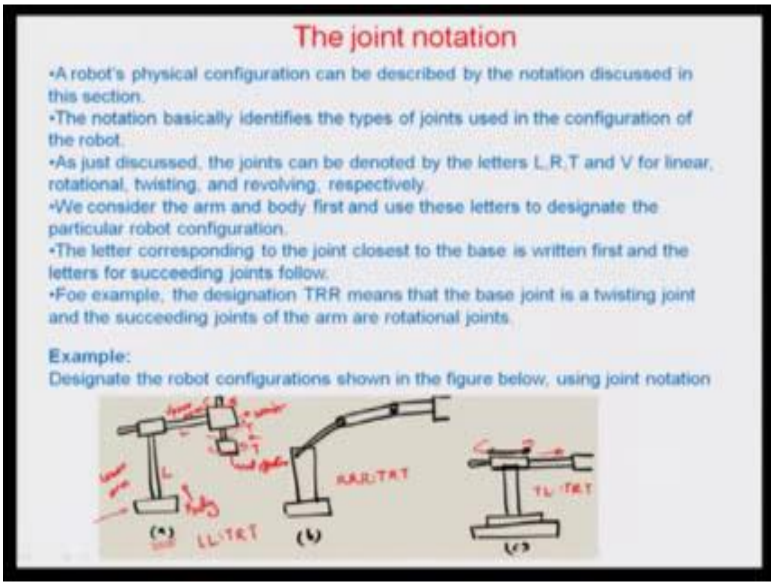

In line with this, we had done several joint notations earlier, where we were talking about to start from the body side of the robot like, in this particular case; for example, we discussed that in order to notate this particular robot joint, you start from the body of the robot and proceed to the lower arm, then the upper arm, followed by the wrist, followed by the end effecter and you have to mention about what kind of joint, the concerned arm would be (refer time: 01:09) to represent this, the robotic joint fully. So, in this particular case for example, we started with a linear lower arm; we started with a linear upper arm and then, we started with a twisting wrist. The wrist is capable of twisting and rotating. Rotation of the wrist is basically, in this particular case is, in this particular direction and the twisting is in this particular direction so, is the end effecter's twist. So, you have the end effecter also capable of twisting. So, you have a twisting, rotating, twisting kind of configuration. So, in fact, we represented this joint notation as linear lower arm, linear upper arm and twisting wrist, rotating wrist and twisting end effector kind of configuration. In the similar manner, this can be represented as a rotating lower arm, rotating upper arm and rotating upper second arm. Then you have obviously, the TRT; that is the twisting rotating and twisting configuration as far as the end effector and the rest goes. In this particular case, you would have TLTRT; that is twisting configuration of the lower arm, linear configuration of the upper arm and then, obviously, the TRT means the twisting wrist, rotating wrist and the twisting end effector.

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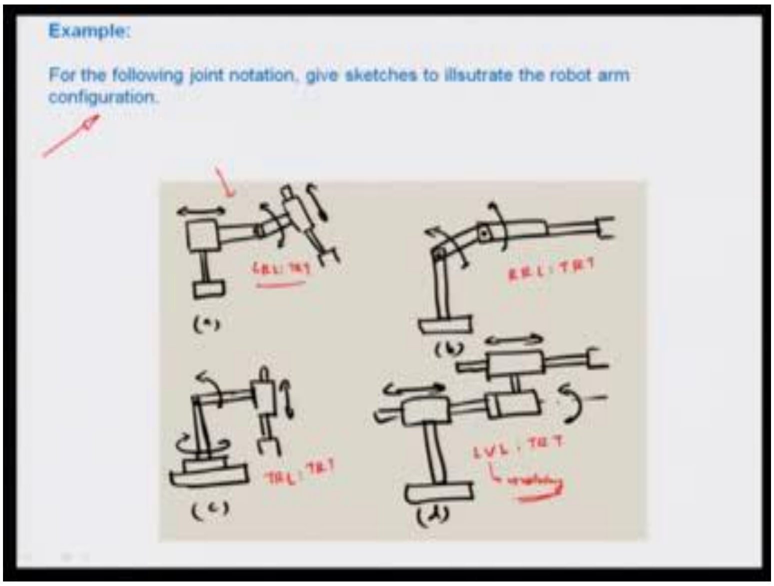

So, this is how you represent most of this robot joints. Some more examples; this can be represented as LRL, TRT and in fact, I would go ahead and request all of you to sort of figure out, how this notation arrives at from this particular joint. Then again, you have RRL, TRT; you have TRL, TRT and finally, LVL, TRT; as you know, the V stands for the revolving kind of orientation. So, that’s how you represent the following robotic joints.

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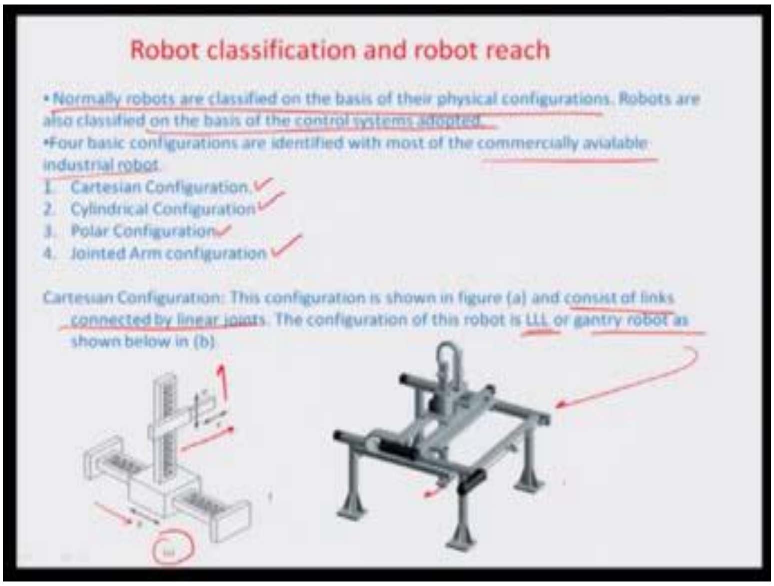

So, having said that now, we would like to go to the classifications and the reach of the various robots. So, normally the robots are classified on the basis of their physical configurations, and they are also classified on the basis of the control systems, which are adopted. So, there are four basic configurations, which are identified with most commercially available industrial robots. One is the Cartesian configuration; another is the cylindrical configuration; then the polar configuration and the jointed arm configuration.

So, the Cartesian configuration is shown here, in figure A and consist of links connected by linear joints; for example, in this case, you can see there is one linear joint in the x direction; one in the y direction; one in the z direction. This configuration of the robot is typically, joint notified as LLL and these are like gantry robots. For example, you can see this is one of the gantry robots, which may be used for doing laser micro machine for example, where the laser head can be mounted here, and the work piece can be mounted on the base so that, you can have even you know, lasers writing on vertical faces as well as horizontal faces of different systems.

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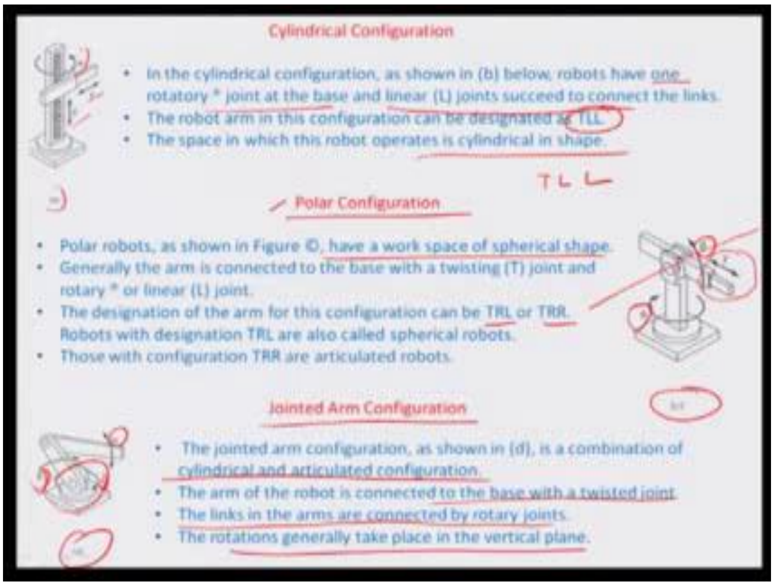

Again, you have cylindrical configuration, where as the name suggests, is shown in B basically. There is one rotation axis like, there is a theta axis over which, the arm can rotate and the y and the z motions are again, linear in nature. So, you have one rotatory joint, and the base and the linear L joints succeed to connect the links. The robot arm in this configuration can be represented as twisting linear, linear configuration. The space in which the robot operates is cylinder. We have similarly, polar configuration as the name suggests, shown in C again, where you have a work space of spherical shape. So, if you have a probability of moving the lower arm around this axis or twisting the lower arm at an angle theta, and rotating the upper arm around this particular axis at an angle beta so; obviously, you are covering and then, you have also a linear actuator at the end, which can be able to make the reach of the robot from one particular radii to another.

So, this actually corresponds towards spherical shape; creation of spherical shape in space and this joint can be notified as either TRL or TRR, depending on what is the end effector like. So, that is how you have polar configurations; obviously, you also have jointed arm configurations as shown in D, which is a combination of cylindrical and articulated configuration as illustrated here, as the arm of the robot is connected to the base with the twisted joint as you can see here; right about in this particular portion. So, you have this mechanism, which twists about the angle theta, about the vertical axis. The links in the arm are connected by rotatory joints as can be seen; one joint moves at an angle beta; another at an angle alpha and rotations generally, take place in the vertical plane. So, that’s basically a combination of cylindrical and articulated configurations together.

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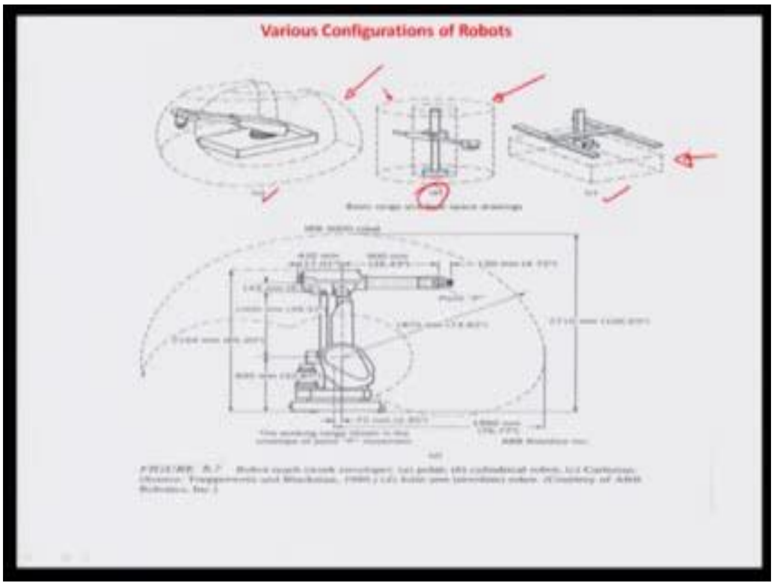

So, these are how robots are generally classified. So, you can see the various configurations of the robot and their reach drawn here; for example, by this dotted figures. This is a cylindrical robot in case B, and the reach that this robot has, is given by this dotted envelope around which, this end effector can basically move, given the base location of the particular robot. Similarly, you have a Cartesian robot as in C and a polar coordinate robot as in A, describing the spherical zone over which, the robot can go; in this particular case, the Cartesian system over which, the robot can basically go and spread. So, that is how you represent different robotic configurations.

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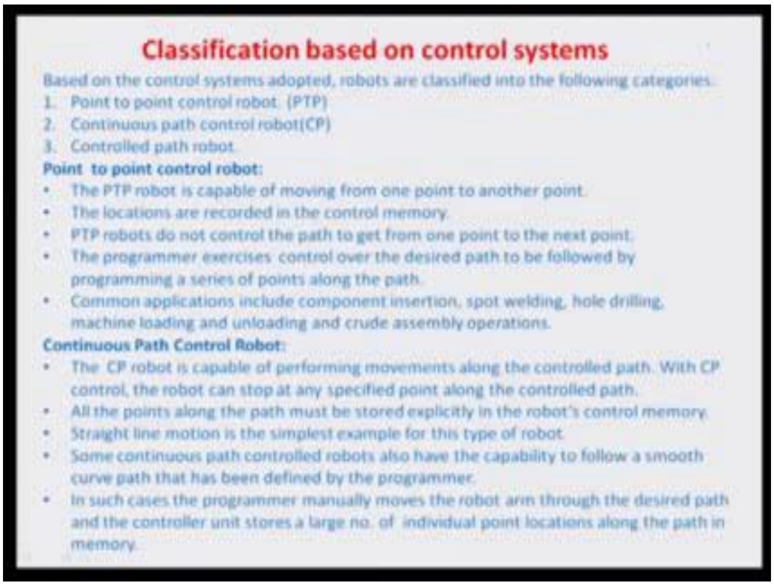

So, we now classify the robots, based on control systems. So, based on control systems adopted, robots are classified into point to point robot; control robot, continuous path control robot and controlled path robot. So, let us look at what these various classifications are. So, the point to point robot is capable of moving from one point to another point. The locations are recorded in the control memory. PTP robots do not control the path to get from one point to the next point. The programmer exercises control over the desired path to be followed by the programming series of points along the path. Common applications of these include insertion spot welding, hole drilling machine, loading and unloading and crude assembly operations, etc. The continuous path control robot on the other hand is capable of performing movements along the controlled paths.

So, with the continuous path control, the robot can stop at any specified point along the controlled path. Basically, it is a continuous operation. So, the simplest example is the straight line; for example, you know if you have a robot moving equal to so, in a straight line; for example, if we take the robot and lead it to go along a straight line and you know, record the control points in between in the memory; obviously, dependent on the resolution, stage resolution, another factors. Whenever you execute the motion or the complete motion to go on a straight line, the robot will just follow those control points, which have been recorded in the process of training it, by taking it along physically on the path of the straight line. So, the only difference between the point to point and this case is that in a point to point control, you once given the location of the destination, the robot cannot be stopped in between.

So, it starts from a certain point; ends at a certain point; in between points, there are no ways of stopping or not executing the particular trajectory, and that is a big problem in the point to point, but in the continuous path control; now, because you have already had a training phase, where the whole path has been planned into discretized coordinates and those coordinate locations have been stored in the robot control memory; it is easy for the continuous path control process to stop the robot at any given path. Some of the continuous path can also be curved paths. So, the curve paths can also be typically, defined. The programmer manually moves the robot arm, even it is a curve or it is a straight line or any other particular motion. The controller unit is supposed to store the large number of individual point locations, along the path in the memory. That is how the robot learns. There are other higher level robots which work on controlled path mechanisms.

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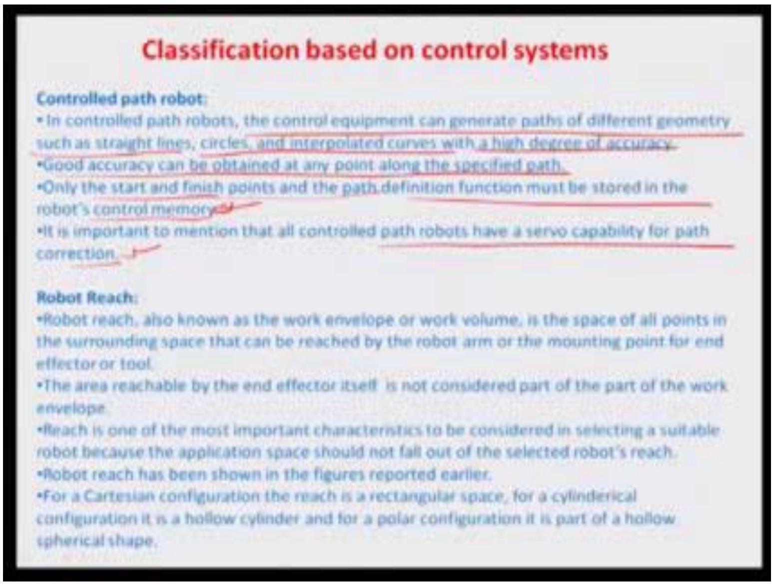

So, only difference in the controlled path is that the control equipment can generate paths of different geometry, such as straight lines, circles and interpolated curves. So, there is a relationship, which is available algebraically, in which there is some computational first hand activity, carried out by the robot controller itself. So, the question there is could accuracy, by means of looking at the resolutions of the various stages, looking at the controller resolution to map the data so on and so forth. That defines what is the resolution of the least count of motion, on a certain guided path or a controlled path as given by a relationship. So, for example, y equal to m x plus c is a straight line equation. So, if a robot is supposed to go on a straight line automatically, computationally, the predicted y versus x coordinates would be generated, which will give you a set of control points for the robot to automatically, self-guide on that particular path.

So, robot reach is also known as a work envelope or work volume in the space of all points with the surrounding space that, can be reached by the robot arm. I think we had already shown you the envelope, the dotted envelope around spherical coordinate robot or spherical accessible robot or a cylindrically accessible robot, etc. It really depends on two things; one is the mounting point or the end location that with the base of the robot is fixed and what is the reach of the end effector, given the maximum flexibility executed in that system and maximum stretch executed in a particular system. So, that is how you will define the robot reach. So, reach is definitely by and large, one of the most important characteristic to be considered in selecting a suitable robot, because the applications pay should not fall outside the selected robots reach. So, that way the robot motion cannot execute the job properly if the applications point is outside its domain. So, for a Cartesian configuration, the reach is a rectangular space. Cylindrical configuration; it is a hollow cylinder. Polar configuration; it is part of a hollow spherical shape; all you have seen before by the dotted lines mentioned earlier.

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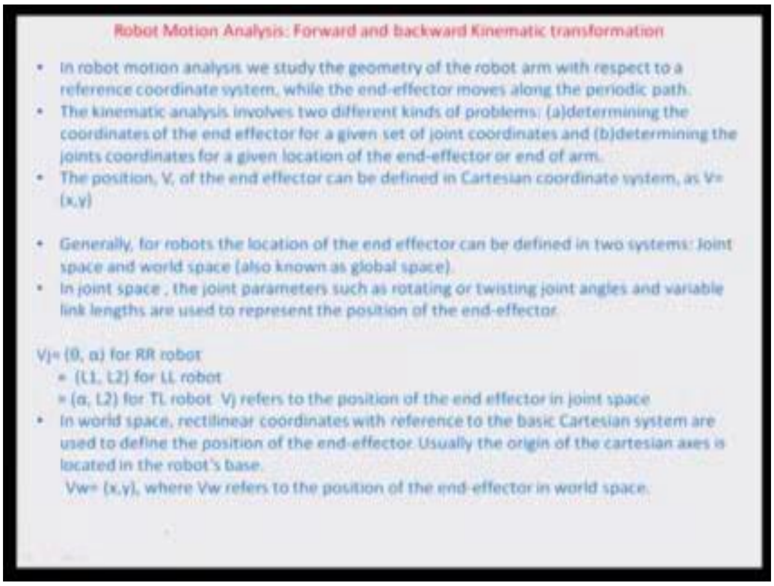

So, the other important aspect in robotics is obviously, about the kinematic transformations. They are, robots are as we already know, our systems with various linear revolving, rotating, twisting kind of links, and there are different length aspects and angular aspects which are associated. So, obviously, there is a geometrical relationship between the base over robot and the end effector in the way it moves, with respect to the base. So, in robot motion analysis; obviously, we study this geometry of the robot arm with respect to the reference coordinate system, which is typically taken as the base of the robot in most of the cases; while the end effector moves along the periodic path. So, the kinematic analysis involves two different kind of problems; one is obviously, to determine the coordinates of the end effector for a given set of joint coordinates and angular relationships, and the vice versa, which is determining the joint coordinates for a given location of the end effector and the end of the arm.

So, it is basically in one case, a forward kinematic transformation, starting from the base of the robot towards the end effector, and another is the backward kinematic transformation. So, the position V of the end effector can be defined in Cartesian coordinate as x, y and generally for robots, the location of the end effector can be defined in two systems; one is the joint space and the world space, also known as the global space. So, in the joint space, the joint parameters such as rotating or twisting joint angles and variable link lengths, are used to represent the position of the end effector. So obviously, for a rotating-rotating kind of system, you have two different rotation coordinates; one is let us say theta; another is alpha. So, the position of the end effector in the joint space is recorded in terms of a theta and alpha angle. Similar cases in the case of a linear-linear robot system, where you have two different link lengths; let us say L 1 and L 2.

So, these are mostly used for defining the position of the end effector. If it is a, you know, twisting linear kind of a system, you have a twisting angle and length, which is associated to the rife, the v j or the position coordinate of the end effector. So, in a world space rectilinear coordinates with reference to the basic Cartesian system, are used to define the position of the end effector. Usually, the origin of the Cartesian axes is located at the robots space as I referred before, and v w refers to the position of the end effector in the world space. So obviously, if the origin id shifted, then the base of the robot, then there is a problem; otherwise, whatever is the readout of the end effector in the joints space, is usually considered to be that in the world space as well

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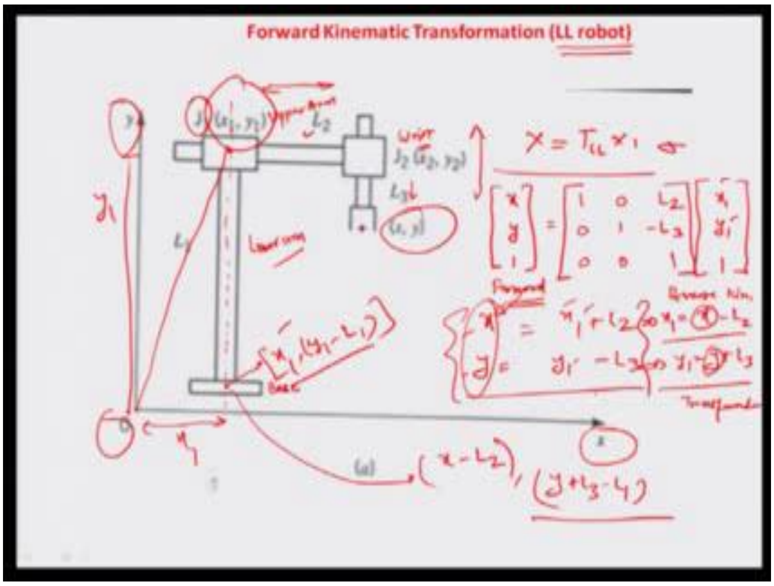

So, let us look at the various systems which are into place. This is for example, a linear-linear system. So, you have this for example, is the LL robot; a linear-linear robot, which means here that this right here is the base of the robot. Let us just classify first, the different aspects related to of the robot. This is actually the, you can say, the lower arm and it is pretty immovable. So, basically there is no possibility of linear motion along this particular arm. The only two linear motions in this particular case; one is linear along L 2; another is a liner motion along L 3. So, you have a linear-linear system here, where the upper arm is able move and so is the end effecter or the wrist, you can say, is capable of movement. This is the wrist, having said that; obviously, if we were to change everything in terms of the world coordinate system, here is the origin of the world coordinate system in this particular case. It is a very generic case. You can see the base is not really aligned at the world coordinate system.

There is a read out of a joint j 1 here, which is x 1 y 1 in this particular space. So, this right here is x 1 and this right here is y 1; that is how read out is. So obviously, with respect to x 1 y 1, we will probably, have to find out; use some kind of a homogeneous transformation, where we can actually plot what is the x and y. So, we will use the following transformation equation for that x equal to TL L x 1. I am not really going into the details of how mathematically, these can be established; this I have done in very detailed manner while doing the computer aided design. So, in a similar manner, let us say in this case, the matrix which comprises of the end effecter position that is x and y coordinate, can be represented as x y; one it is of course, a 2-d space that we are working in. So, the transformation matrix for establishing the linear-linear movement can be represented as 1, 0, L 2, which is the length of this particular link and similarly, 0 1 minus L 3; again L 3 is in a reverse direction.

So, it is on the minus y direction. You have to be very careful about establishing this and then, you have 0, 0, 1 as the dummy coordinate. So, the other aspect here; x 1 is obviously, the coordinate system in the world space; that is z 1, y 1, 1, which is being read out very well, with respect to the origin of the world space. So, if we know where this particular joint j 1 is located, and in fact, this joint has a relationship with the base; so, we can actually further allow this particular base here to be represented as x 1 and y 1 minus L 1. So, that is how you can actually see with respect to the base as well, but the forward kinematic transformation here, means x becomes equal to x 1 plus L 2, and y becomes equal to y 1 minus L 3, and that is how you can actually read out the point x y with respective x 1 y 1. So, everything is converted now into the joint space from the world coordinate system x 1 y 1. If supposing, we knew the location of the or we wanted to know the location of the base in this particular case, the obvious answer to this would be that the base is located at x equal to x 1, which is actually x minus L 2 and it is located corresponding to y 1 minus L 1, which is actually y plus L 3 minus L 1. So, that is how you can locate the base, once this end effecter position is determined with respect to the world system.

So, that is how you do the forward kinematic transformation. You can actually go back and do the reverse order of it. So, you can say that if I knew x and y; so, if you knew the position of the end effecter, then I derive from end effecter position, the world space coordinate. So, in this particular case, as you know x 1 is equal to end effecter position minus L 2, and the y 1 is equal to y plus L 3; the end effecter position y coordinate plus L 3. So, these are the reverse transformations. So, these are the reverse kinematic transformations. So, this is the forward; that means, from the world coordinate system to the end effecter position and the reverse kinematic is if we know what is the end effecter position can be mapped back what is the world coordinate system or what is the joint space, based on that. This is how you map the kinematic transformations.

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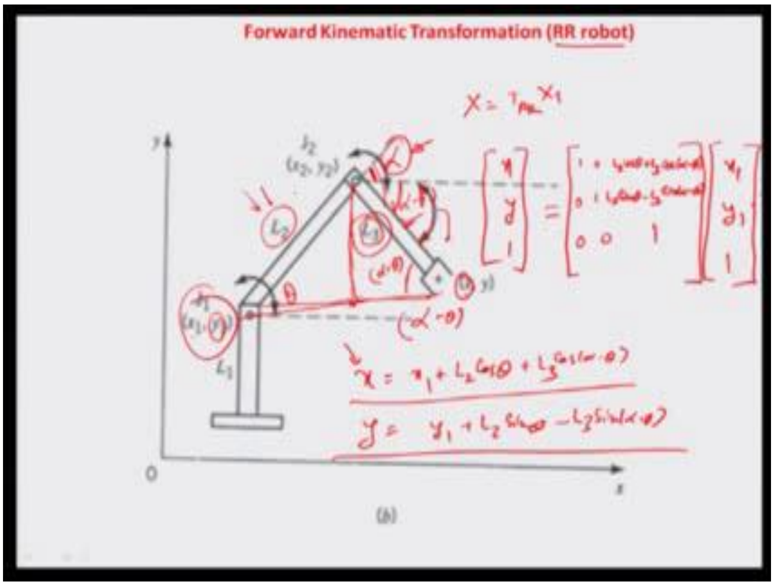

Similar example can come in case of rotation-rotation kind of systems. Here you have two links as you can see lower link being fixed. So, this is the base of the robot really, and you have a lower arm and an upper arm as given here; let us call it L L and U L and here, you already know that there is a movement of rotation along the joint j 1 in the two-dimensional space, which is rotating at an angle of theta, along the j 1 point. Then, let us say the link L 3 is rotating with respective to the L 2, but then with respect to the world coordinate system that is with respect to the horizontal or x axis. It is rotating at an angle alpha. So, having said that now, there would be existing transformation and we can right this equation as x equal to the transformation matrix of this double rotation PRR times of x 1, where x becomes the end effecter space, which is x y 1 coordinate x y 1, and the TRR in this particular case, becomes equal to 1 0 L 2, cos of theta plus L 3 cos of alpha minus theta and 0 1 L 2 sin of theta minus L 3 sin of alpha minus theta, where alpha is basically, the total motion which has been moved with respect to, I am sorry, this total motion with respect to of the L 3 with respect to L 2, as described by alpha, as I had verbally illustrated it before.

So, this angle really becomes equal to alpha minus theta, because theta is this angle which is describing the motion of L2 2 with respect to the horizontal and the total angle that it has moved with respect to the initial link L 2 is basically alpha. So, this right here is really, alpha minus theta. So, that is how we have represented this and then, you have 0 0 1 and this right here is the x 1 coordinate, which is related to world space for the joint j 1 x 1 y 1. What it essential means is that we are looking at coordinate x here, which is right about this point, which is actually equal to x 1 coordinate here, plus we add the component of L 2, which would contribute to displacement of the point x from x 1, which is L 2 cos of theta. So, L 2 cos theta is really, this much movement, because of the angular twist of the link L 2, with respect to the horizontal and then, the other part here really, is about the link L 3 and you have cosine component, alpha minus theta. So, plus L 3, which is this link right here; so, the cos of alpha minus theta, which is actually same as this alpha minus theta, relative motion of link L 3 with respect to the world coordinate system, which comes under picture; so, L 3 cos of alpha minus theta. So, that is how x is described; y again, the end effecter position is described in terms of y 1 plus L 2 sin of theta.

So, obviously, there is going to be an addition between this y 1 and y 2 as given here. So, a part of it would come as contribution from L 2 sin theta. So, this link right here is at least, L 2 sin theta displaced from y 1 in the vertical direction and then, you have minus of again, L 3 times sin of alpha minus theta, which is actually the negative contribution, because this link has now moved below the horizontal. So, that is how you describe the y. So, obviously, if I were to, this is the forward kinematic transformation. So, we can actually, write down the reverse kinematic transformation in this particular case by just changing, given the end effecter position, how will you calculate the different joint coordinates like what is the link L, length of the link L 2 or L 3; you can find out from the reverse transformation that will do a little bit later. So, that is how you do the rotation-rotation robot.

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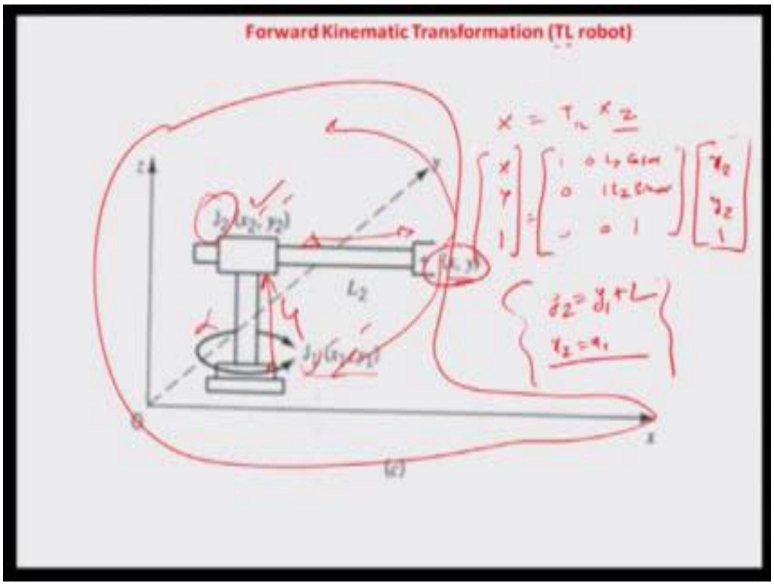

We also have another case here; the twisting linear robot here. Robot is twisting along with joint j 1. So, there is an angular movement alpha, along this twisting. So, it is capable of actually, going in this x y plane in both the directions and then, there is a linear movement L 2 j 2, with respect to the end effecter position x y. So, that is why we call it a TL robot and here also, if I look at the transformation equations, the x would be actually, the transformation for the TL configuration and times of x 2, where this x 2 y 2 here is obviously, the location coordinate of the joint j 2. So, the base here in this case, is the joint j 1, which is the first joint, which is performing this twisting rotation. So, here I can write the transformation as x y 1 equal to the transformation matrix, which is in this case, 1 0 L 2 cos of alpha, 0 1 L 2 sin of alpha, 0 0 1 times of x 2 y 2 1.

Obviously, if I knew the link length here as L 1, I would say that I have a relationship that y 2 is equal to y 1 plus L and x 2 is same as x 1. So, that is how I would be able to convert or get the location of the joint j 1, once this world coordinate system is defined. So, these x 2 y 2 are x 1 y 2 are defined in this whole world coordinate system and the end effecter position is actually, what we are trying to determine in this particular case for this transformation. So, that is how you do the forward kinematic transformation. So, obviously, if we were to look at can we do the reverse. So, that is how the forward kinematic transformation of all the three systems; that is the linear-linear, the rotator-rotatory and the twisted-linear kind of robot arms have been defined.

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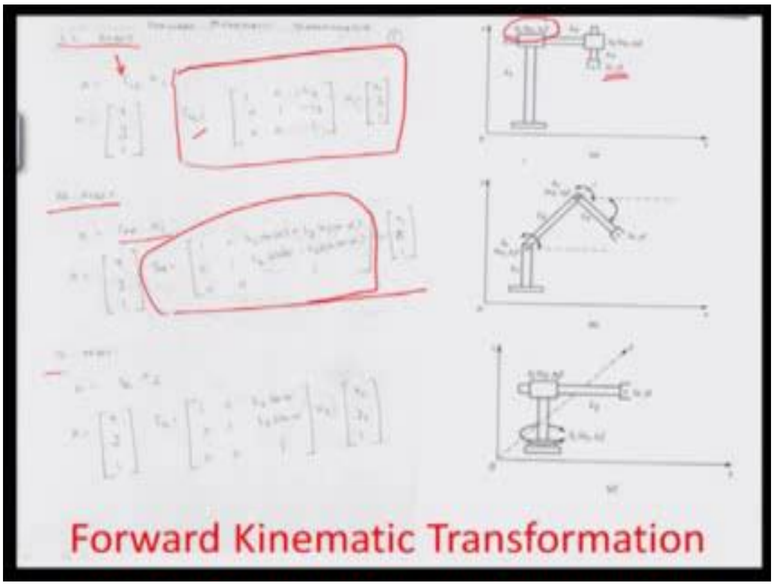

So, in a nutshell, if you look at the forward kinematic transformation here, this like mentions about the combined, you know, how the transformations, the forward direction would happen. So, if x 1 and y 1 are in the global coordinates position factors of joint j 1; the first joint; so, obviously, the end effecter x y would be related as the character x is the transformation matrix, t linear, linear x once similarly, for the RR robot, the rotation-rotation robot. You have a coordinate transformation given by x equal to TRR x 1, where TRR again, you know, this particular matrix right here, as we derived in the last step and similarly, for the TL robot.

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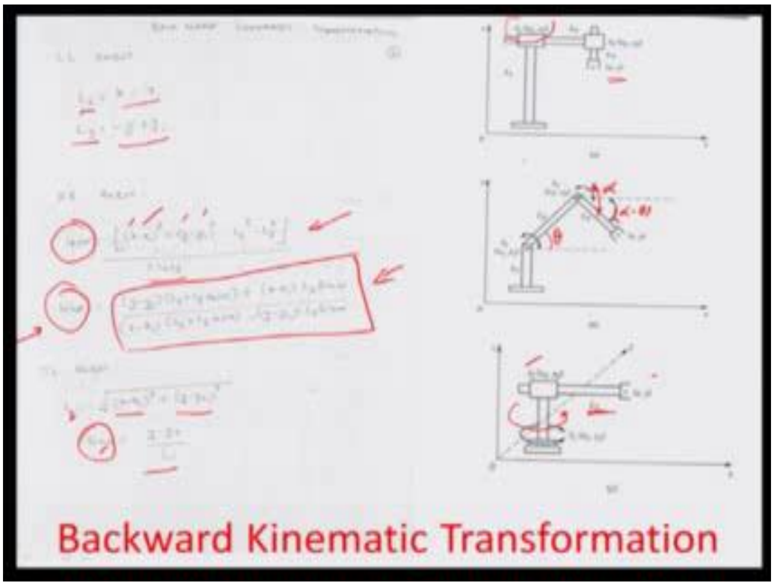

The similar kind of transformation can happen in the backward direction if you know the end effecter position vectors and also the initial position of the joint j 1. So, you can obviously, be able to find out what are the link lengths. So, these are and the joint space you know, you basically transforming from the global coordinate system into the joint coordinate system. So, L 2 and L 3 can be calculated as x minus x 1 and y 1 minus y. Similarly, if you wanted to look at the joint space what are the angles of movements; so, cos alpha and tan alpha, divided by either the link lengths and the global coordinates of the end effecter as well as the base of the robot as x minus x 1 square, plus y minus y 1 square, minus L 2 square minus L 3 square by twice L 2 L 3, equals cos of alpha, where alpha again, is this particular angle of motion as you know, this is the overall angle of the motion and this is the angle of the link L 2, with respect to horizontal angle theta.

So, therefore, this becomes alpha minus theta. Tan of theta here, can be defined as y minus y 1 times of L 2 plus L 3, cos alpha plus x minus x 1 times of L 3 sin alpha, divided by x minus x 1 times of L 2 plus L 3 cos alpha minus y minus y 1 L 3 sin alpha. So, I leave it on to the audience to sort of figure out how these reverse transformations have happened given the forward transformation. These have been detailed in manufacturing systems technology; part 1, and the CAD module. Similarly, if you wanted to find out the joint link length L 2 between the joint j 2 and the end effecter, can be looked at by looking at x minus x 2 square, plus y minus y 2 square whole under the root and similarly, the twist angles, sign alpha can be determined as y minus y 2, divided by L as the amount of you know, angle that has been moved in a axis vertical, parallel to the z axis in this particular case. So, these are the backward kinematic transformations.

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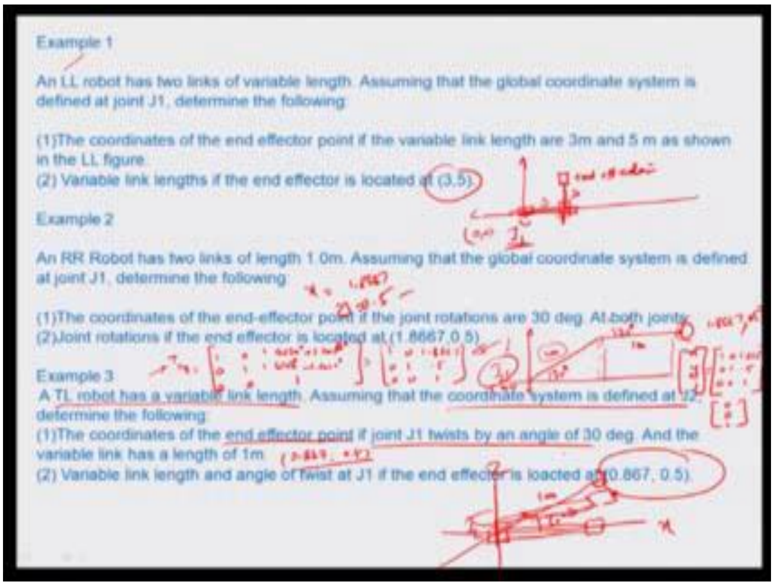

Let us do some problems examples; let us say an LL robot, linear-linear robot has two links of variable lengths, assuming that the global coordinate system is defined at joint j 1, determine the following coordinates of the end effecter points; link lengths are given to be 3 meters and 5 meters; obviously, if I were to look at this particular robot system, saying that the global coordinate system is defined at joint j 1. So, therefore the joint j 1 is defined at the point origin. So, this probably is the definition of this kind of robot and the j 1 joint signifies the base of the robot. The other end effecter is again, a variable length; this is the end effector. So, when we are talking about 0 0 as the global coordinates for the joint j 1, the coordinate of end effector points at variable link lengths are 3 meters and 5 meters; meaning thereby that you have 3 meters and 5 meters as the length L 1 and L 2. So, therefore, the coordinates of end effector should be 3 5, and the variable link lengths if the end effector is located at 3 5, also should be 3 meters and 5 meters. So, very simple forward and backward transformations; this is the forward transformation and the backward transformation, based on the logic that has been given earlier. Similarly, if a RR robot, rotation-rotation robot has two links of lengths, 1 meter assuming the global system is defined at joint j 1.

So, in this particular case, let us say you have a RR robot, defined in this particular manner. So, the first link which is at 1 meter in length is basically, or positioned about the origin. So, that joint j 1 comes at the origin exactly to 0 0 of the global coordinate system and the other link. So, this link has gone about 30 degrees. The other link also rotates in the other direction about 30 degrees, which meaning thereby, the link comes back to the normal position. So, this rotates again by 30 degrees, meaning thereby, that this link is at 0 angle with respect to the horizontal and this is about another 1 meter. So, obviously, we need to find out what is the end effector's position coordinate right about here, which I can just apply the matrix and find out or even you know, geometrically, it can be found to be 1 plus the cosine component of 30 degrees or of 1 meter, which is 0.8667. So, essentially, this should be 1.8667 and the y component here, should be the sine component of 1, which is about 0.5 meters.

So, that is how we define the end effector's position on this particular case also, by the transformation matrix the TRR in this particular case, would be represented as 1 0 1 cos of 30, plus again, 1 cos of 0 0 degrees, and because this is alpha minus theta, which is actually equal to 0 now, 30 minus 30 and then, the second line becomes 0 1 and L 2 sine theta; that means, 1 sine of 30 degrees minus 1 cosine of 0 degrees and then, you have 0

0 1 as the transformation matrix TRR. So, this actually becomes equal to again 1 0 1.8667 and 0, 1, 0.5, 0, 0, 1, and this actually is multiplied to 0, 0, 0, 0, 0, 0, 1 in order to find out the new coordinate system. So, the position vector for the end effector x y 1 should be equal to this TRR 1 matrix 1, 0, 1.866, 0, 1, 0.5, 0, 0, 1 times of the matrix 0 0 1, which is the coordinate vector of the joint j 1 in this particular case. So, this x y would actually, become equal to 1.667 and y would become equal to 0.5, as illustrated here.

So, you will using the transformation as well you see, were able to figure out a map, the end effector's position, given the joint j 1 position of the origin. So, a similar case of TL robot and this I leave to your judgment; how would you work on it. So, you will have to assume the coordinate system as defined at j 2. So, meaning thereby, that the joint j 2 in this particular case, happens to be the coordinate system. This is the joint j 2. So, it is capable of twisting around this axis and also, capable of moving linearly. So, that is why it is a TL robot and you have to find out the coordinates of the end effector if the joint j 1 twists by an angle of 30 degrees. So, basically, this twist here of the joint is by certain angle. So, it goes here in the x y plane; this is the x y plane; let us say. This is the z axis right and so, this twists by 30 degrees and it is able to, the total length of the variable length of the arm is about 1 meter. So, you will have to find out what is the end effector's position coordinate. So obviously, it be the cosine of 1 and sine, cosine of 30 degrees and sine of 30 degrees times 1, and you can actually figure out, do the variable, do the backward transformation figure out that if the end of the effector position is defined. You can actually see what is the angle of twist or even the link length etc. So, that is how you can actually attempt these problems by looking at the transformation matrices.

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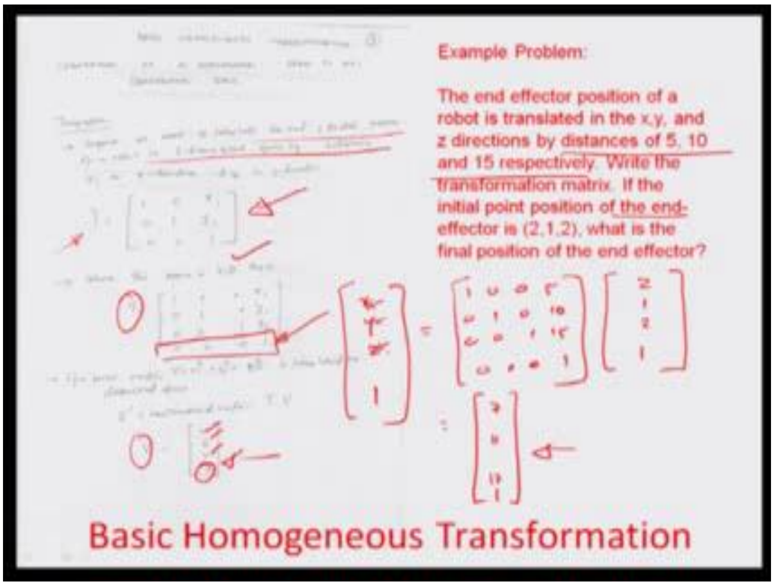

A little complexity is added by putting a third dimensions. So, here for example, you want to translate the end effector position of a robot in two-dimensional space. So, obviously, this is a sort of translation matrix that you are looking at particularly, in a linear-linear system, but when the space is a 3-d space, then obviously, you will have to add a dummy variable and this I had illustrated clearly, in the coordinate transformation module that we have done in the manufacturing system technology, part 1. So, basically homogenize the matrix by adding or taking the matrix from a n space to n-dimensional space to n plus 1-dimensional space and then, that becomes very easy to again, multiply and find out the modified coordinate systems. So, here in this case, we just add a dummy variable 1 to the three-dimensional coordinate system that is there, RST. These are the initial vectors and this is the transformation matrix.

So, the transformation matrix into the initial vectors becomes the final end effector position. In this particular case; for example, there talking about distances 5, 10 and 15 respectively, translated in the x y and z directions by the end effector. So, we will have to write the transformation matrix if the initial point position of the end effector is 2, 1, 2. So, therefore, the transformation matrix can be written down as 2 1 2 1, times of the whole vector space; here 1, 0, 0, 5, distance of movement 0, 1, 0, 10, 0, 0, 1, 15 and the dummy variable 0, 0, 0, 1. So, that becomes the location of the end effector. So, let us lay this out as x, y, z and 1 and so; obviously, as you can see in this particular case, you know the transformation x, y, z, 1 would result in 7, 11 and 17 respectively. So, that is what would be the modified end effector’s position in this particular case.

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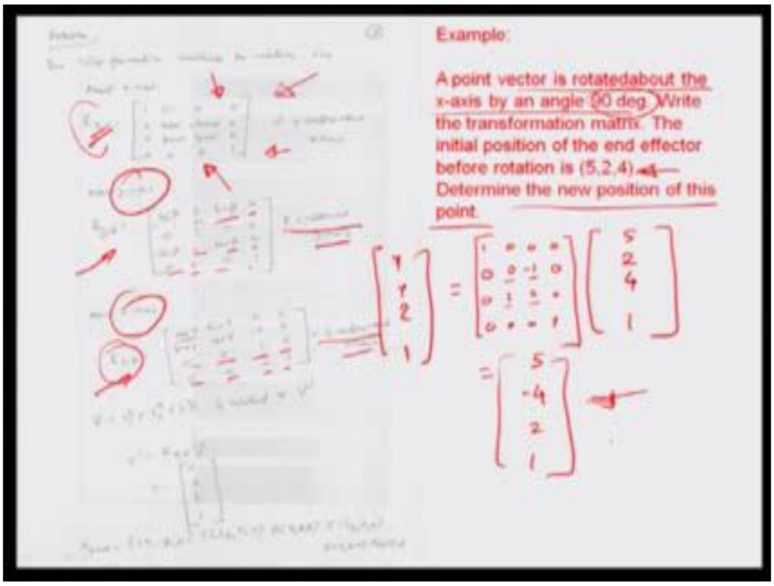

You can do a similar kind of a transformation with rotational coordinate systems. So, let us say a point vector is rotated about x axis by an angle 90 degrees. So, you will have to write the transformation matrix in this particular case. The initial position of the end effector before rotation, is given to a 5, 2 and 4. So, you want to determine the new position of this point. So, obviously, the rotation vector if it about the x axis, is given by the transformation matrix here, 1, 0, 0, 0, cos alpha minus alpha sin alpha, 0, 0, sin alpha, cos alpha, 0, 0, 0, 0, 1 and alpha is rotated about the x axis in this particular case, as has been given as 90 degrees. So, we would like to apply this transformation to the modified or homogenized vector. So, initial position of the end effector before rotation was 5, 2, 4. So, we multiply the transformation matrix here, which is 1, 0, 0, 0, 0, cos of 90, which is 0 minus 1 sin of 90, 0, 0, 1, 0, 0, 0, 0, 0, 1.

So, that becomes the final point of the end effector after the rotation has been executed here. This is cos of alpha and cos 90 degrees or sin of 90 degrees and again, sin of 90 degrees and cos of 90 degrees. So, if we look at how the rotational space has been ordered or matrix, the transformation matrix has been given about; the x axis rotation is represented here. I am not going into the detail of how to prove this, because they have been an extensively done in the CAD part of this course, which was manufacturing systems technology, part 1. So, obviously, now we can write this modified coordinates as 5, minus 4, 2 and 1. So, that is how we do the modified coordinate of the end effector particularly, in this kind of situation. So, we will have to be very careful about applying these translating vectors, about y axis and z axis, the translating vectors or the transformation matrix changes as cos beta 0 sin beta 0; beta is the rotation about y axis 0, 1, 0, 0, minus sin beta 0, cos beta 0, 0, 0, 0, 1 so on and so forth, and about z axis again, if gamma is the rotation, then you can actually have the transformation matrix written as cos gamma, minus sin gamma, 0, 0, sin gamma, cos gamma, 0, 0, 0, 0, 1, 0, 0, 0, 0, 1 so on and so forth. So, that is how you basically, modify the coordinates. I think we have covered more or less, everything that needed understanding in the robotics area.

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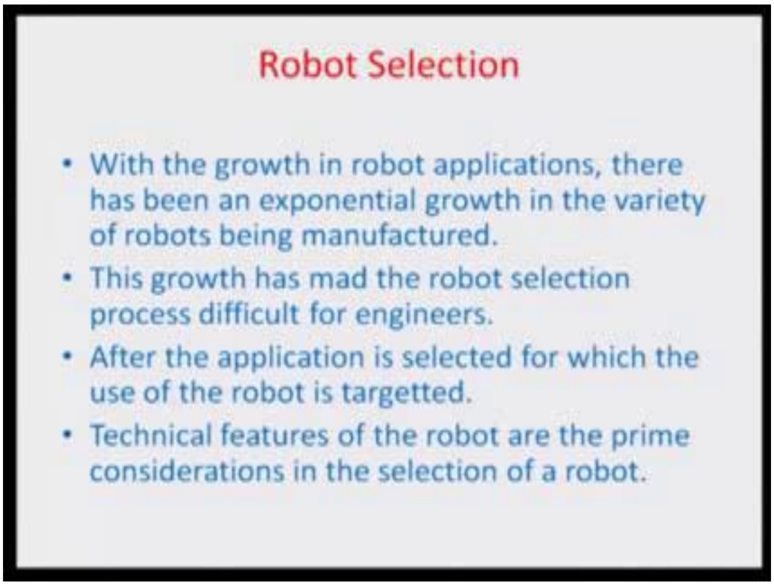

So, the other most important issue is about the robots selection, and then also the application of robot to various industrial processes and systems. Obviously, because the robotic application in the industry has, sort of grown heavily and there been an exponential growth in the variety of automated techniques and operation; the applications, obviously, of the robots have increased to a vast numbers and the technical features, which are involved in planning and suiting the requirements to a certain robot, also has outnumbered quite a bit. So, what are the prime considerations in selection of robots?

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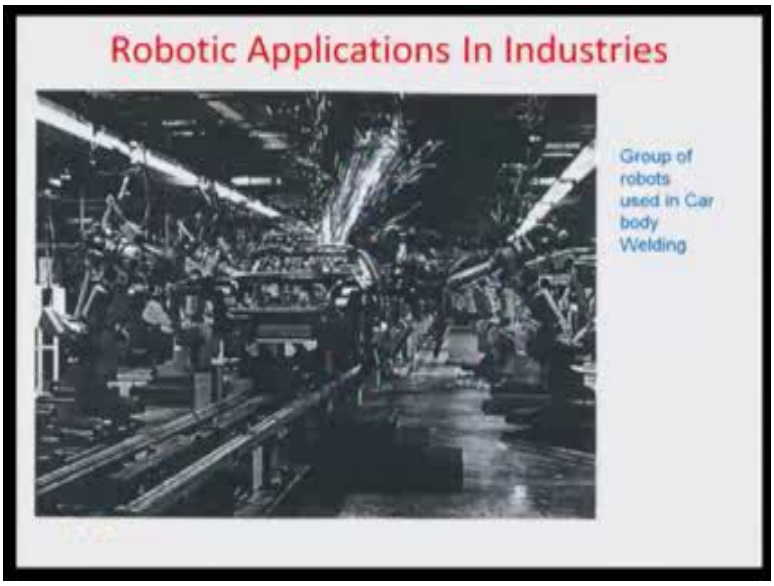

Let us just briefly, look at one or two of these very main guidelines which would be used for doing selection of robotic system to certain processes.

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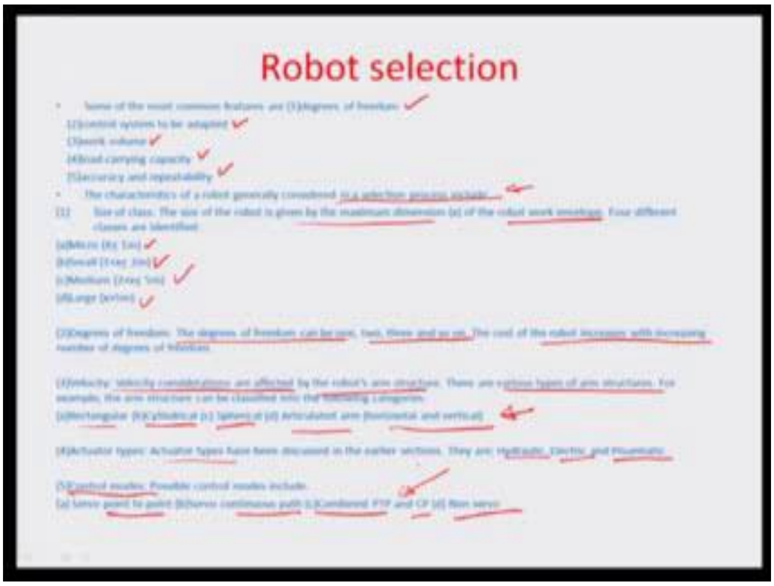

So, the most important features that we need to look at when we select a particular robot for a certain situation are obviously, number one; degrees of freedom; what all is needed in terms of its motion sequence; control system that has to be adapted; the work volume that it has to cater to. Typically, all robotic applications are for a repetitive kind of, assembly line kind of work; load carrying capacity, accuracy, repeatability so on and so forth. So, the characteristics of a robot generally, considered in a selection process, include the size of class, the size of the robot, is given by the maximum dimension x of the robot work envelope. So, there are different classes; there are at least four different classes, based on the different ranges of x, which can be a accomplished. These are the micro, which typically goes for less than 1 meter range, less than or equal to 1 meter range of the working envelope, or small range, which is actually between 1 and 2 meters; medium between 1 and 5 meters, or medium between 2 and 5 meters. Then again, large ranges for at least, more than 5 meters also.

The other issues; the degrees of freedom; the degrees of freedom can be 1, 2, 3 and so on. So, the cost of the robot; obviously, increases with number of degrees of freedom, additional number of degrees of freedom. There can be velocity considerations also, which are affected by the robots arms structure. So, there are various types of arms structures; for example, the arms structure can be a rectangular, cylindrical, spherical, articulated arm or horizontal and vertical; all of these, we have more or less seen earlier. The selection process can also be on basis of actuated types and there are various types of actuators; hydraulic, electric and pneumatic. Each of them has its own pros and cons. I think we have illustrated quite a bit of it towards the beginning of this lecture and then; obviously, the control modes, which are very important. They can be either, a servo point to point, a continuous path or a combined point to point continues path or a non-servo mode of control. So, these are mainly the so called most important criteria, which have to be used, looking at a certain application to fit a certain robot with certain specification to that particular application.

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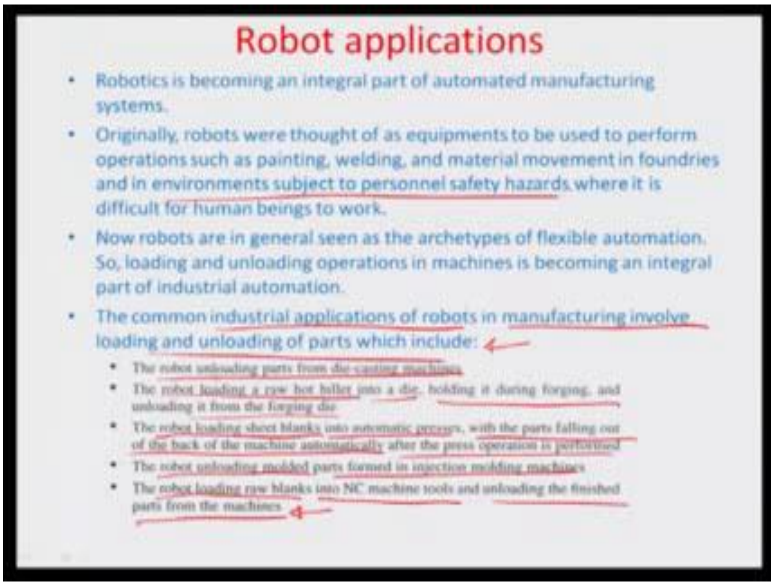

So, I would just like to now, look at some of the typical applications, which are becoming an integral part of the automated manufacturing system. So, the common industrial applications of robots in manufacturing, involve typically, loading and unloading of parts and they can include various domains, like loading, robot unloading parts from dye casting machines or robot loading a raw hot billet into a die; holding it during forging and unloading it from the forging dye; robot loading sheet blanks into automatic process with the parts falling out of the back of the machine automatically, after the press operation is performed; robot unloading molded parts formed in injection molding machines or robot loading raw blanks into NC machine tools and unloading the finished parts out of the machines so on and so forth. So, basically the concept when you know the robotics really, emerged was that it would be typically, subjected to those environments, where there would be a personal safety hazard, involved with deployment of manpower and so, that was the initiation of where robots would really, start to occupy.

Now, it has expanded to variety of domains. In fact, wherever there is a flexible automation, it is probably become an integral part and necessary part of manufacturing processes for industrial automation to be complete. Let us just look at some represented pictures of some different robots. This right here shows welding robot in a car industry. It is a weld shop. So, this is basically, probably, a line which is you know, it is a final line in which, the car body is already more or less assembled and roof needs assembly and the remaining parts, like the front fenders, left and right, the main floor, the side body, etc. and all the frame work has already been put in place. So, you can see a variety of robots here, which are doing welding operation. Most of them are spot welding operations on this car line.

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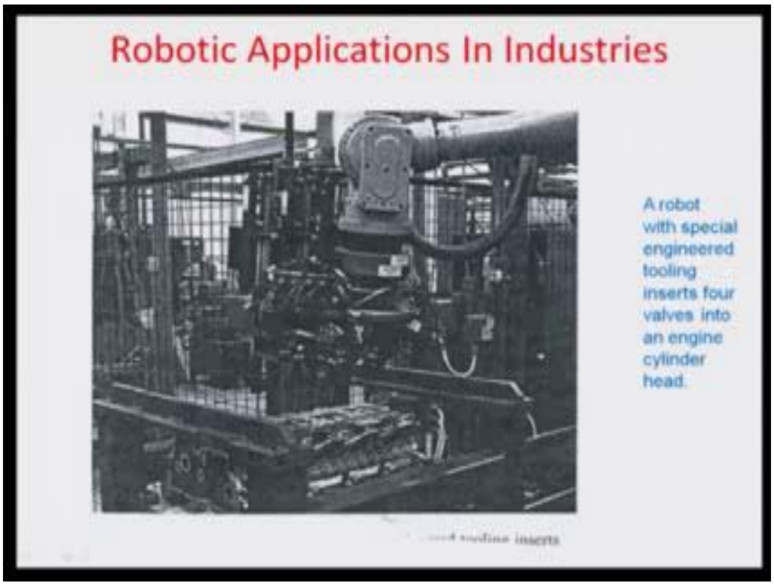

Another application here is basically, robot with special engineering tooling. So, it basically, inserts four valves into an engine cylinder head; obviously, matter of precision again. So, every time, there is an engine cylinder in place. The valves have been inserted into the head of this engine cylinder, before assembling into the final block and there is a matter of precision.

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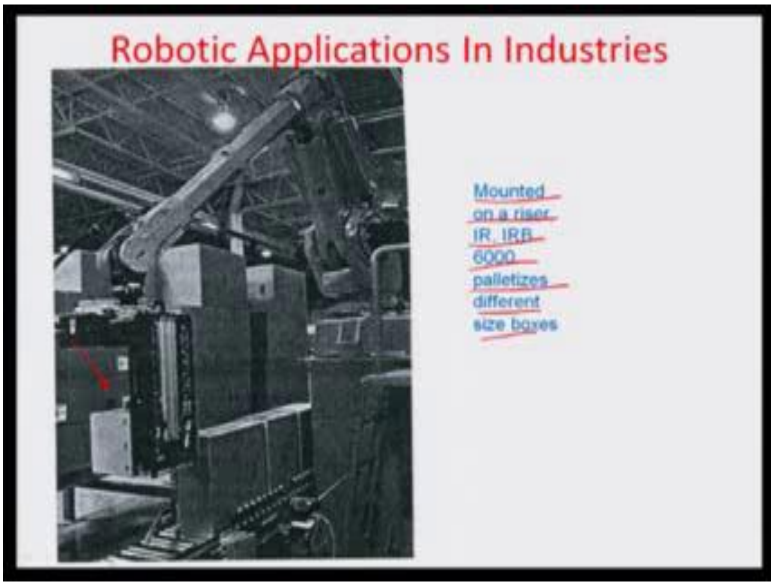

So, again very good application of robotics; this right here is a robot mounted on a raiser; IR IRB 6000, palletizes different size box. So, it picks and places basically, the boxes from this location into the location, desirable; probably, it is some kind of a conveyorized system, which is applying to another end user, who can be an assembly line or which can be again a weld line. So, this component need to be destalked and supplied for which again, repetitive operations and robotics is deployed.

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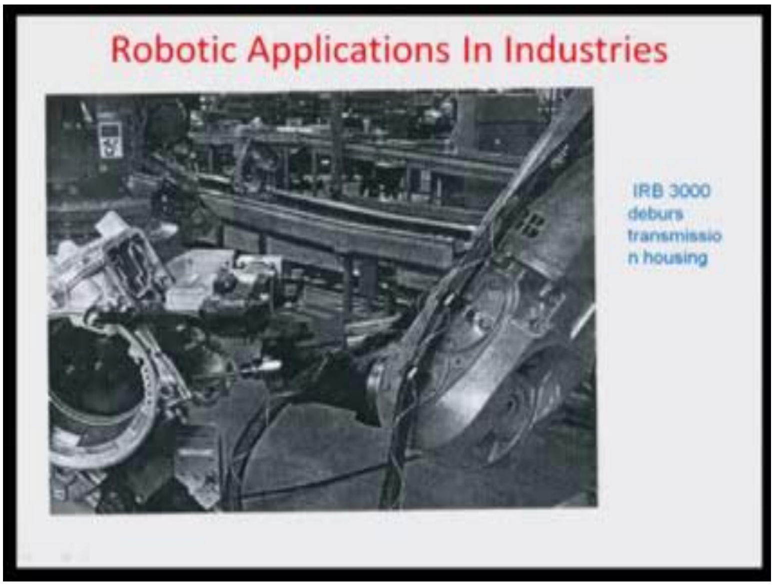

Again, you know, a deburring robot, IRB 3000, which is deburring transmission housing; very important for again, assembling gear boxes on to the engines. So, it is another fundamental robotic application for industries. This is one, where IRB 2000; it shows you know, celent application in head lamps particularly, you know, the head lamps need to be rain proof and so, there is more over less requirement of putting celent on the inner and outer covers, between the inner and outer covers of the head lamps.

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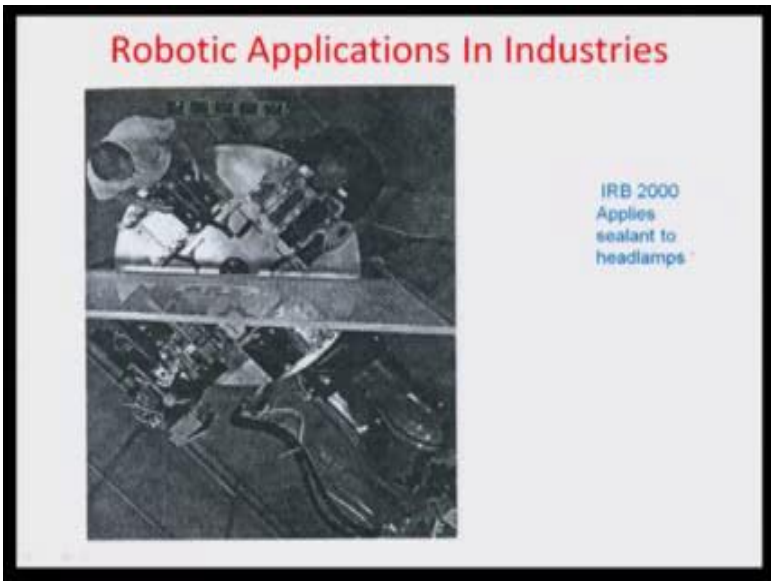

Here the same as being done on a robotic line; it is in fact a top view that is being shown here and this right here, is probably the celent application robot doing his job.

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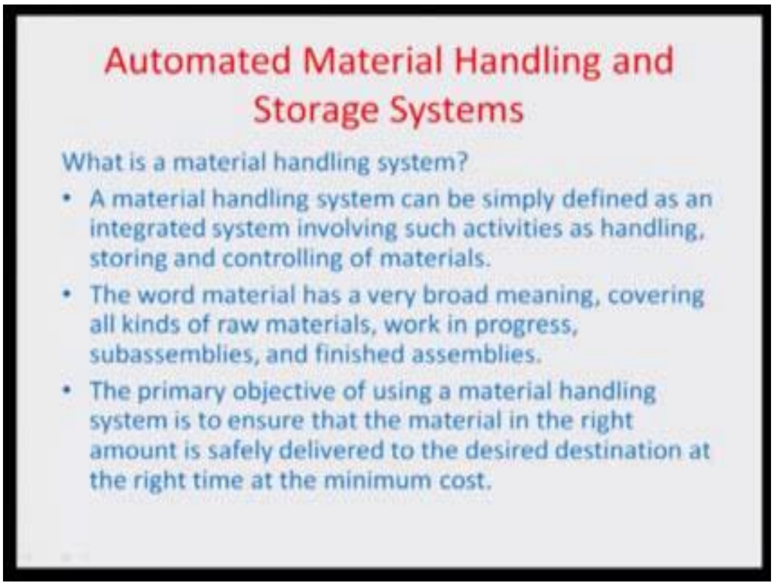

So, that is about more or less, everything that we add on robotics applications. The other important off shoot of this automated industrial applications, happens to be material handling and storage systems and here, there is a lot of research, which is ongoing in most of the industries with the view point of saving inventory cost, inventory carrying cost and trying to minimize too, the level of the sort of lean manufacturing, which we have talked in details in the earlier lectures in manufacturing systems technology, part 1.

So, what is a material handling system part of industrial automation? So, it is a system that can simply be defined as an integrated system, involving such activities as handling, storing and controlling of in the materials and obviously, the word material has very broad meaning. It can cover all kind of raw materials. It can cover work in progress, during in an assembly, for example, or during a sub assembly, for example. So, you have sub-assemblies and finished assemblies, all involved as materials and the flow of which is needed at some point of time in the whole production process. The primary objective of using a material handling system is to ensure that the material in the right amount is safely delivered to the desired destination at the right time, and that with a minimum cost. So, therefore, this question of automated material handling on storage system arise.

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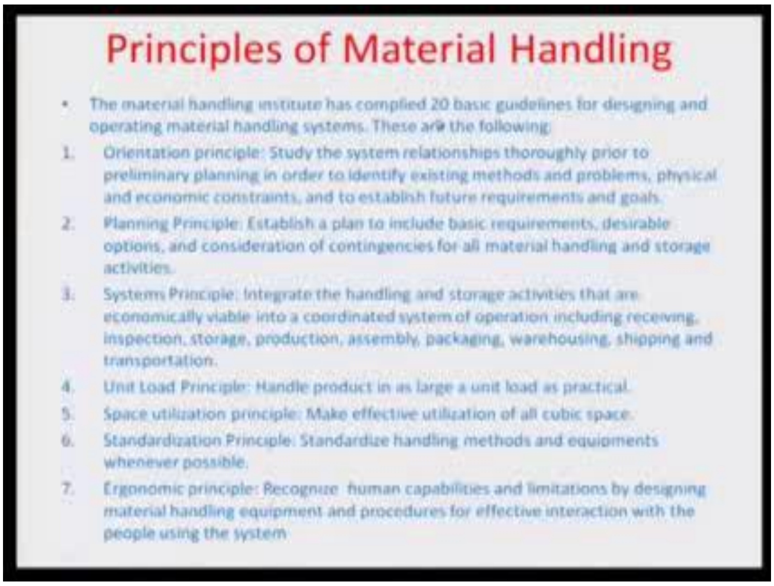

So, let us start with some of the basic principles of material handling as figure out by the material handling institute. It has basically compiled about 20 basic guidelines, some of which I will be sharing below, for the designing and operating material handling systems in place. So, the first principle is orientation principle; that means, study the system relationships thoroughly, prior to preliminary planning, in order to identify existing methods and problems, physical and economic constraints and to establish future requirements and goals for an organization. That is in fact, the first element of study to begin with, just before planning any material handling system. Then there is a planning principle, which establishes a plan to include basic requirements and desirable options and consideration of contingencies for all material handling and storage activities. Things like what is the distance of the wending source from the consumption source, etc. and how much is the level of inventory that has to maintain as planned at this particular planning level. Then there is a systems principle. So, basically look everything as a systems approach.

So, you have to integrate the handling and storage activities that are economically viable into a coordinated system, also known as (refer time: 52:03), if you remember in the lean manufacturing, there was something (refer time: 52:06) in the sub assembly level, there would be a coordinated movement of the various units so that, they could be finally assembled. So, this system of operation may include all aspects, including receiving of the material, inspection of the material, storage of the material, production, assembly, packaging, warehousing, shipping and transportation; all as a systemic approach. So, everything needs to be integrated within the material handling plan; that is the principle, guiding principle of the material handling institute. Then there is a unit load principle, which handles the product in as large a unit load as practical. So, that number of times the handling has to happen goes down, because now at a unit, you can supply many material together. Obviously, there has to be very important space utilization aspects.

So, space utilization principle makes effective utilization of all cubic spaces, wherever possible for storage applications; introduce vertical spaces, wherever there is a question of fitment and assembly, you have to layout material horizontally. So, moving from vertical into horizontal, has to be done on you know, a three-dimensional map has to prepared, which can be of optimum distribution. Standardization principle again, which standardize the material handling methods and equipment, whenever possible; obviously, when you are limited by the industry, which produces these handling methods and equipment and you cannot have a basic requirement in your material handling, which needs specialized equipment for that particular handling situation. Then there is ergonomic principle, which recognizes human capabilities and limitations by designing easy material handling equipment and procedures. This would be more, because you want to reduce the burden of the load on the individual, who are involved in the material handling, and they can effectively, interact with the equipment, material handling equipment. So, therefore, ergonomic planning of the material handling is very much needed.

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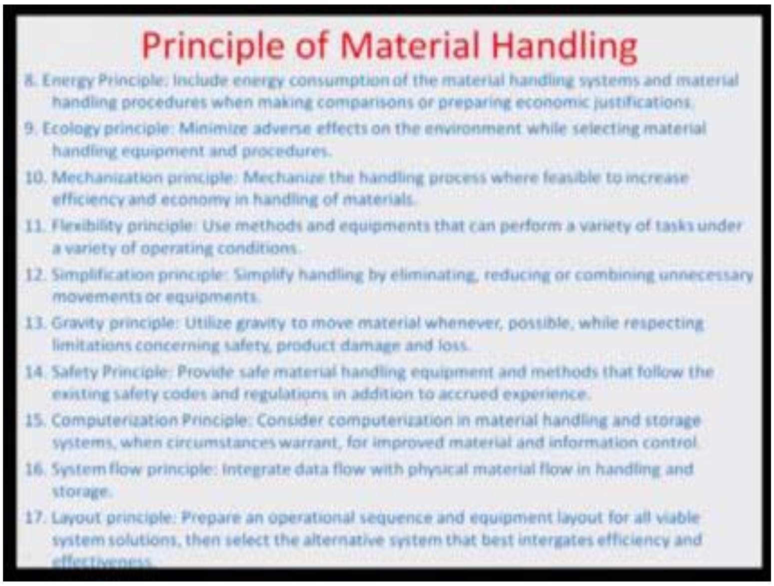

Then there are many other aspects, like energy principle. Nowadays, energy obviously, is very precious. So, you have to include the energy consumption of material handling systems, material handling procedures when making comparisons of preparing economic justifications. This comes actually, at the level of selections. So, therefore, more of gravity feed reserve is, let us say things, where active energy is needed, active material handling systems; they have been replaced slowly by the gravity speed systems, because of the minimization of the energy principle. Obviously, the minimization of adverse effects on the environment is a big issue in selecting the material handling equipment particularly, on the procedures, you should not be too far away from the environmental norms, whenever you are planning a material handling system.

As far as possible, mechanize; so, mechanize the handling process, where feasible to increase efficiency, economy in handling of materials wants so forth, you should have a flexibility principle, where use methods and equipment that can perform of a variety of tasks; that can reduce your capital expenditure on the material handling. So, you can design probably a roller shoot that can be used for off-loading from the truck, a bin, as well as some kind of a specialized jig you know, for giving different components. So, that it can be located near to that assembly point, where it is to be delivered. So, this flexibility in choosing the equipment and the materials, which actually includes roller shoots and conveyors or even (refer time: 56:00) belts, which are use for the various transportation mechanisms. There has to be overall flexibility governing choice.

So, by and large, we want to make systems, which are simple and easy to use. So, simplify the handling and that can be done by reducing or combining unnecessary movements of the equipment. So, that is what the simplification principle states; not when crisscross points particularly, the parallel flow of the mathematical would be a much better alternative. You have gravity principle. So, utilize gravity to move material, wherever possible, while respecting limitations, concerning safety, product damage and loss. You have safety principles. So, provide safe material handling equipment and methods that follow the existing safety codes and regulations in addition to the accrued experience. Then obviously, you have computerization principle. You have systems flow principle, where you integrate data flow with physical material flow in handling and storage. Some of these are very important for lean manufacturing issues and so forth.

Layout principle, where it prepare an orientation sequence and equipment layout for all viable systems solution and then, select the alternative system that best integrates efficiency and effectiveness. So, some these principle are more or less, used by at the planning level when you were defining the overall material handling system. One of the aspects or one of the very important issues, which come up particularly, in you know, automated factories when we are talking about automated material delivery at the place of the fabrication or assembly of these materials is the use of so called automated guided vehicle or AGVS.

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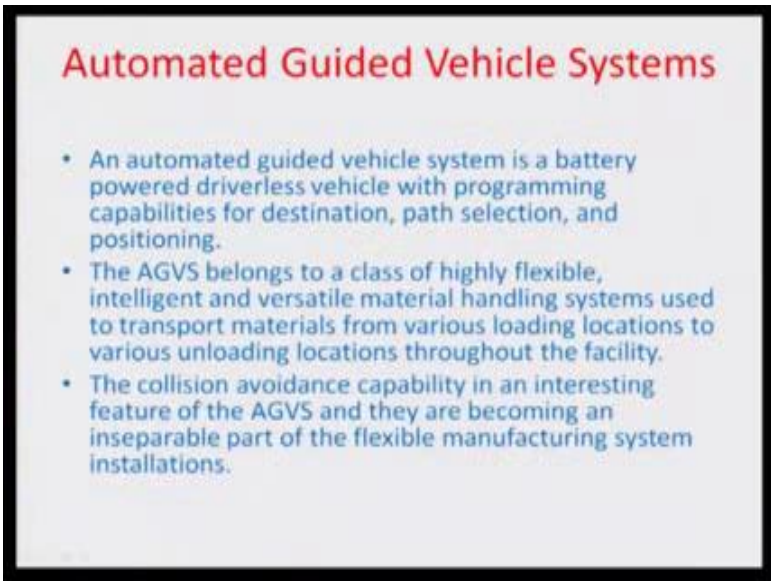

So, an automated guided vehicle really, is a system, is a vehicle system, which is operated with battery power and it is by and large, driver less. So, you have to have a path and a programming, associated with such a vehicle. So, that you can have the capability of auto unloading and loading into different places particularly, on large assembly lines, etc. So, it belongs really to a class of highly flexible intelligent and versatile material handling systems, used to transport materials from various loading locations to various unloading locations, throughout a facility. Particularly, in the industrial automation, it is a very important component when we are talking about high volume production. The whole idea here is that the path learning has to be done in a manner so that, there is a sort of, a less interaction while movement and more or less, parallel flow of material movement along with the AGVS and not only that there should be a auto mechanism within the AGV, which should be able to avoid collision.

So, in a matter, in a manner you know; although, it is not a complete robotic system, you can say that there it is at least, a partial robotic system, which would have some intelligent capabilities, like senses, etc. built in and the directives can be given to a path, which can be laid out, either as a florescent light path or paint path or as some kind of a electronic assistance by an underground cable so that, it can help to move the AGV in a particular direction from time to time. Obviously, these automated guided vehicles are becoming a very important and inseparable part of these flexible manufacturing system installations these days.

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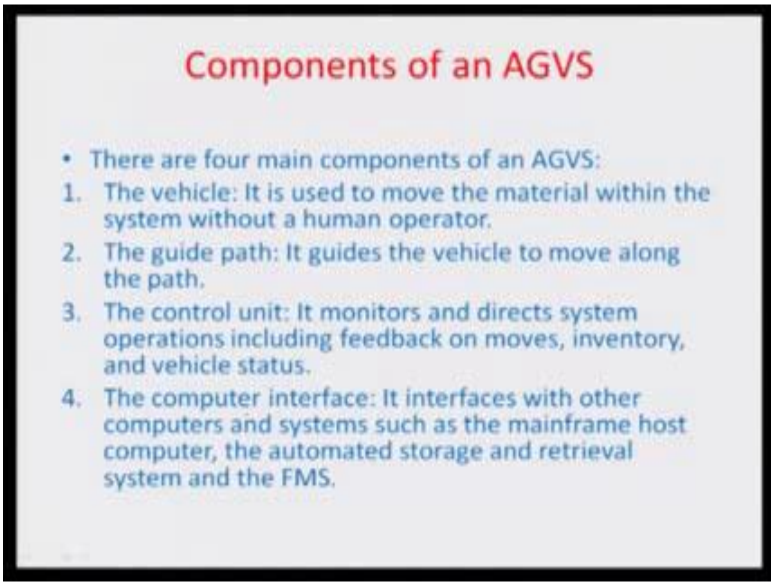

So, what are the main components of an AGV; obviously, the first is the vehicle itself. It is used to move material within the system, without human operators or human involvement. You have the guide path. So, it guides the vehicle to move along the path, which is desirable for it to take. You have to have an onboard control. So, there is some kind of a controller, which is there; controller unit, which monitors and directs system operations, including feedback on moves, inventory and vehicle status, so on and so forth. There has to be some kind of an overall computer interface, which can interact with this whole flexible manufacturing system, and it can automate the process of material delivery and loading, unloading, wherever needed. So, such systems are normally mainframe based systems, which is a sort of a host computer, and it plans the delivery of materials, following short at different places along with FMS system.

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There are several different types of AGVS, which are available are available to meet different service requirements. They include AGVS towing vehicles; AGVS unit load transporters, pallet trucks, forklift trucks, light load transporters and assembly line vehicles. So, these all form under the category of the automated guided vehicle system.

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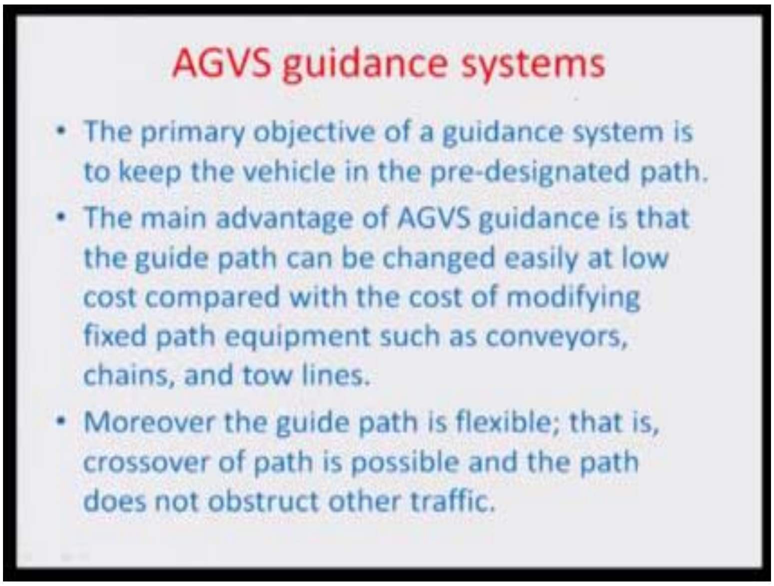

Let us look at the guidance systems in an AGVS. The primary objective of a guidance system in an AGVS is really, to keep the vehicle in a pre-designed path or track so that, the very less interference between two or more vehicles, plying parallely, to different stations to meet their material requirements. The main advantage of the AGVS guidance is that the guide path that can be changed easily, at low cost, compared with the cost of modifying fixed path equipment, such as conveyors, chains and tow lines. Moreover, the guide path is flexible; that is crossover of the path is possible and the path does not obstruct other traffic. So, it is all by signal matching, a frequency matching, that some selection of the path can happen if you have a unit, which can recommend a particular frequency or do a local frequency selection on the vehicle unit itself.

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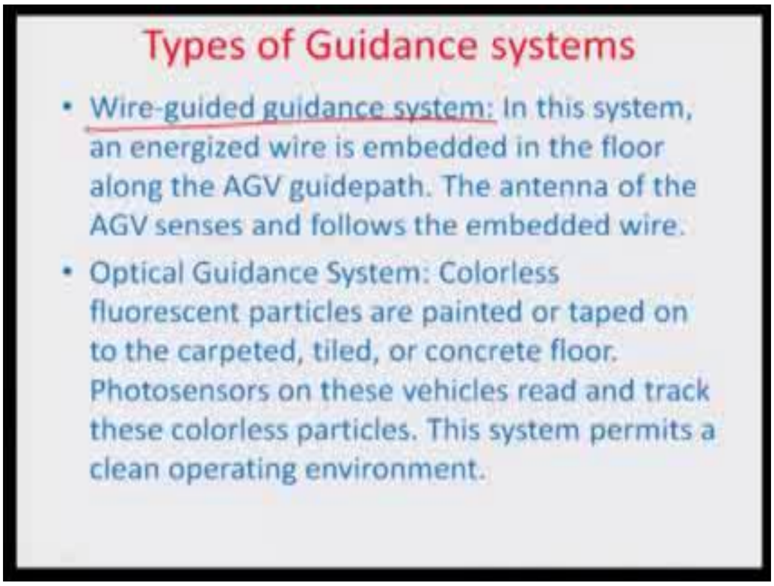

So, typically there are either, wire guided systems or there are optical guided systems. I will probably, give you a brief of both. So, in the wire guided systems, an energized wire is embedded in the floor, along the AGV guide path of the antenna of the AGV sensors, and follow the embedded wire. Wherever that is the path selection issues, you can do it either a path switch or you can do it with some kind of frequency at differ. I am going to come into the detail of that just in the next step. The other broad category is the optical guidance, which comes from a colorless fluorescent paint, and they are particles which are painted, fluorescent in color or even taped on to the carpeted tile or concrete floor. There are photo sensors on these vehicles, which will be read and track these colorless particles, and process the information signal. The system would permit a clean operating environment this way. You do not need to really get into that additional work of laying out wires, wherever the new paths need to be developed within assembly line, let us say; otherwise also, the systems present a very complex in nature. So, typically the optical guidance system is used for most of the time when we are taking about the AGVS systems.

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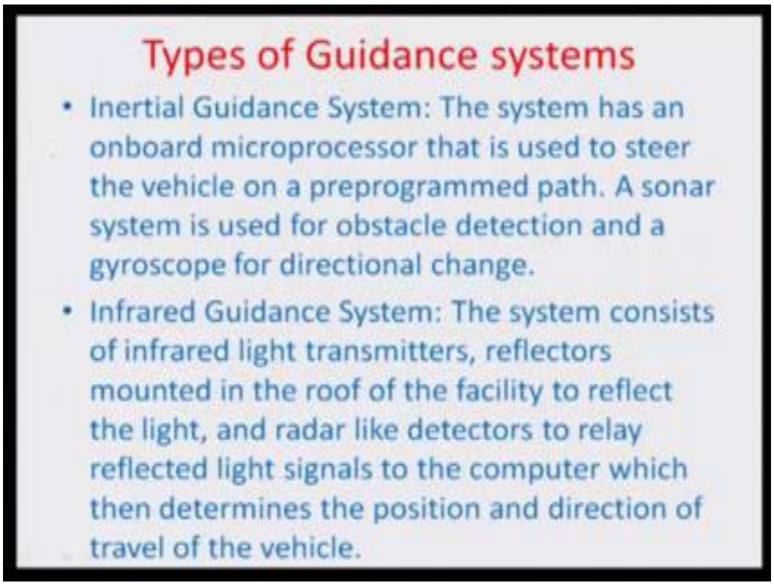

There can also be inertial guidance systems. The system has an onboard microprocessor that is used to steer the vehicle on a preprogrammed path. A sonar system is used for obstacle detection and gyroscope for directional change in this particular case. There can be an infrared. So, typically in this category, a sonar censer is used for performing the obstacle detection. An algorithm, control algorithm is used, wherever there is a reflected wave coming out of an obstacle; just tried to direct the vehicle into a different track. So, therefore, there are no obstacle collisions in the process of the movement of the vehicle. There is also gyroscope, which actually, tries to sense the different aspects of motions, related to the vehicle on which, one can calculate how much distance the vehicle has gone and how it needs to go so on and so forth. There is also an infrared guidance system, where the system consists of infrared light transmitters, reflectors, mounted on the roof of the facility, where this AGVS systems need to be installed. So, these reflectors reflect the light and the radar like detectors, relay the reflected light signals to the computer, which then determines the position and direction of travel of the vehicle. You can program from a control station, where the AGVS trying to go or it has to go so on and so forth.

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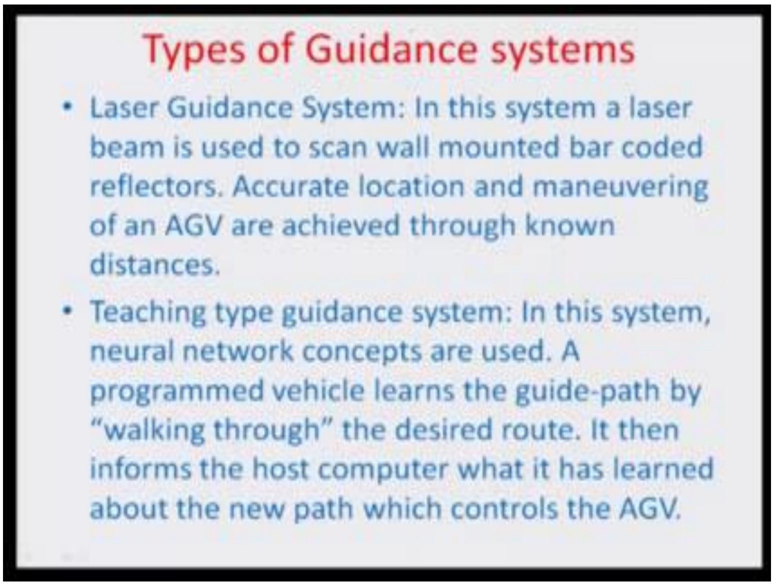

There are laser guidance systems in a similar manner and in this system, laser beam is used to scan on wall mounted bar coded reflectors, gives you an idea of the positions they are accurately located earlier. You have a library of such reflectors all round in the facility. So, you can actually maneuver, based on the read outs of the bar codes and then, try to direct the AGV to go toward a specific bar code when you are doing this. Then also, there are teaching type guidance systems. In this system, the neural network concept is used. A programmed vehicle is actually physically, taken by walking through the desired route and the computer learns about that and then, again programs. Whenever it is running on a programmed mode after this teach mode is over, it can actually go through the similar kind of a route as has been planned earlier and then, informs the host computer what it has learned about, and the new path is used for control guidance of the AGVS so on and so forth. So, these are the various types of guidance systems, which are used in the AGVS.

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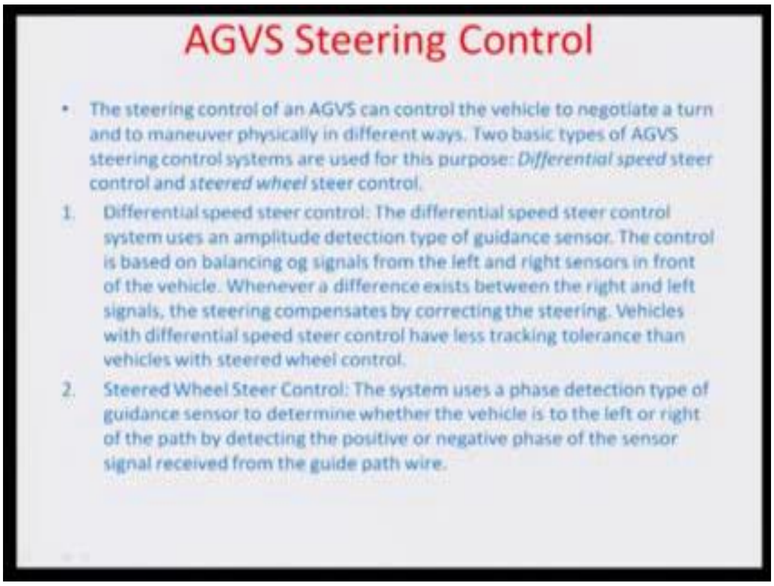

Let us look at how to steer or how to perform steering control, local steering control. Obviously, steering control of an AGVS can control the vehicle to negotiate a turn and to maneuver physically, in different ways. There are two principle types of steering controls that this AGVS has; one is called the differential speed steer system and another is the steered wheel control. So, let us look at both, separately. So, in the differential speed steer control, the system uses an amplitude detection type of guidance sensor and the control is based on balancing of the signals from the left and the right side of the sensor. So, that is how basically, the signals come, because of the rotating wheels; wheel base; from the wheel base of the AGVS. So, it is in the front of the vehicle typically. So, if you have the left and the right signals, having a mismatch; obviously, there has to be some kind of a steering action so that, the AGV is put back into track. Obviously, the differential speed would happen to set in a turn, but if you don't want turn or you want avoid the turn, you have to give a reverse signal so that, it keeps back on track. That is the whole idea.

So, whenever a difference exists between the right and left signals, the steering compensates by correcting the steering. Vehicles with differential speeds steer controls have less tracking tolerance than vehicles with steered wheel controls. The steered wheel control system uses a phase detection type of guidance sensor to determine, whether the vehicle is to the left or right of the path by detecting the positive or negative phase of the sensor signal. This signal is typically, obtained from a guide wire path. So, such steering controls actually, can be utilized only when there is a particular signal path, which is into picture, which is actually a wire path kind of control. Obviously, if you have an optical signal in place, and you have a florescent read out if there is a change in the color coding of the florescent, only then this kind of frequency based selection can be obtained for doing steering control on the AGVS.

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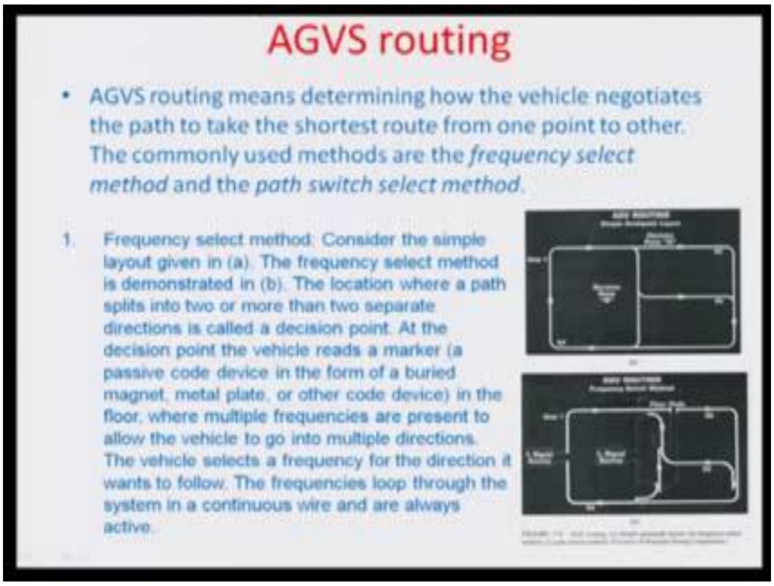

Let us look at some of the routing system. So, there are two different methods, which are used for it; one is called the frequency select method and another is a path switch method. Let us look into both aspects. So, this right here is a routing scheme of the AGVS. It is a simple path guide layout, which is given here. This is the frequency select method, being incorporated on the guide path layout. Obviously, the AGVS has to take, perform a decision making, whenever there is a question of a turn that it needs to be executing. So, if there is an AGVS vehicle, moving all the way to this junction; at this junction, it has to take a decision, whether to tried to take left or would go forward in this particular direction. So, how do we do that?

Consider this simple layout given in A and the frequency select method is demonstrated in B. The location, where a path splits into two or more, then two separate directions called a decision point, like right about here, is a decision point or may be here, you have another decision point and probably here, another decision point; wherever, there is a splitting up into two or more tracks. So, at the decision point, the vehicle reads a marker, which is passive code device in the form of a buried magnet metal plate or other code devices in the floor, where multiple frequencies are present to allow the vehicle to go into multiple directions. So, the vehicle selects a frequency for the direction it wants to follow. So, if supposing I had a different frequency on this end and different frequency here. Let us say this is f 1 and f 2, which are stored on the floor through some kind of middle plate of some kind of a bar code. So, the scanner at this particular position would try to select between this path, whether the path is going to be here or the path is going to be here, by looking at the differential frequencies here, and matching with its database and the programmed path what frequency it needs to select for going into the correct path.

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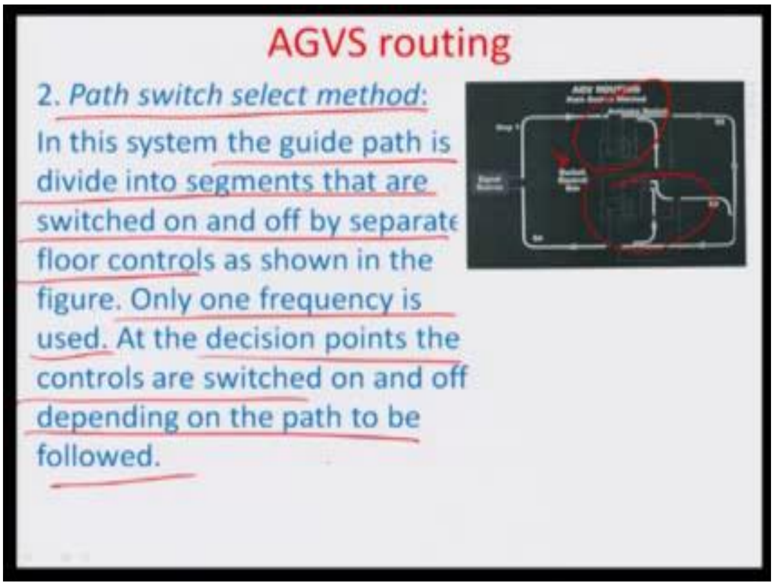

So, that is how you would do the frequency select or frequency based select method. On the other is a path switch select method. In the system, the guide path is divided into segments that are switched on and off by separate floor control. You can see here, there is a control for this path, part of the path, and there is and other control for this part of the path, and there is some kind of a control switch box, which would then be able to cater by switching on to different segments of this path. So, only one frequency is used in this particular case. You need not actually, get a bar code or some other scanning, additional installation in place. So, at the decision point, the controls are switched on and off, depending on the path to be followed so that, correct tracking of the AGVS can happen at the decision point. So, these are the two principle methods of doing the routing; the AGVS routing.

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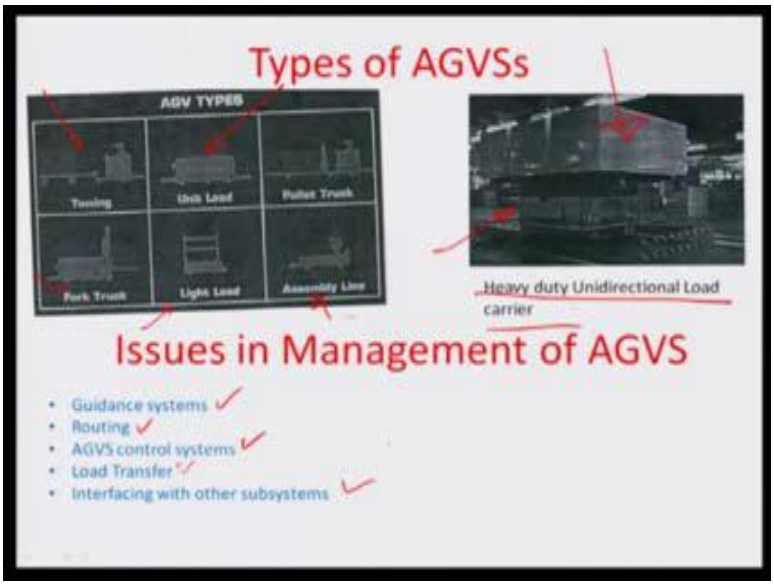

Let us also look at some of the types of AGVs, as I had discussed before. You can see semantically, how they look like. This is the towing unit; this is the unit load movement unit. In fact, actually, see the unit; heavy directional unit load movement in the AGVS scheme. This is the real AGV in industry, which is carrying a unit load. There is a fork track unit again. There is a light load and there is an assembly line unit. These are all different kinds and types of unit. So, the critical issues in the management of AGVS, happens to be the guidance systems, the routing, the control system of the AGV and then obviously, the main purpose, which is the load transfer; what is the capacity of the AGVS to take loads and then, how you can interface with other subsystems, like the flexible management system, etc. so that, you can actually, get the requirement from the sub system and then, put into place so that, the material handling happens in the place, where it is needed in the right quantity in the right time so on and so forth, under the principles of whatever lean manufacturing issues, industry has to go through.

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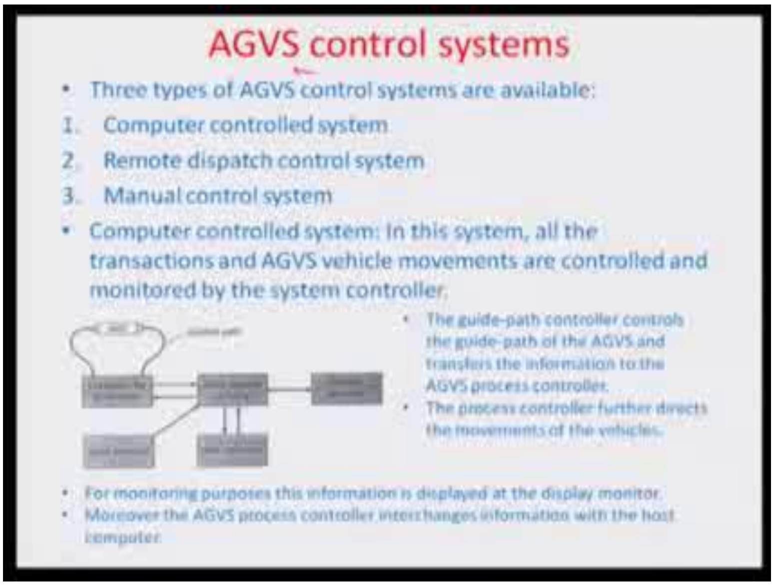

As regards the control systems, the AGVS have different kinds of control systems; obviously, there is a completely computer controlled system; there is also a remote dispatch control system. Then obviously, the manual control system. So, computer controlled systems happen to have all transactions and vehicle movements as controlled by system controller; a main system controller and basically, the idea is that this process controller is going to be giving signal to the guide path, which is this unit right here, and then, it also is able to display whatever is going on. The computation basically, has a requirement comes from the host computers. So, the planning happens here, based on the requirement received from the computer about the various requirements at the different stations of the materials. So, there is an input terminal; there is a host computer, which would do all the computation, regarding what material in what quantity at what place, and then obviously, the controller would define the flow path in a manner so that, the AGVS can go to the correct location so on so forth.

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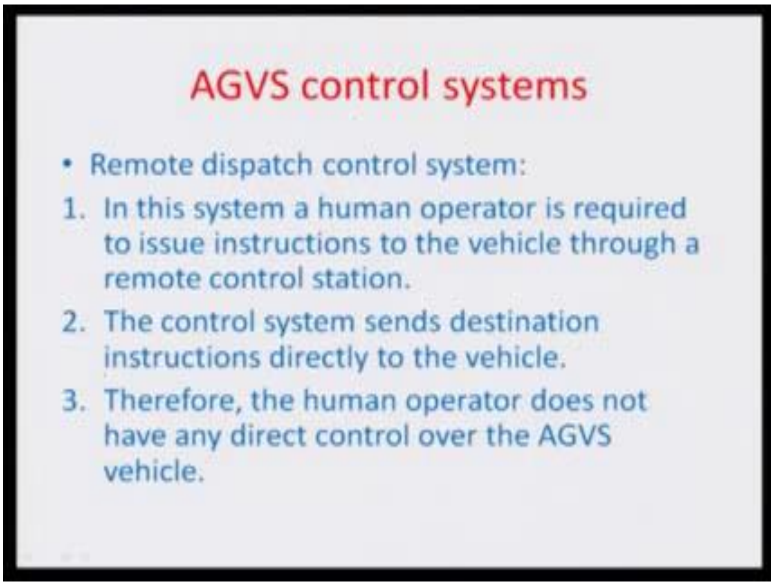

So, mostly AGVS systems are more or less, in a very high volume production computer control. The other mode is remote dispatch control system. So, in this system, a human operator is required to issue instructions to the vehicle, through a remote control station. So, this is something, which is more semi human you can say, but you know, used in situations, where the load on the AGVS system for doing material handling is substantially, lower and computer complete control would be needed when you are planning to have bulk handling of the materials through the AGVS around. So, basically the control system sends the destination instructions directly, to the vehicle. So, you basically, as a human operator plan; where he AGVs need to take what kind of load and deliver to work station. Although, the human does not have any direct control over the AGVS vehicle, but it can actually, plan and say that how much is needed at what station. So, that is remote dispatched control system.

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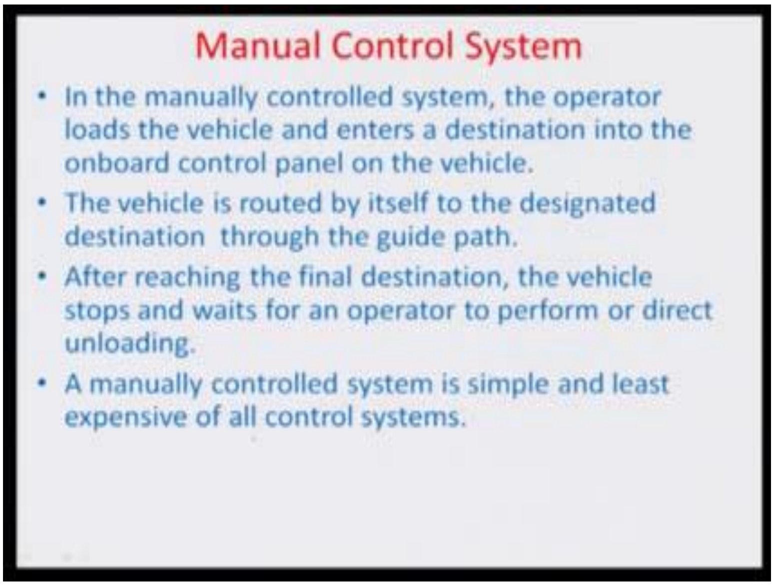

The other one obviously, is manually fully controlled. So, the operators load the vehicle and enters a destination into the on board control panel of the vehicle. Vehicle is routed by itself to the designated destination through the guide path. So, it also has to look into the other vehicles and the other traffics, which is around for planning its own motion; try to take the shortest path that way. There is some kind of an algorithm planning, which is involved to do the correct guidance, using as much as, as less as obstacle on its path with the shortest route, but then again, you know this is the completely, manually controlled, because the loading, unloading has to be done at the operator end. So, after reaching the final destination, the vehicle stops and waits for the operator to perform a direct unloading. So, here the AGVS has to be dispatched back by the concerned assembly line operator or the operator, who is waiting for these particular materials.

So, as soon as the material goes to the station, has to dispatch the AGVS back by sending a signal or a switch so that, the AGVS can start moving back. So, by and large, these manually controlled systems are quite simple and least expensive of all the controlled systems. Some of the industries do employ these kind of systems particularly, in bumper paint shops or other paint applications, where there is you know, particular requirements based on the different vehicles, which are in place and also, sometimes between bumper paint shops to the assembly line, where the bumper is fitted; there would be a requirement of quite a number of these manually controlled AGVS. Otherwise, in most of the applications, where there is a high volume of goods to be planned and delivered; preference is always for the computer operator or the fully computerized control, computer controlled AGVS systems.

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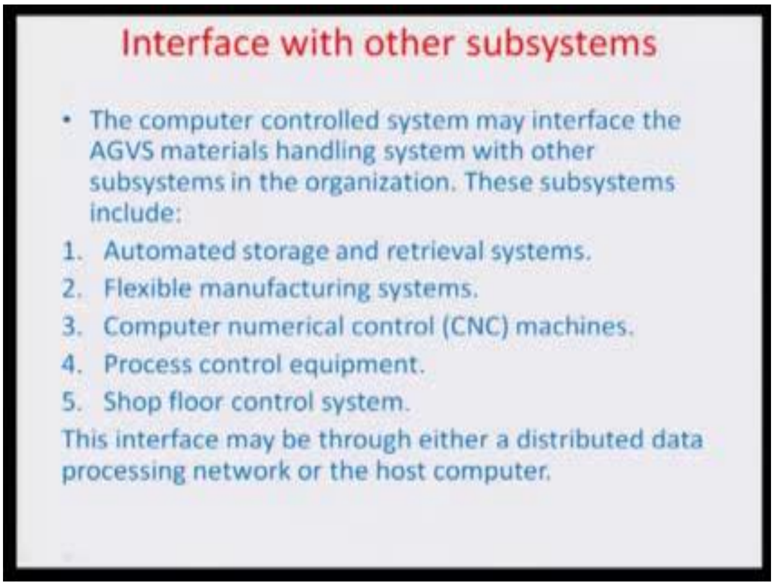

So, having said that, there is obviously, going to be an interface of the automated guided vehicles with the other systems, subsystems, which are available, which includes the automated storage retrieval systems, ISRS, flexible manufacturing systems; sometimes, there CNC machines. So, they need an interface with these machines. They also need an interface with process control equipment and various other shop floor control systems, which are available. This interface may be thorough, may be either through a distributed data processing network or through a unified host computer, which will actually do all the steering and maneuvering, based on data from all these different sub systems, but the integration becomes a real challenge at a host computer level.

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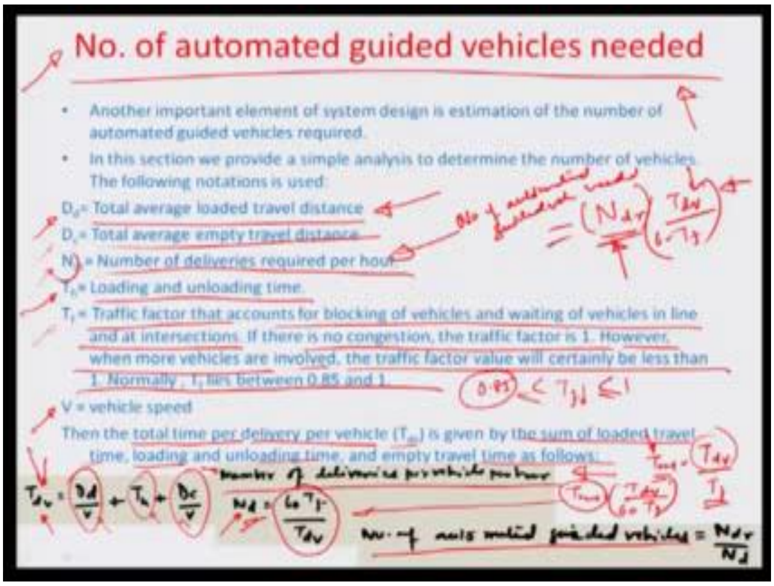

I would also like to learn little bit about the number of automated guided vehicles, which I are needed particularly, in a situation to balance the load of deliverance of materials. So, let us say, sort of calculate the minimum number of automated guided vehicles, which would be needed if the total average loaded travel distance of the vehicle is given as d d, and the total average empty travel distance given as d c, and the number of deliveries required per hour is given as n d r, based on the demand, and the loading, unloading time is given as h and also, the traffic factor that accounts for blocking of vehicles and waiting of vehicles in line at intersections, etc. is given as t f. So, if there is no congestion, the traffic factor can be considered to be 1; however, if when more than one vehicles are involved, the traffic factor would certainly be less than 1. Normally, t f would lie between 0.85 to 1.

That is how you have to plan your system as design your system. So, then if supposing, we consider v to be the vehicle's speed, then the total delivery time, per delivery per vehicle, t d v will be given by the sum of loaded travel time and loading and unloading time and the empty travel time as follows. So, you have the total time for average loaded travel distance d d to be moved, is d d by v; v being the vehicle speed. The total whole time, where the loading and unloading process happens is t h and then obviously, the total empty travel distance is d c n; that divided by v, gives the total empty traveling time. So, if you suppose that the number of deliveries per vehicle per hour is n d so, if we really wanted to look at the number of deliveries per vehicle per hour; it is sort of frequency of the trips, you can say.

So, if supposing t d v is the total time of delivery of a single vehicle, the first aspect that we want to look at is that how the t d v will change if the traffic factor, which is basically, blocking of vehicles and waiting of vehicles is involved, would change. So, the t d v will obviously, increase, because of the intersection or waiting. So, therefore, you have to divide this real, you know, you have to sort of calculate this time real that it takes, in case there is a traffic blockage or obstruction by dividing the v d f with the t f factor. So, if the t f is low, supposing there is low t f value; obviously, the total time needed for the delivery to happen; the real time of the delivery, you can say, would actually be higher than the total time of delivery that is needed, only by looking into the loaded distance and unloaded distance and the loading and unloading time; sum or summation.

So, if these were in minutes, if the number of deliveries per vehicle per hour needs to be computed, it would really be the inverse of this real time. So, it is a sort of frequency you know, which can put into place, which you call n d here, which is actually 60 t f by d t v. Basically, it is just the inverse of the real time that it would take for doing one delivery; starts the delivery frequency for one vehicle. Obviously, if we had n d r as the number of deliveries required per hour, this n d r multiplied by the frequency, or divided by this frequency, or may be just multiplied with the real time of one delivery, which is actually the t d v by 60 t f, which actually give you the number of automated guided vehicles, which are needed. So, this is the deliveries per hour and this is the total time needed for performing one delivery; so, one delivery of one vehicle. So, this is basically, how you calculate the number of automated guided vehicles which are needed.

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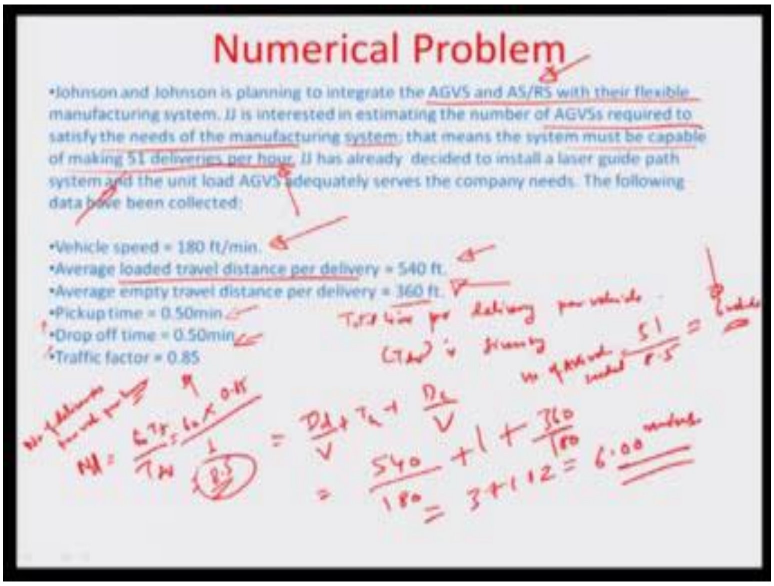

Let us look at a problem example, where Johnson and Johnson is planning to integrate the AGVS and obviously also, the automated storage retrieval system, which I will just mention about after this topic with their FMS system. JJ is interested in estimating the number of AGVs required to satisfy the need of the manufacturing system; that means, the system must be capable of making 51 deliveries per hour. So, that is how they are planning, and they have already decided to install a laser guided path system and unit load AGVS, adequately serves the company's needs.

The following data has been collected. The vehicle speed data is 180 feet per minute and the average loaded travel distance per delivery is 540 feet, and the empty travel distance per delivery is 360 feet. We need to and also, the pick up and drop of time have been given to be half a minute, half a minute each, and the traffic factor is 0.85. So, we want to calculate what is the number of vehicles, which are needed. So, let us first look at the total delivery time. So, total time of delivery per vehicle, t d v is given by the total average loaded time; the total hold time plus the total empty loaded time. In this particular case, the average loaded travel distance is 540 feet at the rate of 180 feet per minute; so many minutes, plus the hold time and pick up time; that is the drop of pick up time is about close to 1 minute. Here, 0.5 plus 0.5, plus the empty travel distance is about 360 at the rate of 180 feet per minute is about 2 minutes.

So, you have about 3 plus 1 plus 2 is about close to 6 minutes as the total delivery, the total time per delivery per vehicle, and add on the traffic factor to this thing; I mean, the total amount of number of deliveries per vehicle per hour, comes out to be 60 t f by t d v, which is 60 times of the traffic factor 0.85 by t d v, which is 6 in this particular case. Then it becomes 8.5 number of deliveries. So, this is the delivery frequency per vehicle per hour and obviously, we need 51 deliveries per hour. So, if this were the number of deliveries per one vehicle in one hour, for set of 51 deliveries needed, typically, 51 by 8.5 is about 6 vehicles would be needed to do this job of given 51 deliveries per hour. So, that is how you calculate the number of AGV vehicles, which are needed. This is the sort of the optimum plan and there are many other optimization issues, like distance criteria, etc. which can come into picture when you have a realistic situation in place. So, I think I am kind of done with the topic of automated material handling control. The only other issue, which is being left over, is the automated storage and retrieval systems and basically, this is a most modern concept particularly, when we are talking about storing of high volume inventory material of lower sizes.

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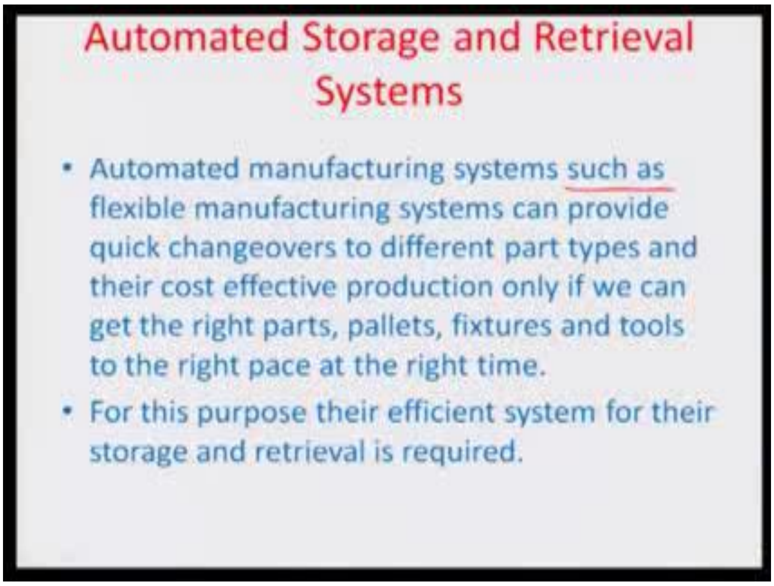

So, the automated manufacturing systems such as FMS, flexible manufacturing systems can provide quick change over to different part type and their cost effective productions, only if you can get the right parts, pellets, fixtures, tools, etc. to the right place at the right time. So, for this purpose, there efficient system of storage and retrieval is needed and by and large, if it can be automated, it is even better. So, that's why this is AS, RS systems come into place.

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So, basically, what are the functions of the storage systems and some of the definitions of the ASRS? So, receiving identification and sorting, dispatching to storage, placing in storage, retrieving from storage, order accumulation, packing, shipping and record keeping for raw materials, purchased parts, work in process, finished products, pallets, fixtures, tools, spare parts, rework and scrap, office supplies and so forth have traditionally being considered to be the function of storage system all these storage systems.

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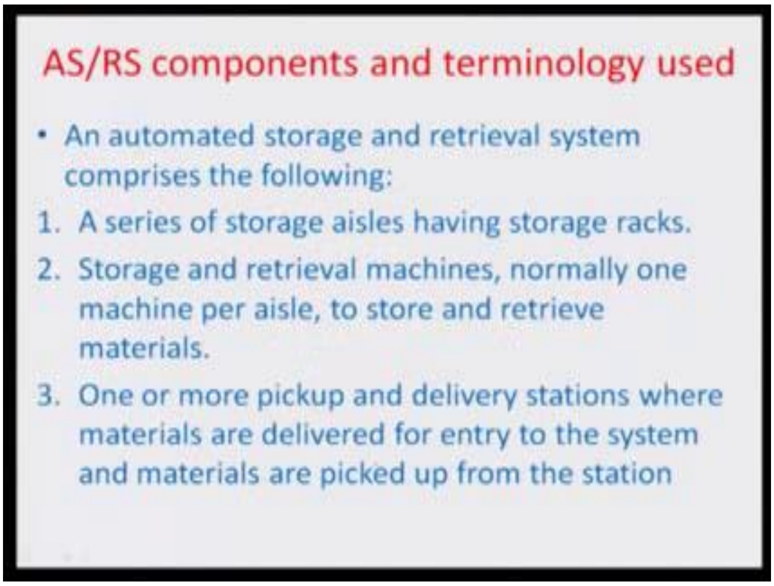

For a particularly, an automated storage retrieval system typically, comprises of the following; one is series of storage aisles, having storage racks and then also, storage and retrieval machines; normally, one machine per aisle to store and retrieve the material; one or more pickup and delivery stations, where materials are delivered for entry to the system and materials are picked up from the station.

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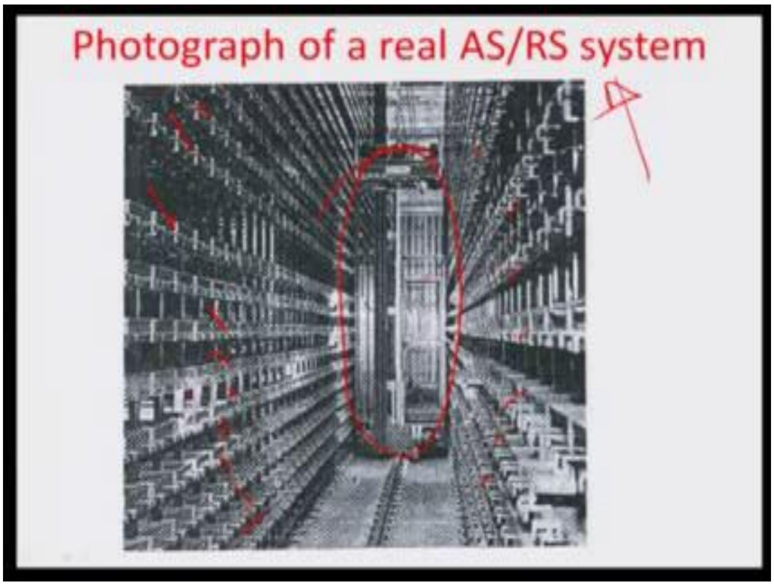

This, for example, shows such a delivery point. So, you have several bins as you can locate in these particular regions, as kept us rows and columns, and they are all numbered. Similarly, there are different rows and columns on the other side. This itself is the machine, which would actually go and retrieve a particular bin from a particular path and bring it you know, as programmed. So, this is how a real ASRS system will look like. So, typically when you are talking about high level inventory of tools for an assembly line; for example, or let us say pallets and fixtures for a press shop or a dye shop, or even like a weld shop and so on; you have to use some of these ASRS system in this place particularly, when the volume of the productions are very high volume.

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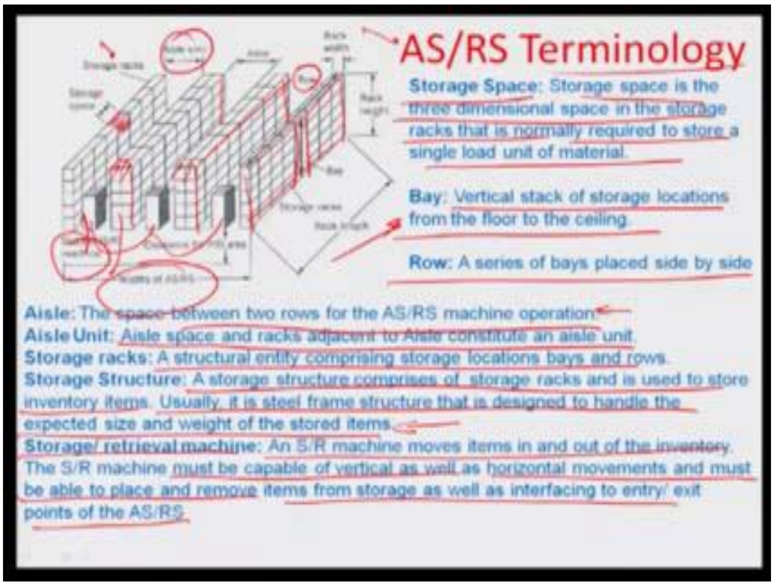

So, typically, the whole ASRS system as can be seen in the width of this whole ASRS system, is defined as various you know, zones and there is a certain terminology used for these zones. For example, we have storage space, which actually, reflects one such container here, which is basically, meant for storing a certain amount, certain part by a certain amount. It is a three-dimensional space in the storage rack that is normally, required to store single load unit of material. There is also a bay. So, the bay is somewhere, in between here; vertical stack of storage location from the floor to the ceiling. Obviously, there is a row or series of bays, side by side. So, you can have you know, different rows for one series of bays, as can be looked into here and then, another row, another row; these are all horizontally placed series of bays as rows. We have an aisle unit, which is the space between the two rows for the ASRS machine operations. So, typically this is the stacker machine that is in the picture as you saw earlier, and there is a stacker machine at each of these locations or sometimes, even a single stacker, which can go and access some of these rows and columns, where a particular unit needs to be carried from, which is otherwise, stored in that particular space. So, you have an aisle unit, which is the aisle space and racks adjacent to the aisle, this particular unit through which, the stacker machine can move and then, you have storage racks; a structural entity, comprising storage location bays and rows. You can see these are the different storage racks, which are into picture. So, this is one rack. Then, this is again a second rack, a storage rack; this is third storage rack, fourth, fifth so on and so forth. Obviously, there is a storage structure.

A storage structure comprises of storage racks and used to store inventory items. Usually, it is steel firm structure that is designed to handle the expected size and weight of the stored items. So, the infrastructure which is needed to house these bins, these different bins is basically, the storage rack, storage structure. Obviously, you have the storage retrieval machines, the SR machines, move items in and out of the inventory. The SR machine must be capable of vertical as well as horizontal movements; must be able to place and remove the items from storage, as well as interfacing the entry exit points to the SR. So, that is how you define the ASRS mechanisms.

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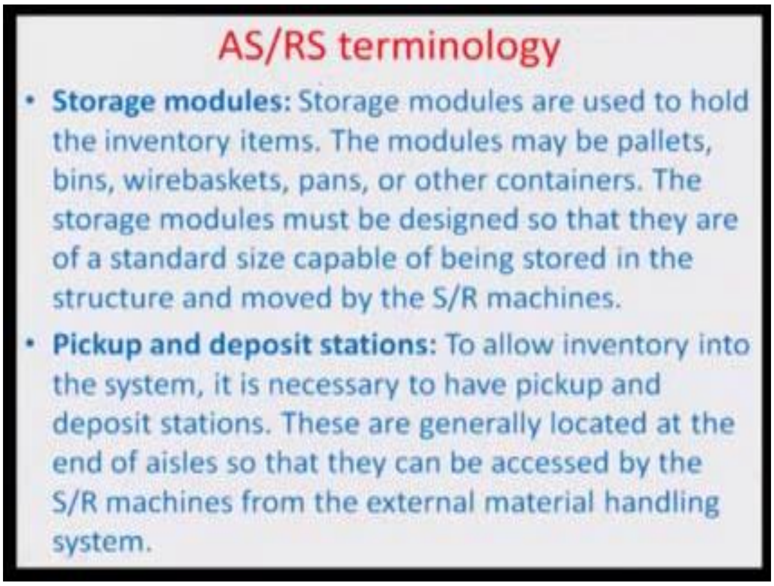

Obviously, the terminologies, which are used here is basically, one is the storage modules. So, the storage modules are used to hold inventory items. The modules may be pallets, bins, wear baskets, pans and other containers. Typically, the principle of design here, is to make it as visible as possible. So, that the basket can be seen at a glance and it can be planned as to what is falling short so that, it can be replaced. The storage modules must be designed so that, they are of standard size, capable of being stored in the structure and moved by the SR machines. So, these pallets are very two-dimension and then, there are pickup and deposit stations, which allow the inventory into the system. It is necessary to have pick up and deposit stations. These are generally located at the end of the aisle so that, they can be accessed by the SR machines from the external material handling system.

So, this hall combined together, formulates the ASRS system, as you can see here. There are lot of additional considerations, which go into the design of ASRS systems, which are probably, not going to cover in this particular course, but typically, highly automated industrial system would typically, have robots at one end and then, there is also a automated material handling system, like AGVS that we discussed in details and also, this automated storage and retrieval systems. These are over and above, the conventional shoots or conveyors or rulers or gantry kind of systems, which are already in place in most of the industries. So, this brings to a completion; this particular module of the course on manufacturing systems technology, part 2. Typically, in this module, in this particular course, we covered over and above, some of the things left over in part 1, like quality and how you can define quality, and how you can measure quality by statistical quality control principles. We also tried to cover some of these automated (refer time: 1:32:42) handling systems, etc. that the modern day industry envisions to have.

Thank you very much for attending this course and wish you all the best for your examinations.

Thank you.

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