Production Technology: Theory and Practice
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Lecture – 22
Adaptive Control Systems

Hello and welcome to the discussion sessions of this lecture series on production technology theory and practice. Now let me remind you that we started in our last session the discussion on the NC and the CNC machines. And in particular we discussed the concept of adaptive control system; it was told that adaptive control system something that adapts itself to the environment.

That means that suppose during the machining process if for some reason the forces changing or if some other parameters are changing then the adaptive control system will be able to correct those disturbances, eliminate those disturbances by manipulating feed or speed or both automatically. So, these systems become more complicated more expensive because we have to have a series of sensors for sensing different signals.

Suppose you have the excess of vibration occurring or excess of force occurring in that case the accelerometer or the force dynamometer used and so on. So, you have to have some kind of sensor to sense what is happening and to find out whether it is the extra force which is coming rather than what is given what is desired or what is given as an input.

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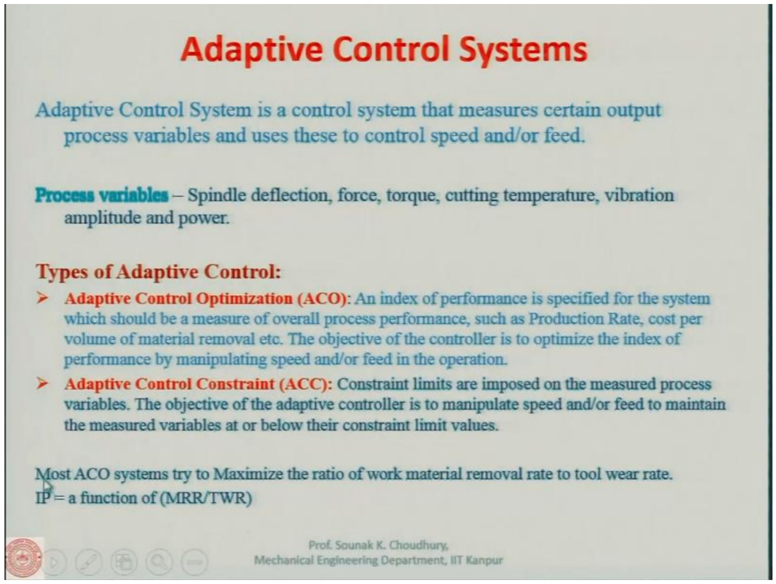

Next, it was told that additive controls are of 2 types, it was discussed in the last session that it can be either adaptive control optimization or it can be adaptive control constraint. In case of adaptive control optimization, an index of performance is specified for the system. Now that index of performance should be a measure of overall process performance such as production rate or production cost. The objective of the controller is to optimize the index of performance that has been selected by manipulating speed and or feed in the operation.

In the second case, that is when it is adaptive control constraint, a constraint level or constraint limit is imposed on the measured processes or measured process variables. The objective of the adaptive controller is to manipulate speed and or feed to maintain the measured variables at or below their constraint limit values. So, you can see that in both cases of adaptive control systems, the parameters switch the adaptive control, and based on the speed or feed or both of them.

That is the same that is either speed or feed or both. And by manipulating the speed and or feed, the adaptive control system then adapts itself with the environment and with the environment means when the parameters are changing. Then I said that most adaptive control optimization systems try to maximize the ratio of work material removal rate to the tool wear rate.

That means the index of performance which is selected is convenient to have that MRR divided by TWR because this reflects many of the aspects of the process because it is the material removal rate and the TWR ratio. So, material removal rate, for example, the production rate is reflected here, tool life is reflected in TWR and so on. So, this is convenient that if we can optimize this index of performance which is the ratio of the MRR and the TWR then the adaptive control can be successfully operated.

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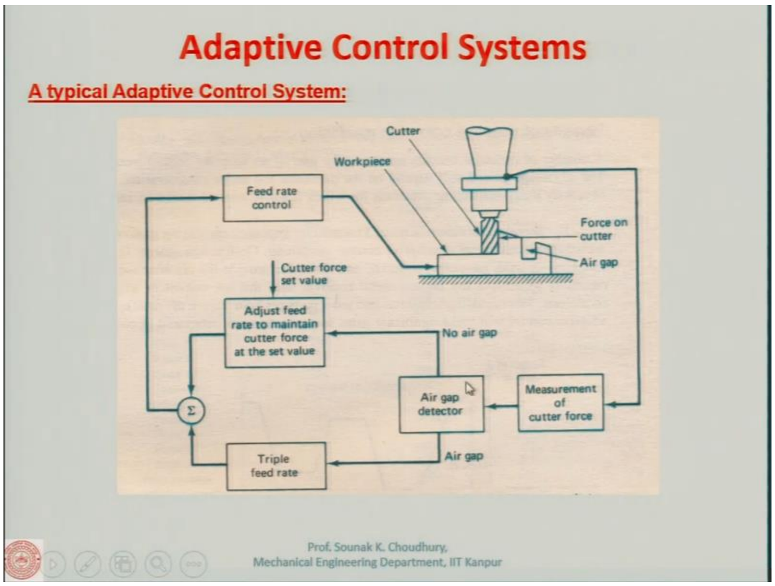

Let me give you an example of a typical adaptive control system. So, let us say we have the face milling cutter and this is the workpiece. Now here what happens that this is the interrupted cutting and in between we have some sort of air gap. The system contains a sensor which senses the cutting force, continuously the cutting force is measured.

Let us say this kind of a dynamometer which we have discussed. Now while the milling cutter is removing material from the workpiece, cutting forces are continuously measured here. Here there will be an air gap detector, which means that when the milling cutter will cut through the metal and then it will go through the air it will not cut. And then again it will start cutting this other part where the material removal is required.

So, that air gap will be detected. How to detect the air gap is simple because in that case the force becomes 0, now in case the air gap is detected in that case the command goes to increase the feed rate 3 times and if there is no air gap in that case the metal has to be removed. Therefore adjust feed rate to maintain cutter force at the set value. Now this is the cutter and here the force is being measured continuously.

So, in case it has to go through the metal, in that case the feed rate has to be adjusted to maintain the cutter force within the set value and we have a set value for the cutter for selection. Now whether there is an air gap or there is no air gap. And this value goes into the feed rate control. Suppose there is no air gap, in that case cutting will be normal in the sense that there will be not much of an effect because the force is already equal to the set value. Now this force will be reduced when there will be an air gap.

In case this there is an air gap and the tool goes through the air gap then feed rate is being triplicated; then there is no signal from here. And this triplicated feed rate will go here and feed rate will be controlled; it will actually be implemented here. So, you can see that this is a closed loop control system, this kind of a control system is called the adaptive control system. So, here you can see that there is a set value and we are not optimizing the parameters, as we have said here, index of performance.

This kind of adaptive control system is called the adaptive control constraint. Because the force value is set and if it goes down or it goes up in that case it has to be adjusted. For example, in this case there is no air gap it goes through the metal but it may so happen that in between there will be inhomogeneous hardness, hardness is inhomogeneous, if the hardness is more and this is encountered by the tool, i.e. by the milling cutter here, in that case the feed has to be adjusted and the set value is here.

It will always compare with the set value and the value which is coming from the measurement of the cutting force because there is no air gap. So, it will come through this in case this is becoming more than the set value, then the feed has to be adjusted, the feed rate has to be adjusted – decreased; in case it goes through the air, the cutter can travel fast because there is no material removal.

So, in that case you can increase the feed rate by 3 times. So, whatever is the result, it will come here and to implement that, whether the feed has to be increased or decreased that will be done by the feed rate controller and it will go as the implementation to the machining zone so that the feed rate can be increased or decreased to adjust the change in the cutting force.

So, here is the parameter which is the disturbance, force is increasing or decreasing. This is the disturbance which is coming from outside now the adaptive control system which is actually this circuit has to adapt itself. So, it will come as a signal and immediately it will tend to increase or decrease the feed from the time it is sensing.

From that up to the time it is actually implementing the difference is very less, we have to try to minimize the difference in this time. So, it has to be immediate; this is called the lagging, that is, by the time the signal is implemented some time has been elapsed. Let me tell you this can be within the timeframe of 0.01 second. By the time it is sensed and up to the time it is implemented the difference can be 0.01 second. This is rough estimation of many of the adaptive constraint processes.

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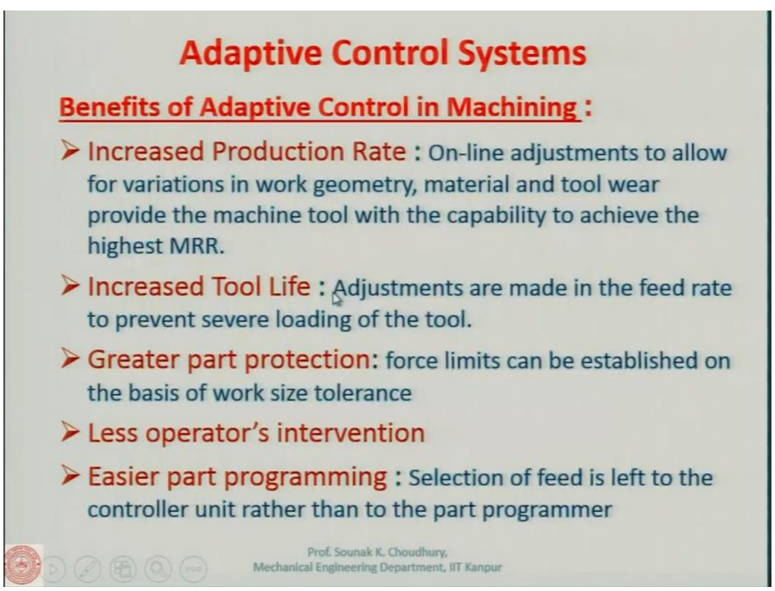

Benefits are many fold like the increased production rate, that is, the online adjustments to allow for variations in the work geometry material and tool wear provide the machine tool with the capability to achieve the highest MRR and highest MRR means the high production rate, increased tool life because adjustment can be made in the feed rate to prevent the severe loading of the tool.

Take example again, coming back to this we are saying that here it is continuously being evaluated and the feed is adjusted. So, the tool is actually safe now the not much of a load is on the tool I mean there cannot be a sudden load coming to the tool so that the tool life could be decreased, or the tool can be broken, because there is always the feedback system which is working, sensing the forces and the feed is being adjusted constantly.

Now greater part Protection Force limits can be established on the basis of work size tolerance, what will be the limit in the force that depends on the work size tolerance; if the tolerance is very close the force limit will be accordingly maintained, less operators' intervention because if you see in this diagram no operator is required in fact because here it is the sensors that do the work.

And the implementation signal is given here. So, there will be no human being and the involvement of the human being is not necessary. Easier part programming; selection of feed is left to the controller unit rather than to the programmer. How much feed has to be given, either it will be increased, how much it has to be increased or it has to be decreased, how much it will be decreased? Operator does not have to think about it.

Or the programmer does not have to think about it; you do not have to make that adjustment in the program because program has nothing to do; this is the instantaneous this is a dynamic process, it can change during the process any time it can increase or it can decrease anytime. So, it is a dynamic process and you as the programmer cannot even guess and cannot predict. So, the task of the programmer is easier. Because all these adjustments, all this calculations and the decision that how much feed has to be adjusted, this is done by the adaptive control system itself and not by the programmer.

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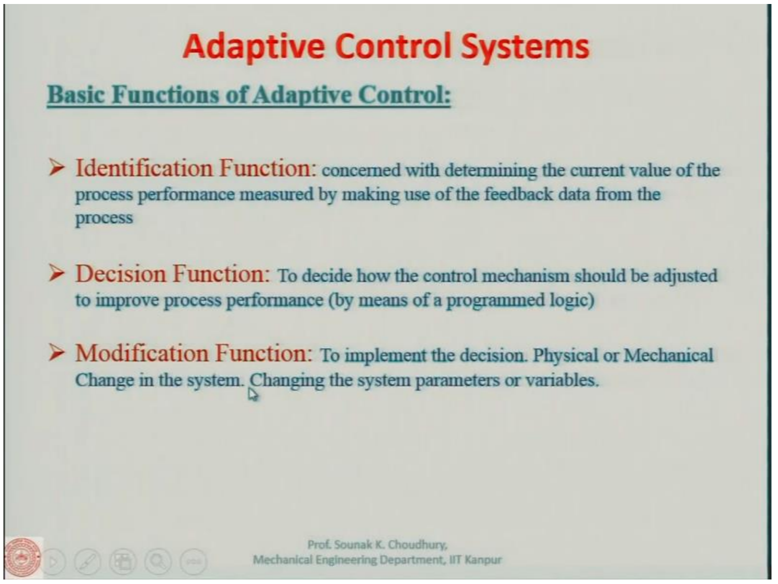

Basic functions of the adaptive control system are identification function, decision function and the modification function. So, you can see that these are the functions which normal human being does everyday. Now that we identify something that what to do, then we decide how to do that and then we modify whether we have done is correctly done or not.

So, let us see here how the adaptive control functions identification function concerned with the determining current value of the process performance measured by making use of the feedback data from the process current value, what is the current status coming back to this here. So, this is actually this is determining the status of the process and whether the cutting force is within that set value or it is fluctuating, it is becoming more or it is becoming less.

Instantaneously it will actually send the signal that what is the current status of the process, what the process is going through. Now next is the decision function to decide how the control mechanism should be adjusted to improve the process performance by means of program logic. Here this value of the force is equal to the adjusted value. So, the entire circuit is silent because there is nothing to be done, feed does not have to be adjusted because this value of the force measured is equal to the set value.

Now the moment it will increase or decrease then it will be activated. In that case what we are saying is that this will be decided what to do and how to do that, to decide how the control mechanism should be adjusted. It has to be increased it has to be decreased or how to improve the process performance. And that will be done by the program logic which is all here. Here is the program logic, the main function of which is to calculate the discrepancy between the current value and the set value.

And then it will decide what has to be done with the feed, whether it has to be increased or it has to be decreased. And then accordingly it will be implemented. And the third function is the modification function and the modification function is to implement the decision by making physical or mechanical change in the system, changing the system parameters or variables. Then finally it will modify whether it has been done properly or not. So, basic three functions of the adaptive control system which are very similar to what human being also does, that is our brain does, that is identify, decide and modify.

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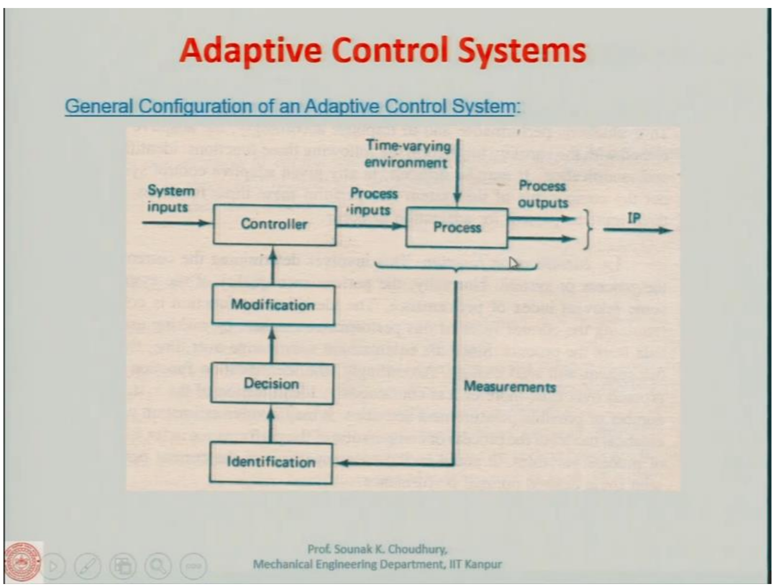

So, here you can see the general configuration of an adaptive control system in the block diagram. This is the process. Now in this process we have some process input and we are getting some output. On this process there are some time varying environment and by that we mean to say that there are certain kinds of disturbance.

Disturbaces can be the change in the force, change in the temperatures, change in the vibration. The output and the disturbance are the signals which will be continuously measured. So, the measurement is done for the input parameters to the process as well as for the output parameters. Input and output parameters will also vary.

I mean output parameters particularly will vary depending on the time varying environment because time varying environment will change the input although I do understand that it will change the process performance and it can change this inputs. So, overall, that will be detected when both these signals will be measured continuously, here it identifies whether it is correct or whether there is a discrepancy between the output and the input.

And the discrepancy is only because of the time varying environment. So, as soon as it identifies that there is a discrepancy then it sends it to the logic circuit to decide what to do. Now the decision is made, that is the feed has to be increased or speed or feed these are the two parameters that the adaptive control system change.

So, the adaptive control system then decides that the feed or speed has to be changed and then it sends this signal or decision to the modification function. And the modification function sends the voltage signal to the controller so that the feed or speed can be changed. So, the system input we will have some signal that will go through the controller.

And the controller can suggest that you change this system, you multiply that with some coefficient and that coefficient is decided here based on the identified values of the output and the input whether there is any discrepancy or not and accordingly it will go as a process input and the process will be changed. Once again, it will be done instantaneously and with a time lag of *0.1 sec* or even less than that.

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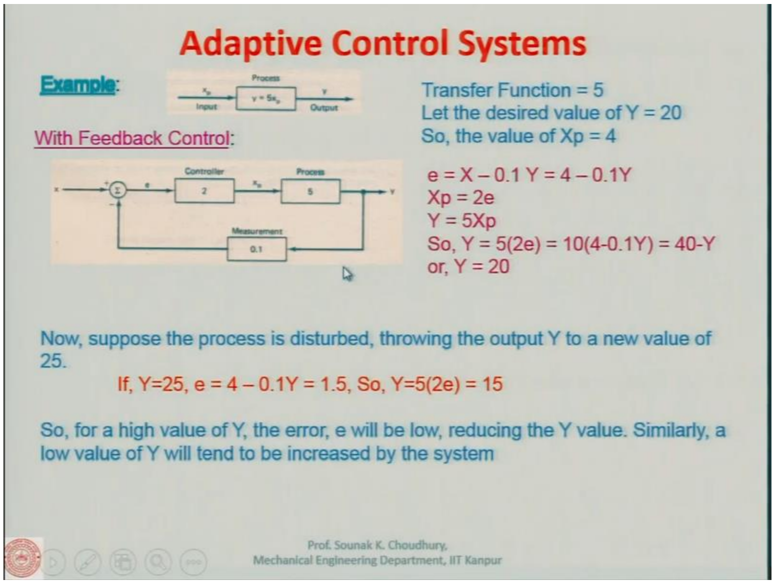

Now let me give you an example of the control systems and show you how the adaptive control system can be helpful in establishing or in controlling the output parameters. Whereas many of the NC systems, many of the closed loop systems even that we have discussed in the numerical control machines I mean earlier that they are also not capable of doing that let us take an example.

Suppose we have a system where the transfer function is 5; let the desired value of the output will be Y. Let us say we have a process like this, some process which is described as $Y = 5X_p$, X p is the input, some input which may be in terms of voltage, in terms of some value. This will go through the black box here and it will be multiplied by 5. So, this is the gain of the process.

Therefore, at the output it will be equal to 5 into X p, the X p is the input. So, therefore we said that this The output by input, $\left(\frac{Y}{X_p}\right)$ is called the transfer function which is equal to 5. This is the gain of the process. Gain of the process is but the following. Just imagine an amplifier. You increase the decibel level 5, 10, 15 so you are increasing the gain. This is the gain which means this is kind of an amplifier it is the amplification factor.

So, here also we are amplifying the input value by 5 and giving it to the output as $Y = 5X_p$ which is the equation or how the process can be described. So, the transfer function is 5 that is output divided by input. And let us say that the desired value we want, the output to be some 20 unit; therefore, the value of the input should be $\left(\frac{20}{5}\right) = 4$ so this X p has to be equal to 4.

Now we will make a feedback controller. To control the process we have to have a controller and let us say the process gain is always 5, we are not changing that and X_p is the input and Y is the output. So, this is the process here it is the process and through the process we are adding a controller and then we are adding a feedback system; this is the feedback control. Now as I said that with the feedback control there will be a sensor.

It will continuously measure the output and it will go through some kind of an amplification. It will come to the input and the input value will be summed up with the measured value and it will create an error signal which means it will create a signal so that to compensate for the error whatever is coming. This error signal will go through the controller and then it will come as an input to the process.

This input to the process can be changed accordingly depending on the measured value. Here this is the feedback control system. Now let us say the error signal this is equal to this X minus the signal coming from the feedback loop. This is the negative feedback control system, which is mostly used because input is considered to be the plus on which the output signal is superimposed, this is minus.

Therefore, the error signal is this input signal minus this signal or this signal will be $0.1Y$. Now, $X = 4$ there has to be $(4 - 0.1\ Y)$ now the X_p next this will be $2e$ means Y will come to that, then Y output will be $5\ X\ p$, X_p is that $2e$. Therefore the Y overall this will be $Y = 5 \times 2e$ X_p is $2\ e$ and $e = (4 - 0.1\ Y)$.

Therefore, Y will become equal to 20 . So, this process is established process or processes in equilibrium where we wanted some output which is 20 and we are giving the input as 4 and then we will get the desired output. Now suppose the process is disturbed, let us say for some reason and the reasons can be many, we are saying that for some reason the process is disturbed.

And the output has been changed from 20 to some value, let us say 25. So, now suppose the process is disturbed throwing the output Y this to a new value of 25. Now if $Y = 25$ then we go in the reverse way; the error signal, e will be $(4 - 0.1 Y)$ and Y is 25. So, it will be 1.5, so Y = 15 again coming here, $Y = 5 \times 2e$.

You can see here there is no contradiction let us say $Y = 25$ then error signal from this point of view is (25 - 0.1) and this will be added to the 4 or 4 minus this. So, this will be 1.5. Therefore, from here you can find out that Y is becoming which is $(5 \times 2e)$ and the error signal is 1.5. So, it will be 15 that means with this type of feedback control system, if the Y becomes 25 then after a time lag it becomes 15.

This means that such kind of a feedback control system is not capable of controlling the process and not capable of controlling the output keeping the output as a desired level because we wanted the output to be at 20 all the time whatever happens . So, suppose if the disturbance happens and this becomes 25, the task of the system should be that it has to bring back the system with the output of 20 which is the desired value.

So, for a high value of Y when it is becoming higher the error e will be low that we can see because we have taken its amplification here as 0.1, reducing the Y value because Y has become from 25 to 15, so it is less than 20. Similarly, if the low value will be there let us say it has gone from 20 to 15 then it will increase, the output Y will tend to be increased by the system in the reverse way. Therefore this system is not capable, that is, such feedback control system we cannot use to stabilize the system output.

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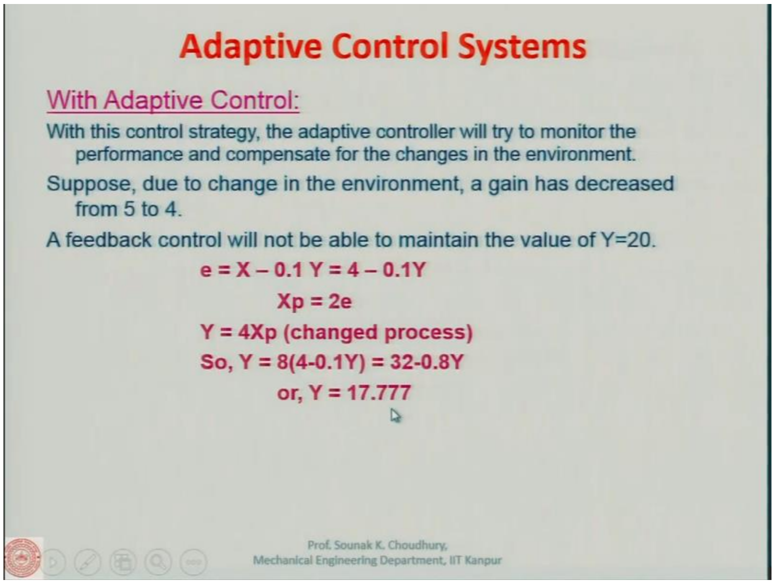

Now with adaptive control system the adaptive controller will try to monitor the performance and compensate for the changes in the environment. Suppose due to change in the environment again the gain has decreased from 5 to 4. In the next example we will see that in that process because of some disturbance from outside, this process gain has been changed from 5 to let us say 4, then what happens? Let us see.

In that case how the feedback control system will behave? It will not be able to maintain the value $Y = 20$. Then the value of e will be $(X - 0.1\ Y)$ keeping that and here we have the $(4 – X)$ has become (4 - 0.1Y). Now $Y = 4\ X\ p$ now it has become 4 instead of 5. Therefore, Y value which is $(4 \times 2e)$, can be calculated as 17.777.

So, we have calculated the same way as in the earlier case, only thing is here the process gain has changed from 5 to 4 and accordingly we are changing the process here. So, Y is equal to then 17.777 which is not 20, it could not be stabilised.

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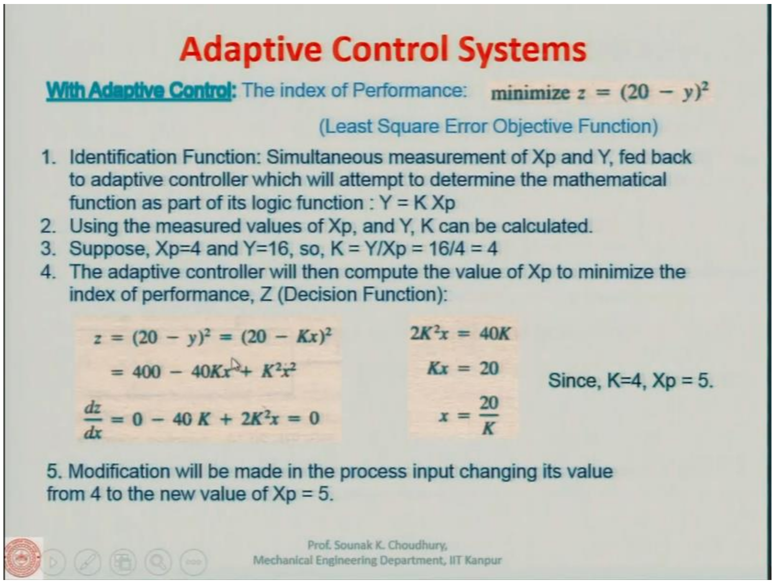

Now let us see with adaptive control. Here let us say the index of performance we will select is z which is $(20-y)^2$. This is called the least square error objective function. 20 is the desired value this is the y which is output so $(20-y)^2$ is the index of performance and then our task as the adaptive control system will be to minimize this z.

Now we have to 3 functions, we have identification function, we have the implementation and the decision, decision and the modification these are the 3 functions. So, then what we do in identification function is the simultaneous measurement of $X\ p$ and y.

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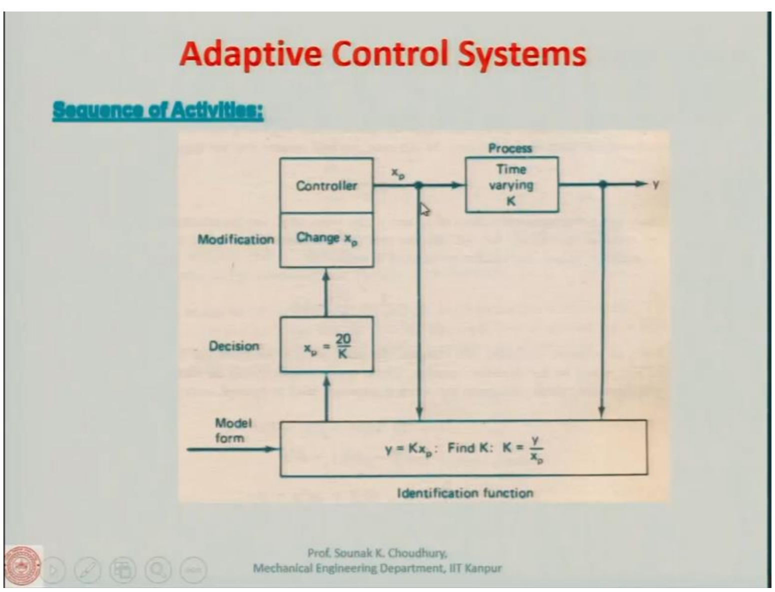

Like we have given in this example that input and output all both will be measured simultaneously and then the feedback control system will attempt to determine the mathematical function as part of its logic function $y = Kx_p$.

So, anytime it changes, K value will change. Let us say this is in general we are writing that this is the logic function as $y = Kx_p$.Using the measured values of Xp and the Y we can find out the value of the K for any instance. When the Xp or Y change at any instance K can be found out by continuously measuring Y and X p.

Here in this example as I said that we are measuring this continuously. Here also X p and Y we will continuously measure and we will find out the value of the process gain at any point of time when the X p and Y may change to some other values. Suppose the X p is 4 at an instance and *Y = 16* then *K = 4* but X p can have 4.1, and Y may have 16.2. Accordingly we will find the K for that instance of time.

This is a dynamic process where *X p* and *Y* may change and whenever it changes then the value of the process gain can be calculated because we already know the equations. Now I am showing it in a very simple example you understand that any process can be in a similar way analyzed and the process can be very, very complicated.

So, this kind of equation will be very complicated equation but the decision-making logic instrument in the additive control system will be capable of calculating instantaneously what will be the value of the K if the Y output and the input *X p* change. Now suppose for this particular value when we are having K = 4 the adaptive controller will then compute the value of X p to minimize the index of performance Z that is the decision function we have taken.

So, $z = (20 - y)^2$ which is equal to $(20 - Kx)^2$ *X* and *X p* are the same. So, in that case it will be this value. Now you have to minimize this, so the first derivative should be equal to 0. So, if you take the first derivative it will be this value as shown in the slide. From here the K = 20 or *x* value is $\left(\frac{20}{K}\right)$. Since $K = 4$, so, X will be 5. That means the modification then will be made in the process input changing its value from 4 to new value of 5.

So, if the process has become 4 then X p value will be changed to 5 instead of 4. So, this is the conclusion that the adaptive control will decide and then it will implement that way. This is the entire process of the adaptive control system and how it can actually work. So, this is how it can actually happen that output an input can be continuously measured this identification function and this is the model which is formed find K, $K = \left(\frac{y}{x_p}\right)$.

So, this will be decided then $x_p = \left(\frac{20}{K}\right)$ then the modification is changed the X p and modification is given to the controller, controller sends the signal and then it changes the X p from 4 to 5 as we said. So, this is the block diagram saying the same thing that we have described in this adaptive control system process that means what has been told here in this analysis is that the simple feedback control system is not capable to stabilize when the system is disturbed.

But adaptive control system will always be able to keep the output at the desired level. We have considered adaptive control optimization in this example since we have optimized the index of performance and we are minimizing this. Therefore, it is the adaptive control optimization. However, adaptive control constraint can also be used that we I have already shown in a block diagram.

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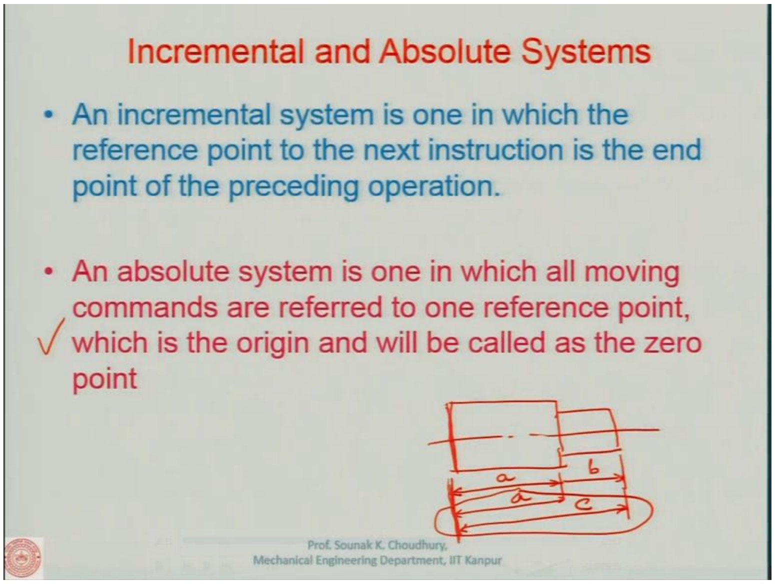

Now let us discuss what is the incremental and the absolute system. Incremental system is one in which the reference point to the next instruction is the end point of the preceding operation and absolute system is one in which all moving commands are referred to one reference point which is the origin and will be called as the zero point. Why it is important because the manufacturer of the NC and the CNC machine will determine initially whether it is going to be an incremental or absolute system.

So, they can keep it either way, now in the program you have to tell what you want depending the system that has been adopted. Suppose we have a shaft. I will give a simple example and these are the 2 different diameters shaft has. So, the dimensions can be like this let us say this is *a* and this is *b* or the dimension can be like this. and this these are the 2 methods this is *a* and let us say this is *c*.

So, either it can be given in this way when it is all moving commands are referred to one reference point, this is the reference plane or it can be the next instruction is the end point of the preceding operation. This is the preceding operation of this, this is the end point. So, we will see that in details at a later stage.

Now let me talk to you about the principle of the part programming how the part programming can be done. This part programming will be in very details shown to you in the lab and I will also show it to you in a PPT before the lab session that how the part programming can be done in an example, however some of the points I would like to nevertheless tell in this lecture.

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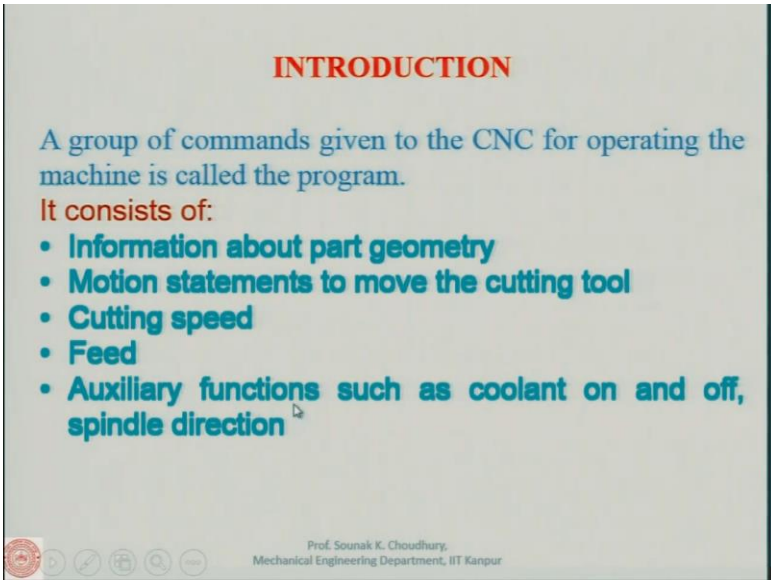

Let us say a group of commands given to the CNC for operating the machine is called the program, first of all. So, the program will consist of 5 points, that is the information about the part geometry, motion statements to move the cutting tool, cutting speed, feed and auxiliary functions such as coolant on and off spindle direction rotation of direction of the spindle clockwise or anti clockwise and so on.

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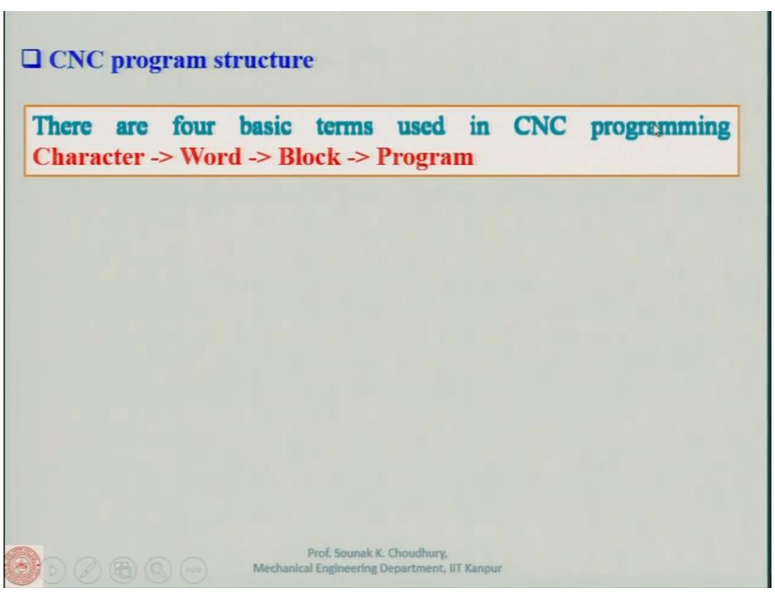

Program structure: there are 4 basic terms used in the CNC programming character, word, block or and the enter program.

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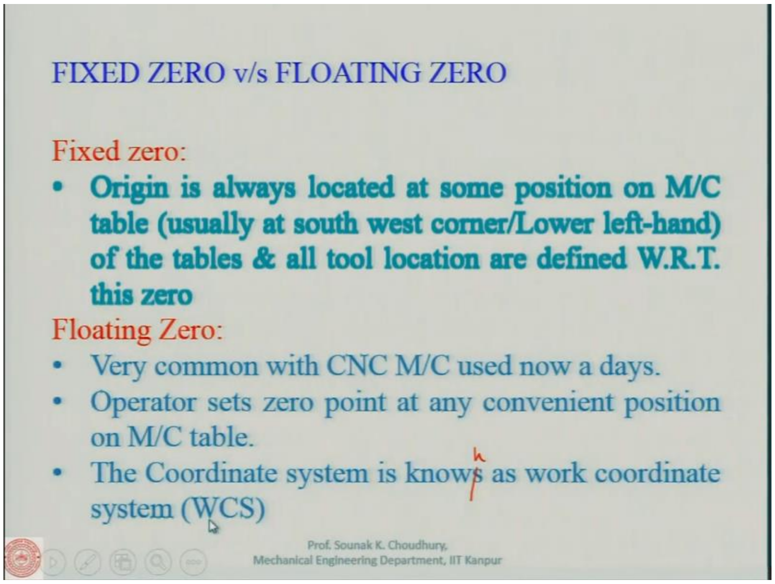

Now fix zero versus the floating zero: fixed zero is the origin that is always located at some position on the machine table usually at southwest corner or lower left hand of the table and all 2 locations are defined with respect to this zero. So, this is the fixed zero normally it is set by the manufacturer; he can take it some point at the left side or southwest corner meaning that here somewhere at the left because it is convenient.

And then either give it with respect to this point that all the other dimensions will come with respect to the fixed point and the fixed point is here. Now there is a floating zero also floating zero is very common with the CNC machine used nowadays. I mean the modern operator sets zero point at any convenient position on machine table meaning that it may not be convenient for me or you as an operator to operate your dimensions with respect to the fixed zero that has been decided by the manufacturer.

So, in the modern machines what is done is there is a floating zero so wherever you would like to put your zero. What we mean by zero is that all dimensions will be from there. I will show it to you later on how operator sets zero point at any convenient position on the machine table. The coordinate system is known as work coordinate system. So, this coordinate system when you have the zero point at any convenient position, this is in every version called the work coordinate system WCS.

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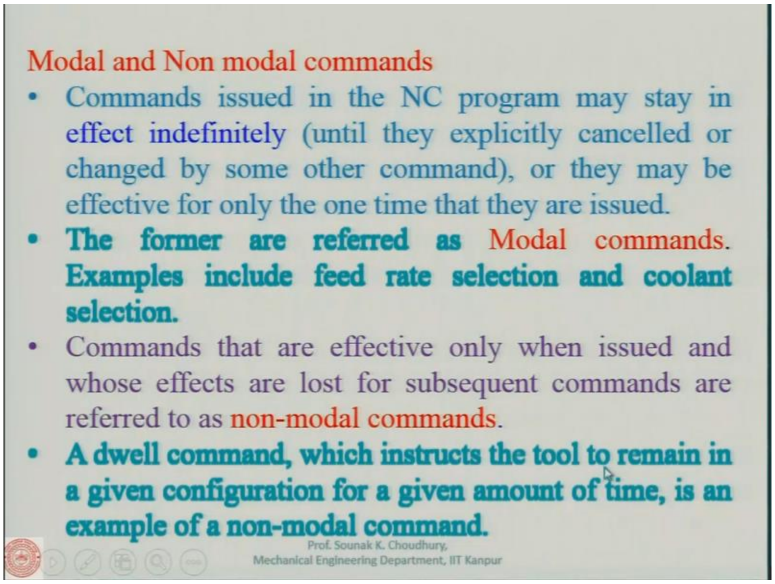

Now the modal and non modal commands are the following, that is, commends issued in the NC program may stay in the effect indefinitely until they are explicitly canceled or changed by some other commands or they may be effective for only one time when they are used. The former is referred to as a modal command. So, this is the modal command where it stays indefinitely until unless you change.

Examples include feed rate selection and the coolant selection. Now the commands that are effective only when issued and whose effects are last for subsequent commands are referred to as a non modal command. Now let me give you an example, suppose in one program in one line you have selected certain value of the feed, let us say 0.1. Now in the next line of the program you are not putting anything meaning that if it is the model command that means the previously selected feed is still remaining valid.

Now in the next line you are selecting again feed and giving the value as 0.2. So, once you are giving the value of 0.2 that means that 0.1 value which has been given earlier is cancelled now. You have to specify in the program whether it is a modal command or it is a non modal command; in the non modal command once you are giving the feed in one, line like in this case, in the next line also have to repeat that.

Otherwise, the command will not be valid in the next line if you are not repeating that the feed, *f* is remaining 0.1 in that case the F will be taken as zero if nothing is written there. So, this is the non modal command, a dual command which instructs the tool to remain in a given configuration for a given amount of time is an example of a non modal command.

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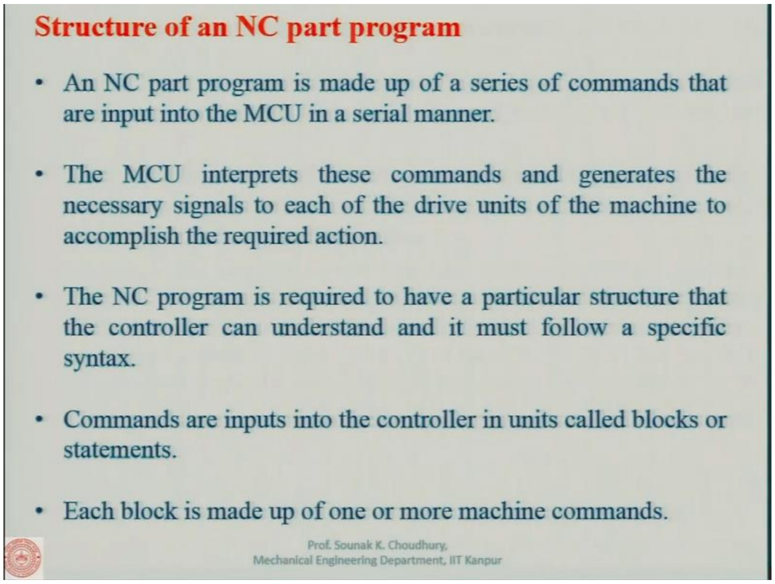

Now the structure of an NC part program is made of a series of commands that are input into the MCU in a series manner. The MCU interprets these commands and generates the necessary signals MCU is the machine control unit to each of the drive units of the machine to accomplish the required action. Now program is made inseries of commands. Those commands can be written in the alphabet A, B, C, D in the M code G code.

Miscellaneous is the M code G code is the preparation and so on. I will show you each of these commands. NC will interpret them, NC program is required to have a particular structure that the controller can understand and follow a specific syntax, that is the program, that is this G code, M code etcetera so that the NC, MCU can actually interpret.

Each block is made up of one or more mission command. Many commands could be there or a particular command could be there depending on what kind of machining, what kind of operation you are performing.

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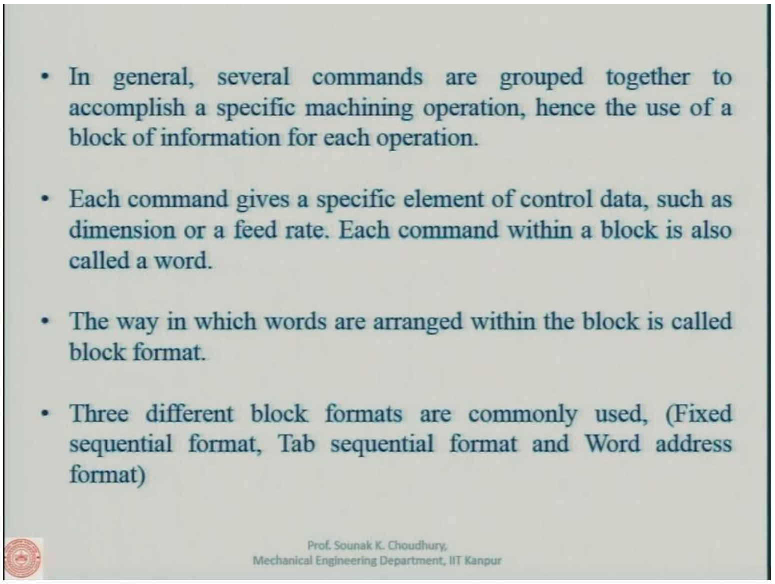

In general, several commands are grouped together to accomplish a specific machining operation, hence the use of a block of information for each operation each command gives a specific element of control data such as dimension or the feed rate. Each command within a block is also called a word. Now we have a block of few commands and each command is a word.

I mean you have to just write the program the way in which the words are arranged within the block, called a block format. Three different block formats are used, namely fixed sequential format, tab sequential format, and word address format.

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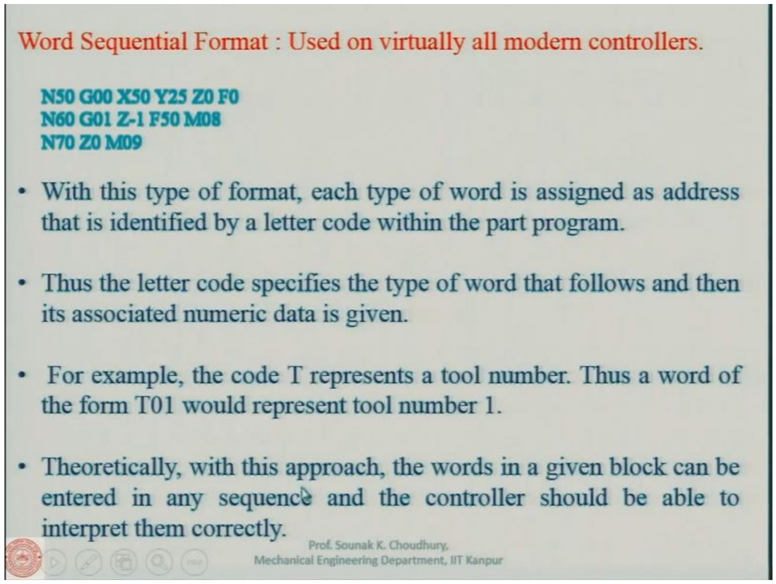

Sequential format is used on virtually all modern controllers, for example this is a program in 3 lines. With this type of format each type of word is assigned as address that is identified by letter code within the part program, this is the letter code X, Y, F, G, N there is the letter code specifies the type of word that follows.

And then it's associated numerical data, let us say X is what to do, and what is the value; 50 for example; the code T represents tool here. So, T01 means the tool and tool number 1. Theoretically with this approach the words in a given block can be entered in any sequence and the controller should be able to interpret them correctly.

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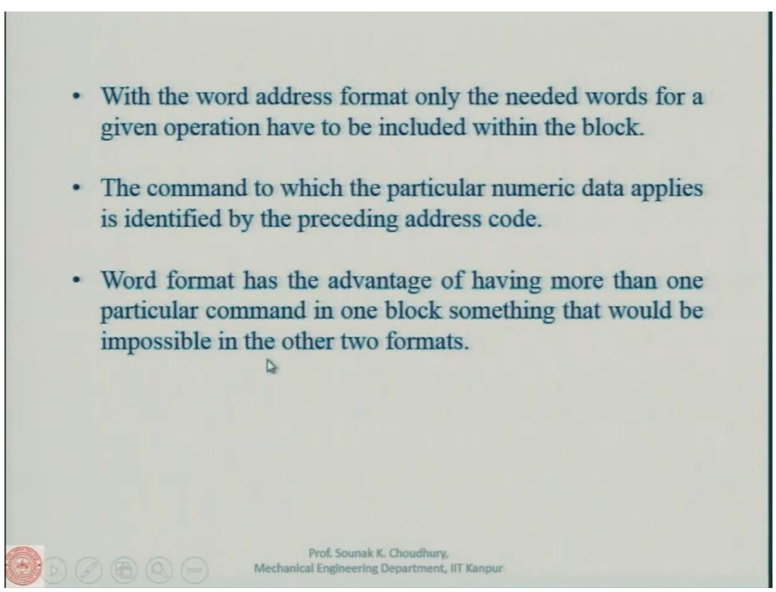

With the word address format only the needed words for a given operation have to be included within the block it and so on. So, what format has the advantage of having more than one particular command in one block over something that would be impossible in other 2 formats and so on. So, these are the differences between the 3 formats and how they differ from each other.

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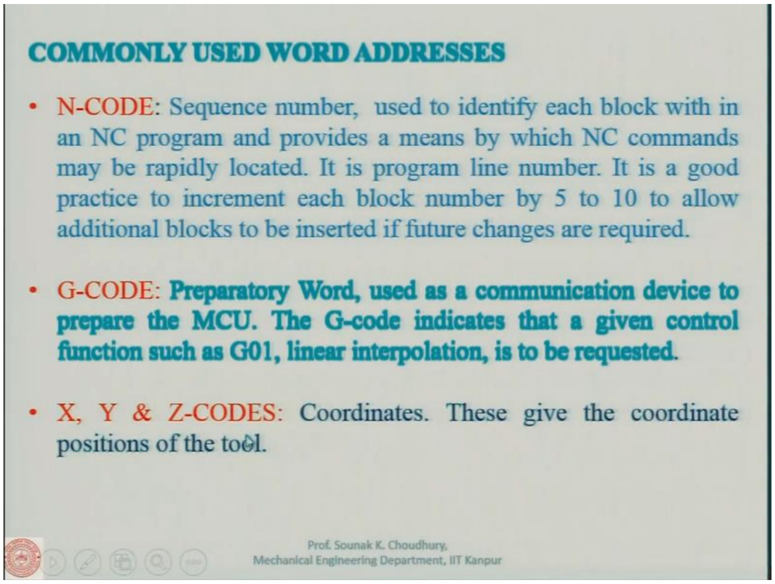

Commonly used addresses are the N-CODE which is the number here N is 50, N is 60, N is 70, so this is the number of this line each line is given by a number N-CODE, this is the sequence number; G-CODE is a preparatory word used as a communication device to prepare the MCU machine control unit. The G code indicates that a given control function such as G01 for example, stands for linear interpolation.

So, if it is given in the program that it is G01 G can be 01, 02, 03 and others which are tabulated. I will show you a table where all these codes are interpreted, what is the interpretation of each of these codes. Now G-CODE is the preparatory word it is given here as 01, 01 particularly means linear interpolation. Now X, Y Z-CODES these are the coordinates.

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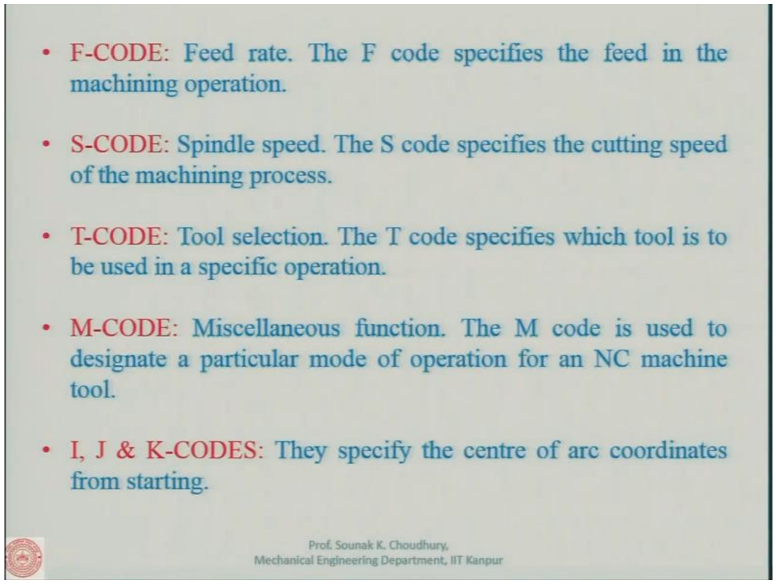

F-CODE is the feed, S-CODE is the spindle speed, T-CODE is the tool selection, M-CODE is a miscellaneous function I, J and K-CODES they specify the center of an arc and particularly it is when you are giving the circular interpolation. We will see that I, J and K codes can also be given as a circular interpolation.

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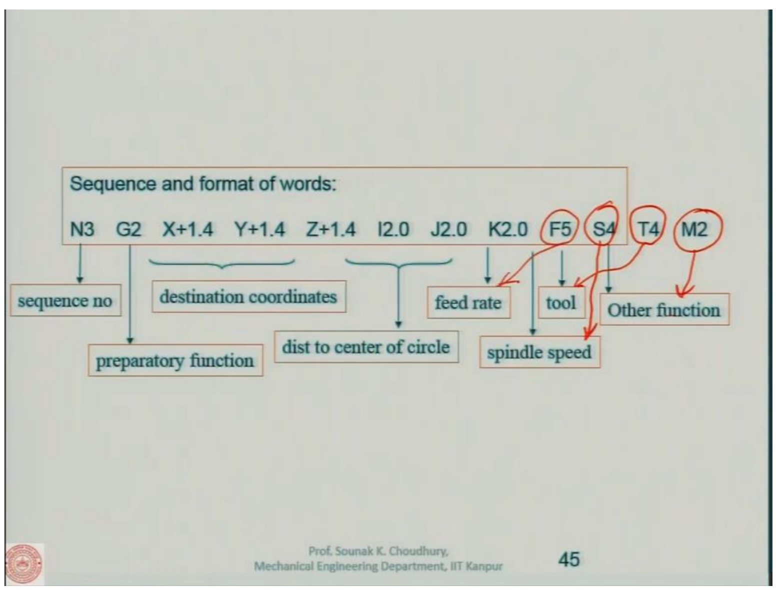

This is an example of whatever we said; that is the sequence and format of words. Let us say we have this as a program. Now this is the sequence number, number 3, G is the preparatory function particularly the value here is the 2. X and Y are the destination coordinates. X, Y coordinate Z coordinate; this is the distance to center of a circle, that means I and J are the center of a circle.

I, J, K will be the distance to center of circle, F is the feed rate, S is the spindle speed I am sorry this has been shifted here S is the spindle speed actually, this comes in here, tool is here. So, this is the tool function and M is the other functions, miscellaneous. So, spindle speed is S, F is the feed rate here.

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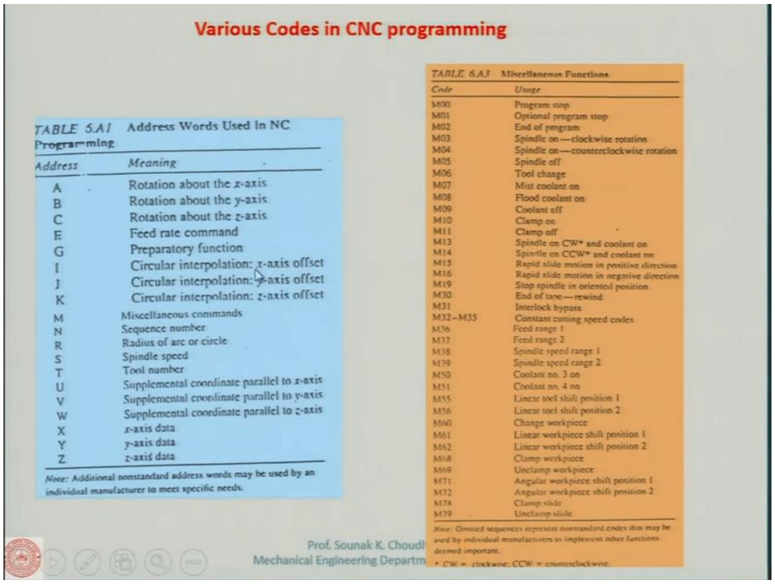

Now here these are the two tables, the one that I was telling you that this is the table which shows the address words used in the NC. A to Z this is the M miscellaneous code, miscellaneous code you can see that there are many, many of them and each of them has a meaning and you do not have to remember all of them and you cannot remember all of them but when you will be practicing the programming, you will see that most of the normal miscellaneous commands you will be knowing automatically because you will be using them very frequently.

Otherwise, you will always have that table in front of you and you can use that table to find out which command to be given depending on your machining process. So, for example M01 this is optional program stop, end of program you say M02, it will end; you want to rotate the spindle in the clockwise direction you write M03; to the anti clockwise direction counter clockwise it is M04; you want to switch it off it will be M05.

Since there will be no intervention of the human being everything should be done by the command given to the machine. So, these are the codes that have been coded in the machine that machine should understand if it is given here. The combination of all those will make a program. And you will have each of them tabulated, you will be knowing them from the table, you do not have to remember them by heart.

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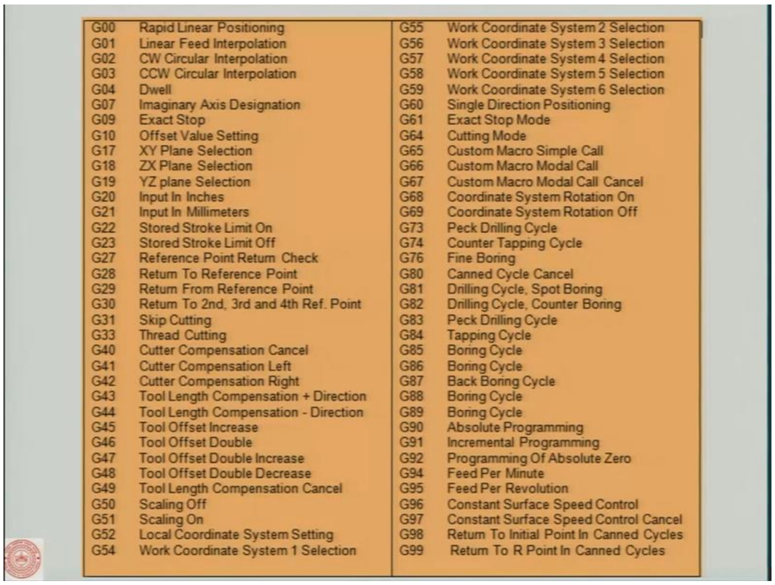

G00	Rapid Linear Positioning	G55	Work Coordinate System 2 Selection
G01	Linear Feed Interpolation	G56	Work Coordinate System 3 Selection
G02	CW Circular Interpolation	G57	Work Coordinate System 4 Selection
G03	CCW Circular Interpolation	G58	Work Coordinate System 5 Selection
G04	Dwell	G59	Work Coordinate System 6 Selection
G07	Imaginary Axis Designation	G60	Single Direction Positioning
G09	Exact Stop	G61	Exact Stop Mode
G10	Offset Value Setting	G64	Cutting Mode
G17	XY Plane Selection	G65	Custom Macro Simple Call
G18	ZX Plane Selection	G66	Custom Macro Modal Call
G19	YZ plane Selection	G67	Custom Macro Modal Call Cancel
G20	Input In Inches	G68	Coordinate System Rotation On
G21	Input In Millimeters	G69	Coordinate System Rotation Off
G22	Stored Stroke Limit On	G73	Peck Drilling Cycle
G23	Stored Stroke Limit Off	G74	Counter Tapping Cycle
G27	Reference Point Return Check	G76	Fine Boring
G28	Return To Reference Point	G80	Canned Cycle Cancel
G29	Return From Reference Point	G81	Drilling Cycle, Spot Boring
G30	Return To 2nd, 3rd and 4th Ref. Point	G82	Drilling Cycle, Counter Boring
G31	Skip Cutting	G83	Peck Drilling Cycle
G33	Thread Cutting	G84	Tapping Cycle
G40	Cutter Compensation Cancel	G85	Boring Cycle
G41	Cutter Compensation Left	G86	Boring Cycle
G42	Cutter Compensation Right	G87	Back Boring Cycle
G43	Tool Length Compensation + Direction	G88	Boring Cycle
G44	Tool Length Compensation - Direction	G89	Boring Cycle
G45	Tool Offset Increase	G90	Absolute Programming
G46	Tool Offset Double	G91	Incremental Programming
G47	Tool Offset Double Increase	G92	Programming Of Absolute Zero
G48	Tool Offset Double Decrease	G94	Feed Per Minute
G49	Tool Length Compensation Cancel	G95	Feed Per Revolution
G50	Scaling Off	G96	Constant Surface Speed Control
G51	Scaling On	G97	Constant Surface Speed Control Cancel
G52	Local Coordinate System Setting	G98	Return To Initial Point In Canned Cycles
G54	Work Coordinate System 1 Selection	G99	Return To R Point In Canned Cycles

Similarly, the G code you see there are 100 G codes and each G code like in the M code are all tabulated and each of them have some meaning. For example, very popular is in a linear positioning, circular interpolation clockwise and counterclockwise - these are very commonly used, we will see that in programming. XY plane selection ZX plane selection 17, 18, 19 they are also used you have to put it in millimeters.

So, you have to make the program, make the machine to understand whatever dimensions you are giving, these are in millimeter or inch. So, this command has to be given earlier in the program that everything that is given in the program will be in millimeters. So, this is given by G21 and so on you can see that there are many, many of those commands and each of these commands mean something.

So, depending on that whatever is the code and whatever is this value, you have a particular meaning of that and the combination of that is a program.

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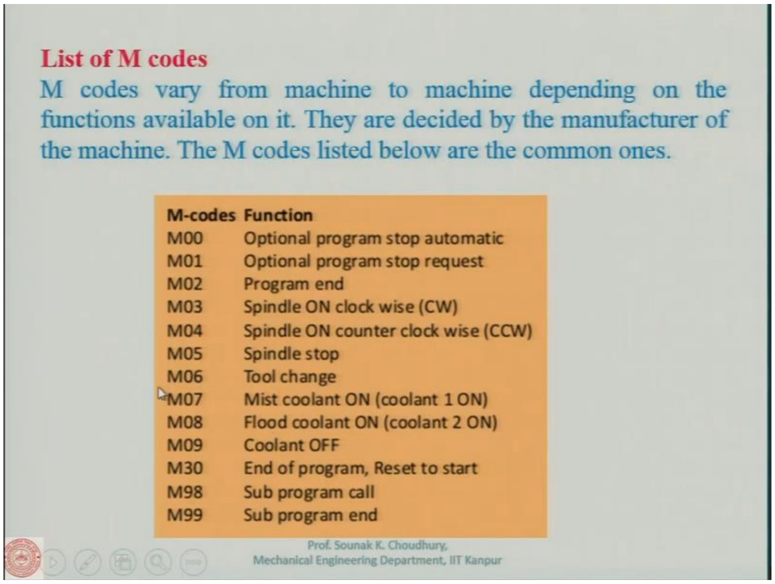

For example, this is the M code, M05 code is to stop the spindle, tool change will be M06 and so on. Even whether you want to do the mist coolant or the flood coolant that also should be given in the program because again there is no intervention of human beings. So, a human being is not there and cannot change the coolant from mist to flood.

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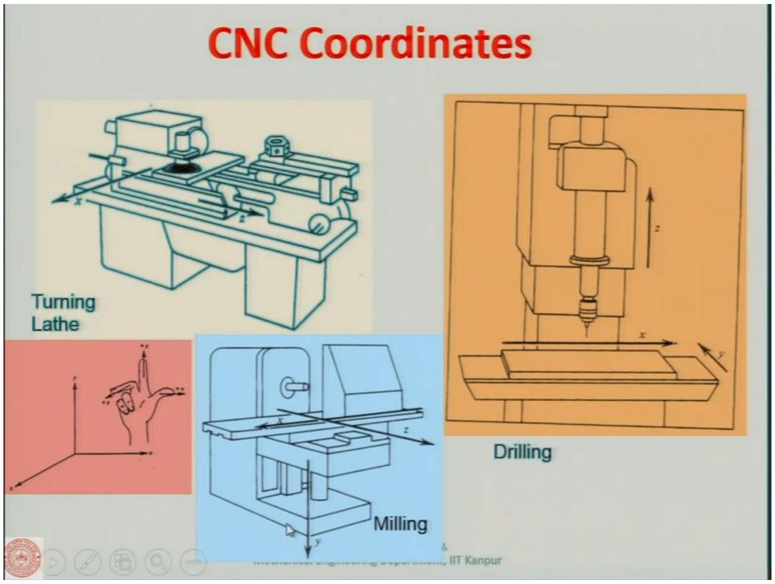

It has to be given in program and finally these are the coordinates. I told you already that in case of turning lathe the movement in this direction is considered to be x axis and in this direction is the z axis. In case of drilling this is z this is x this is y, in case of milling this is z this is the horizontal milling and this is the z and this is the y; by the way in case of vertical milling this will be similar to this that is z, x and y.

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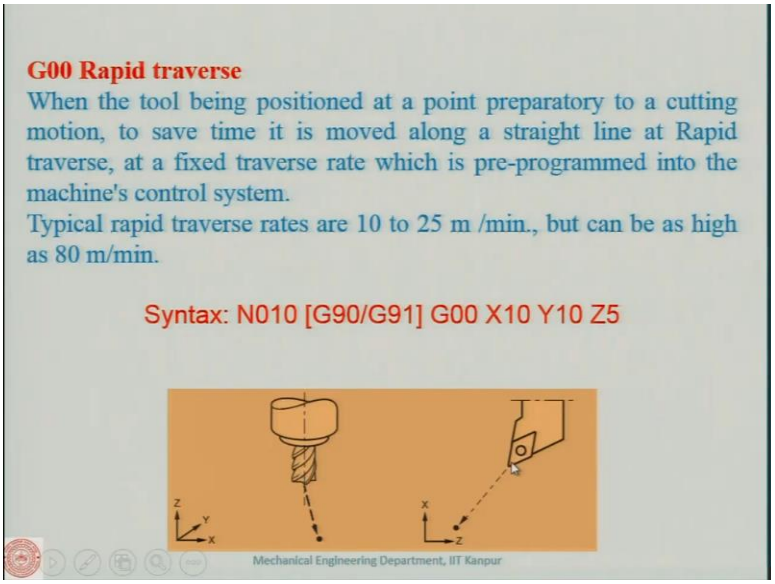

The rapid traverse is given here. There is a program for the rapid traverse and there is a code for the rapid traverse that means rapidly how to move the tool from the 0 position to the actual position that you want near the workpiece.

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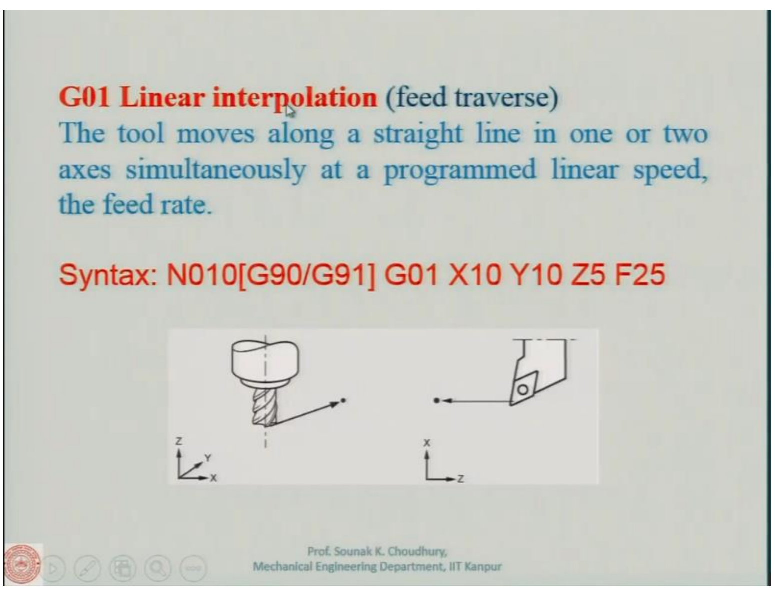

I have already explained to you what is linear interpolation so I am not really going into more details.

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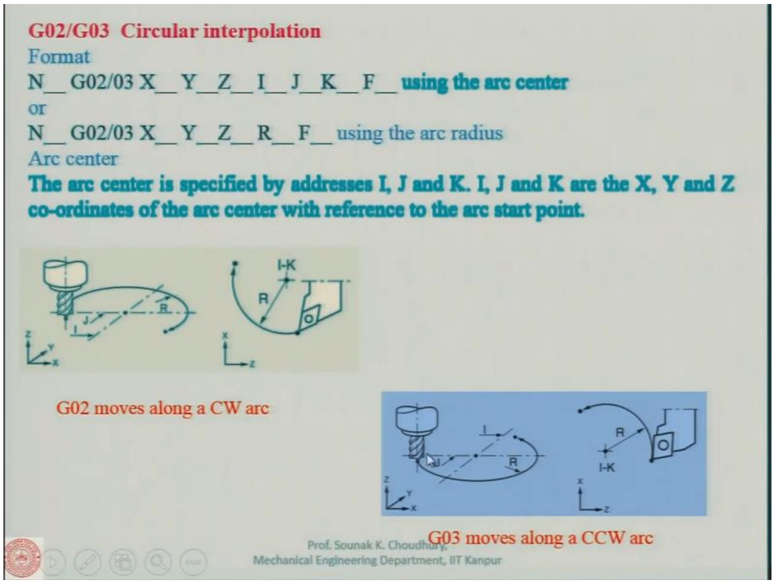

These are the circular interpolation that means either you can give it by the I, J, K that means these are the coordinates or you can give it by the radius as I said. So, circular interpolation means I already told you earlier also that this has to rotate in a circular way because you have to make part of the curve or a sector of the curve.

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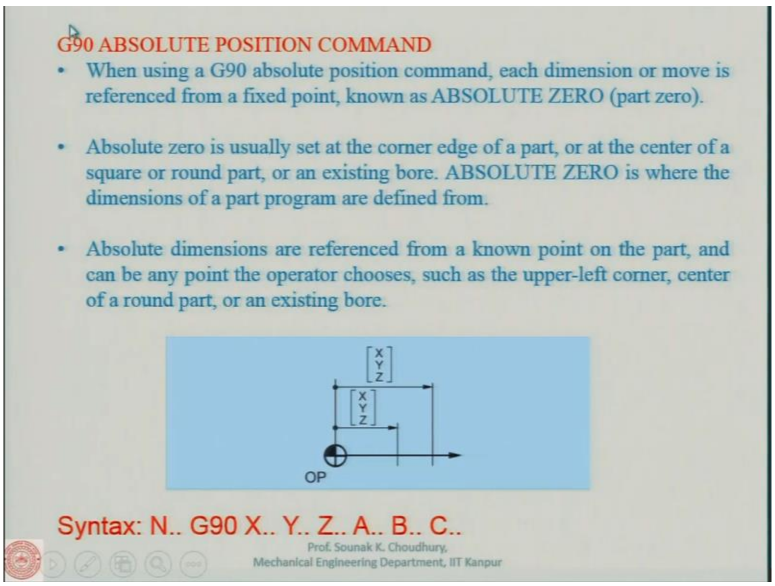

Absolute positioning: I already explained, the details are given in the slide. So, you have to say what is incremental what is absolute in the program, if it is absolute the code is G90 and so on.

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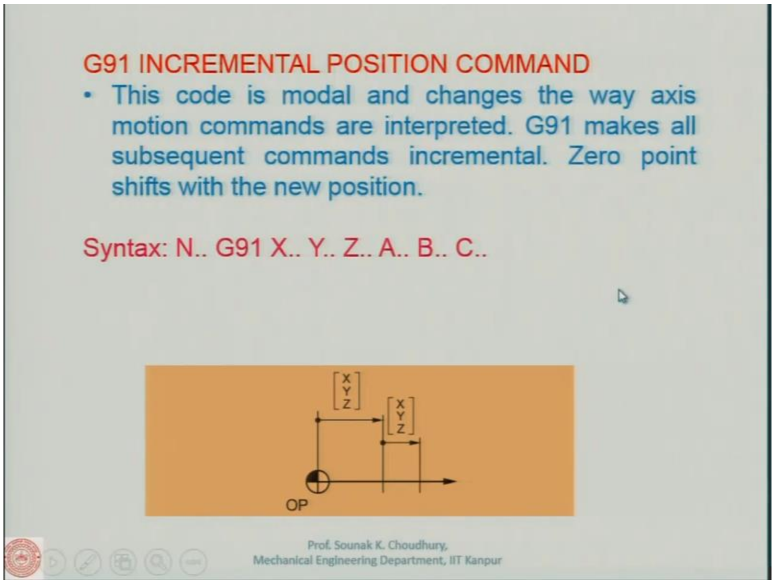

In brief what I want to say is that these are the easy commands which you can find out from the table and accordingly you can make a program depending on what is the type of the machining that you are going to make. I will give you examples in the lab as well as before the lab I will give you a power point presentation and there also I will show you how the part program is made in details.

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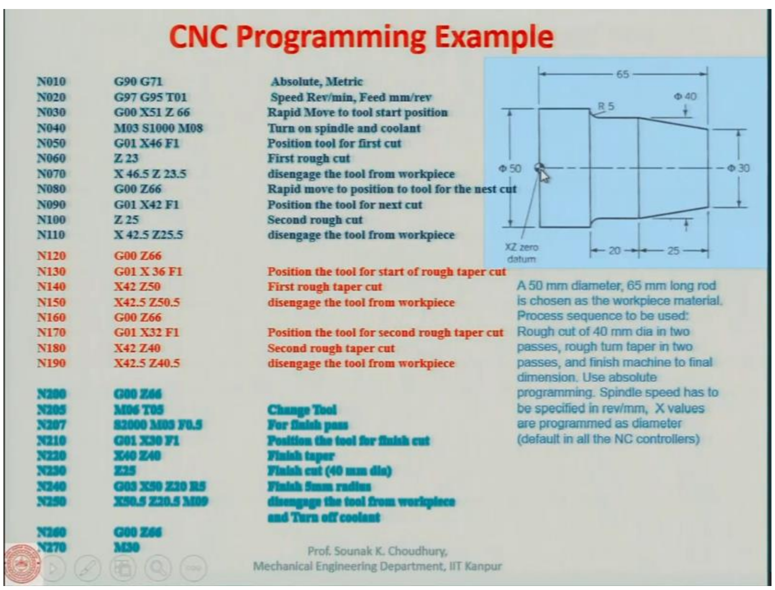

For example just quickly I will go through that. Let us say we have a part to be made here. So, these details I will tell you before the lab as I said. So, here this is the 0 you decide and all these dimensions which are given in the program will be given relative to this point. Each of the codes has a meaning, those details I will show you in the laboratory. That is all what I wanted to tell you about the computer numerical program and the details we will show you in the lab.

I will show you specially the programming part before we go to the lab. That is all for this session. We will start another topic in the next discussion session which will be metrology. Thank you for your attention.