Quality Design and Control
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Lecture – 52
Quality by Experimental Design (Contd.)

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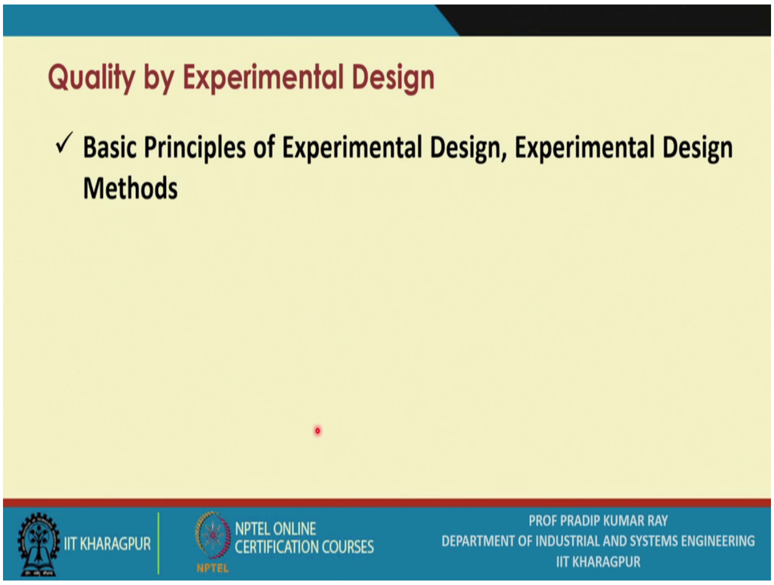

During this lecture session on quality by experimental design, the topic I am going to discuss that is basic principles of experimental design and experimental design methods.

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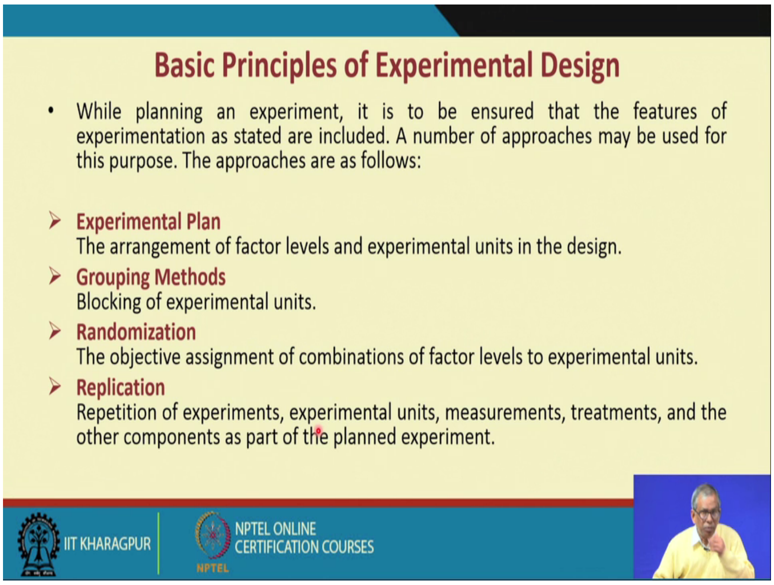

Now, while you carry out an experiment, for product development purpose, during offline quality control stage certain principles you have to follow ok. So, this is a technique, this is a tool you use and as you are aware and that any tool you propose or any tool you are going to use certain basic principles you have to follow.

So, related to experimental design what are those basic principles? So, I am going to identify first those principles, I am going to discuss those principles first before I discuss the experimental design methods. So, while planning an experiment. So, the during the planning stage ok, you need to identify the response variables you need to identify, you know the input variables and the parameters as well as you also must know must be aware of that what are the uncontrollable noise factors you may consider in experimentation.

So, all these the details you must document during the planning stage of an experiment the during this planning during the planning the stage, it is to be ensured that the features of experimentation as stated, already we have mentioned that what are the features of an experimentations like the simplicity like the degree of the belief ok. So, many other features we have considered in fact, in the previous lecture session.

Now, make sure that all these features are included in experimentation. Now for inclusion of all these features, a number of approaches may be used; what are these approaches? First one is you must have an experimental plan, what is an experimental plan? The arrangement of factor levels an experimental units in the design, is it ok, experimental design means the combination of say the input factors ok, one set of say the input factors is essentially a a an experimental unit and while you will consider one experimental unit related to a particular factor you select one particular level.

So, against a particular say the factor, how many levels you should consider. So, this is basically coming under experimental plan. So, all these details first you work out, then what is the grouping methods, I have already mentioned that what is a block. So, blocking of experimental units; that means, suppose you want to carry out the experiments under different conditions. So, the set of experimental units in a particular condition is it maybe refer to is one block, is it ok. So, there could be in a particular experiment you can have one block or there could be multiple say the blocks.

So, this is referred to as the blocking principle, randomization; the objective assignment of combinations of factor levels to experimental units; that means, suppose, you select all those combinations; that means, the experimental units, suppose there are expect three eight such experimental units. Now a you do experiment with one experimental unit now out of 8, how do you select a particular say experimental unit ok.

So, this selection should be based on the random assignment, is it ok. So, so the principle of randomization you have to follow, what is replication the replication means repetition of experiments; that means, on the that the same experimental unit ok, you carry out an experiment and not only once, but the several times, at a particular experimental unit for each experimental unit. So, this is basically now there are you know the certain conditions actually you know the effect of whether the variability which you get is due to some random causes or due to some assignable causes.

So, you must have clear idea if you find that this is due to some random causes; that means, in the selection of the factors is considered to be appropriate, but if you find that when you go for the application; that means, there will be the differences in the output response variable their values and if these differences are due to is significant and; obviously, you know maybe means certain very important input variables.

So, this sort of the you know the in depth understanding of the system or the or the in the understanding of the design you will have by applying the replication principles. So, what are these the four principles you have experimental plan grouping methods randomizations and the application; that means, repetition of experiments experimental units or the measurements like if you refer to say reproducibility repeatability in measurement systems you know the area or the while you while you determine the measurement systems capability, is it ok. So, the repetition of experimentation is there.

So, the treatment combinations and the other components as part of the planned experiment; so, sometimes you know this experimental unit, this is one experiences the experimental unit is referred to as the one treatment combination.

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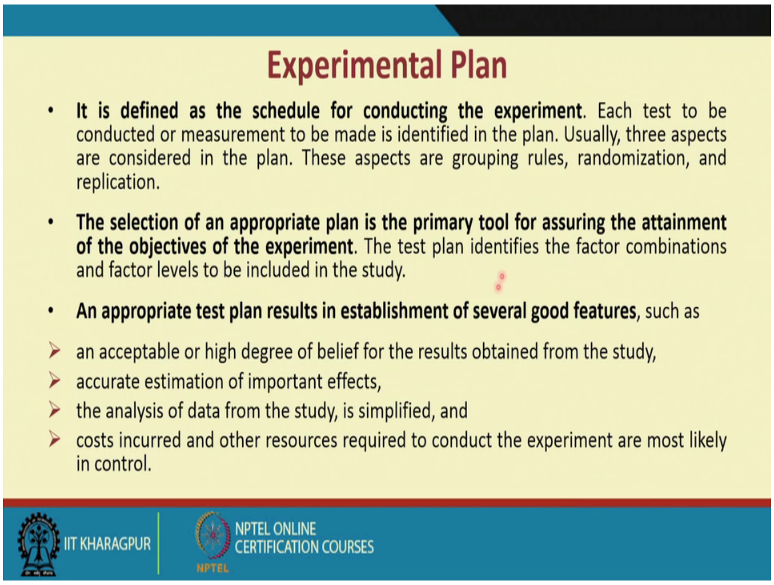

So, what is the experimental plan? Some details; we have you know written on this; it is defined as the schedule or the conducting the experiment. So, selection of an appropriate plan, it is the primary tool for assuring the attainment of the objectives of the experiment, is it ok. So, you must have an appropriate plan if the plan is say inappropriate; that means, you may get the results from the experimentation, but these results are not reliable

The test plan identifies the factor combinations and factor levels to be included in the study. So, if you have an appropriate test plan, how do you gain in several ways an acceptable or a high degree of belief for the results obtained from the study; that means, results are a very very reliable accurate estimation of important effects analysis of data from the study is simplified and costs incurred and other resources required to conduct the experience are most likely in control; that means, if the experimental the test plan is appropriate, it might mean that ah; that means, that the cost incurred for doing the experiment may be at the minimum level.

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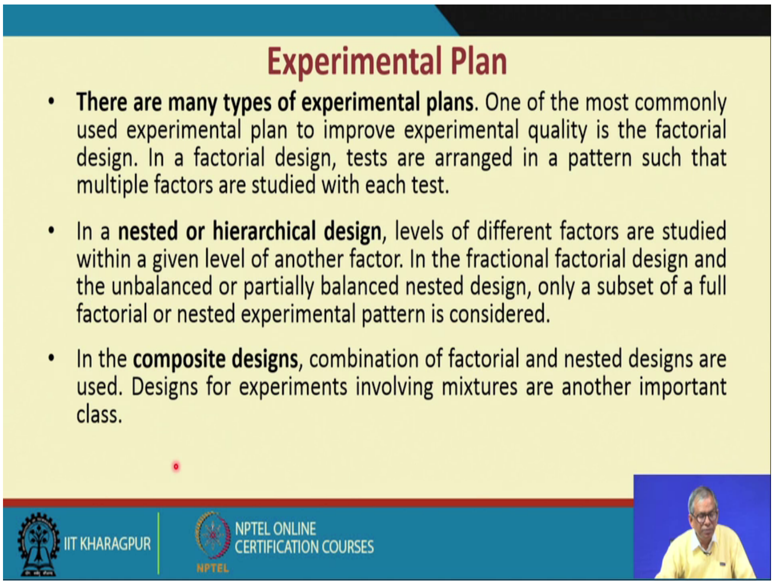

There are many types of experimental plans, right. So, we have already you know we will be discussing those experimental methods. So, each method when you try to follow you must have is a separate experimental plan; that means, experimental plan may vary from one particular method to another, there are two types of another designs we will be referring to one is the nested or hierarchical design ; that means, the levels of different factors are studied within a given level of another factor, is it ok, that is why it is refer to the hierarchical design in the fractional factorial design and the unbalanced or partially balanced nested design.

So, just right at this point in time, we have not yet discussed the details of the nested or hierarchical design just make a note later on if the time permits we will be referring to certain examples related to hierarchical design or the nested design.

In the composite designs combination of factorial and nested designs are used is it ok. So, the factorial design we will be discussing in detail. So, if you combine a; so, the factorial design with the nested design what you get what you get you get a composite design; that means, when your time depending on what type of product you are dealing with how complex the product design is. So, you have to select that whether it is a case of hierarchical design or it is a case of say the composite design ok.

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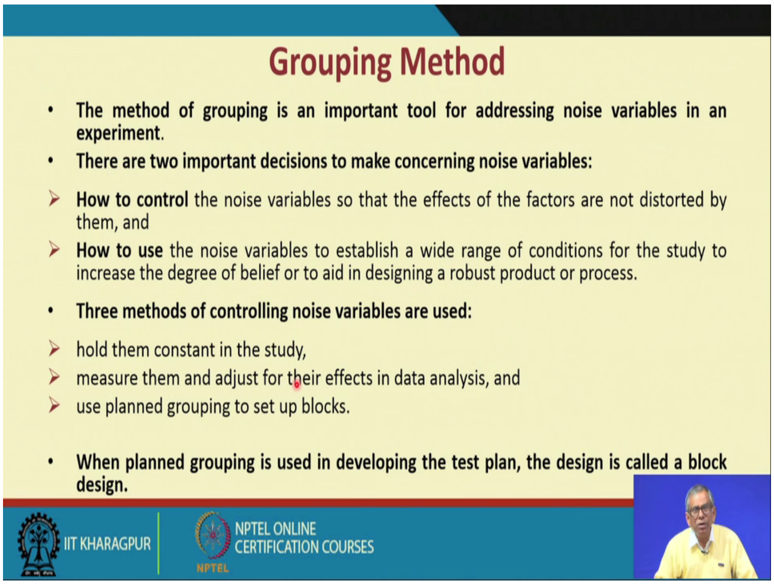

So, this point just you keep in mind, later on we may refer to these cases, what is the grouping method the method of grouping is an important tool for addressing noise variables in an experiment, is it ok, this is very important. In fact, like say you know like say the blocking principles you apply.

Now, there are two important decisions to make concerning noise variables, is it ok, first one is how to control the noise variables like that suppose the temperature is the noise variable. So, how to control them ok, while you carry out a particular experiment. So, you have to set the value of say the temperature at a particular level. So, how do you do that and how to use the noise variables to establish a wide range of conditions for the study to increase the degree of belief; that means, here is an experiment, I have conducted where you know I say that all sorts are possible the conditions I have explored.

So, I have considered; that means, whenever you say all possible types of combinations directly or indirectly you are referring to consideration of many types of uncontrollable noise factors, is it ok.

So, how to control the noise variables there are three methods what are those hold them constant in the study, if it is 35 degree Celsius. So, let it be; let it remain at 35 degree Celsius for all, you know the treatment combinations measure them and adjust for their effects in data analysis, is it ok. So, that adjustment is also possible if you have enough data use plan grouping to set up blocks; that means, you say that how chosen 3 levels of say the ambient temperature and with and this three are only 90 percent of the cases these three are the only possibilities.

So, accordingly, I will do the experiments under three specific conditions of the ambient temperature when planned grouping is used in developing the test plan; the design is called a block design I have been mentioning.

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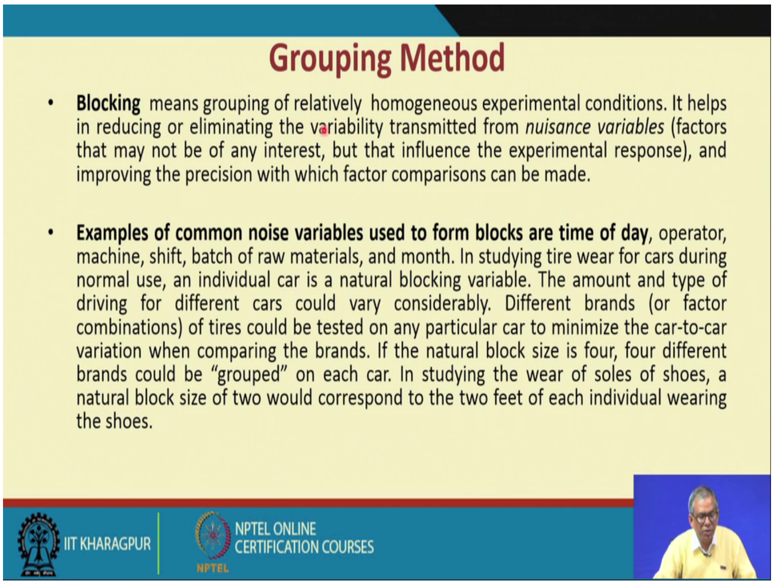

Now, the blocking means just one liners you I have I have written that is the blocking means grouping of relatively homogeneous experimental conditions, is it with respect to one particular condition and say all the you know the experimental units are at the same condition, it helps in reducing or eliminating the variability transmitted from nuisance variables factors that may not be of any interest or that influence the experimental response, if you cannot avoid it exists and improving the precision with which factor comparisons can be made. So, this is the basic the principles of blocking.

Now, there are several examples. So, these are examples of common noise variables used to form blocks are the time of day, that is one example ok, at I have already pointed out the operators, is it ok, if you change the operator; that means, it is a different block machine, if you change the machine ok, shift ok, if you shift you know say the morning shift to the afternoon shift ; that means, the morning shift data can be considered as one set of block and the afternoon shift data may be considered is another say another block.

Batch of raw materials and the month in studying the wear for cars during normal use an individual car is a natural blocking variable, is it [laugher] the amount and type of driving for different cars could vary considerably different brands or factor combinations of tires could be tested on any particular car to minimize the car to car variation when comparing the branch, is it ok.

So, I am just discussing a particular the situation and if the natural block size is 4; 4 different brands could be grouped on each car in studying the wear of soles of shoes a natural block size of two would corresponds to the 2 feet of each individual wearing the shoes ok.

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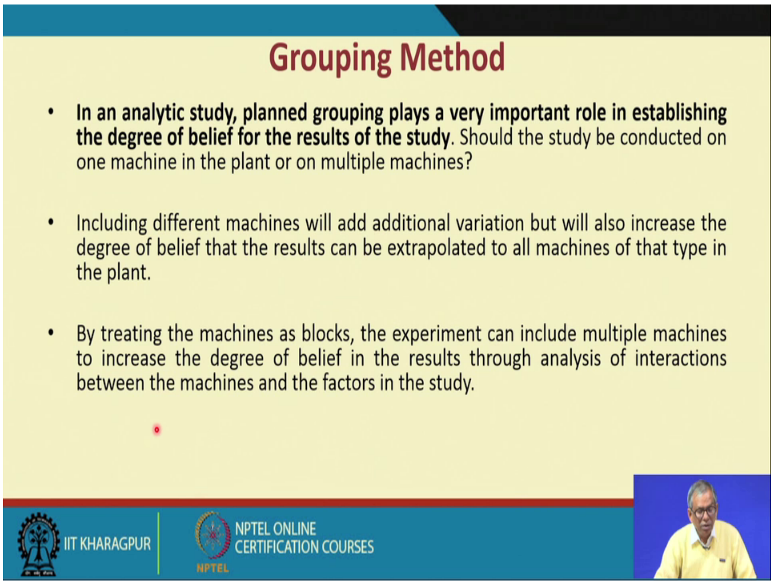

So, this is these are the ways you apply the grouping principles in an analytical study plan grouping plays a very important role in establishing the degree of belief for the results of the study ok. So, this you must keep in mind. So, the blocking principle is to be used almost in a all sorts of situations including different machines will add additional variation this is just an example, but we will also increase the degree of belief.

Suppose you want to study say the performance of a particular cnc machine. So, if you just restrict yourself to just one particular cnc machine; that means, whatever the results you you obtain those results are valid those results are applicable only for that particular machine. Now suppose you want to generalize right, the machining centers cnc type so;

obviously, what you need to do; that means, you need to consider in your experimentation not only one brand, but the several brand of the cnc machines ok.

So, by treating the machines as blocks the experiment can include multiple machines to increase the degree of belief in the results to analysis of interactions between the machines and the factors in the study ok.

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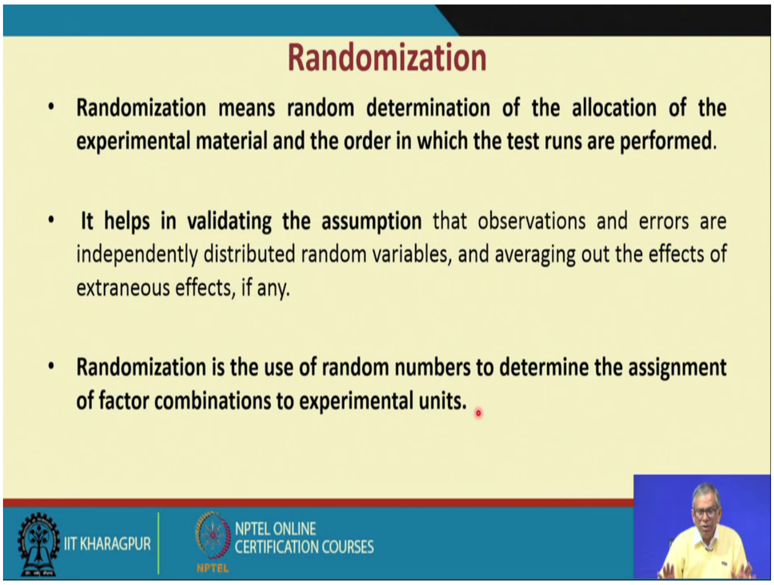

So, what is randomization means the random determination of the allocation of the experimental material and the order in which the test runs are performed I have already explained. In fact, as it helps in validating the assumptions any experimentation you do; that means, there is an assumption or the set of assumptions.

So, what we believe when that if the principal of random randomization is followed; that means, it helps in validating these assumptions randomization is used of is the use of random numbers to determine the assignment of factor combinations to experimental units. So, the selection of the factor combinations in a particular experimental unit is based on say randomization principle ok,

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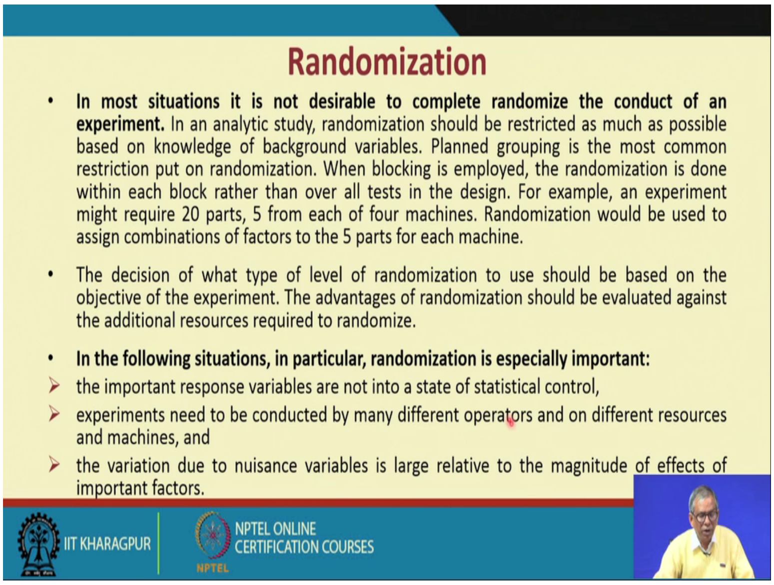

So, in more situation it is not desirable to complete randomization or to complete randomized the conduct of an experiment, it may not be feasible at all. So, here is one example. So, we please go through this particular example ok, it is not that say a 100 percent the randomization is possible or feasible in a given situation

Now, decision of what type of level of randomization to use should be based on the objective of the experiment, is it ok. So, this is the point to be noted and in the following situations three four situations I will explain where randomization is especially important. So, what are those important response variables are not increased state of statistical control ok. So, that is point number 1, point number 2 is experiments need to be conducted by many different operators are not different resources and machines.

So, that is point number 2 the variation due to nuisance variables is large relative to the magnitude of effects of the important factors, is it ok. So, here; obviously, you know you need to consider the randomization principles.

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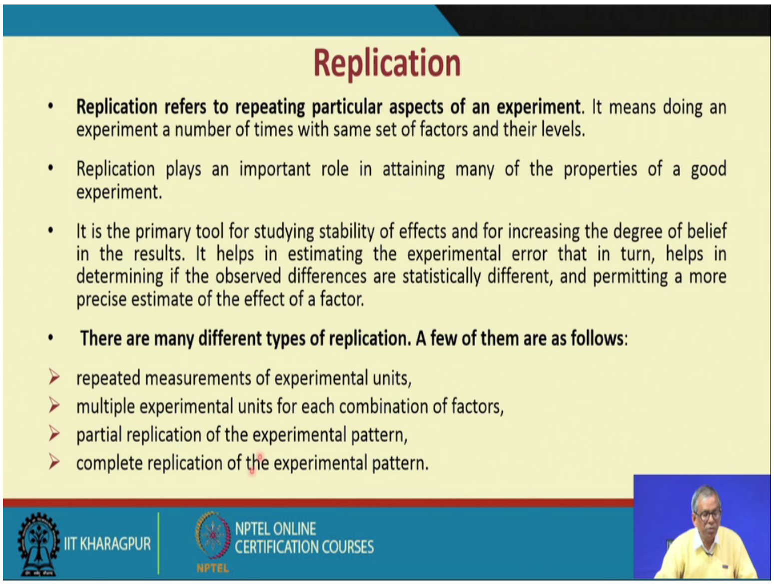

Now, replication already you have defined; that means, you it refers to repeating particular aspects of an experiment replication plays an important role in attaining many of the properties of a good experiment. So, everywhere almost in all cases we go for a say replication and it is a primary tool for studying stability of effects and for increasing the degree of belief in the results.

So, there are many different types of replication some of them are like this like repeated measurements of the experimental units, is it ok, like we do when we to study the measurement error multiple experimental units for each combination of factors. So, this we have already mention partial replication of the experimental pattern partial replication and complete replication of the experimental pattern ok.

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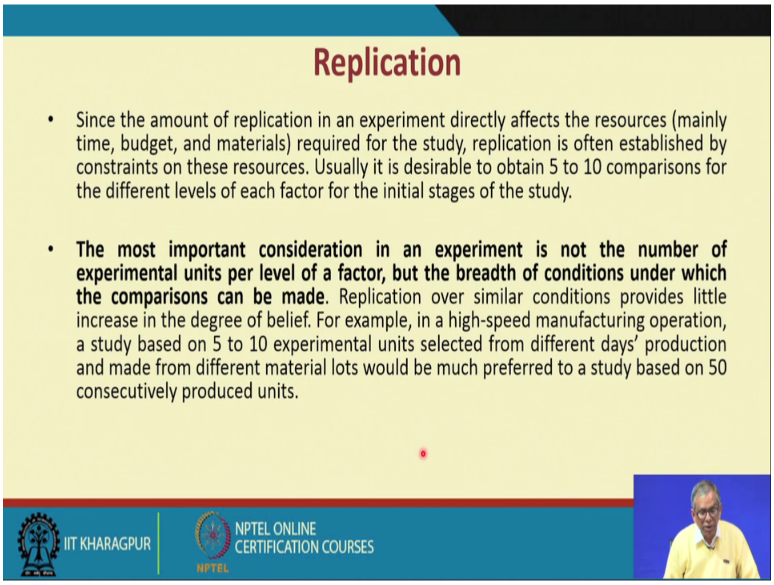

So, these are the cases where you know the different types of replications you may oft for the most important consideration in an experiment is more the number of experimental units per level of a factor, but the breadth of conditions under which the comparisons can be made replication over similar conditions provides little increase in the degree of belief.

So, you need to change the condition in many a time for example, in a high speed manufacturing operation, a study based on 5 to 10 experimental units selected from different base production and made from different materials lots would be much preferred to a study based on fifty consecutively produced units is it. So, I think the point is made very very clear ok.

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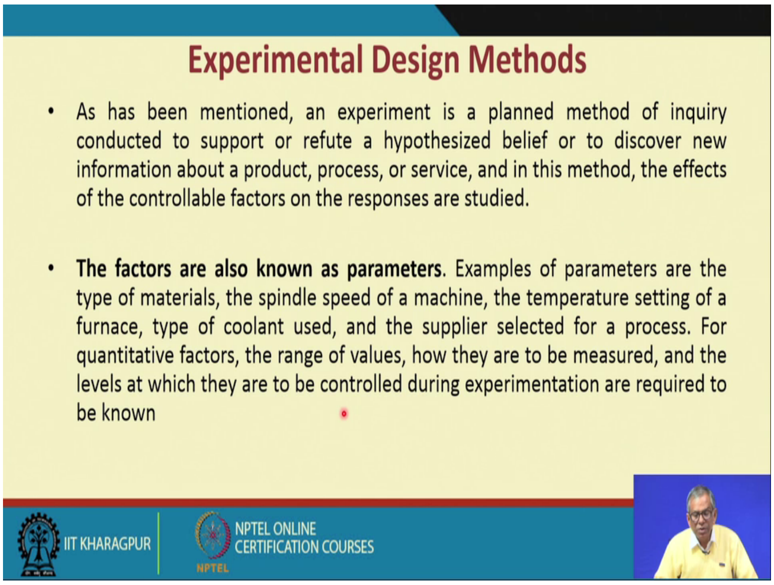

So, replication is an important principle now what are the experimental design methods, there are many as I have been telling you and an experiment is a plan method of inquiry conducted to support or refute a hypothesized belief.

That means, whenever you carry out an experiment what is your background knowledge the background knowledge is you know the inferential statistics; that means, the hypothesis testing, you must have a the thorough knowledge in hypothesis testing. So, through an experiment what do you do you try to discover new information about a product or the process or the service? So, that is why during the product development stage particularly at the prototyping stage use of experimentation is very very common, is it ok.

Now, this the factors which you have mentioned like these are also referred to is the parameters and sometimes these factors are also referred to as the input variables. So, examples of parameters like say in order a for you know for in the for making the process in you know the controllable or say controlled; what you try to do you apply you know the control charts; that means, make sure that the process using statistical control and for that one exercise you carry out that is the process settings and we refer to the process parameters.

So, what are those examples of the process parameters? So, like say the type of material the spindle speed of a machine the temperature setting of a furnace type of coolant used and the supplier selected for the process. So, there are many examples for quantitative factors the range of values, how they are to be measured ok, like say if you say the spindle speed 500 rpm, how do you measure it?

Then the levels at which they are to be controlled; that means, whether you should control at 500 rpm or for 450 or 650; So, this should be specified and then only you can do experiments for at different levels of the factors.

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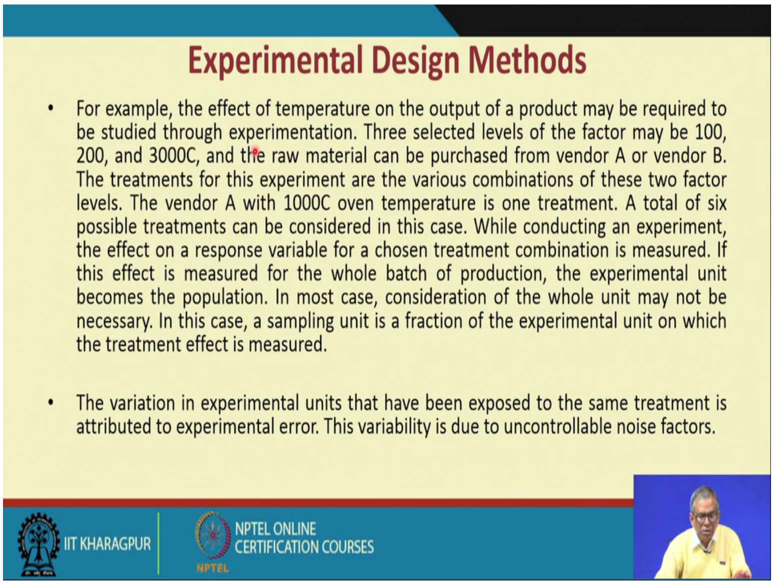

So, this is just I will read this example the effect of temperature on the output of a product may be required to be studied through experimentation three selected levels of the factor may be 100; that means, the temperature is the factor and you have 3 levels; 100, 200 and 3000 degree Celsius; 300 degrees Celsius and the raw material can be purchased from vendor A or vendor B.

The treatments for this experiment are the various combinations of these two factor levels; the vendor A with 1000 degree Celsius, this is one; 1000, 2000 and 3000 degree Celsius. So, the vendor A with 1000 degree Celsius over oven temperature is one treatment a total of 6 possible treatments can be considered in this case ; that means, ah; obviously, you know 3 3 levels, you have and you have two vendors, is it ok.

So, there must be 6 combinations while conducting an experiment the effect of a response on a response variable for a chosen treatment combination is measured. If this effect is measured for the whole batch of production the experimental unit becomes the population, is it ok; that means, you have considered all sorts of combinations in most case consideration of the whole unit may not be necessary, is it sometimes no the results are repetitive.

So, when you study a particular system; what they say that the study for the entire population may not be necessary. So, in this case a sampling unit you select and what is the something unit a sampling unit is a fraction of the experimental unit on which the treatment effect is measured it is clear.

So, the variation in experimental units that have been exposed to the same treatment is attributed to an experiment error; that means, same treatment the combination you have considered and you go for application, what do you get that the same the value in the in a particular response variable we may not get, is it ok.

So, this is refer to may be referred to as the experimental error. So, you have come across this particular term called experimental error. So, in any the experiment you conduct you must know that what is the level of the experimental error whether these experimental error is significant or not, is it. So, this variability is due to uncontrollable noise factors, if you conclude like this you say yes error is acceptable, but if you cannot control like this; that means, you have to improve the design methods ok.

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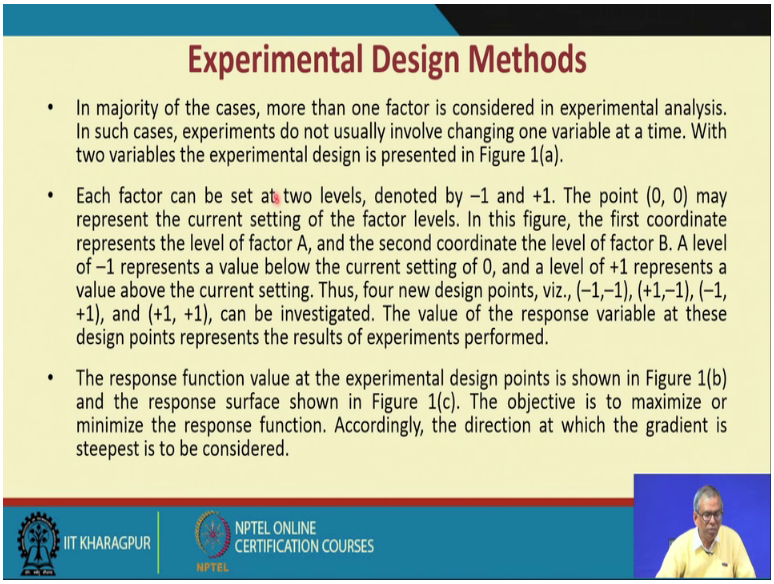

So, in majority of the cases more than one factor is considered in experimental analysis in such cases experiments do not usually involve changing one variable at a time with two variables the experimental design is presented one figure is there. So, what do you do each factor can be set at two levels denoted by minus 1 and plus 1 the point 0, 0 may represent the current setting of the factor levels.

So, in this figure the first coordinate represents the level of factor A and the second coordinate the level of factor B I will show you the figures immediately first you go through this all these details a level of minus 1 represents the value below the current setting of 0 and a level of plus 1 represents a value above the current setting this is just an example.

Thus for 4 new design points minus 1 minus 1 plus 1 minus 1 minus 1 plus 1 and plus 1 plus 1. So, these are the possible the combinations you have. So, for each combination you have to carry out an experiment the value of the response variable at these design points represents the results of the experiments performed. So, the response function value at the experimental design points is shown in the next figure and the response surface shown in this.

The objective is to maximize or minimize the response function that is most important; that means, how do you the measure say the performance of the product; obviously, it is represented by the response function. So, you must be able to create this response function accordingly the direction at which the gradient is steepest is to be considered ok.

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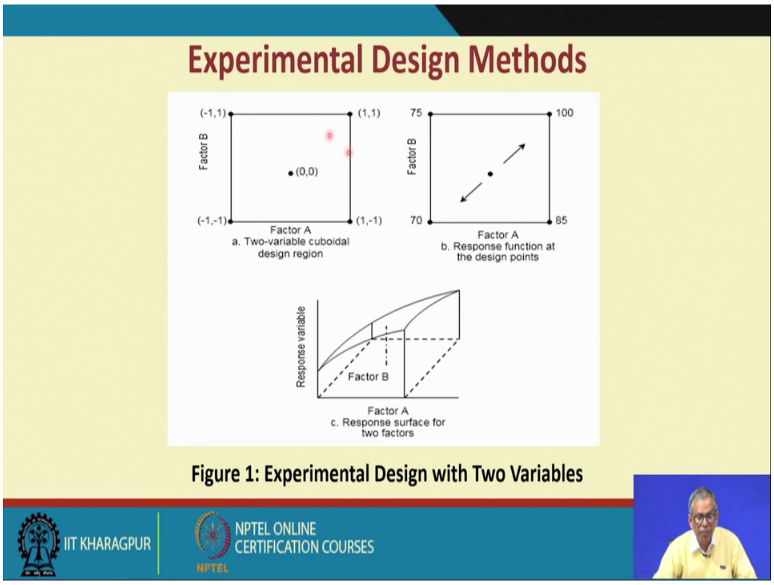

So, this is one case; that means, this is the present level; so, these are the two factors you have considered factor A and factor B. So, these are the four combinations you have and against each combination what is the response value, is it ok, like 70-75, say 185, then what do you do? You consider the factor A and the factor B with respect to factor B response surface for the two factors you considered. So, this is the response surface ok.

So, there is a methodology called response surface methodology normally once the experimentation is over the next topic we discuss; that is the response surface methodology the students who are interested in studying the response surface methodology any textbooks on a statistical design of experiments, we will find there are few chapters. So, there is one chapter towards the end that deals with these response surface methodology

So, please refer to this one, is it ok. So, now, we have we have just discuss the basics and how you know the responses are related to means if you have so many you know kinds of responses suppose you have through experimentation. So, you have come to know so; obviously, you know you can defined the response surface, is it. So, this is the experimental basic experimental design methods.

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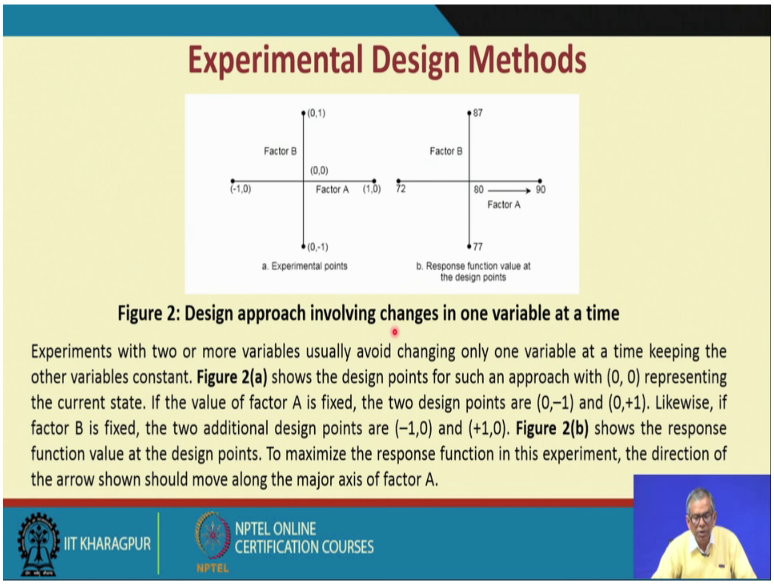

And then what do you try to do these are the experimental points you have and the response function value at the design points, is it ok. So, this is another way you can represent it already we have pointed out this one. So, what do you try to do; that means, design approach involving changes in one variable at a time, is it ok. So, one variable at a time the results are not that conclusive and not that reliable.

So, this figure shows the response function value at the design points to maximize the response function in this experiment the direction of arrow shown should move along the major axis of the factor A; that means, this is if you want to improve the performance what you try to do; that means, the factor A value should be around say increasing value; that means, from this direction you have to move, is it ok.

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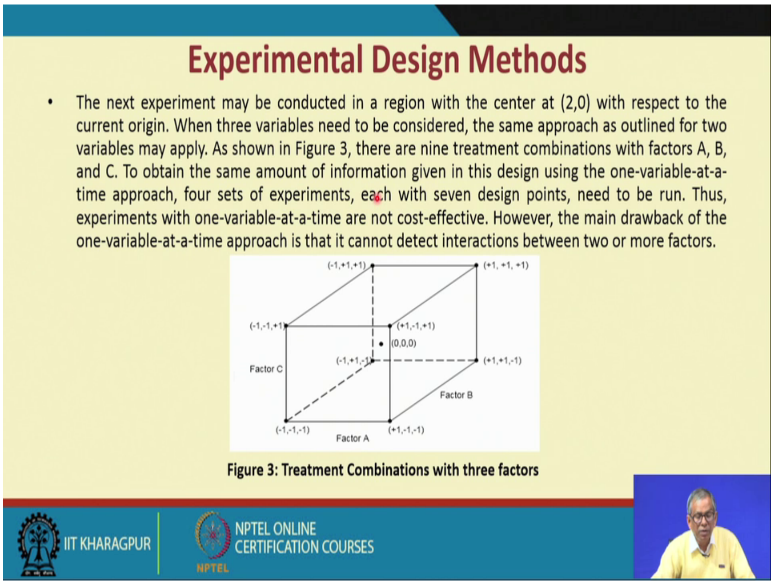

So, this way you can interpret and this is the other dimensions you have added the treatment combinations with three factors previously we consider two factors. Now you have added the third factor that is factor C. So, factor A, factor B, factor C. So, how many combinations you have 1, 2, 3, 4, 5, 6, 7, 8. So, 8 combinations we have. So, there are nine treatment combinations with factors A, B and C, is it ok.

So, here plus 1 combination is here 0 ok; So, when three variables need to be considered the same approaches outline for two variables may apply ok. So, there are nine treatment combinations and to obtain the same amount of information given in this design using one variable at a time approach four sets of experiments each with seven design points need to be done ok.

So, this is this is the way you define the treatment conditions when this is the low level minus means low and plus means high level, is it ok, you may have a specific values.

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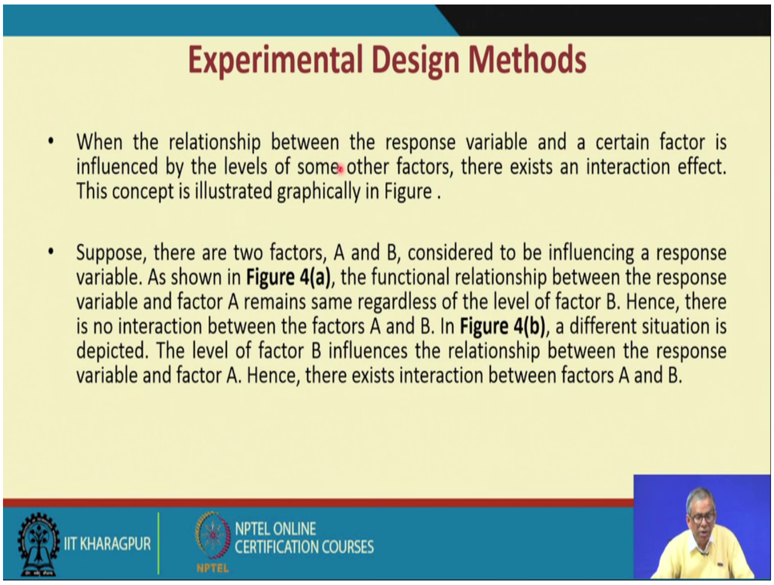

So, when the relationship between the response variable and certain factor is influenced by the levels of some other factors there exist an interaction effect this concept is illustrated graphically in figure.

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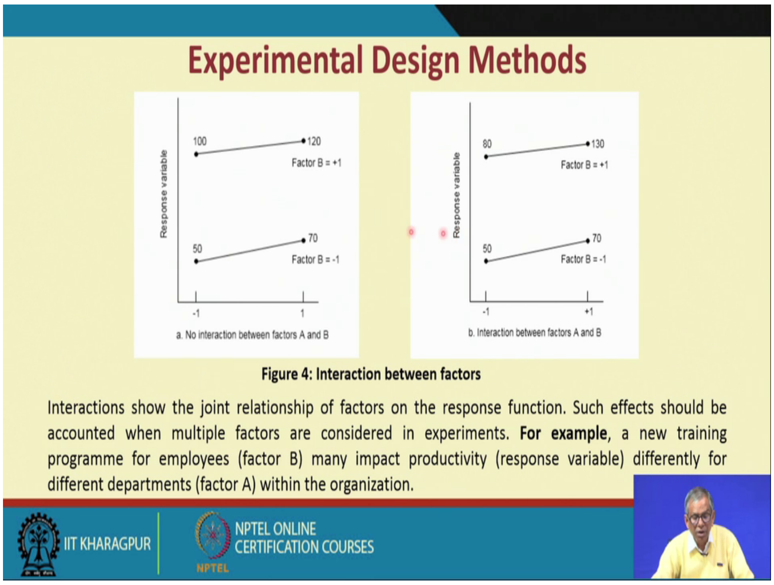

So, here this is the way; that means, here the interaction between factors how do you come to know; that means, here this is the minus level plus level factor B is at the low level factor B at the high level. So, what you find that is this 50, this become 70, this becomes 100, this is 120; that means, the difference is just 20 units.

So, you may conclude that there is no interaction effect whereas, here what do you find that between you considered between factor A and factor B. So, the factors A is at the low level as well as the high level; when it is at the low level ok.

So, then you consider this value that is the 50 for factor B that is the low level and factor B is the high level. Now at these conditions what do you find this is 50 and this is 80 here at the high level of A and what do you find this is at 70. This is at 130; that means, here the difference is 50, here the difference is 20, is it.

So, what do you consider what do you conclude that there is an interaction between factors A and B; that means, while you explain the response variable you should consider not only the main effect that is factor A as well as the factor B will also must consider the interaction effect given by A in to B, is it.

So, such you know the plotting will help you in understand that whether between the factors there is an interaction or there is no interaction.

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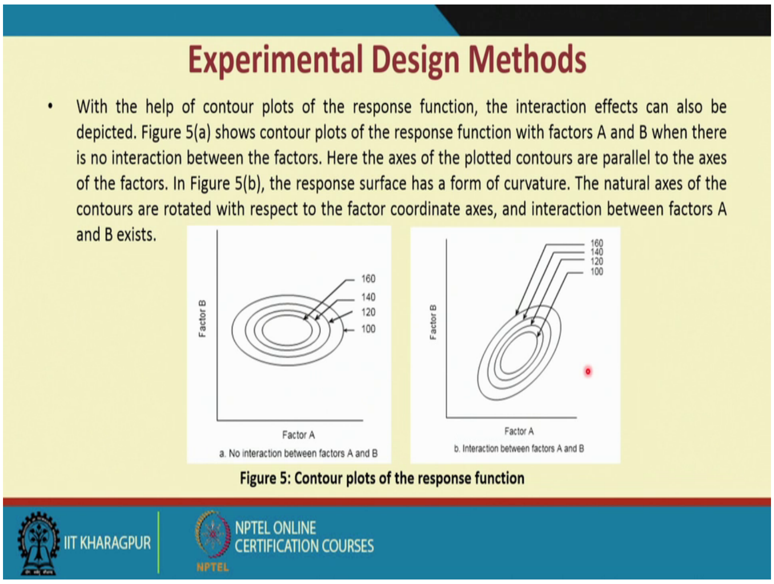

So, the other details you will go through. In fact, like say contour plots and all those. So, please go through them, this is a contour plot; that means, no interaction between factors A and B. So, this is you know the same level you have whereas, if you have this sort of contour plot, is it ok, immediately we conclude that there is an interaction effect; that means, factor A is influencing factor B and this influence is affecting the final outcome that is given by the contour, is it ok.

So, I conclude it here and we will we will move to the third topic in our next lecture session.