Quality Control and Improvement with MINITAB
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Lecture - 40
Taguchi Method

Hello and welcome to session 40 on our course on Quality Control and Improvement with MINITAB. And, this is the last session that we are delivering on a specific topic which is a very interesting topic which is known as Taguchi's method, and how we can use MINITAB interface to do experimentation using Taguchi's method like that. I am Professor Indrajit Mukherjee from Shailesh J. Mehta School of Management, IIT, Bombay.

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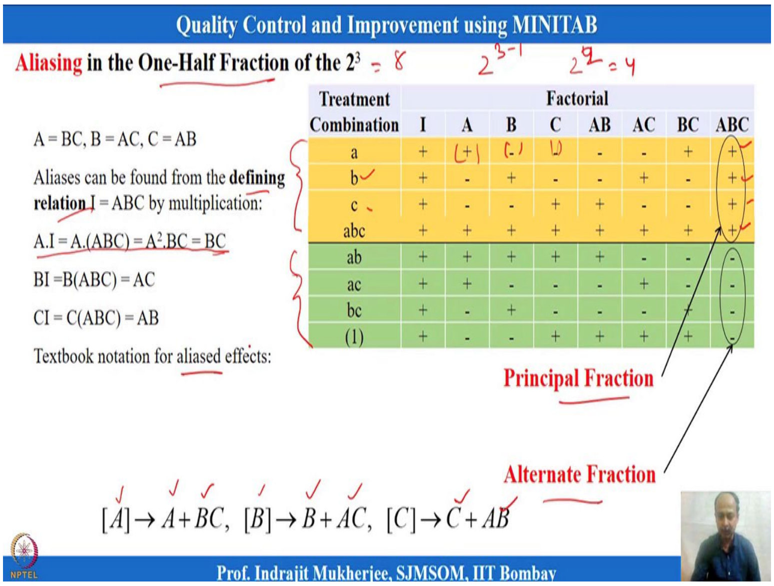

So, in the previous session what we have done is that we have tried to explain a fraction of factorial design, and this concept is only extended in Taguchi's design. So, let me just recap the main idea of the fraction of factorial design. So, when we are doing running factorial design what happens is that as the number of factors increases in the experimentation, the number of experimentation also increases like that.

And, initially what we do is that before final experimentation what we do is that, we try to screen the factors we are not interested into interaction effects and higher-order interactions like that we do not want to study all interactions like that. So, and sparsity of effect principle also says that higher-order interactions do not dominate the systems like that it is main effects are maybe lower-order interactions that are important.

So, using that principle what the experimental does is that they want to screen factors for that they will run not full factorial may be partial of the factorial design they will run. So, over here this is a 2 cube. So, 8 experimental run is required. So, I do not want to spend so much of money in full trials because full trial when you do then all interaction effects you can calculate, but I am not interested into that.

I may be interested in which factor is primarily dominating over here and which effect is very much significant. So, those factors I want to screen. So, that is known as screening experimentation. So, then what will I do is that I will run half of the fraction over here and this is known as one-half fraction that we are running and symbolically we run we say that 2 cubes minus 1 and basically we will run 4 experimentation over here 2 square equals to 4 trials we will run over here ok.

Now, this is one half of the full factorial (Refer Slide Time: 00:42), this is the other half of the full factorial over here; one is known as principle fraction, one is known as alternate fraction over here. Principle fraction is that fraction where if you multiply the sign convention of A B and C, what will happen is that you will get a positive sign over here.

So, similarly when you run B at high level and all other at low level then also sign convention will be positive; when you run C then it will be positive and when you run ABC at high level so, it will be positive like that. So, this is known as defining relationship to define the fractions and you can run one of the fractions principle fraction or alternate fraction.

But, when you running a fraction of the full factorial design what will happen is that some of the factor's interactions will be confounded with each other; that means, they are not separable like that. So, in that case, what happens that when you are estimating the effect of A, actually you are estimating the effects of A plus BC . When you are estimating B, it is B plus AC like that. So, that can be calculated based on this formulation what I have shown.

So, in this case, A multiplied by ABC you have to do which is the defining relationship. So, A square I have multiplied by BC. So, this will be treated as 1. So, in this case BC will remain over here. So, in this case and this by this formulation what we are getting over here we can get which is aliased with which one over here.

So, C is aliased with AB over here. So, this is aliased effects like that. So, this can be seen in any books specific you can see Montgomery’s books on Design and analysis of experiment experiments ok. So, this is a fractional factorial design and we will run one of the fractions like that.

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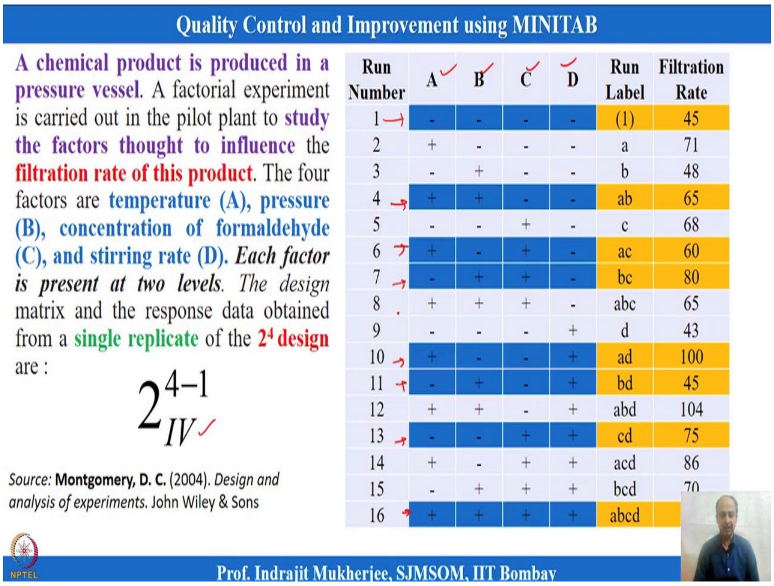

Like one of the examples that we have taken there are four factors over here 1, 2, 3, 4, and only these trials are run because these are the principle fractions this is coming with principle fraction over here. And, when you run the fraction and then we can find out which effect is important which is not and this is basically one half of the 2 to the power 4 fractions.

So, over here and it will have a resolution of 4 over here. So, 2_{IV}^{4-1} design over here and half of the fraction I am running and in this case, we cannot estimate all interaction effects like that, but we can find out which factor is important which is not.

So, resolution IV design and we have also mentioned that as higher the resolution better we can estimate the main effects and lower order interactions like that ok. So, we will always go for higher resolution fractional factorial design most of the time.

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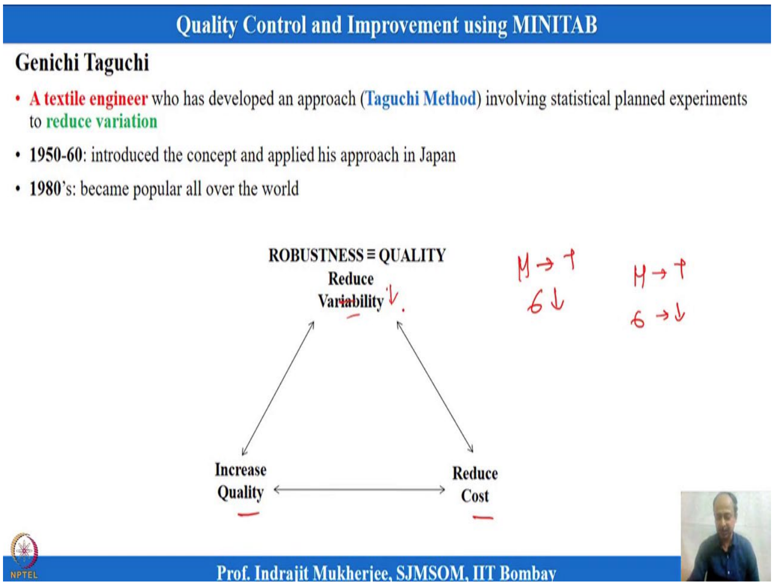

And, this concept of fractional factorial design is used in Taguchi's method. So, we will start with Taguchi's design of experiments. So, Taguchi was a textile engineer, and around 1950 to 60, he introduced the concept of this Taguchi method and which was very popular in Japan at the time point.

And, in 1980, people came to know that this is a well-known technique which can be used in system optimization and process optimization and also in while we are making the designs. So, when we are making the product design also this can be adopted over here.

So, Taguchi's talked about emphasized on reduction of variability. So, earlier experimentation whatever we have discussed, design of experimentation only talks about mean should hit the target values like that, we are trying to optimize and bring the means towards population, mean towards the target values over here, but Taguchi emphasized in reduction of variability over here.

So, he developed a method in which he claimed that the mean of the process will be on target and sigma will be reduced like that and both are done simultaneously. So, simultaneously reduction of variability and bringing the mean to the target with one experimentation we can finish this and we can get a robust setting, which is robust to the effect of noise variables also.

So, introduce another important concept which is known as experimentation with noise ,ok. So, Taguchi says, for improvement of quality, cost of reduction and reduction of variability is the key factor over here and noise interaction between control factors and noise is also one of the important concepts he emphasized, ok.

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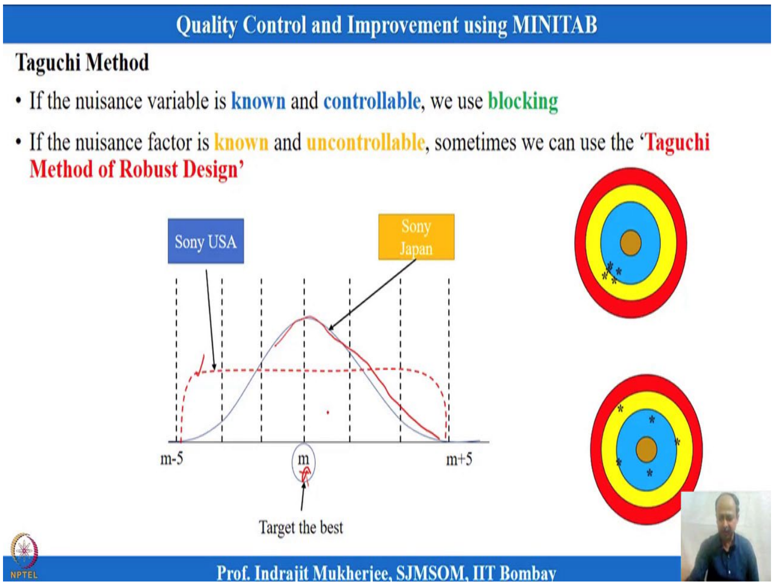

So, then one earlier also we have mentioned that Sony US was manufacturing televisions and also Sony Japan was manufacturing. The variability of Sony Japan was much less as compared because the graph you can see over here is having less variability as compared to the graph over here and they are both accurate and precise.

So, this "m" is the target value that is defined over here and we also mentioned in Cpk analysis that both target and variability is important and in that case more and more it deviates from the target, variability will increase like that and customer does not like that. So, anyway, Sony Japan TV was much popular as compared to when we are when people tend to buy more Sony Japan as compared to Sony US, ok.

And, this is related to both accuracy and precision because when Sony Japan is manufacturing they are not only dedicating to the target values or also the variability they want to reduce on the target values ok.

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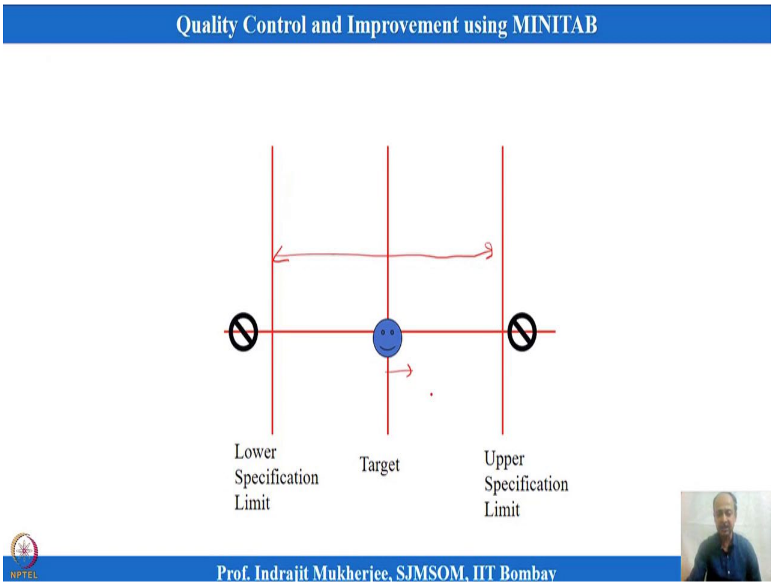

So, this concept of goal post mentality which was earlier that whenever you are within the specification and everything is fine, was the assumption when we have monopoly markets like that. But, later on, this concept changed and Taguchi changed this concept and told that this is not what is actually perceived by the customer.

Customers get dissatisfied when you move away from the target values. Whenever you move away from the target values, basically customers are getting dissatisfied like that.

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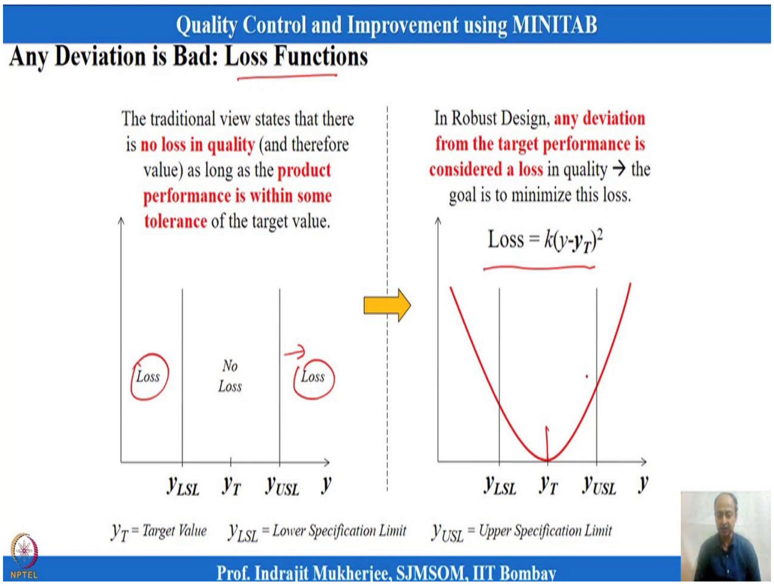

So, Taguchi introduced a loss function approach over here. So, he mentioned that any deviation is bad over here. So, he defined the loss functions. So, earlier it was that loss is only when you go outside the specification. This is the loss and this will be a loss when we go outside the specification.

But, Taguchi mentioned that no, it is a quadratic loss function that he mentioned over here and whenever you deviate from the target values over here. And, then in that case what happens is that there is always a loss associated with that ok. So, he developed a loss function which is a quadratic loss function which is debatable, but still, people are using this one concept loss function concept like that and using Taguchi's method to optimize the system like that ok.

So, this is the loss function approach when you deviate from the target value you incorporate a loss and that magnifies as you move towards the specification and when you are outside the specification it is the maximum that you are encountering. So, that the losses will be much more as compared to when you are near the target values like that ok.

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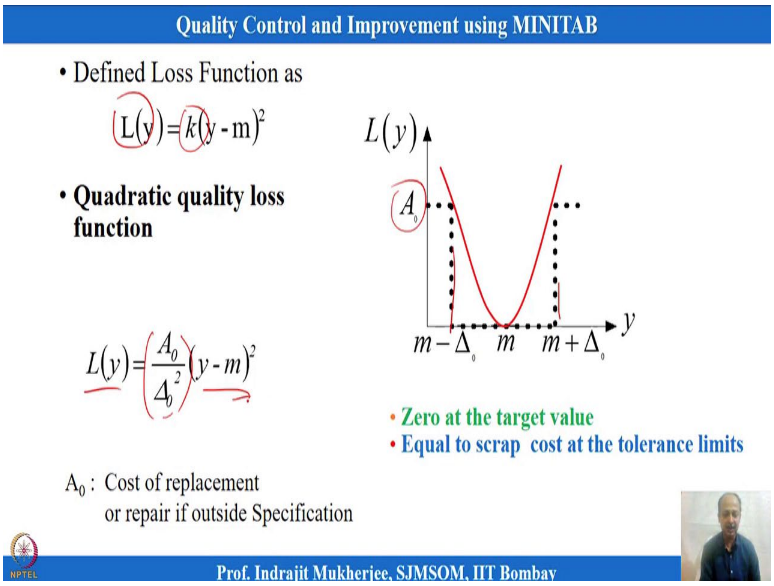

So, this loss function definition leads to a concept of expected loss like that. So, in this case and over here loss can be calculated. If I can calculate the "k", I can also calculate the loss. So, k can be calculated over here based on this formulation when you are deviating from target.

So, the cost associated of EPR when you are going outside the specification is given over here and $(y-m)^2$ is the deviation that is happening and Δ_0 is the tolerance that is given. So, a loss can be defined like above formulation over here. So, this is the loss function.

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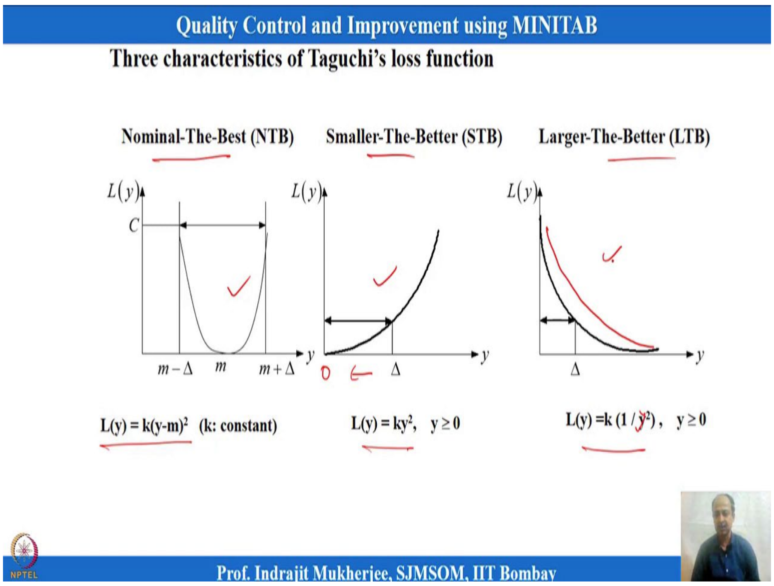

And, Taguchi developed three different kinds of loss function which. So, engineering specification can be he mentioned that there can be three types of specification one is nominal the best what we have taken earlier also and smaller the better or larger the better when we are doing about multiple response optimization we have discussed about this. So, Taguchi developed a loss function for each of these.

So, one of the loss functions is given over here as nominal-the-best, and the loss function is given over smaller-the-better and this is the larger-the-better. So, the more and more smaller the better means if you are if you are near if you are moving to the 0 conditions over here loss will be less like that. So, loss will be less over here and if it is maximization problem it will be reverse function that you are seeing over here.

So, this will be $(\frac{1}{y^2})$ like that. So, based on the characteristic value which is y over here. CTQ values what happens is that loss if you are deviating from the values, loss will be more like that. So, three types of loss function Taguchi developed over here and this loss function will be used to define another important characteristic, which is known as signal to noise ratio.

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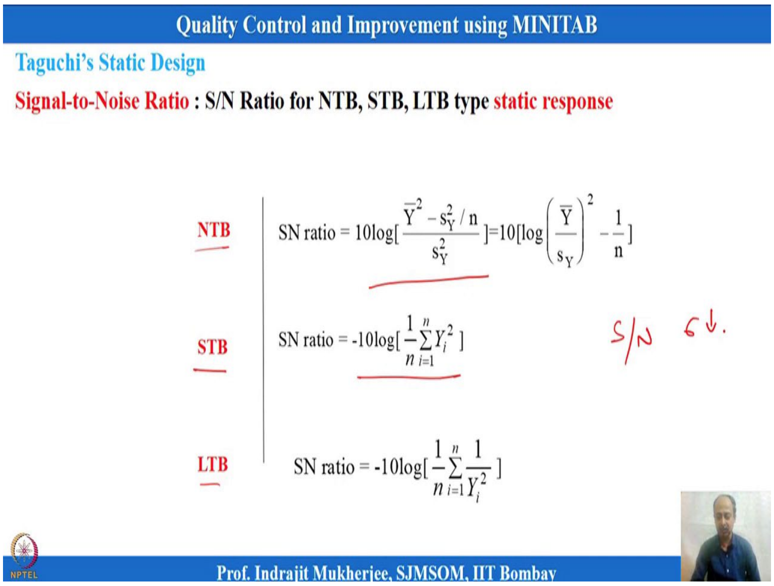

And, based on this Taguchi defined a signal-to-noise ratio. So, if the loss is less, then signal to noise ratio is maximum like that. So, you minimize the loss and you other way you maximize the signal-to-noise ratio. So, in this case what happens is the signal to noise ratio definition is given. So, nominal-the-best he has defined formulation for signal- to-noise ratio for smaller the better he has defined the signal to noise ratio which is minus of 10 log what you are seeing over here.

So, when loss reduces signal-to-noise ratio becomes higher the value of the signal-to-noise ratio increases basically, ok, similarly larger-the-better also. So, everywhere I need to maximize the signal to noise ratio that is the objective of Taguchi's experimentation and if he minimize if he maximize the signal to noise ratio basically he will reduce the sigma or variability of the process variability of the process basically.

So, one of the measure that is used in Taguchi's reduction of variability principle is that I use signal to noise ratio to define the levels of the setting conditions. So, what should be the level of the variables controlled variables like that based on signal to noise ratio ok.

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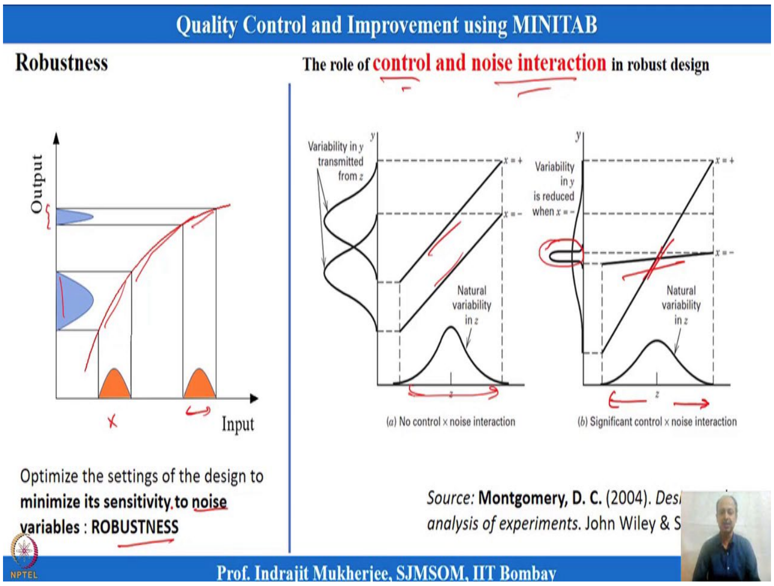

And, Taguchi considered also an important aspects that interaction between noise and control factors when there is a interaction between this one what happens is that there is a region over here where the variability when I change the control factors over here. So, in this case when noise variables are intentionally changed.

So, in an in any experimentation, you will find that we are changing the control variables, but here what Taguchi's experimentation we will change the noise variable also intentionally this is noise variable is known and uncontrollable, but for the sake of experimentation what we will do is that we will intentionally introduce noise and find out the setting of the X variables or control variables where the effect of noise is insensitive basically.

So, in this case what happens is that when you see that in this when Z is varied, in that case it is not. So, if there is no interaction in that case and here there is an interaction what you are seeing over here. So, this is crossing the graphs are crossing each other and here it is parallel. So, you can imagine that if there is no interaction I cannot reduce the variability.

Whenever there is an interaction that is happening between control and noise variable, then there is a possibility of reduction of variations over here, ok and Taguchi wanted to explore the non-linear region over here in experimentation. So, if this is the X condition over here and here it is a linear region, so, variability will be high; if I go to a non-linear region over here what happens is that variability goes down. This is also another important concept.

So, I want to minimize the sensitivity of noise and this is what is known as the robustness idea of Taguchi and setting condition is robust when you even if the noise parameter or noise variables changes conditions. So, in that case, it has the minimum effect like that.

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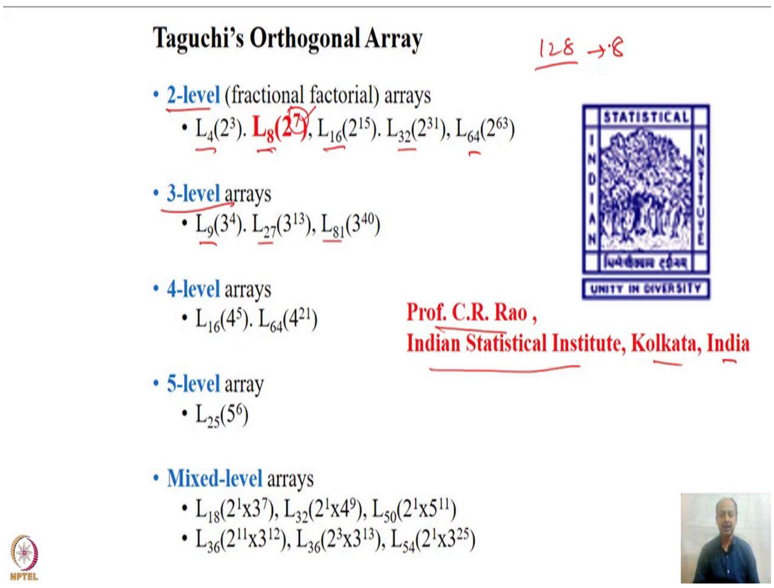

So, experimentation with control variable and noise variables like that. So, here Taguchi took some help on orthogonal array experimentations. So, an orthogonal array matrix was used over here. So, in this case, Taguchi took the help of one of the mathematicians Prof. C R. Rao, who is from Indian Statistical Institute, Kolkata, India.

And he invented actually this orthogonal array concept and in this case and Taguchi adopted this concept over here and he proposed various types of orthogonal that can be used for experimentation like that, ok. And, he wanted to reduce like a fraction of factorial design.

We want to reduce the number and Taguchi emphasized that we should reduce the number of trials and he took highly fractional factorial design and in that case, he defined various types of the orthogonal array to be used for experimentation.

So, if it is a 2-level experimentation you want to use an orthogonal array in that case Taguchi suggested L_4 array, L_8 array, L_{16} array, L_{32}, L_{64} like this. If you are doing a 3-level experimentation then L_9, L_{27}, L_{81} like that. So, every orthogonal array has a specific design and I will show you after this slide. So, an L_8, L_8 means 8 number of trials you have to run over here.

So, 8 number of trials and maximum 7 factors can be studied in L_8 orthogonal array like that ok. And so, drastically out of this 2 to the power 7 experimentation, i.e., 128th experimentation that is required what we are doing is that basically 8 trials we are doing we are reducing the number of trials from 128 to 8 over here.

So, this is the concept of fractional factorial design that is adopted over here and orthogonal array is one of the concept that is taken from fractional factorial design, ok and this this concept will be used.

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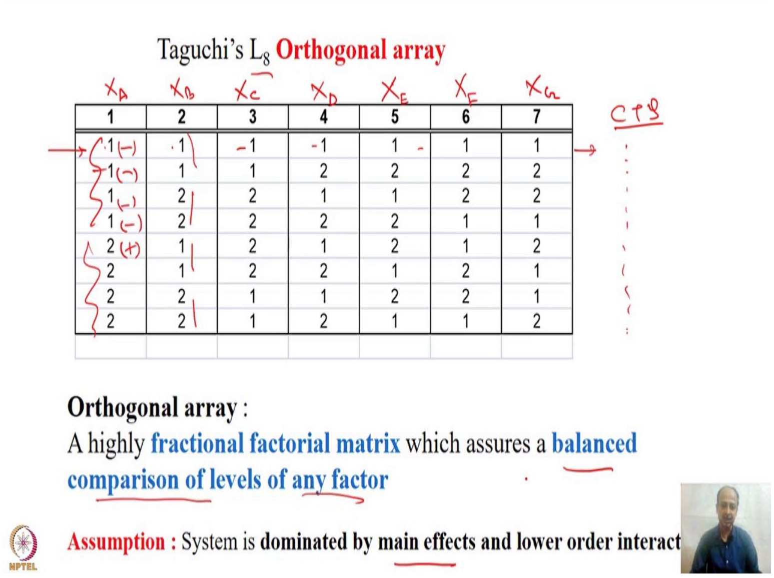

1	2	3	4	5	6	7
1	1	1	1	1	1	1
1	1	1	2	2	2	2
1	2	2	1	1	2	2
1	2	2	2	2	1	1
2	1	2	1	2	1	2
2	1	2	2	1	2	1
2	2	1	1	2	2	1
2	2	1	2	1	1	2

So, in this case, this is one of the orthogonal array that is L8 I mention and Taguchi used a symbolic notation. So, you can think of 1 as minus (-) over here and this as over 2 as plus(+) over here. So, this minus you can think of variable is minus level, this is minus level for factor 1.

So, factor A let say and this is factor B like this, this is C like this and when you are running the experimental trial like this. So, this will be A, B, C, this is D and this can be E, F, G like this. So, if you have 7 factors over here which is A, B, C, D up to G. So, in this case, what you can do is that you can use L8 orthogonal array to see the effects and calculate the effects of A and this is we do not have to run the 2 to the power 7 experimental trial over here.

And, how do you run the trials over here? You are running the trials. So, A will be at lower level, B will be at lower level, C lower level, all at lower level should be run first over here and the CTQ values over here will be noted down and then like this you have to complete the 8 trials based on the sequence that is given.

So, level will be second experimentation level will be first pioneer level 1, level 1, level 1, then at level 2, level 2, level 2, level 2 like this and all this combination if you are running. So, this orthogonal array is basically a balanced design and we can compare the levels of any other factors like that. So, over here you see balanced experimentations over here the number of plus and number of minus are equal over here.

So, this is 2. So, four number of 1s and four number of 2s over here. Similarly, four number of 1s, four number of 2s over here, every column is balanced basically every column is balanced and their independent column over here. So, this is an orthogonal array matrix that we are using over here, ok.

So, the basic assumptions of Taguchi's experimentation is that it is dominated by main effects system is dominated by main effect and I have to reduce the trials over here reduce the number of factorial trials over here. So, in this case we concentrate on main effects. So, Taguchi says that system is dominated by main effects.

So, mostly and system design is dominated by main effects. So, interaction has little effects on the design. So, generally we try to avoid interaction in the design and in that case screening of the factors become easier when we use these methods over here. We do not have to run 2 to the power 7 experimentation; only 8 experimental trial I can get the I can get the condition of A, B and C and whether they are significant whether they are important or whether we can drop that variables like that.

So, whether it is making sense to screen those variables or whether to we will not consider those factors in final experimentation or later on like that. So, this can be used for screening purpose by Taguchi also emphasized that we can use this for optimization that when.

That means, Taguchi is claiming that even if you run only this 8 trials over here instead of 2 to the power 7, I can get the optimal condition which will be which will give me a solution which is equivalent to full factorial design if you are running the full factorial design like that ok.

But, the assumption is that it is dominated by main effects it is dominated by main effects or may be some lower order interactions. So, higher order interactions has no effect on the system like that.

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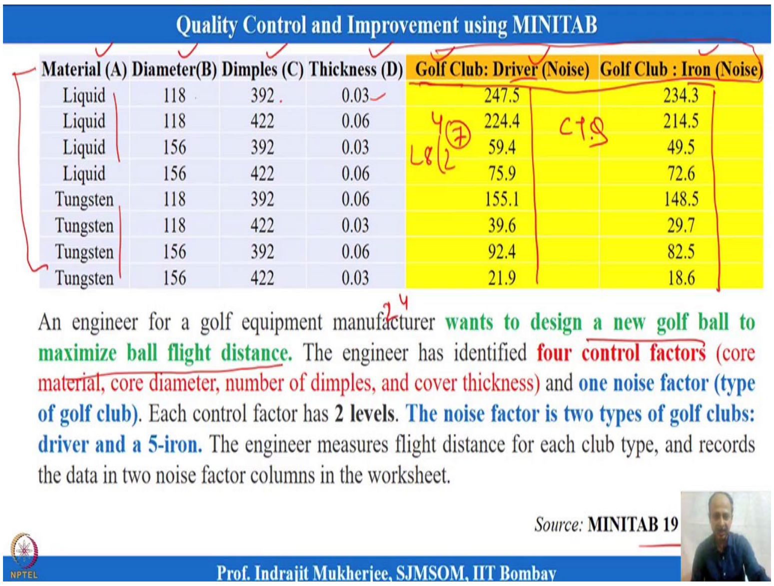

So, this is the concept that is used. So, one of the examples that we are taking over here is taken from source is MINITAB 19. You can find this file in MINITAB 19 support file this is there. And I am taking one of the examples from what they have given like that. So, here I wanted to design a new golf ball over here which will maximize the ball flight distance over here.

So, ball flight distance is these values that you are seeing over here and these are the factors that is considered over here A, B, C, D and there this is 4 number of factor is 4 over here. So, 2 to the power 4 if you can think of full factorial so, if they and all at 2 levels. So, this is 2 levels. So, this is a categorical factor you can see. This is a continuous variable, this is also a continuous variable, this is also a continuous variable over here.

So, in this case these are the four factors and we want to find out the best combination of let us say A, B, C and D which will maximize the ball flight distance and there is noise variable over here types of golf club that we are using one is driver and one is iron and I can use any of them. So, and I am intentionally changing that for experimentation over here.

I took two of them and average the noise is present I want to get a setting where irrespective of the golf club that you that you select I will maximize I will try to maximize the ball flight distance like that. So, one of the one of the array that is taken over here is inner array and the outer array is taken as noise over here as one of the varying factor is golf club over here.

So, in this case so, noise is important. So, interaction between factors control factors and noise that is important over here.

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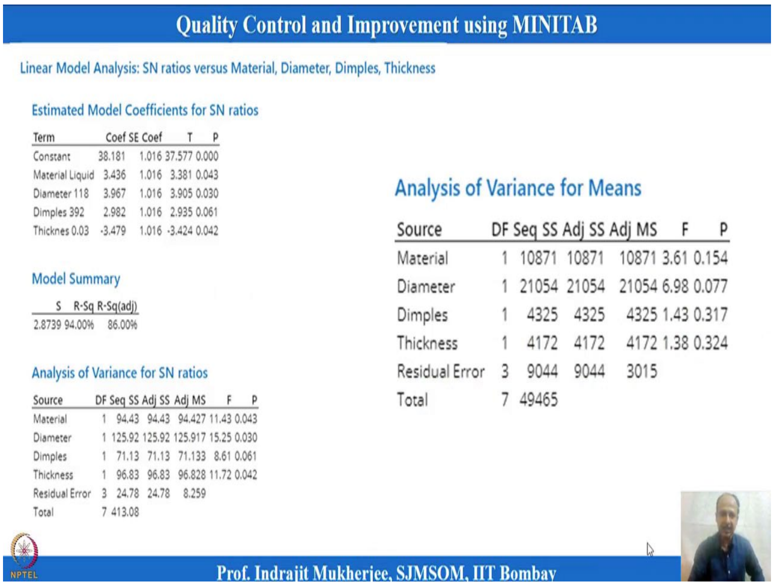

And, we can create the design in MINITAB and we can run the analysis and find out what is the best combination how to do that I will show and when you run the analysis, but you have to mention what you are maximizing. CTQ has to be maximized that has to be mentioned in SN ratio and in that case.

So, let us assume that this trial was run and this is a this is 8 experimental trial. So, L 8 array will be used over here and in this case only instead of 7 factors we are assigning only 4 factors over here. So, although we can accommodate 7 over here, but we have only 4 factors. So, minimum number of trials that is required and mini the orthogonal array the fixed over here is the L 8 which is of best orthogonal array that we can fit. The minimum number of trials with minimum number of trials, so, the L 8.

And, we are doing this and we can generate this design and also do the experimentation how this design is created basically. So, in this case what we can do is that and this levels we can think of one is plus 1, one is minus 1. So, we can also define as level 1 and level 2 like that arbitrarily we can define; one is at high level one is at low level.

So, sign convention of Taguchi is 1 and 2 whereas, in factorial design what we have used is minus 1 and plus 1 like that. So, that is an symbolic configuration we should remember.

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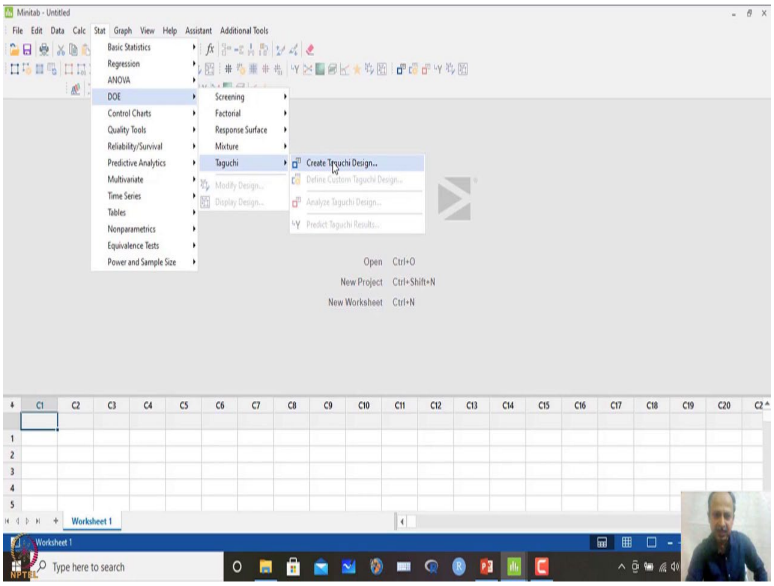

And, let us go to MINITAB file and try to clear create a Taguchi's design. So, what we will do is that we have four factors and we have noise variables over here.

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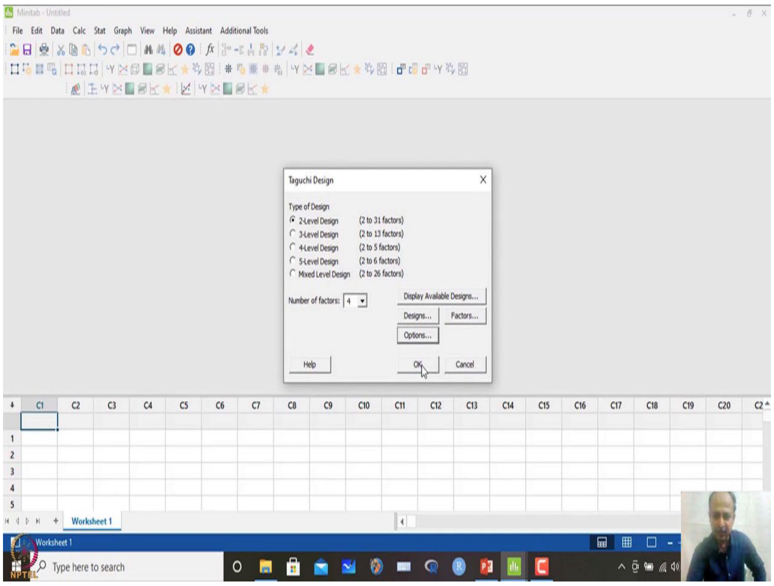

So, what we will do is that Design Of Experiments, Taguchi's design, Create Taguchi's Design over here. Then it will ask that how many levels. So, we are having 2-levels; Number of factors that we have, what is the number of factors? 4.

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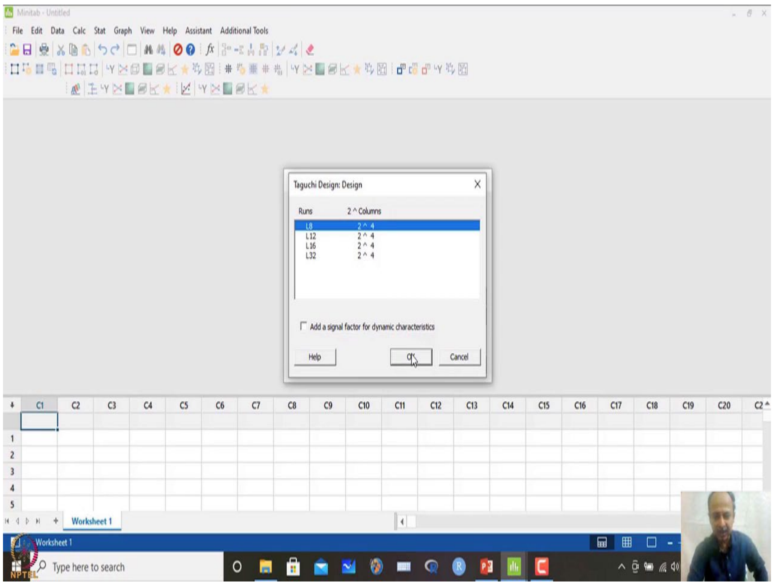

So, then it will you can go to the design and you can see all possibilities, but the minimum number of trials is L 8 and in that case add signal factors, here we are not considering signal factors for dynamic characteristics, this is the static characteristics we are considering over here. So, we will click Ok, we will not click that option.

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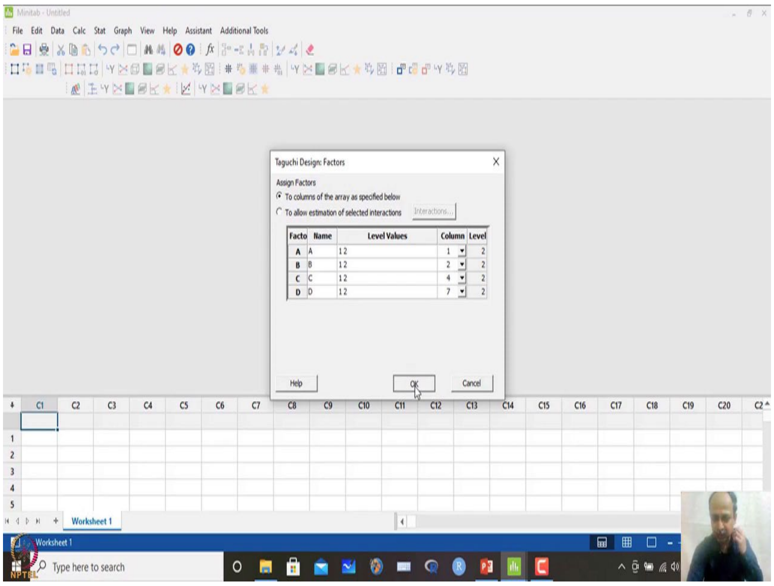

So, in Factors what we can do is that by default columns are specified over here. So, the column number 1, 2, 4 and 7 it is defined by the MINITAB automatically over here and so, this is defined based on a linear graph concept like that. So, we are not going to that. If you are not interested interaction effect, so, in that case you can assign to any of the four columns like that by default.

You can chose first 1, 2, 3, 4 columns like that we can change this which column to assign over here, but Minitab has automatically assigned some columns and that is that is also good to select like that.

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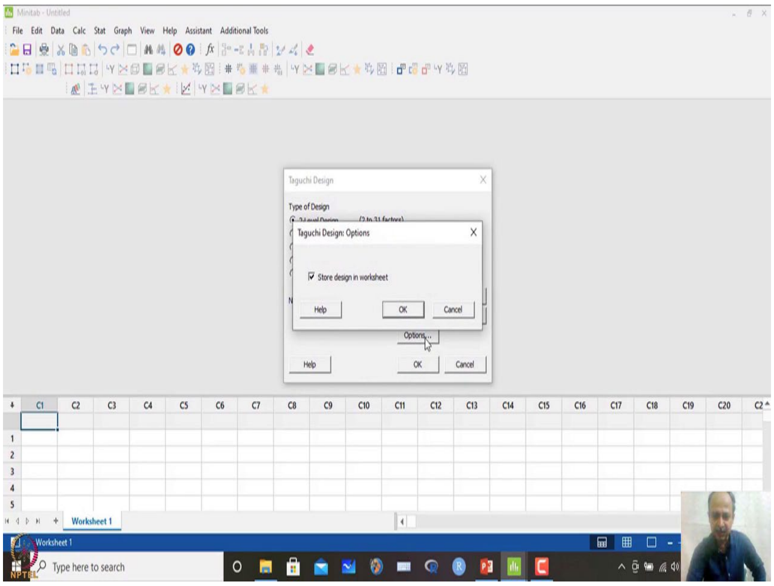

So, next is Options in this case Store worksheet. So, if you click Ok.

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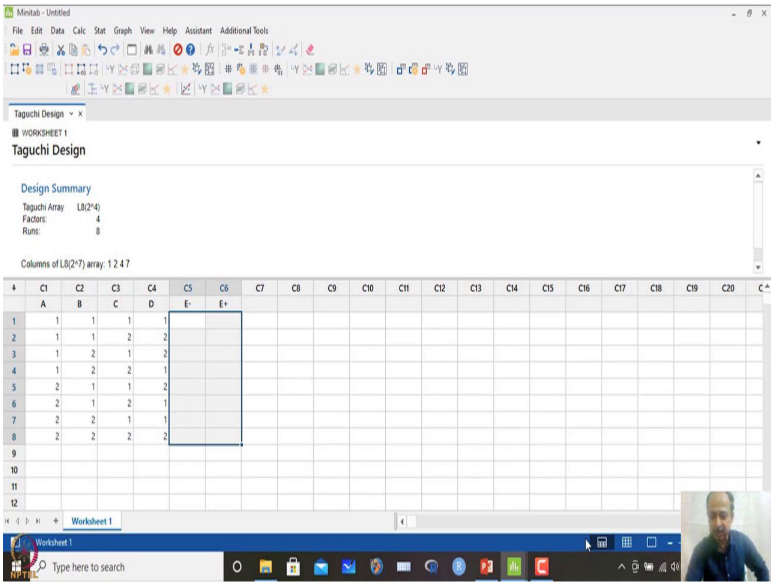

What will happen is that this 8 trials will be created. So, Taguchi's array of L 8 2 to the power 4 that is the trial 16 trials were required, but I will only learn 8 trials over here. So, this is the 8 trials and then what you have to do is that you have to just enter the values of noise 1 at level 1. So, this will be may be level one and this may be at plus 1 over here.

So, A, B, C, D, E at level lower level and E at plus level like that we can define like that. So, then we can enter the values over here for the first experimental with E at lower level and E at plus level with this combination we can just note down the dataset of experimentation over here or the CTQ values which we have to maximize basically. So, when we enter this column then only we can analyze the data like that.

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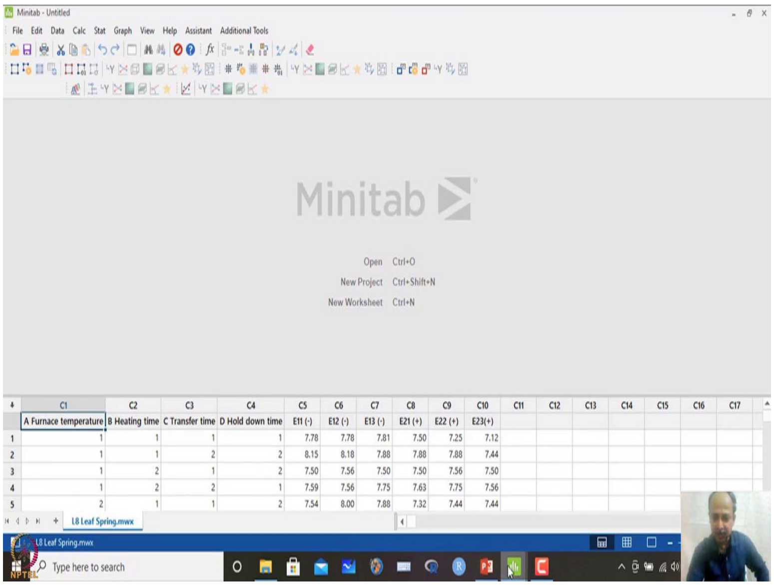

So, this is already entered in the Minitab file over here what you are seeing in the screen.

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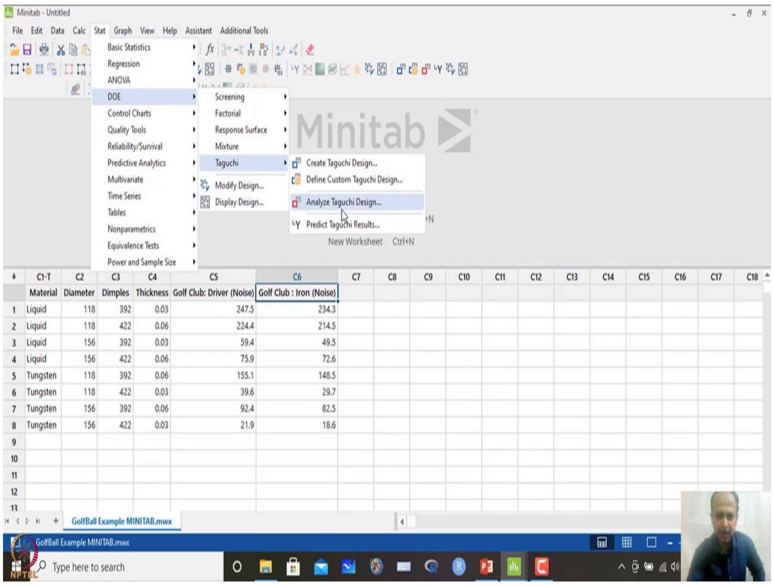

So, this is already entered over here. So, this is already entered. So, we do not want to waste time over here. So, material diameter A, B, C, D this is given thickness and these are the E factors that is one as low level and one as arbitrarily we defined one is low and one is high. Now, we want to analyze this dataset over here. So, what we will do is that Design of Experiments, then we will go to Taguchi's method and Analyze Taguchi's Design over here.

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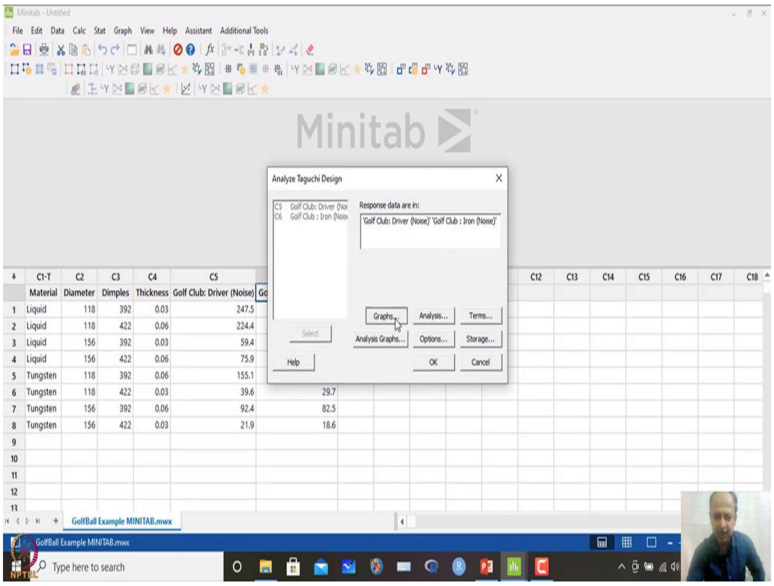

So, you have to define that these are the two response variable data is over here.

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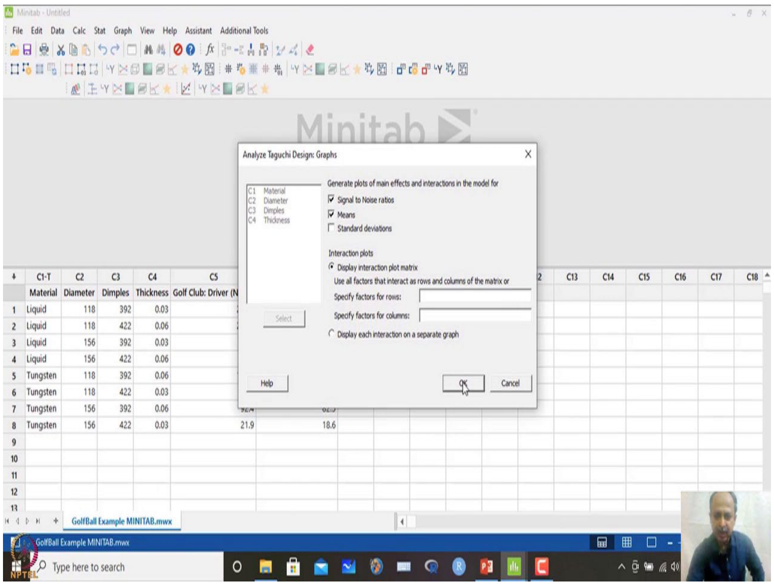

Then you go to Graph. What you have to do is that mention Signal to Noise ratio and Mean over here. So, these two will be ticked over here.

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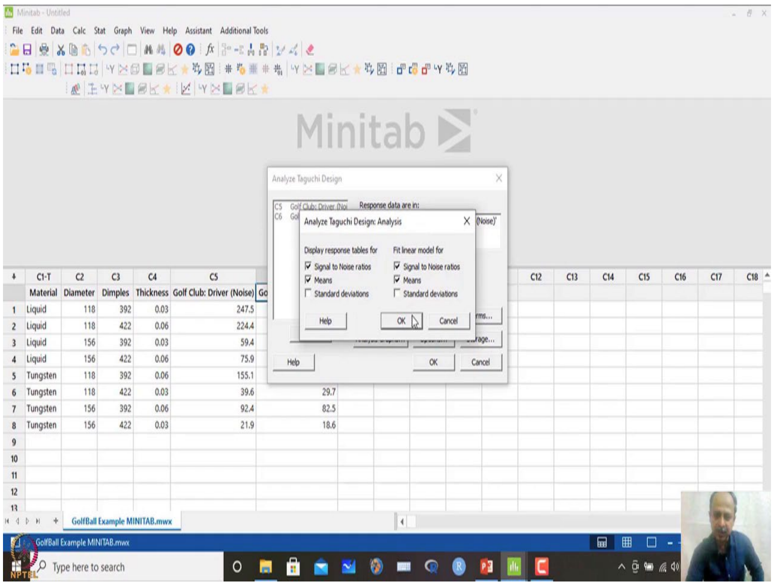

Analyzed you go for Display Signal to Noise ratio and also fit models over here. You click for Signal to Noise and Mean over here. So, this will be you click this one.

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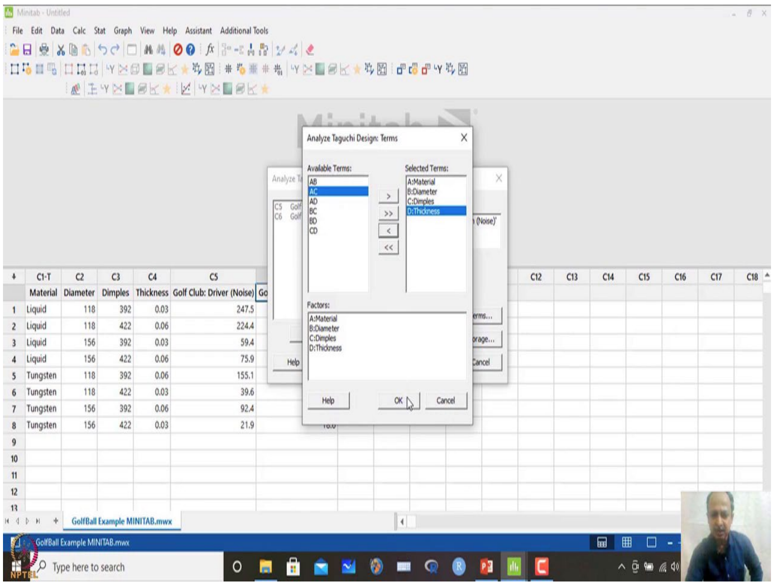

Then Terms I do not want to study interaction terms. So, you can remove this one. I can only want to study A, B, C, D and E because I am just screening that one may be with this also we can define what is the optimal.

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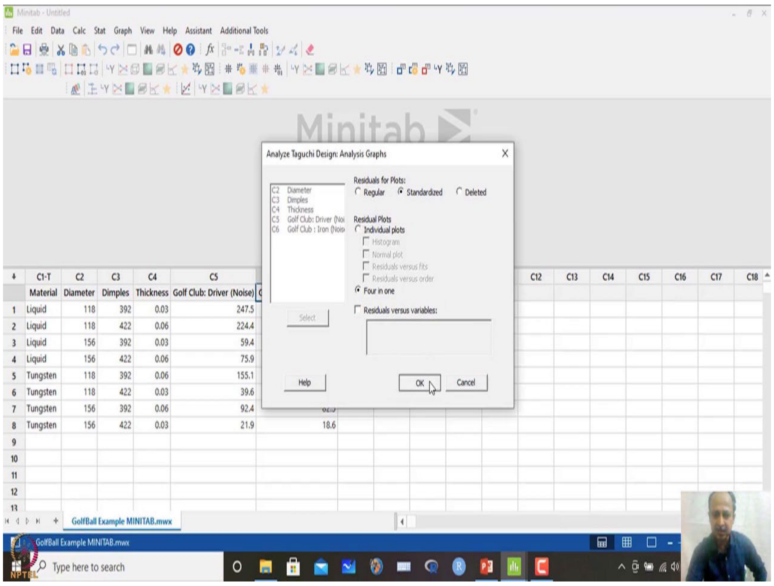

So, here if you want to analyze the error, so, we are not interested at this time point.

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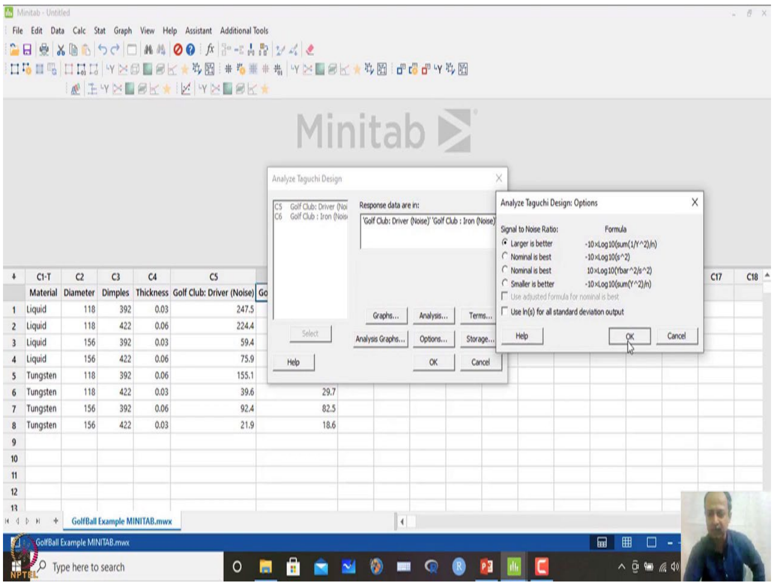

And, here what you have to mention over here is that this Options what you want to do with the response over whether we want to maximize. So, Signal-to-Noise ratio what type of Signal to Noise ratio like what we discussed. So, we will mention that we want larger is better type of functions. So, this is the formulation that will be used by MINITAB and the it will report the signal to noise ratios. So, I click OK over here and then I click OK.

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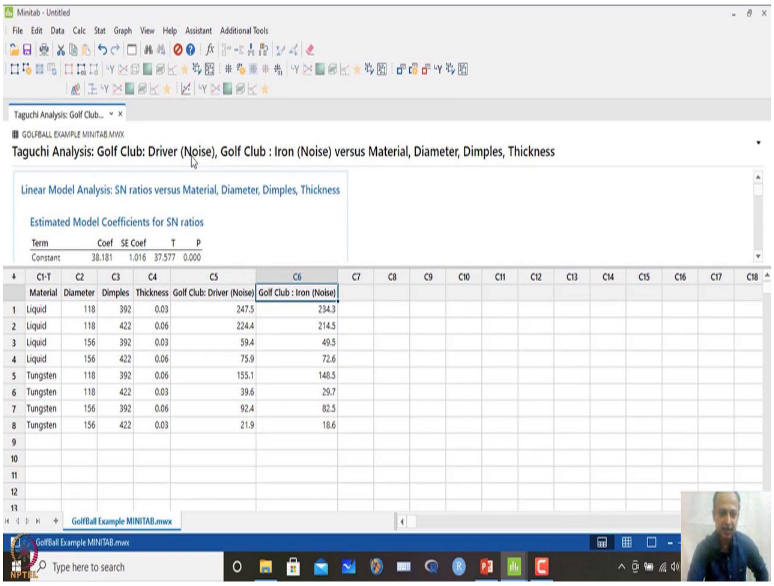

And, what will happen is that you will get the conditions which is which is basically important for us ok.

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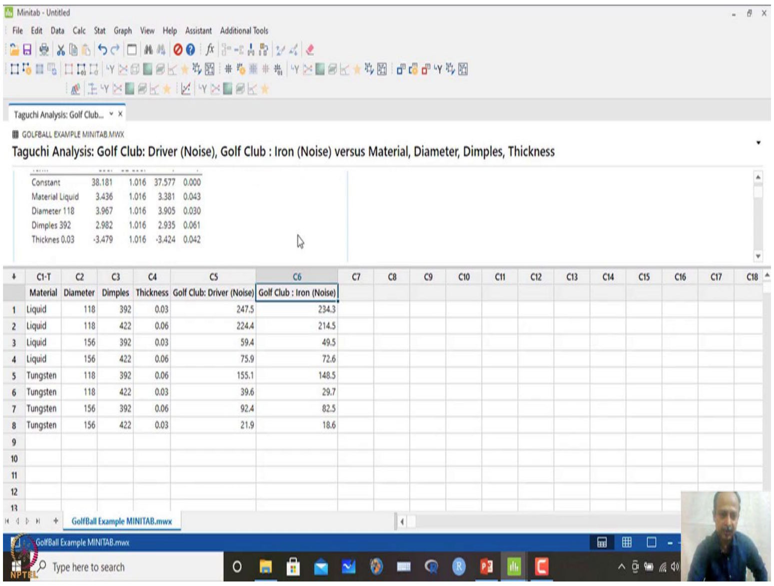

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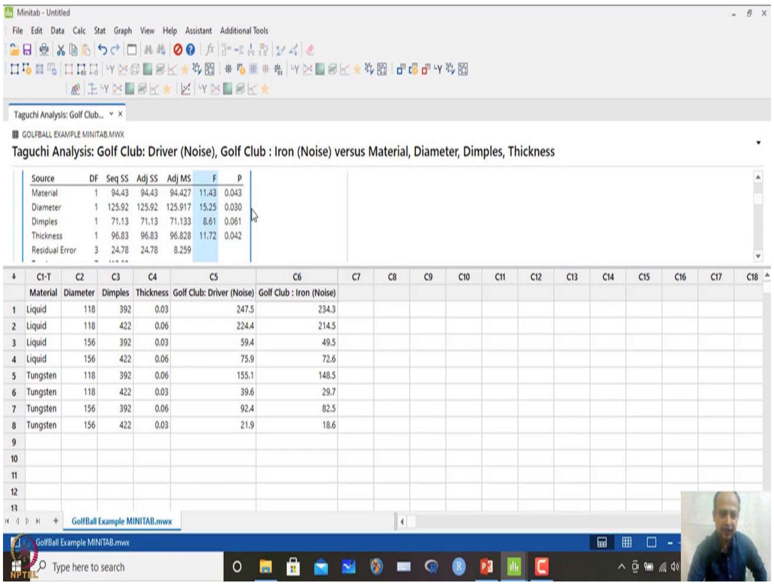

So, what is required is that we will consider the we will consider the ANOVA analysis of this. So, this is excel. We will consider excel over here. So, let us just place that once. So, it is easier for you to see also ok and how do you set the conditions like that. When you are optimizing also using Taguchi's method how do you do that? So, what we do is that first we see the signal to noise ratio and based on that we set the variable levels like that.

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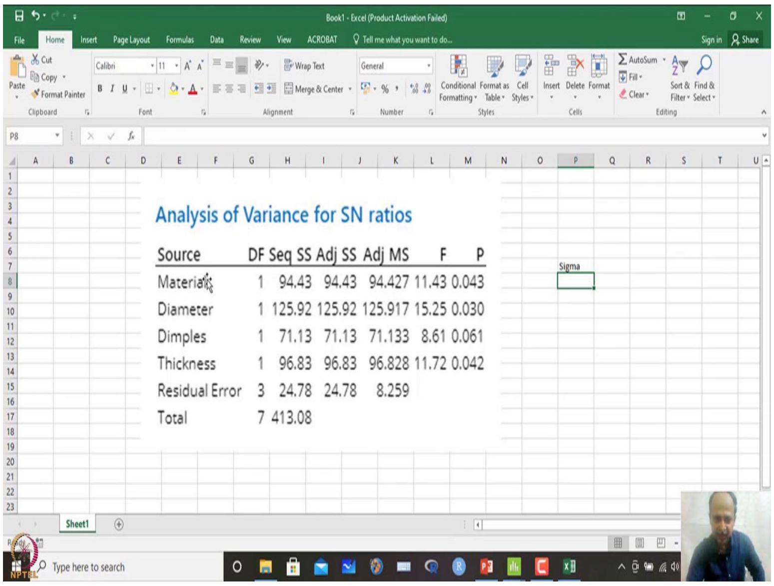

So, over here I am just copy pasting this one and what do you see over here is that material is significant; that means, P-value is significant over here, diameter is also significant because P is less than 0.05, dimples this is not significant more than 0.05, but very near to 0.05. So, over here either you can consider this one or you can set it at any levels like that based on another.

So, first we see the SN ratio. SN ratio is related to sigma over here. So, when we are mentioning. So, this is related to sigma, it impacts the variability basically. So, whenever and thickness also impacts the variability. So, in this case 0.042. So, now what you have to do is that see the SN ratio plots and based on that we set the levels of material, diameter and thickness. So, this can be set.

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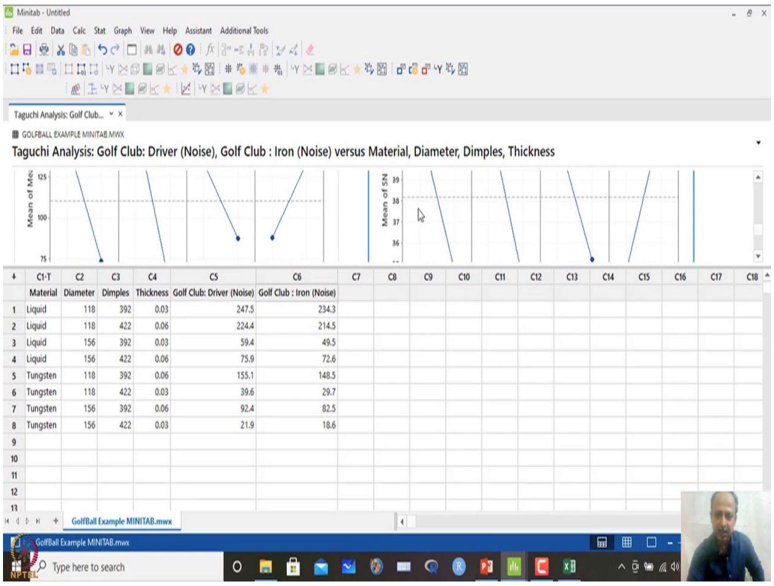

So, what is given by Minitab software is that if you go down over here you will find a conditional you will find this SN ratio plot over here, ok.

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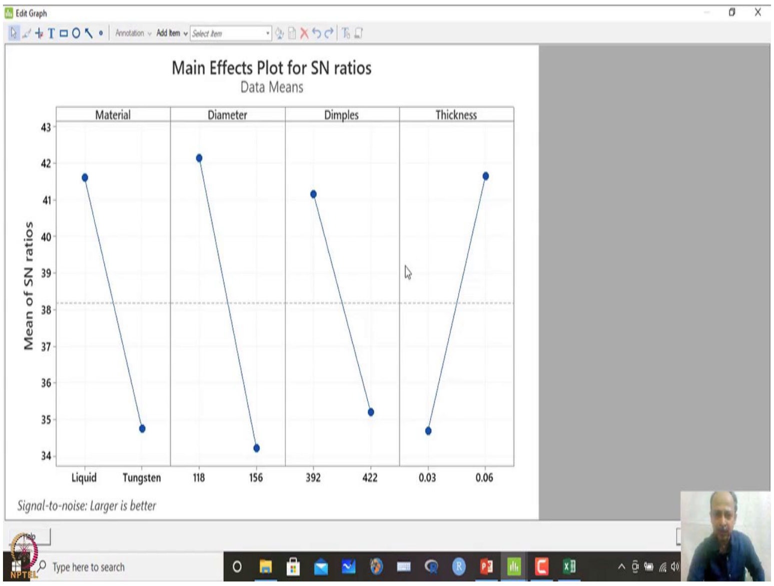

So, material was significant diameter was significant this was not significant and thickness was significant like that. So, in Taguchi's method we have to maximize the SN ratio, whatever may be the characteristics always we try to maximize the SN ratio. So, material type SN ratio this is the SN ratio axis over here. So, material type liquid should be selected because that is maximizing the SN ratio over here.

So, liquid so, we have just set this level one of material is let us say liquid then diameter also level one because that is also maximizing the SN ratio and that has impact on variability. So, first we have to select those variables or factors which are impacting variability and set this set the condition of this variable of this factors like that.

So, over here material we have selected at liquid level this is 118 diameter and then thickness we have to select the level 2 that is point 0 0.06, let us assume that one as level 2. So, this will be taken and if you also consider the dimple over here so, this is not significant statistically. But, it is showing that level 1 is predominant aspects, but at least this three will be set material, diameter and thickness over here this will be at level 1, level 1 and this will be at level 2.

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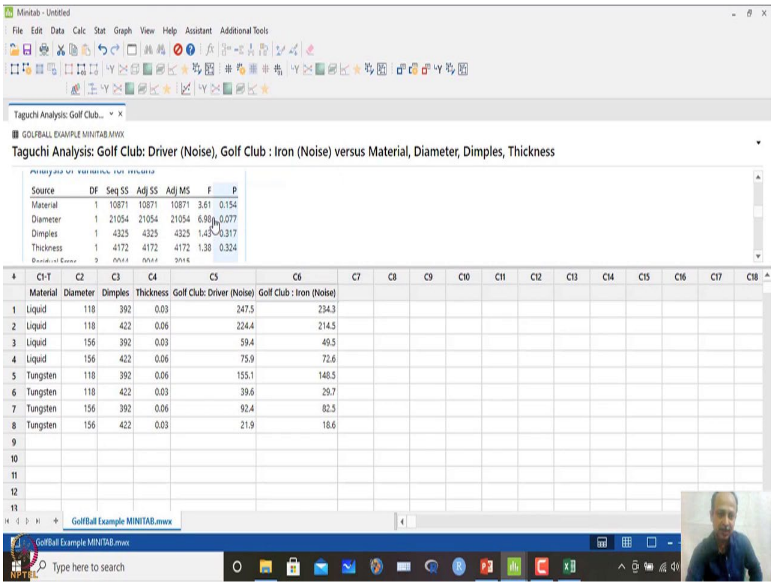

So, this is the first diagram and then you have to see that which of the variables that impact the mean. So, over here there will be a mean analysis also, analysis of variance of mean. So, I can copy this one and I can paste over here.

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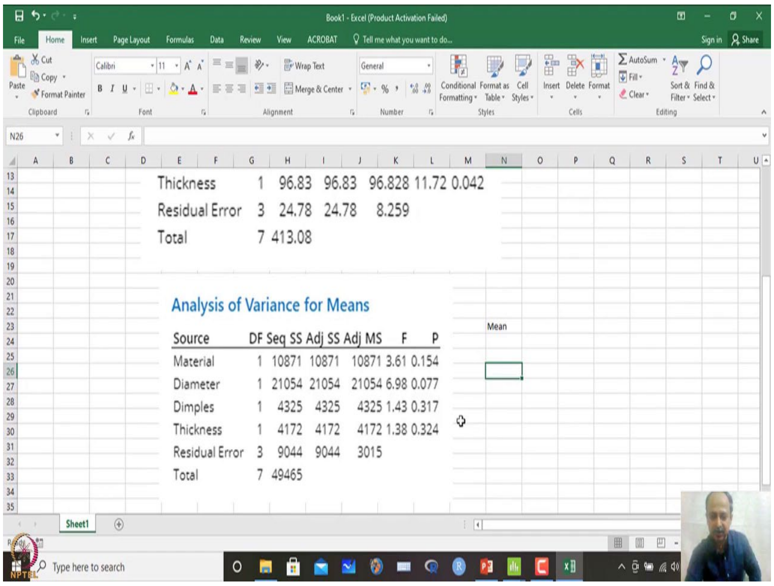

So, below this one you can also copy this one and this are the this ANOVA analysis will tell that which factor is basically influencing the mean over here. So, what we are observing over here none of the factor is influencing mean over here. So, whatever setting we have to do we can do for the variability reduction over here and then try to predict what will be the if this is the setting, what is the what is the maximum distant that it gives basically ok.

So, these are the only factors that we have considered for experimentation and based on that we have to we have to finalize ok over here. So, we can go by the sigma if you assume 0.06 and if the upper limit of P value we set at point point one rather than 0.05 all are significant for the sigma reduction over here. So, in this case what we can do is that we can set these values.

So, material at level one diameter at level 1, thickness at level 2 and dimples what we can see is that this what we have seen over here is the based on this trial. So, and this diagram will tell me.

So, that SN ratio diagram. So, dimple will be at level 1. So, level 1 for material, level 1 for diameter, level 1 for dimple and thickness will be at level 2 only. So, this is the final combination that we want to see. First three is level 1, last one thickness is level 2 like that.

So, then based on this. So, this is the experimentation that we have run and with in presence of noise this was analyzed, ANOVA analysis was seen.

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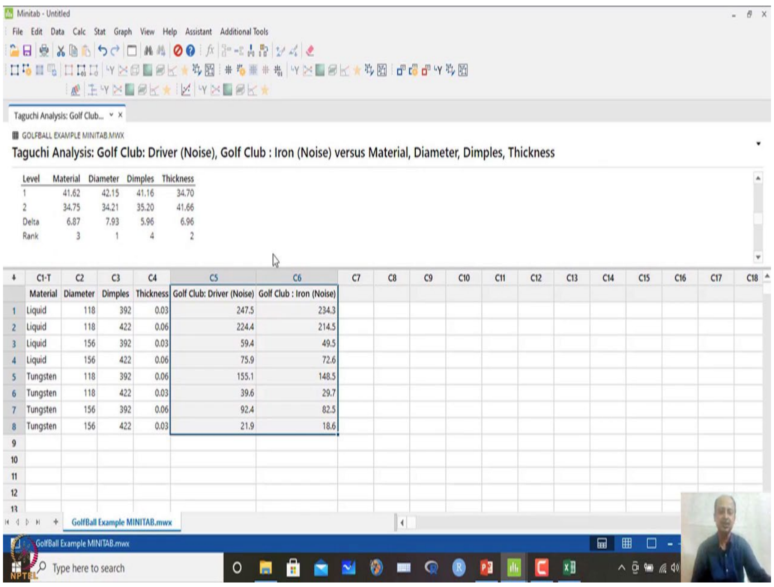

And, first we have seen the SN ratio ANOVA analysis and based on that we have we have identified which factor influences the sigma values and those factors are set at a certain levels based on the SN ratio maximization principle. And, then what we have done is that we have seen the mean whether some factors are impacting here it is not.

So, in that case we will go by the factors that we have selected levels we have selected using the SN ratio principle and the final levels that is factor one is at level 1, factor 2 level 2, level 1 level – first three factors are level 1 and the last one are level 2.

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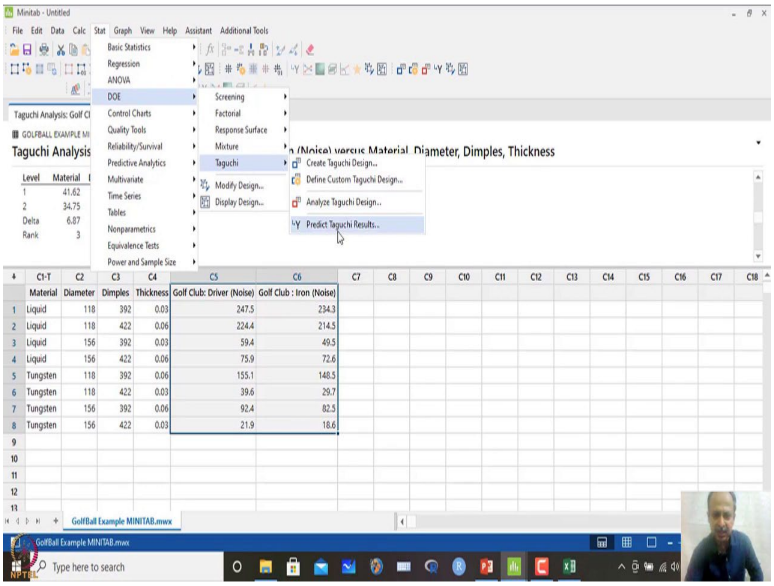

So, also what we can do is that here you have the options of predicting the Taguchi's results over here.

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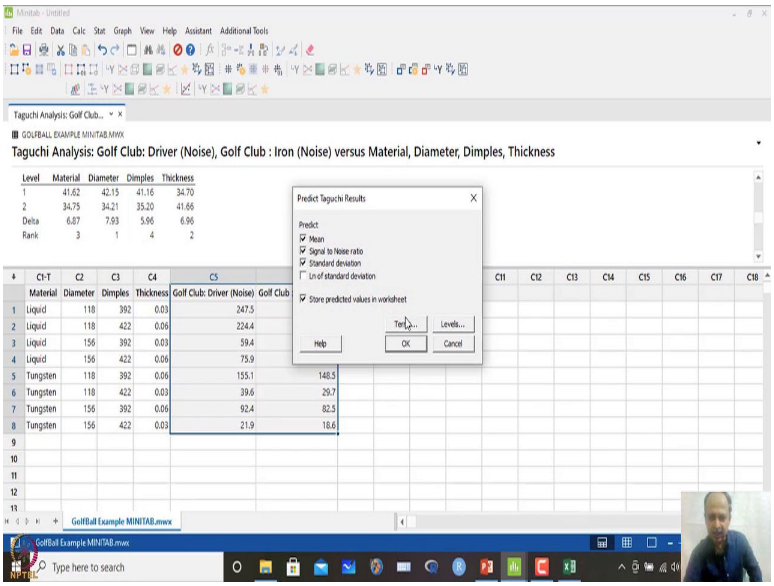

So, you want to predict what will be the Mean, Signal to Noise ratio, Standard Deviation like that.

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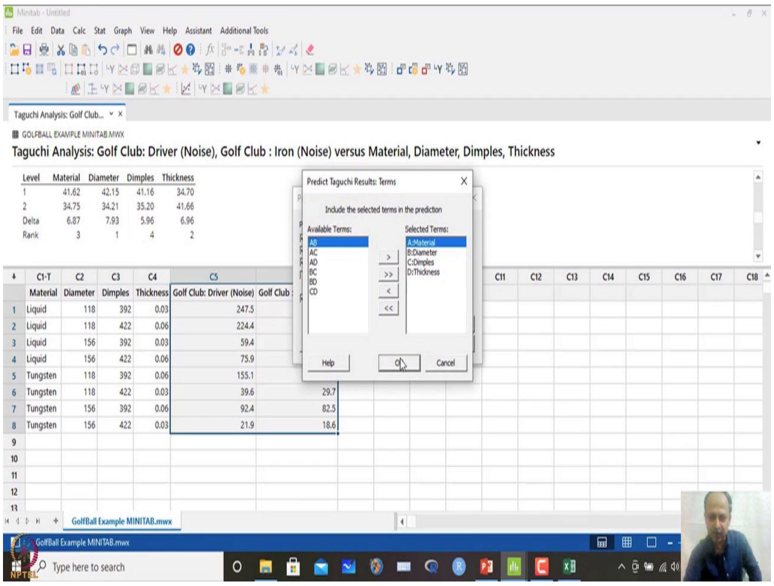

And, what you want to see is that what are the effects over here. So, that we want to see over here. Terms for prediction is only the main effects that we are taking.

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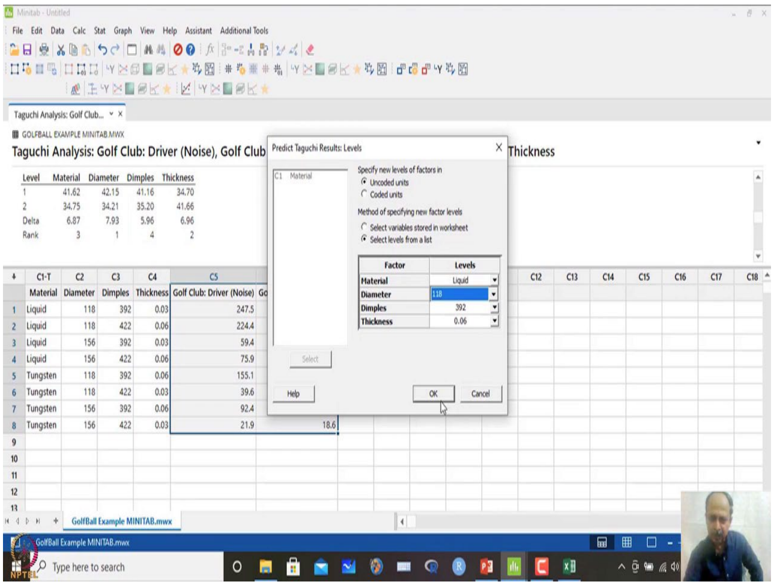

And, levels over here we can we can select the levels from the list like that. So, this is liquid over here. So, this is 118 like that and this is thickness is point this will be 0.06 like that that we have taken as level 2 and dimples we have taken level 1. So, this is ok and diameter also we have taken level 1. So, that is not an issue. So, we will we will select OK over here and then click OK and we can see what is predicted one.

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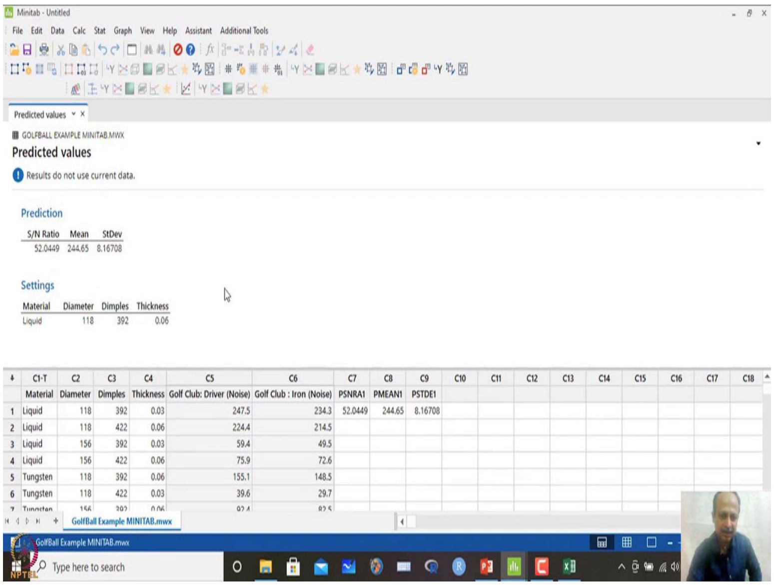

So, over here you will get the prediction.

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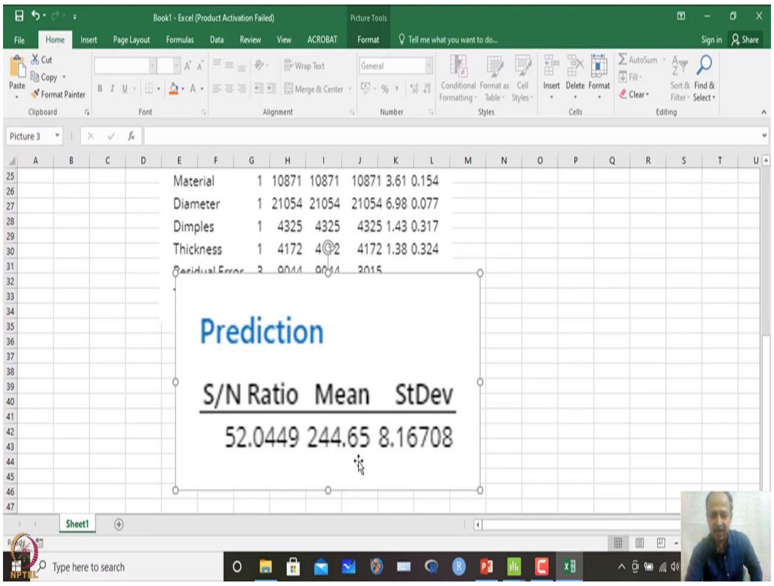

And, the confirmative trial has run to see that whether analysis or the setting condition gives near to this prediction what is given over here. So, it is predicting that SN ratio will be around 52 over here, high SN ratio is expected over here and the mean value will be around 244 that is the maximum you can reach of distance and the standard deviation will be around 8.16.

This is the prediction based on Taguchi's analysis experimental analysis over here and there will be another important analysis that we will see over here while you are analyzing the results.

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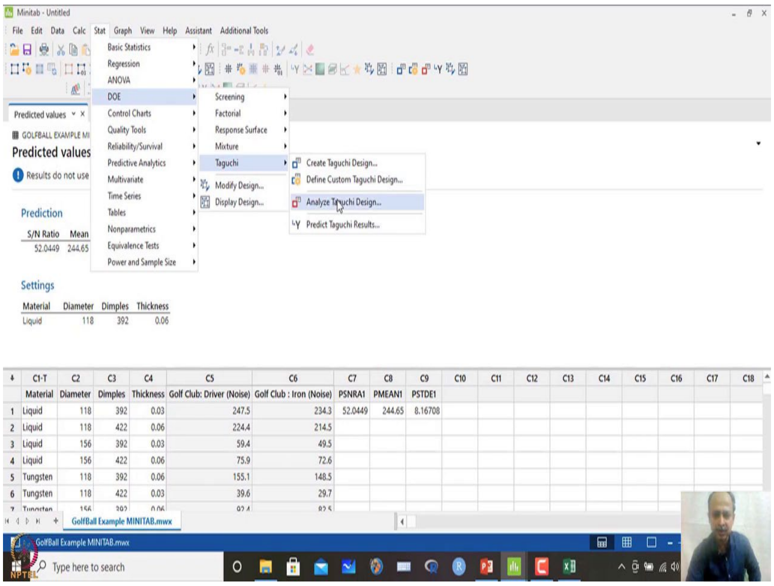

So, in this case we will go back to the analysis again.

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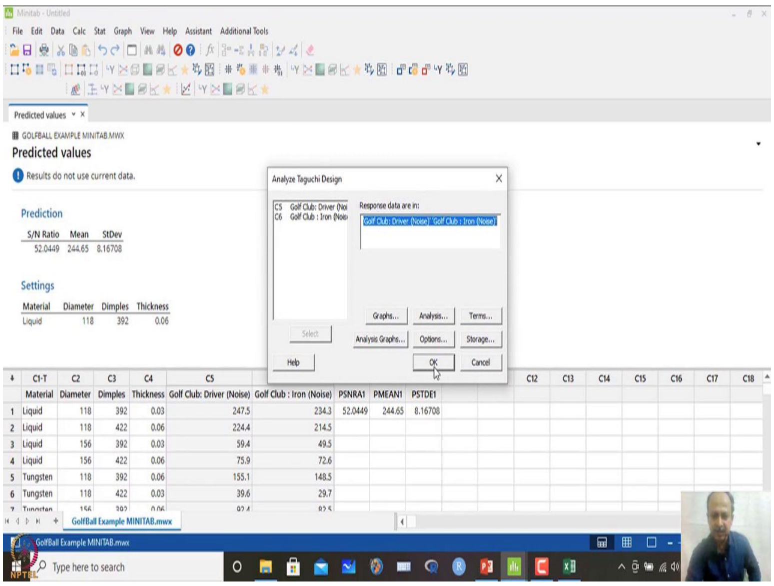

So, we will go to Taguchi's method, Analyze Taguchi and everything is same conditions.

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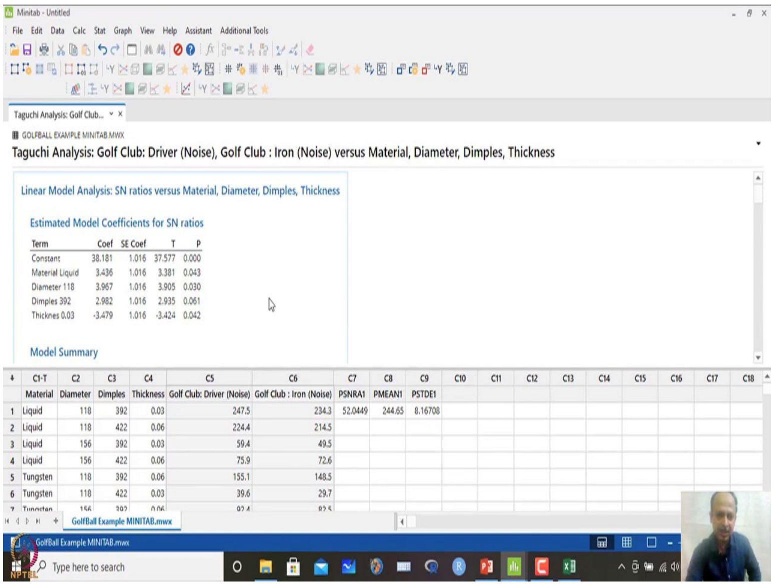

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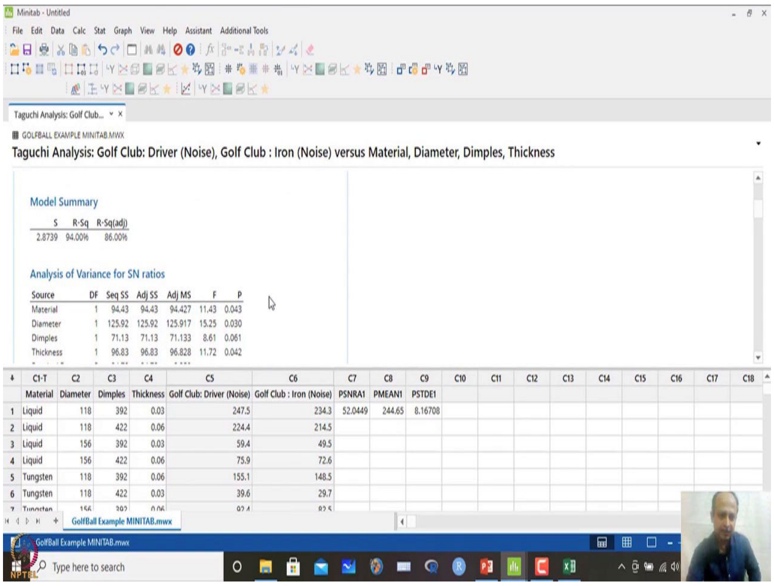

So, what we have seen over here is that and this is ANOVA analysis shows R square value is quite good 9 94 percent over here.

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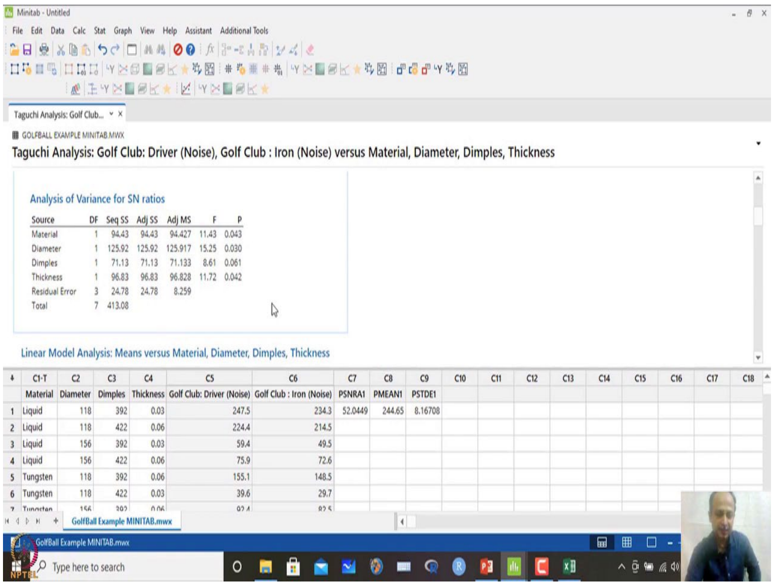

Explain variability by considering all these four factors without considering interaction effects like that.

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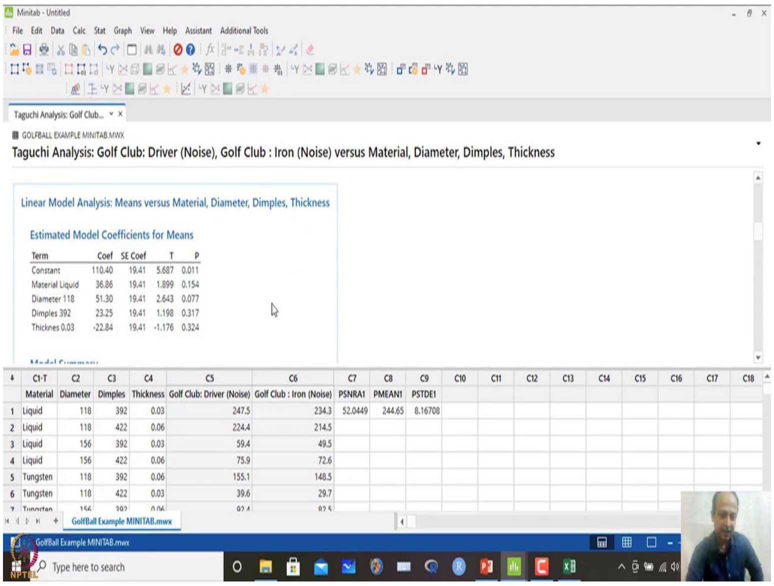

And, it will give you it will give you mean analysis is also given, SN analysis was written separately over here.

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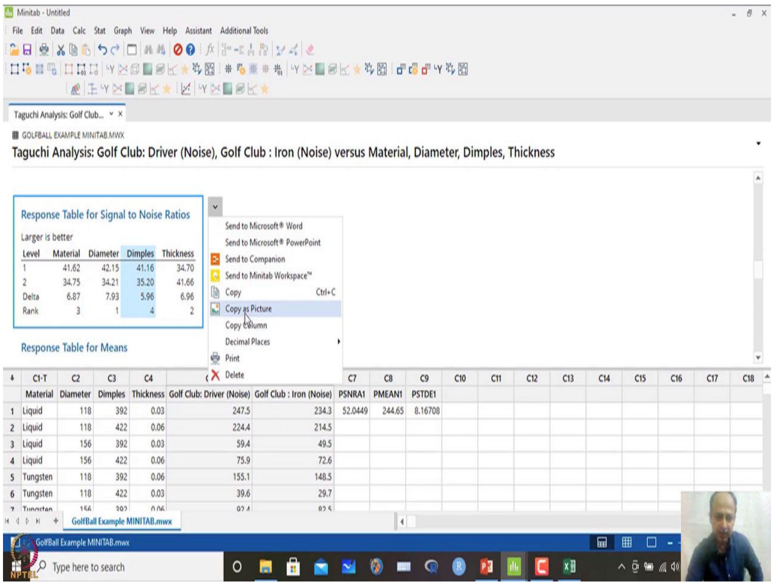

And, here you will get a Signal to Noise ratio tables over here. You can copy this one we can see what it shows.

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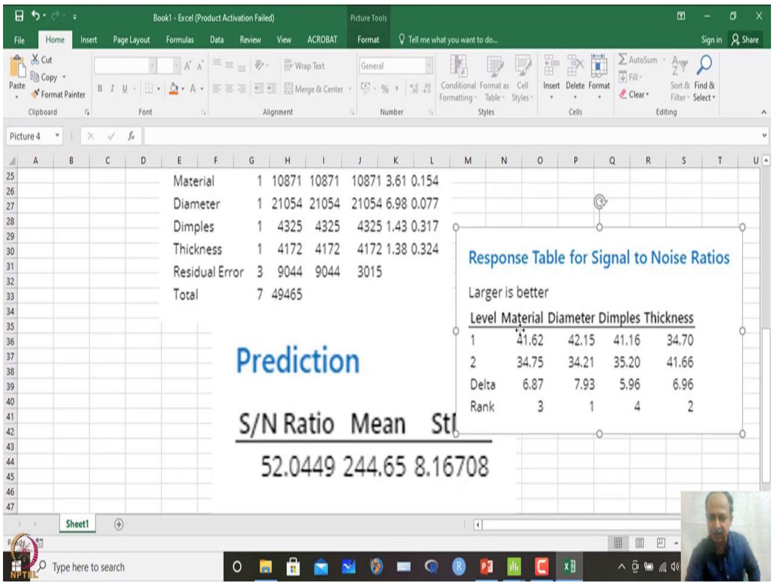

So, here you will find another important analysis which is known as which effect is rank of the variables like that. So, for SN ratio which is rank 1, which is rank 2, which is rank 3 like that which has maximum impact. So, diameter it is show rank 1. So, it will just subtract maximum for the minimum one and it will calculate a delta value over here and delta is calculated 7.93, i.e., if you subtract (42.15 - 34.21), you will get 7.93.

Like this you can calculate all delta values for the all the four factors and then you can rank based on the values. So, rank 1 is for the highest delta values over here which is 7.93; that means, diameter has maximum influence on the CTQ that is considered over here maximizing the distance of travel of the balls like that. So, in this case this is rank 1, similarly for which is impacting most variability.

Variability which is impacting more, diameter is first, then thickness is second, material is third and the last one is this and also you have seen the P value is less ok. So, even the P value will indicate which is important which is most important or significant like that ok. So, that will be shown over here. So, this analysis also says that that which you can be ranked.

So, diameter is the first one then we can consider material and then thickness and the last one will be dimple that that is also visible over here ok.

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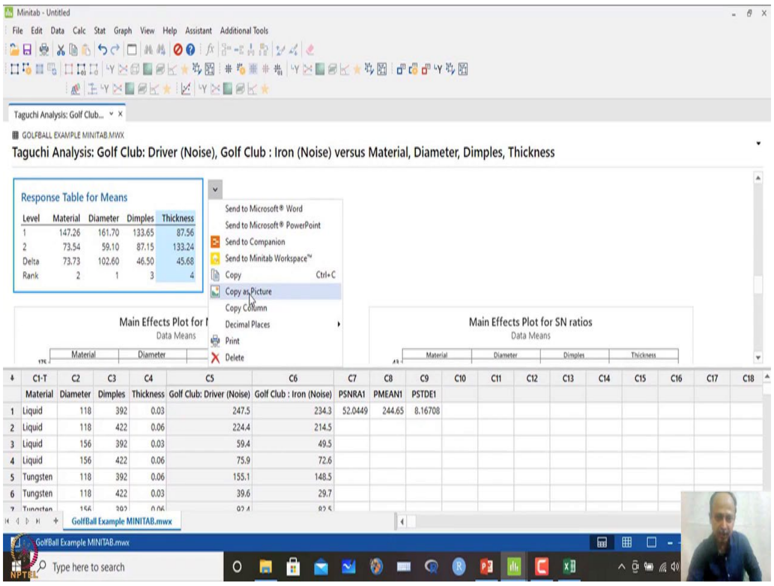

So, similarly, you can also see this analysis of this mean analysis and also ranking of that. So, if you go to the mean also so, which is impacting mean like that. So, ranks is also provided in this analysis over here.

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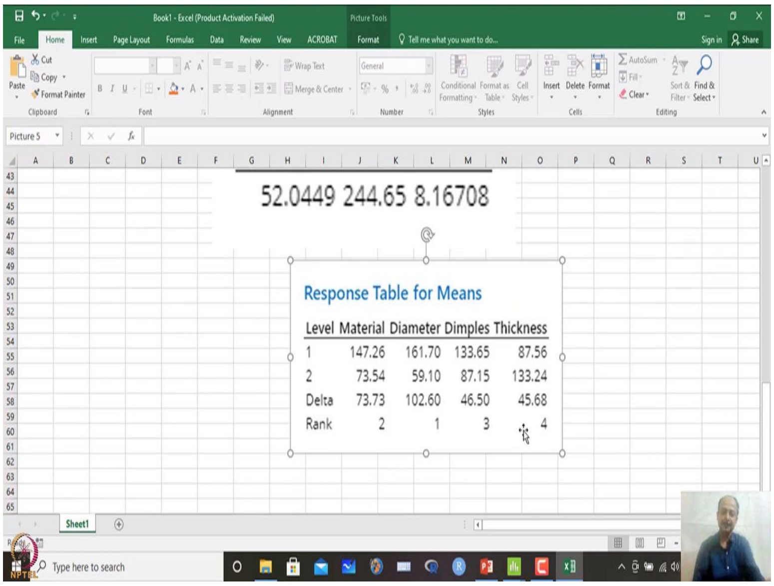

So, you can just place this one and see and you will find that which is important which is not, ok. So, ranking can also be done like that. So, there can be so, this specific example what we have taken over here is basically four factors over here. So, 2 to the power 4 experimental trial were required, but we have done only 8 trials over here.

And. when number of when number of experimentation increases what happens is that we will find this Taguchi's method as very much useful techniques over here. And, only thing is that it is controversial from statistical point of view people contradicts these techniques and also the quadratic loss function that we are taking, but it has been observed that this gives results.

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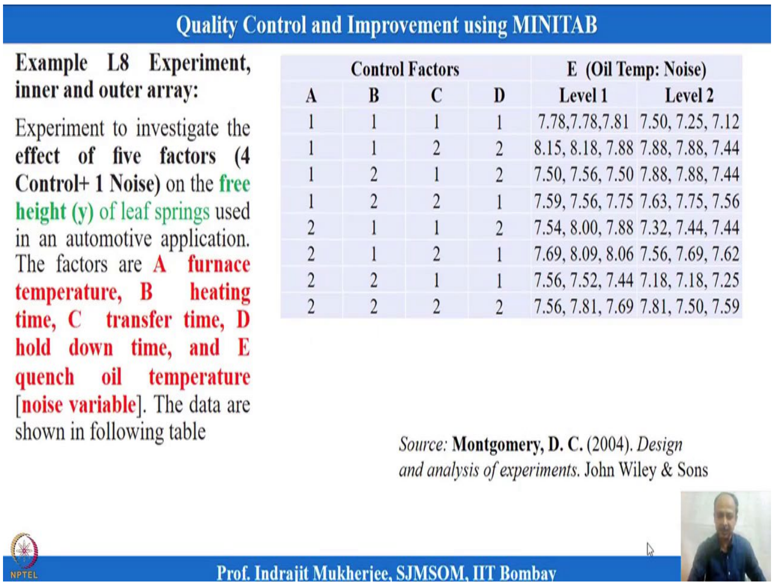

And, there are many more examples we can take like this factor we have considered L8. This is taken from Montgomery's Design of experiments books and there are four factors over here. And, there is the noise factor is taken and the it has level 1 and level 2 experiment was done.

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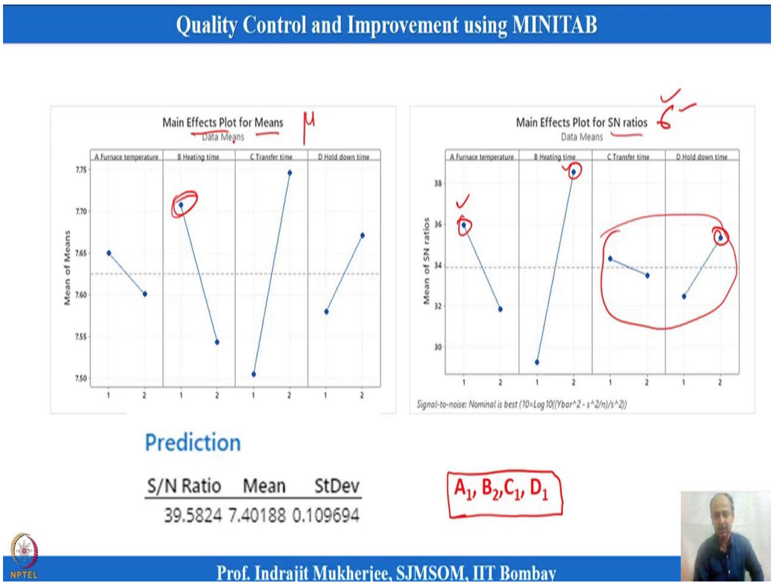

And, the levels are also defined and like this. So, this experimentation and final level was defined over here as A1, B2, C1 and D1 like this. So, this experimental trial also can be seen and based on the concept that I have given in the earlier example that can be similarly implemented over here.

And, first you see the SN ratio maximization concept and then based on that you find the setting whichever factor is significant and then go to the mean effects plots like that mean effects plots of the mean and based on that you set if some of the factors are impacting the mean values.

So, this is related to mean over here, this is related to sigma over here. So, first we see the sigma and then try to find the settings over here. So, I have to maximize. So, these are the settings that we are considering over here and in this case and this may not be having any effect that is why this is considered as D1 over here.

So, either first analysis will be on sigma and based on that which is significant we have to set those variables to the levels and then we see the means without impacting or changing the settings or what we have set based on SN ratio, the other variables if they are significantly impacting the mean then we can change those levels because those are not impacting the variability.

So, that is why we can adjust that one based on the a mean concept over here. So, if I have to maximize then in that case we will select variables and the levels based on the mean effect plots like that. So, these are the two plots that we have to use simultaneously over here.

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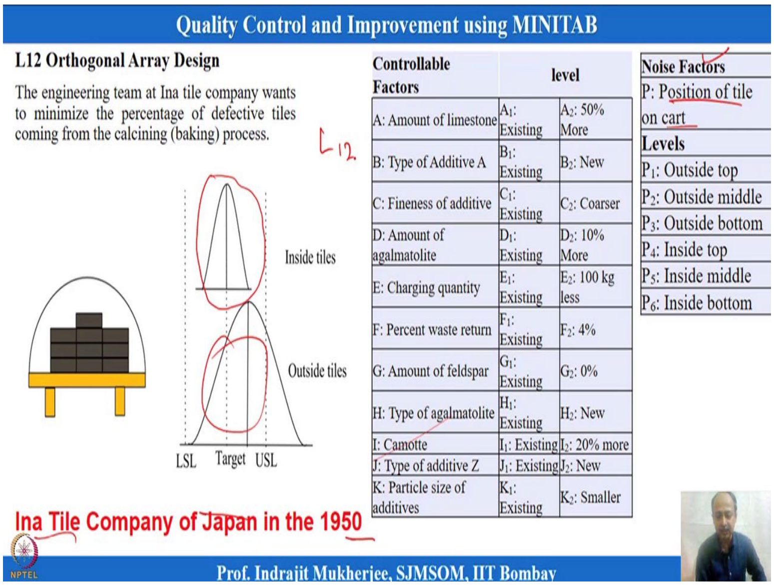

If you want to study interactions also that is also possible in Taguchi's experimentation, and this is one of the important examples that is taken most of the time – Ina Seito's examples. So, this is Ina Tile Company in Japan 1950. So, they are finding in the furnace the heat distribution is heat distribution varies within the furnace.

So, in that case, dimensional we are getting different dimensions in the inner tiles and out outside tiles how they have optimized. So, there are 12 factors selected over here and noise variables are also selected over here which is the positioning of the tiles and based on that optimization was done and this was taken as an example.

So, every Taguchi's when we talk about Taguchi's experimentation this is one of the experimentation that is very popular very popularly shown and L12 orthogonal array can be used over here. So, based on that we can select the final levels like that ok.

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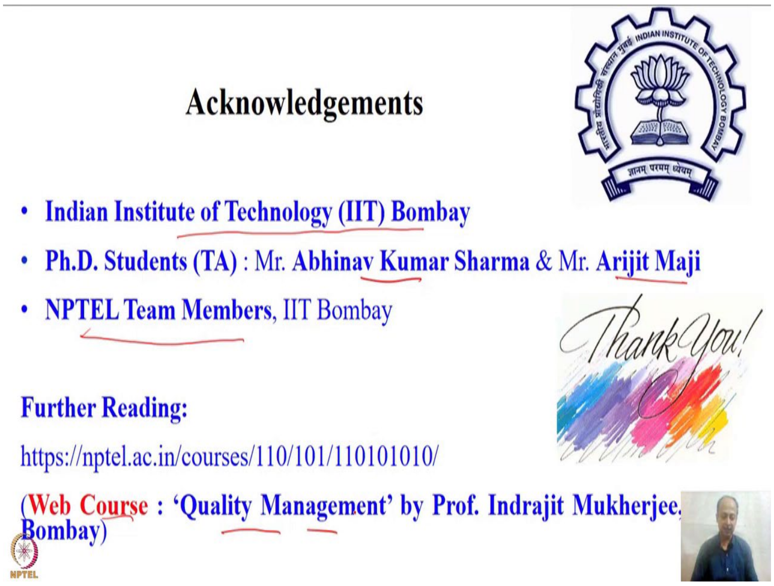

So, over here what is important is that I should this lecture this all 40 lectures that we have done this is because of the help that we have to acknowledge the people who have helped me so much in developing this course and developing the questionnaires and assignments and final exam questions like that.

So, two of my Ph.D. students Abhinav Kumar Sharma and Arijit Maji have worked very hard and one of them has developed slides and another one of them has concentrated on the question paper and sometimes both have contributed to both the things like that. So, they are the main contributors.

And, I would like to thank IIT, Bombay, so, for giving me this opportunity to deliver these lectures and make it available to many people who wants to learn quality control and design of experimentation using MINITAB software's like that. But, I would also like to thank this NPTEL team who has helped me like Bharthi maam is there, then Mr. Omkar is there, then we have Mr. Vijay were there.

So, these are the peoples who have I am continuously in touch and we have delivered this as per the need of and requirements of the NPTEL. And, you can also see because this course requires some understanding on quality management and you can see the web course that was developed earlier by me and in that case you will get some ideas.

You can read those materials over there and try to see more concepts about quality experimentations. So, that will also helps. So, I mentioned in the initial units of understanding of basics on quality management like that either web course or this any video course like that. But, you can see this web course like that and material that is given in this web course, that will give you an initial understanding of this area quality managements like that.

And, we have only emphasized on the control aspects like control charts we have emphasized on to that and we have not gone by any methodology like Six Sigma and other details. So, but all these concepts are very much aligned with each other and they are systematically placed so that some methodology can be developed whether it is TQM, whether it is Six Sigma methodology all will talk about control.

And experimentation control and experimentation and, that is the only way you can improve quality basically, ok. So, we have used MINITAB as an interface you can use R as an interface. So, you keep on working on any interface that is not the I do not want to emphasize that you have to only work on MINITAB you can work on any interface like that.

And whichever is convenient to you whichever is convenient to you, but I have only demonstrated MINITAB software over here use of MINITAB software in quality control and or we can analyze the data based on this. But, there are n n number of software's which is also good SAS is there JMP software is there.

So, so many software's are available for the analysis, SPSS is there ok. So, people are using different software's based on the convenience and based on the availability. So, you have to also check whether the software is available in the public domain whether you can purchase that one.

And, a trial version is available for MINITAB is always there you can always practice using that thing and, but if you have a if you have licensed version in that case what happens is that it becomes easier to study this course ok. Data is given in the books that I have mentioned every data is available there and you can see the books and extract the data.

And, you can see the video how I analyze the data like that and later on you can experiments and make a confirmative trial and see that it really makes sense or not. So, all these things can be in real life you can implement this one and see that graphically what is happening.

So, visualization of the data is very important and analysis should be very correct and the assumptions of the techniques that we have we have discussed is also important also. If it is a continuous variable CTQ is required and then ANOVA analysis is to be we need to do ANOVA analysis and for the CTQ should be continuous raise the condition. And, we cannot violate that condition and say that any variables we can analyze by any way like that. We have learned some of the techniques.

So, I suggest is that assumptions of the models, assumptions of the techniques should be seeing first, limitations of the techniques should be also seen, and based on that you try to implement some of the ideas that we have discussed over here ok. So, thank you for listening and I wish every success for all of you who have registered for the examination.

Thank you.