Quality Control and Improvement with MINITAB
Prof. Indrajit Mukherjee
Shailesh J. Mehta School of Management
Indian Institute of Technology, Bombay

Lecture - 31
Measurement System Analysis

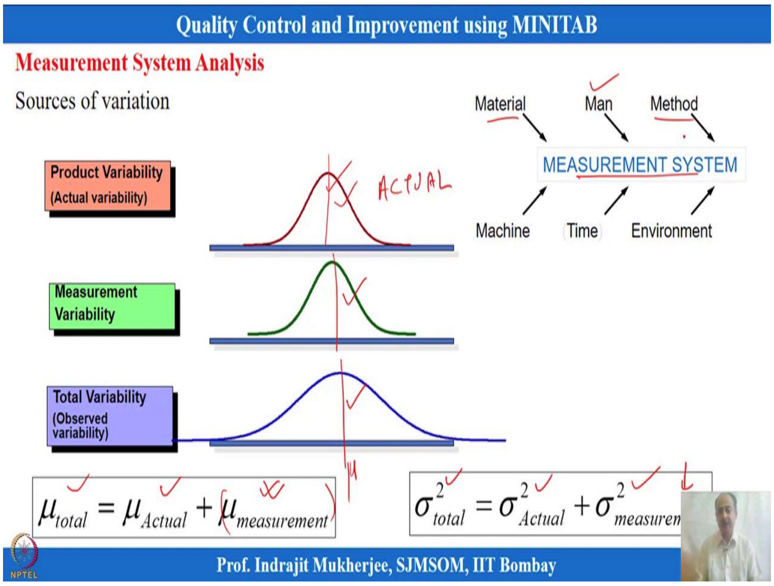
Hello and welcome to session 31 on Quality Control and Improvement with MINITLAB. I am Professor Indrajit Mukherjee from Shailesh J Mehta, School of Management, IIT Bombay.

So, in previous session studied that when we are experimenting with two factors, in that case how to make conclusion and make a judgment which factor is important which factor is not and whether interaction is prominent or not and overall judgment about what should be the optimal settings for a given experimentation that we have conducted.

Considering those are the only factors which influences the overall CTQs and we are making a conclusion based on the readings that we have generated by experimentation like that. Now, the authentication means these readings that we have taken whether that is accurate or not depends on the instrument that we are using for measurement like that.

So, it is always preferable to ensure that the instrument that we are using to get the measurements or overall variability of the process or CTQs should be correct and that will be minimum error in the instrument. And if the instrumental error is minimized in that case, we can ensure that whatever conclusion that we are drawing will be correct based on the instrument. If the instrument is correct everything will be correct, otherwise process capability and this design of experiments have no meaning if the instrument is incorrect and gives you some reading, which is not even closer to the true readings.

(Refer Slide Time: 01:49)



So, all this to ensure that the instrument is correct, we need to understand one important topic which is known as Measurement System Analysis. So, whatever C_{pk} values or variability analysis, ANOVA analysis that we are doing, we are assuming that the overall variability is correct and overall variability, total variability that we are measuring is correct.

But in this case what you have to consider also that the actual variability and this overall variability consists of actual variability, product variability and also some measuremental variations that is happening because the instrument accuracy also impacts the overall reading like that ok.

So, overall total variability distribution will be influenced by distribution of the measuremental variability and the actual product variability over here. So, this is the overall variability. So, also we have to understand that overall process mean that we are generating over here will include the summation of the mean that we are getting based on the product variability actual variability and also the measuremental system variability over here.

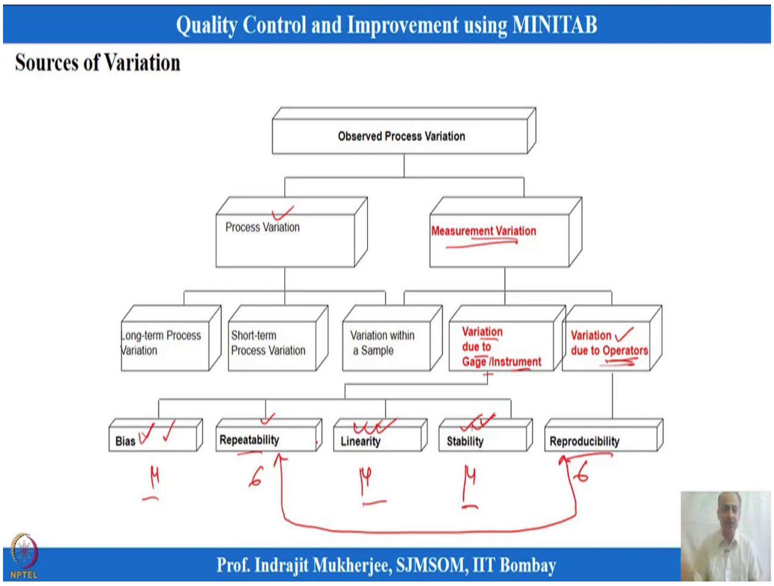
Total mean of the process will be equals to actual mean and also measuremental mean. Similarly, total variability if I am assuming normal distribution assumptions over here so, there are two parameters mean and standard deviation. So, in this case, total standard deviation of the process will depend on the actual variability and also the measuremental variability over here. Our objective is to minimize the measuremental variability so that instrument is quite correct and also to minimize the mean shape due to or biasedness because of this instrument over here. So, we have to reduce in such a way so that the overall variability true means does not shift true means.

So, error has to be minimized. So, biasedness of the instrument should be reduced and also the variability in measurements has to be reduced; measuremental variations in the instrument has to also be reduced. So, that is the overall idea that we are adopting over here. The total variability is influenced by measuremental variability and it is influencing the mean and variance of the overall distribution of the measurements that we are getting for the CTQs.

We can also draw a cause and effect diagram for this because it will be influenced by some of the parameters like person to person variability over here, the types of material that is used to develop this measurement systems and the environmental condition can also impact and the way we are taking measurements that can also have an influence over here. And what type of instrument that we are using that also can influence the measurement system.

So, this cause and effect diagram can also be drawn in case we want to analyse further that what is going wrong in the measurement system like that ok. So, those things can be we can take those initiatives to find out what is going wrong basically in the instrument measurement system. So, cause and effect diagram can be used.

(Refer Slide Time: 04:56)



So, overall source of variability if you see that one is process variation that is what is actually if we consider that one and the measuremental variation. So, measuremental variation is an important aspects which is also influencing my overall observations overall over overall variation of the CTQs ok. And this can be due to two aspects over here; one is known as variation due to gauge; that means, instrument gauge is the instrument that we are using over here.

So, measuremental variation the that can be contributed by the gauge variation due to gauge or instrument or variation due to operator because if you go to a process one person is operating the machine, he is measuring the outcomes of CTQs. And secondly, you go to a second shift somebody else is measuring that one.

So, person to person variation will be there. Even highly skilled operator will measure differently. A person working in tool room will have more precise estimation, but more precise accurate readings he can take as compared to the person who is in production flow and the person like engineers, they are unskilled workforce. So, they will measure something different.

So, variation due to operators can also go into the overall variability measuremental variations over here. So, that can also contribute to the variability of the overall measuremental variability. So, for variation due to gage or instrument we have some kind of studies that will ensure that how much is the variability due to gauge or instrument. One is known as bias studies, one is known as linearity studies over here, one is known as stability studies over here and repeatability.

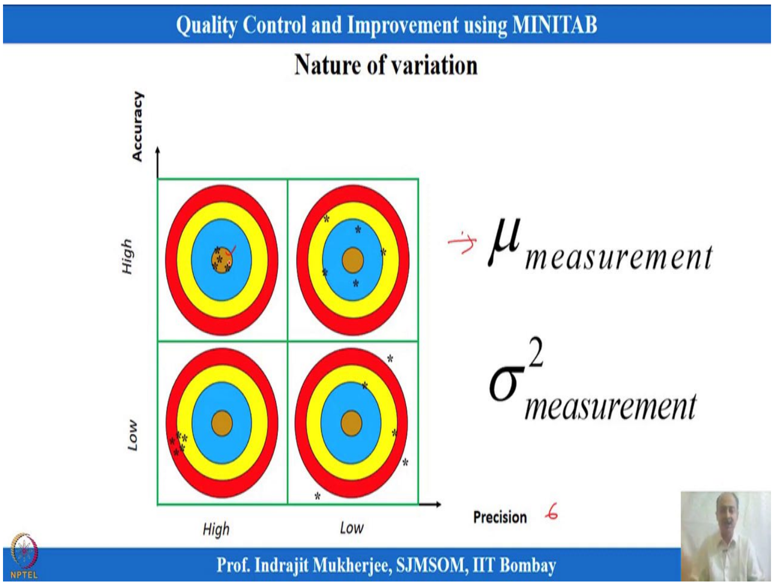
So, this is talking about the mean of the observation, this is also talking about mean shifting over here, this is also mean shifting over here; but this is sigma that is variability of the variability of the instrument that is happening. And variation due to operator also contributes to the sigma part. So, one is contributing to the mean part that studies which is relevant to mean which is known as bias study, linearity study, and stability study over here.

And when we are talking about the variability of the instrument sigma over here, we have two measures one is known as repeatability and one is known as reproducibility ok which is known as gage repeatability and reproducibility studies like that. So, that is GRnR studies like that. So, we have to understand each important aspects over here.

One is known as bias aspects which is basically talking about the location of the instrument average values like that. So, there will be some reference based on which we will make a conclusion based on that, how much is the bias whether it is acceptable not acceptable like that.

Similarly, linearity studies and stability studies. So, first we will talk about location aspects and then we will talk about the precision aspects of that. So, location aspects when we are talking about location, we have to remember we are talking about bias linearity and stability. When we are talking about precision aspects, we are just talking about these two aspects one is known as repeatability and one is known as reproducibility over here ok.

(Refer Slide Time: 08:05)



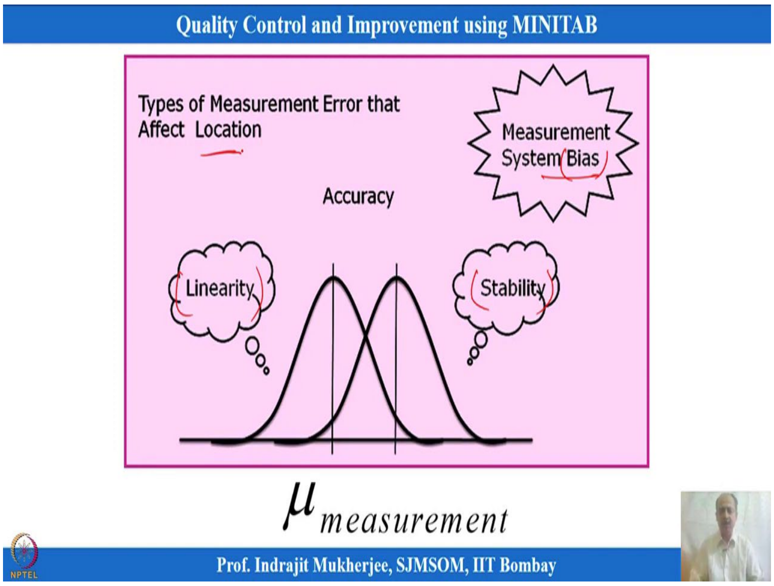
So, this is what we have seen earlier also in the diagrams for when we are talking about accuracy and precision. So, when we are talking about precision, we are talking about sigma aspects of this. When we are talking about accuracy, we are talking about the mean of this over here measuremental system mean whether it is shifting like that.

So, in this case two aspects accuracy and precision what we know earlier also. So, I need the instrument to be very accurate and also precise like that. So, no bias in the instrument and also the variability in measurements that we are getting also should be minimized; that means, repeatability of the instrument should be very high. So, that that two aspects we have to ensure like that.

So, we are talking about mean of the instrument measuring instruments; that should be have minimum bias or bias should be near to 0 and variability also should be near to 0.

So, bias is equals to 0; means from reference point to the average that we are getting from the measurement instrument should be near to 0 like that. So, mean and variance both are important in case of measuremental variation. When we are talking about reducing measuremental variations, these two things are to be minimized so that their contribution to the overall variation or CTQs variation is minimal. That means the overall variation is actually representing the true variation of the process like that.

(Refer Slide Time: 09:25)



So, one aspects over here is the measurement system bias over here. So, bias is one of the term that we are concerned about. Linearity is another important study that is also we need to do. So, and another one is stability study. So, each of them we have to understand what is the meaning of this. So, one is bias, one is linearity and one is stability over here.

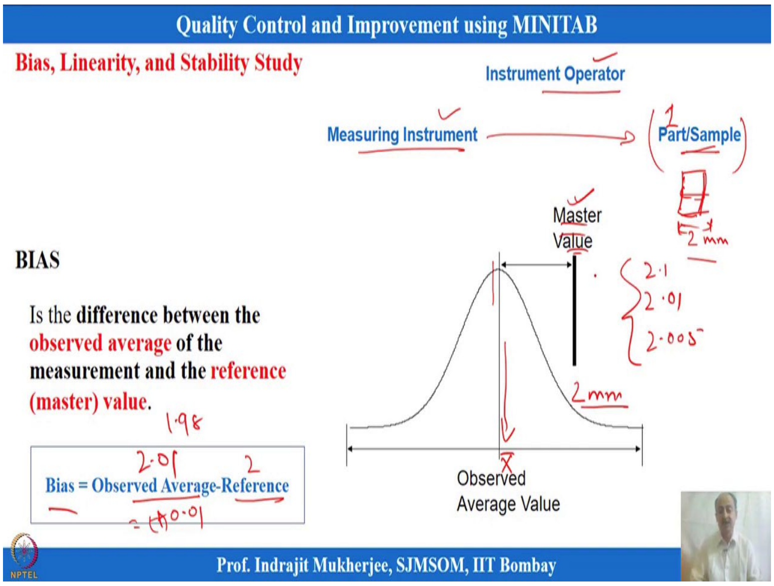
So, and if there is any error so, what will happen is that the mean will shift from the true measurements. So, there will be bias. So, we want the bias to be near to 0 and linearity is the total scale of measurement that we have for this instrument like that and everywhere the bias should be close to 0. So, there will be not be significant difference at different length range of measurements that we are taking from the instrument. We will go into the details of that. So, let us go step by step; what we want to understand is bias first, then linearity and then stability like that which is talking about the location or mean of the measurement system over here.

So, one way one is influencing the mean and one is influencing the variability. We are talking about the mean those studies which basically says how much there is a shift in bias, how much is the shift in how much is the overall bias and how much is a trend of the bias like that whether it is acceptable or whether we need to send it to calibration and do some rectification on that.

And you may have also observed that when you go to the shop floor and you see some operator is measuring something some. Before they measure the CTQ, what they do is that they have a reference dimension kept in the shop floor and what they will do is that they compare instrument reading with correct reading of that.

So, there is no variation of the true reading from the measurements that they are getting with the instrument. Let us say Vernier Calliper what reading they are getting? There should not be any difference like that. So, they will do that before they take the reading of CTQs like that. So, those are some of the things you can observe if you go to a shop floor like that ok.

(Refer Slide Time: 11:38)



So, first we will explain bias of a reading that we are talking over here and then we will talk about linearity and stability studies like that. So, bias is the difference between the observed. So, I will have a part over here. I will have a part reference part let us say and maybe that dimension is given as 2 millimetre like that and then I have a measurement instrument which I will use to measure this part several times. I will use this part and there is only one single part.

Let us say only one part we are having over here and that I am measuring same operator; operator will be same and that operator, we measure it several times operator will measure it several times and you can do it blind studies like that you will not say the operator, this is the same part that you are measuring over here.

You can just you can just say that these are the parts that you have to measure over here and he does not know whether the same part is given or not. So, to ensure that there is no biasedness in the observation that he is mentioning like that he or she is mentioning like that.

So, he will have a single operator over here and he will have a single instrument over here and the part will be thrown randomly like that. He will not know which means the part is same or not. He will not tell that this is a biased study like that. So, we will give the same parts time and again, but the operator will not know this is the same parts like that and the measurement will be taken.

So, you will have a average observations of the because operator will say this is two point 2.01 something like that if the least count of the instrument is 2 plus of decimal. So, he may also say that this is 2.005 like that if it is three place of decimal like that, we can measure like that and this can be he can also say this is 2.1 like that.

So, the measurements will differ every time you are giving the part and he does not know that the part is the same part like that. So, there will be variation in the observation; there will be variation in the observation. And the overall observation mean you can measure over here. So, that sample observations and the master observation which is 2 that is also we have information that the 2 millimetre dimension.

And how do I get this master value over here? This is sent to calibration or this instrumentation that lab that rectifies if there is any problem with the instrument or metrology lab we can think off. So, in that case what happens is that they gives you some master value of a particular specimen.

So, you send it to the mass this specimen or one of the one of the product that is being that you have produced and the CTQ also mention that what is the what is the width of the width dimension, I want of this and tell me accurate reading of that. So, they have a precise instrument to measure that one and they will say that this is 2 mm. So, masterpiece is the value is with you which is 2 mm and then you ask the operator to measure it several times like that.

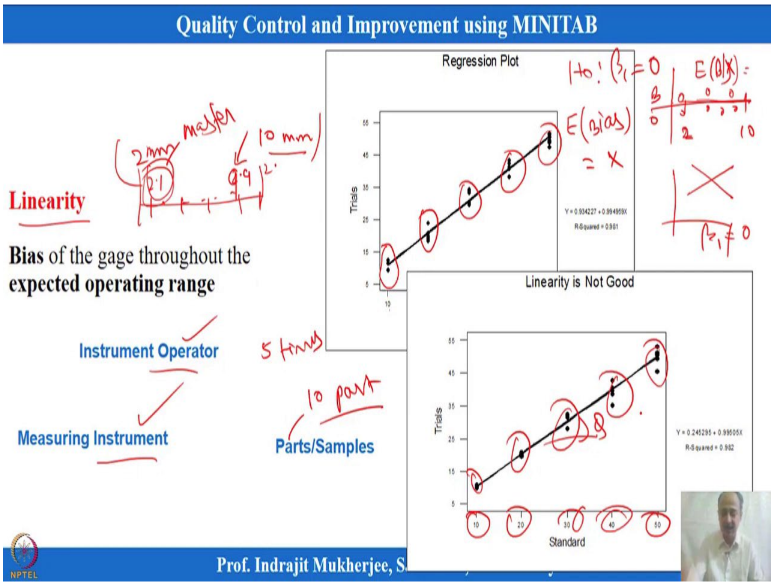
So, on an average whatever average that you are getting and from the reference value. So, bias is equals to observed average from the reference value. So, this is 2 and observed average let us say 0.1. So, in this case bias will be equals to 0.01 like that. So, this is the positive bias on these aspects. You can say that this is the positive bias that is defined over here. And if it is 1.98, then in that case, it will be negative bias like that.

So, bias can be on the positive side it can also be on the negative side. So, what you have to remember over here when you are doing a bias study; it is the same instrument, same operator, same parts and you are making you are asking the operator to measure it several times like that. When you measure it several times, there will be variation in the readings like that. What the operator says? Because operator does not know the same part is given to that person like time and again like that.

And this is a cross sectional study; that means, you have done the study at a specific time point and based on that you can calculate what is the bias of the bias of the instrument like that, what is the bias because on an average is the operate is measuring something and the master value is different that means, some amount of bias already exist between the actual observation and the master value that is given by the metrology lab to you ok.

So, these measurements we can get what is the bias of the instrument and MINITAB does it automatically for you. If you get if you say the master observation and you give the actual observation, it will give you what is the bias and what is percentage bias and all this information, we can get and we will see it in MINITAB how it is done.

(Refer Slide Time: 15:56)



This is one important aspects. The second important aspects which talks about location is linearity over here throughout the operating range; throughout the operating range of the instrument. So, if an instrument can measure from 2 to 10 mm dimensions like that. So, in that case this is the operating range of the instrument like that. So, within this operating range, we have to select parts at different locations in the operating range over here.

Let us say this is one of the part which we have selected over here 2.1 over here, this is 2.9 over here and this is 2.0 this is approximately. So, this is 2 mm, 2.1 like this. So, this is let us say 9.9 over here and this is 10 mm I have to measure like that. So, I will select a part which is I will select a master which is equals to 2.1. I will also select a master which is equals to 9.9; like this maybe 10-15 masters we have to collect.

And we have to keep it for this linearity studies like that and each of these masters has to be measured by the operators. So, there will be operator and instrument will be same. Only we have different plots let us say 10 parts within this operating range of the instrument and each of the parts will be measured by the same operator and with the same instrument.

So, at every point we will have a number of observations. Let us say we are measuring it 5 times. So, I will have 5 observations at a given at a given reference value. Similarly I will have a number of observations at different reference value over here.

And these trials will be conducted. So, in that case what will happen is that at every location we will have a bias, at every location we will have a bias. And based on those bias information at every location throughout the operating instrument and we will get different biases like that and we can also calculate an average bias.

And then what is expected is that if this is the bias over here and this is the zero point over here and you have taken the reference value from 2 to 10, let us say and it is expected that all the values should be close to 0 over here.

And if you draw a line over here through this so, you will not get any trend. So expected value of the bias what we discussed in regression over here for a given value of x which is from reference value 2 to 10, we do not expect any slope over here which is significant like that.

So, but if the bias changes and we have a slope in the bias like that on the positive side or negative side and the slope is significant or β_1 is significant over here and not equals to 0. So, in that case that is a that is a concern for us. So, we do not want that linearity measures that we are using over here which is represented by slope over here. Slope should not be significant; that means, we should not get a significant regression equation out of this.

So, what is expected is that slope is near to 0. So, we are testing and hypothesis where $\beta_1 = 0$ and we are making a regression equation of the bias over here. So, bias is regressed with the value reference value that is x over here which is changing. So, this is starting from some values and it will let us say from 10 to 50 over here; so, 10 to 50 something like that 30, 40, 50.

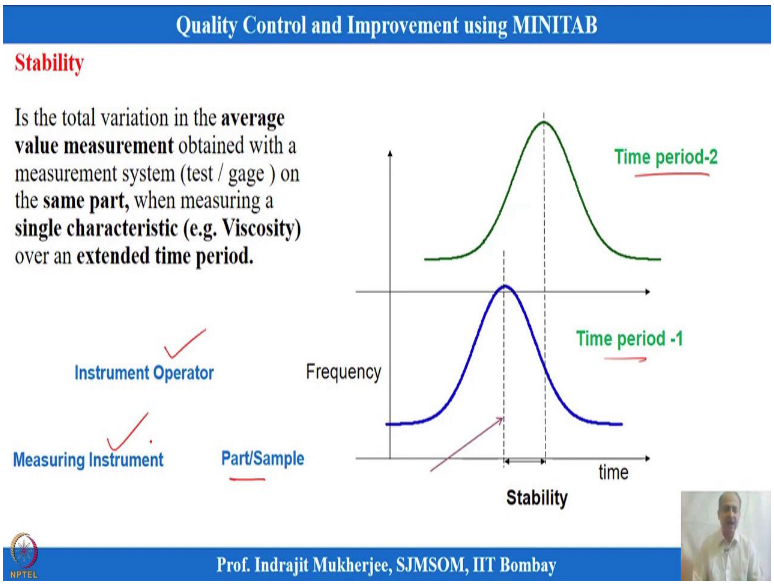
So, 5 reference values we have taken over here and every point we have measured some observations over here, we have five set of observations over here and we want this slope to be $\tan\theta$ should be equals to 0. So, MINITLAB does it automatically for you and tells you what is linearity over here and that we can see with an example.

Linearity is the change of bias towards the operating range and we need to ensure that the slope is near to 0 or $\beta_1 = 0$ that hypothesis testing, we are doing over here ok.

And if slope is significant then we have to see why this is happening basically in the instrument. Then again cause and effect diagram and based on that we take some corrective action. We send it to metrology department and they do the corrective action and send it back.

When I am measuring on the lower side, let us say low bias if I am measuring on the higher side higher bias like that if it is high bias; in that case that is not expected bias should be insignificant throughout the operating range like that. So, this talks about bias over the operating range like that. So, this is linearity study what we have discussed.

(Refer Slide Time: 20:44)



And the third important another aspects which talks about location is the average value which is changing over a period of time. So, here time is given a dimension so, longitudinal study. So, in this case time period 1 and time period 2 like that, we have a reference value.

So, we have a single part, we have a single operator, we have the same measuring instrument and the same part will be measured at different time points and the reading how it is changing over time. So, that can be monitored using control chart techniques.

Sometimes what happens is that viscosity changes with respect to time like that. So, when I am measuring the instrument at a given time point viscosity is showing something and different time points it will show. So, instrument should measure the same CTQ and same samples time and again time and again measurement should be same it should not change like that.

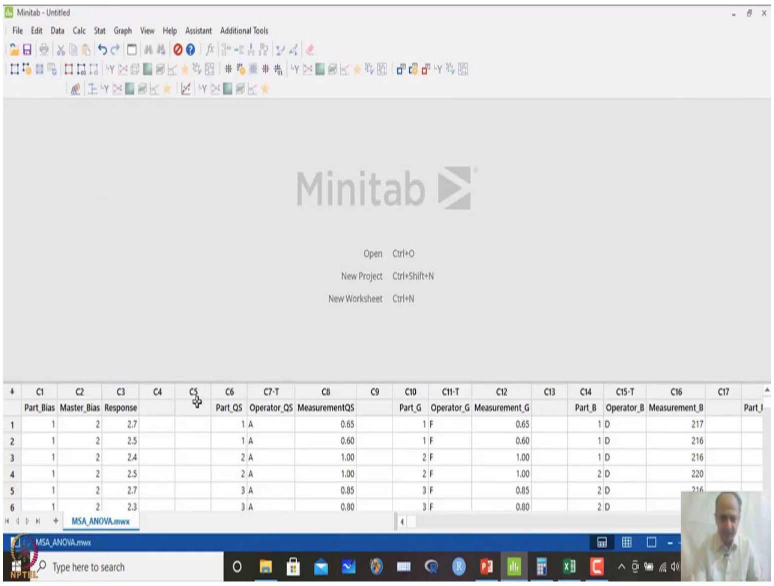
So, instrument should be precise. So, time does not have any influence over the readings that you are generating like that. So, maybe at different operating range or temperature that is environmental temperature should not influence like that. So, in winter the measurement should be same as in summer also. So, measurement should be same for a given piece observations like that.

So, this is what is known as stability studies. So, that we can see that throughout the time period that we are measuring and the instrument measured the same dimension every time. It gives you the same observation, same measurement. It does not change with the environmental conditions. So, that has to be ensured which is known as stability study over here. And this is monitored based on this bias how the bias is changing it can be monitored using a control chart mechanism what we have discussed earlier, how the bias is moving whether some abnormality is observed with respect to time that can be seen like that.

So, all is talking about locations over here one is talking about a single sample and the bias of that bias of the measurements that we are getting or whether the average readings is different from the reference rating like that. And if you change bias throughout the operating range that is studied in linearity and the change in bias with respect to time when we are studying that is known as stability studies that we are doing over here.

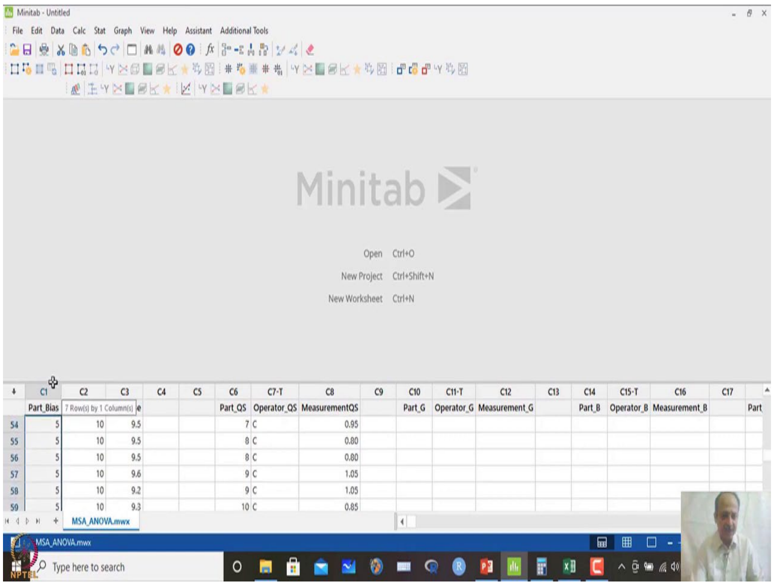
And these are the three aspects that we need to study initially to understand and we will do the bias and linearity study using an example over here. So, we can take certain examples over here and what we are doing over here is that we will take an example of linearity study a linearity biased linearity study like that.

(Refer Slide Time: 23:33)



So, we are going to an example over here where part observation is given in C1 and the masterpiece reading is given in C2, C3 is the response over here.

(Refer Slide Time: 23:46)

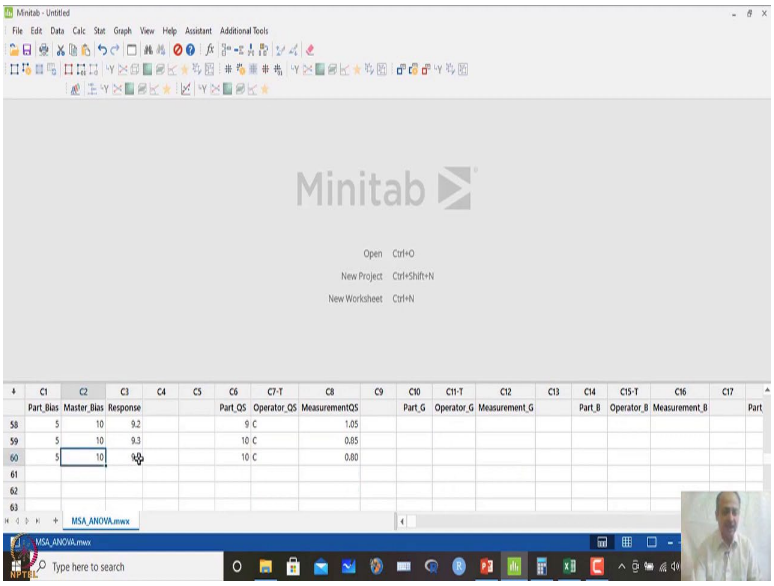


So, initially what we are doing is that we have different parts. So, part 1, 2, 3, 4, 5. So, different 5 parts are selected over here. And in this case each part is having a master value over here. So, first part is having a master value of 2 and second part is having a master value of let us say 2 mm, 4 mm like that and like this 5 parts as a master information. So, master value of this part 5 is 10 mm; let us assume over here.

So, each of these parts are measured by the same operator over here and there are 12 observations you can see. So, 12 measurements are taken and the response is given.

To an operator I am giving five parts randomly and the person does not know which part I am giving and he will give you some response what is the value of that. So, master value was 2 he reported 2.7 like that.

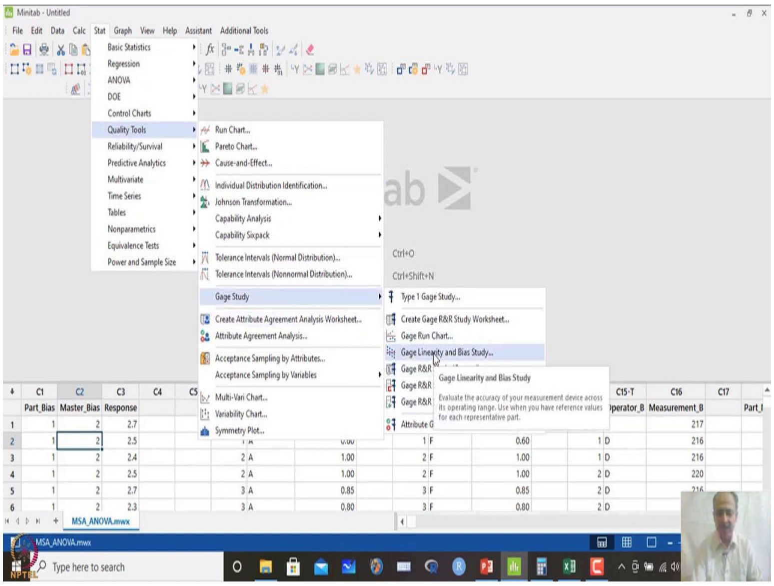
(Refer Slide Time: 24:56)



Similarly, the master value was let us say last one 10 and the he was delivering the observation is 9.4 like that based on the instrument that he is using ok. So, I am doing the bias and linearity study together. So, there is the and MINITAB gives you overall readings like that and we can make conclusions based on that ok.

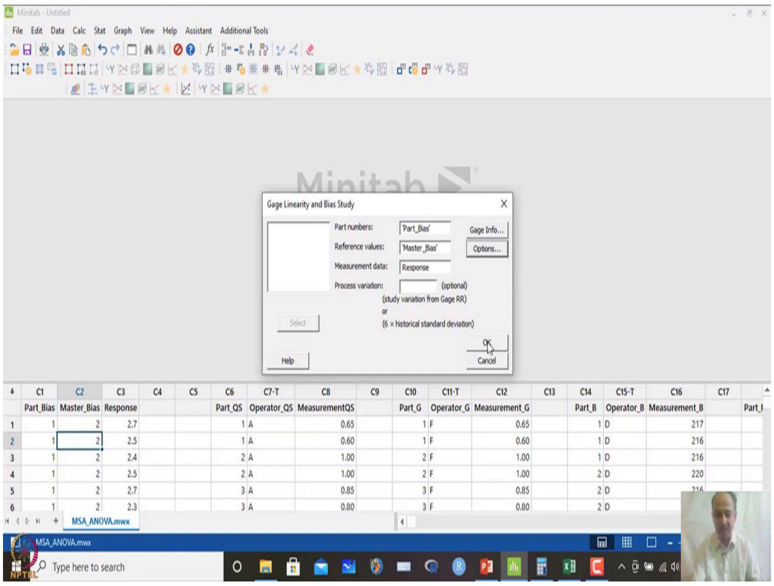
There is a master value for these parts and the response is collected from a specific operator; we are not changing the operator over here. So, same operator we are using and we are changing the parts and the master value of the parts are different over here. So, I want to see bias and linearity study together over here and the results can be seen.

(Refer Slide Time: 25:36)



And when we when I go to stat, what you have to do is that I go to quality tools over here and when the gage studies are there over here.

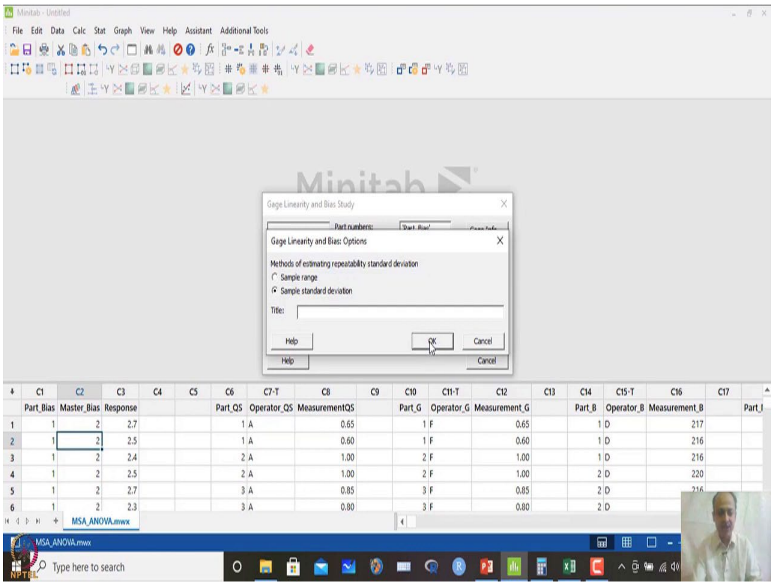
(Refer Slide Time: 25:46)



So, if you go to gage studies over here and go to gage linearity and bias study over here. So, in this case what you have to do is that you have to mention that now what is observations that you have got. So, part numbering. So, this is the first column C1, I am giving reference value is given master value is given over here and the measuremental value is given as response over here like that ok these are the observations.

So, in this case they will ask for process variation over here. This is the optional we have to find out the process variability like that and based on that we can make certain conclusion and those are the reference that many companies use like that. So, if I know the process variability percentage of that based on that, I can make a judgment whether the instrument needs correction or instrument is not suitable to be used in the manufacturing like that.

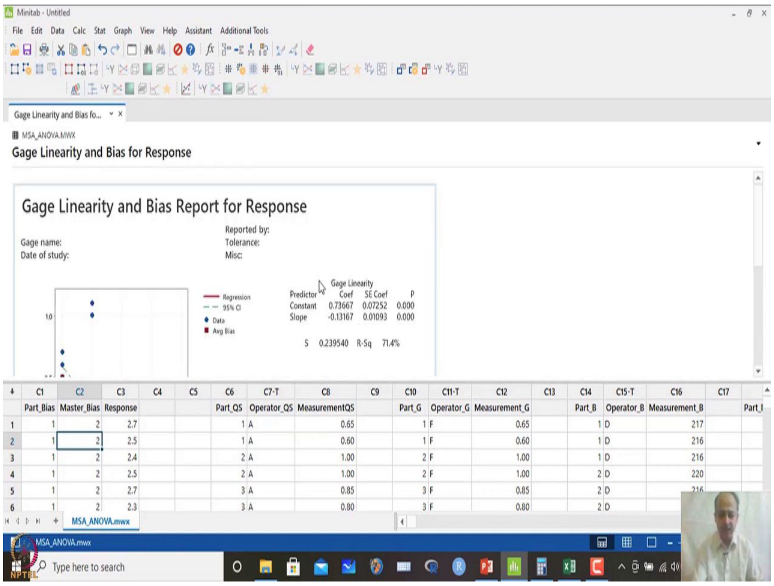
(Refer Slide Time: 26:31)



So, then in options you have to check that the method of estimating repeatability standard deviation over here which will influence the T value calculations like that what options I will click. So, I will click sample standard deviation over here which will say that whether the bias is significantly different or not.

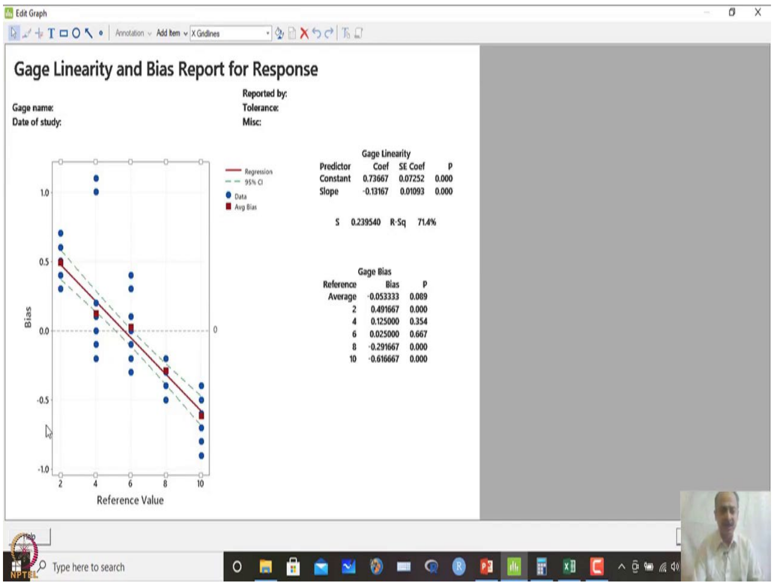
So, that p value interpretation that will come based on the sample standard deviation that we are using ok. So, if you have done this one and process variation, I have not mentioned over here let us at present do not give that one.

(Refer Slide Time: 26:58)



If you click ok over here what will happen is that you will get some values over here; you will get some values that is represented over here.

(Refer Slide Time: 27:02)



So, in this case what you see is that all observations so, reference value is 2 and in that case 2 was the reference value 2 mm, 4 mm, 6 mm, 8 mm and 10 mm and I have taken 12 readings or something like that and this red spot that you see is the average of these values that you have got all the average values are given over here.

And this is the bias line on this side bias on these aspects. So, what is plotted over here is the bias that is for the 12 observation that we have got and the average bias is the red spot that you see over here. At any given reference point what is the average bias from the observed readings that we are getting over here.

So, this is on the positive side, this is on the positive average bias; this is near to 0 and then again negative bias, we are observing on the other two observations over here, 8 and 10 ok. So, this will be shown over here. So, you see for a reference value 2, the bias is shown as the observed minus reference and that is coming out to be 0.49.

And similarly the average values difference from the reference value is given over here. So, last two 8 and 10th observation, you see negative bias what we are observing others are positive 2, 4 and 6, but 8th and 10th observation is negative bias over here.

Then this bias observation with the standard deviation, I have a T statistics and that confirms whether the significant bias is observed or not and p value interpretation. The same p value interpretation we are we are observing over here. So, at a reference value of 2 what the p value is significant over here, what we are observing and then at reference value of 8 and 10 we are observing a significant p values is observed over here.

So, what is important over here is that at the lower side of the reference when I am measuring parts which are at the lower end of the overall process variation that we are measuring over here. So, at the lower end also we are getting a significant bias, on the higher end also we are getting a significant bias; only at the middle range of observations that we are measuring we are not getting biasedness in the instrument like that.

So, the overall average of the bias will be reported over here 0.05 that is the average of all these bias over here and it is showing a negative bias over here. Whether it is significant or not overall average bias, whether it is significant or not that is shown over here as 0.089 we can ignore this one; that means, gage biasness is overall bias average bias is not so significant over here that, but individually if you see this at reference 2 and reference 8 and 10 this is significant the bias is significant and this will be reflected.

So, this study when I plot this one, I am seeing a slope over here and the slope will be so, a regression equation will be fitted by the MINITAB software and it will say that what is the constant value β_0 and β_1 estimation. So, slope estimation is minus 0.13 like regression, it will use a interpretation of p value and p value is coming out to be significant over here and the regression model is having R^2 of 71% like that.

And as the slope is significant; that means, the instrument has linearity and whether to accept that one or that we will see in our next session like that, but 71% R^2 value; that means, a fitted regression model is prominent over here. And if it is not what is expected is that the we should have expected something slope.

And it should have gone through like this, it should have gone like flat. So, we do not expect any slope over here. So, what you do if the slope is not significant so, what is expected is that you may have you may have got a flat line from the 0 bias condition like that.

So, whenever the slope is prominent and θ is prominent over here, in that case what will happen is that regression equation β_1 coefficient will be significant. That is what reflected in the studies over here that the β_1 is significant over here and that is shown over here and the R^2 value is prominent.

And now overall average bias is not significant, but individual it is coming out significant. So, slope is coming out about - 0.13. Now, what is the criteria? So, then to get the criteria whether to accept the instrument or send it to laboratories like that we need some information on process variability because this is measuring a values within a range of 2 to 10.

So, this is basically the overall range of the instrument that or the output CTQ that we are getting. It should be within this mostly within this operating range. So, whenever we are taking the samples of the CTQ from the lower range measurement and also on the high end measurement and one single instrument is used to measure the complete information of CTQ and that instrument linearity we are just checking over here.

So, that we have to keep in mind and in next session what we will do is that we will continue discussion on this. Only thing is that we will incorporate a process variation over here and estimation of process variation over here. So, that we understand whether the linearity is acceptable, bias is acceptable or not and then we will go ahead with the other aspects which is known as gage repeatability and reproducibility which talks about sigma aspects of that.

So, here we are talking about bias or accuracy part over here and whether to accept or not and later on, we will study about the variance of that whether to accept the gage or not based on variability over here. So, if there is any problem we have to send it to metrology lab and they will do the corrective actions or they will replace the instrument like that if it is not correctable like that.

So, bias can be changed and can be adjusted in the instrument like screw we can just see whether any screw is loose or not if it is a mechanical instrument like that and those things can be done in the metrology lab and or it can be sent to the instrument manufacture and they can do that adjustment. And if it is not possible, we have to replace the instrument like that.

So, we will continue discussion from here on linearity and bias and what is the reference point or reference values we should check to say that this bias is acceptable, this linearity is acceptable like that we will continue our discussion in our next session.

Thank you for listening.