Six Sigma
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Lecture – 20
Measurement Systems : Fundamentals

Hello friends, I welcome you to the ongoing journey of Six Sigma and as you know that right now we are discussing the major phase of our DMAIC cycle. And we have already discussed couple of things related to the major phase in the last lecture. Now this particular lecture 20 will deal with Measurement System Fundamentals. And we will try to appreciate the importance of the measurement system, because if your measurement is not accurate then whatever subsequent analysis you will do in the analyze phase will be having no value and it will mislead you to the wrong actions.

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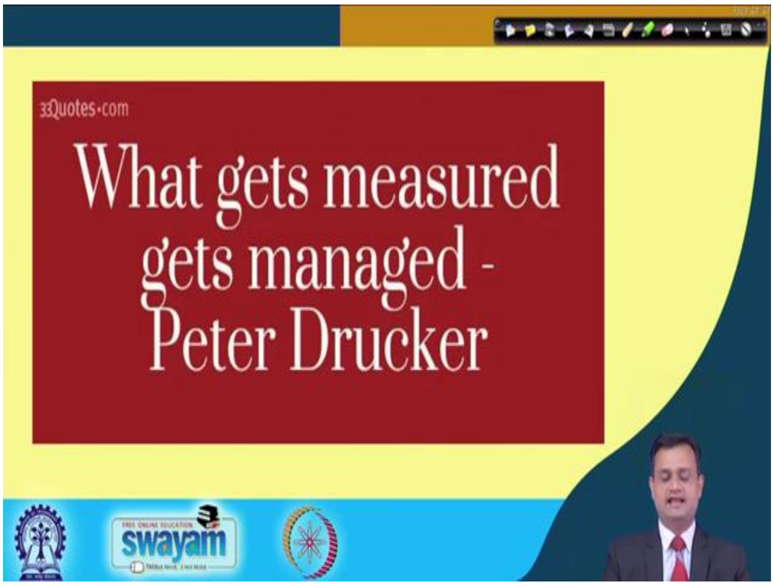

So, there is a good saying, I have also shared this quote previously, what get measured gets managed by peter Drucker. And we all understand the importance of measurement system, but it is more important to see that the measurement system I am using is accurate, precise and hence the data collected really are worthy of analyzing. So, this part we should ensure by understanding the concepts related to measurement system and checking that how accurate, precise my measurement system is.

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So, if we just see the recap then we had 2 lectures on data collection and summarization part 1 and part 2 and in last lecture part 2 of data collection and summarization, we had seen various graphical methods, histogram and bar chart, frequency distribution, stem and leaf plot, box and whisker plot, Pareto diagram and so on.

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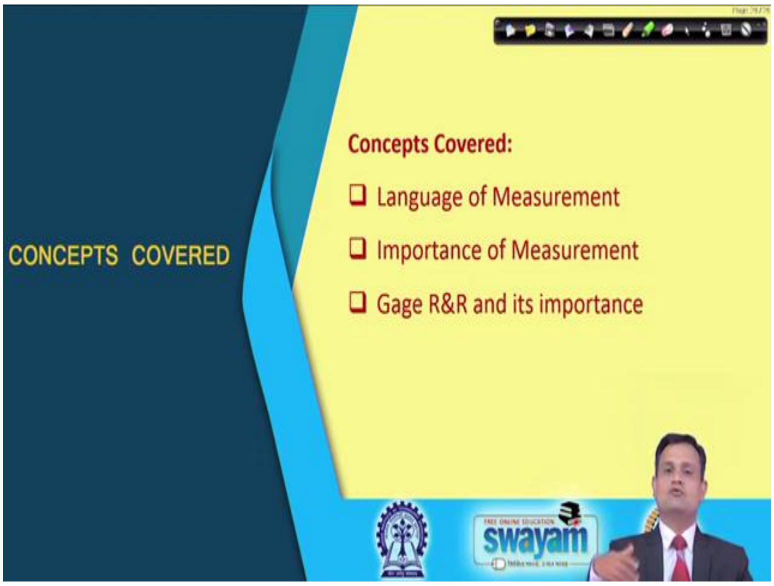

So, this lecture, will basically deal with language of measurement, importance of measurement and measurement system, gauge R & R and it is importance. So, this will help you to be familiarize with the vocabulary, importance, critical dimensions of the measurement system and subsequently in the next lecture we will go into more detail of gauge R & R study that is gauge repeatability and reproducibility study conducted for checking the preciseness of my measurement system.

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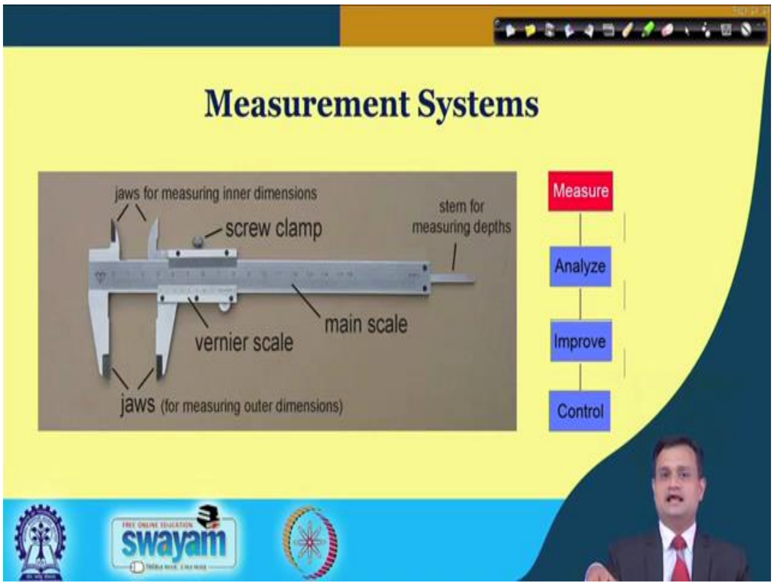

So, you have seen various measuring instruments like, Vernier caliper the simplest one you are using scale or tap, micrometer, various measuring instrument you are using and as I mentioned typically measure phase we are dealing and whatever we will collect that will go in to the analyze phase and then based on my analysis I will initiate the actions for the improvement and control. So, this phase provides the input to the subsequent phase and if inputs are wrong if my measurement system is faulty and inputs are wrong then my analysis will definitely prompt me to take the actions in the wrong direction.

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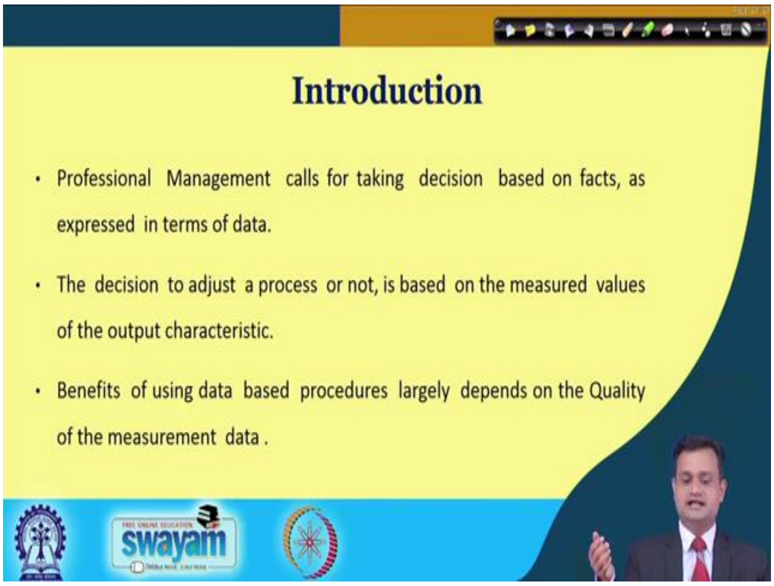

So, professional management calls for taking decision based on facts, as expressed in terms of data. And the decision to adjust a process or not, you will then get prompted to modify process or to do some adjustment with the process and based on the measured value of the output characteristic. Benefits of using database procedure largely depends on the quality of the measurement system and hence the measured data.

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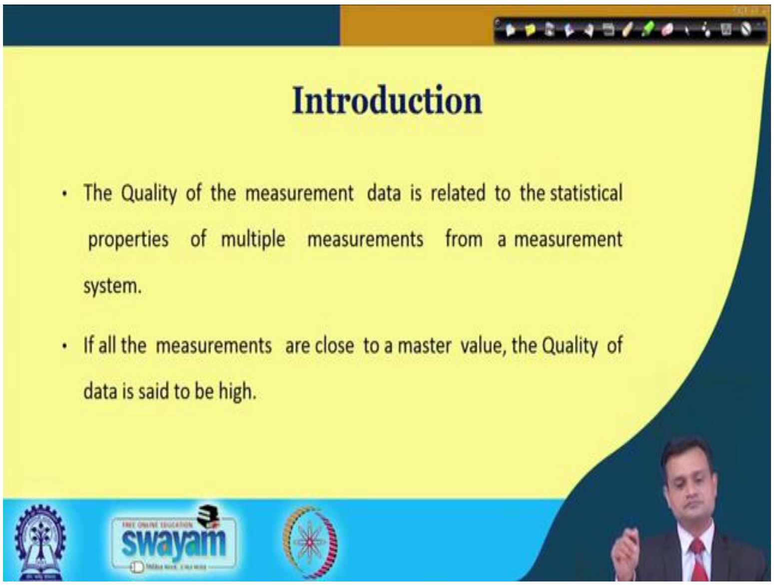

The quality of the measurement data is related to the statistical properties of multiple measurement from a measurement system. And if all measurements are close to master value, that is reference value, the quality of data is said to be very high.

So, if you have a master say tool, measurement tool, bench mark tool or if you check your readings, compare your readings with the measurement system available in very high end laboratory and if they matches with the reference values then you will say that the quality of your data is very high and you can rely on your measurement system. And hence subsequently your analysis and the necessary actions would be in the right direction.

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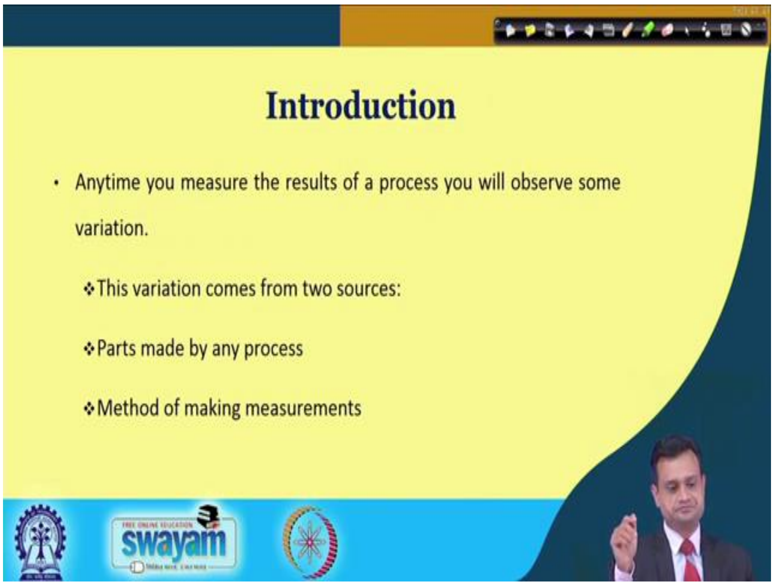

Any time you measure the results of a process you will observe some variation, so, variations are part and parcel of the system we cannot avoid variability 100 percent, there are some natural causes random variations it will take place, but there are concerns when there are some assignable causes. We will talk about various random and assignable causes later on, when we will talk about statistical process control , but mainly say in terms of measurement system you can say that the they variations they come from two sources; number 1 part made by any process.

So, suppose you are manufacturing let us say bearing, then outer diameter of the bearing if you take a sample of hundred bearing you will find there would be some variation, suppose your nominal value is let us say 50 millimeter then 50.1 ,50.2, 49.9 something like that some variability is always there, so long it is within the tolerance limit it is acceptable.

Now, this part is made by some process and this process has inherent variability and hence the output will also have some variability. The second one which is the focus of this particular lecture and we are concentrating on that is the method of making measurement. So, first part is ok, so, long it remains within limit and it is only because of the random variation, but second part if you see if the bias or some kind of error in the measurement system dominates the total variability, then whatever reading you are taking is not actually reflecting the overall health of the process.

So, how controlled your process is that is my interest, so that I can initiate the corrective action, but if my measurement system is faulty, then I would be taking the wrong the decision and try to unnecessarily say take action on the stable process which is producing otherwise the good quality products. So, variability because of measurement system must be countered and it should not unnecessarily give me a wrong impression that my process is out of control or there is something wrong with my process.

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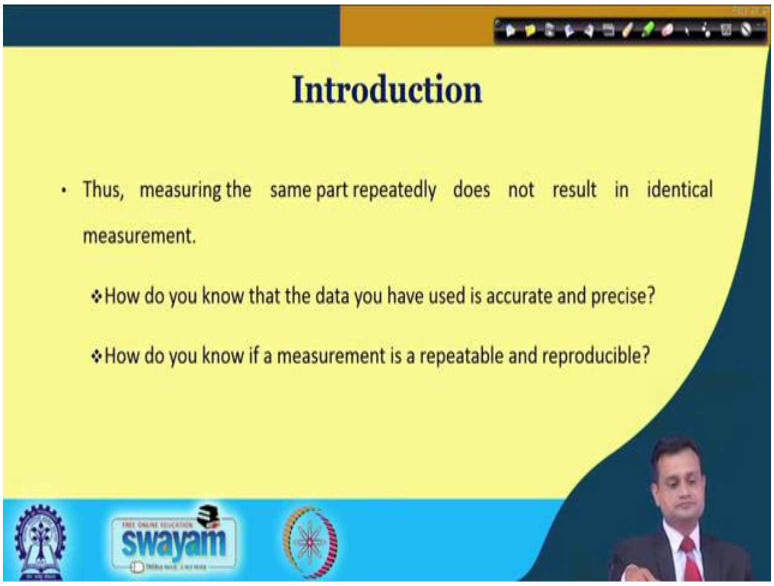

Measuring the same part repeatedly, does not result in identical measurement. So, you will have a situation that you are taking the part you are using some measurement device may be vernier caliper or micrometer and you are taking number of reading, either same operator or different operator we will see the cases.

And you are not getting the reading within a particular range or same reading, then how do you know that the data you have used is accurate or precise? Second is how do you know if a measurement is repeatable and reproducible? So, if you encounter any such situation, then it creates a great suspicion that whether the data I am collecting is really worthy of analyzing or it is faulty.

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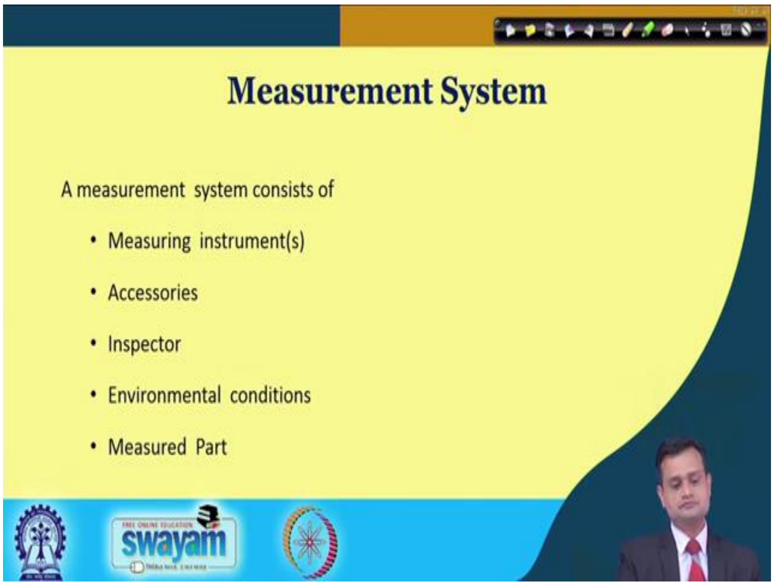

So, typically measurement system evaluation is the most important part as a part of measure phase in six sigma and measurement system typically consist of measuring instrument or multiple instruments accessories you may use to support the measuring instrument or the necessary attachments, then your inspector appraiser who is basically taking the reading or having the interaction with the measurement system.

Environmental condition; yes humidity, temperature and other factors that may have some impact on your measurement system and the measured part. So, this typically creates the complete system of measurement system and we should analyze this components in detail to get a fair idea on the accuracy and precision of my measurement system. Once I have confidence in my measurement system then I will take the readings for necessary analysis and actions.

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So, here I am just putting variety of measurement systems, instruments and the question is how good these are? Should I simply believe, should I simply use them and take the data and analyze them. So obviously, I cannot do it I have to say analyze and first check the accuracy and precision of my system.

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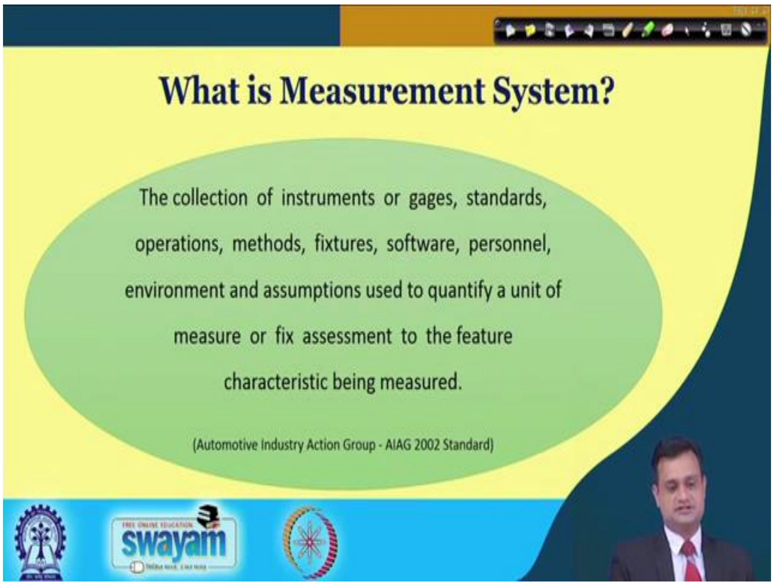

There is a very good definition of measurement system given by automotive industry action group typically called as AIAG and 2002 standard this definition is documented. So, it says that the collection of instruments or gauge s, standards, operations, methods, fixtures, software, personal, environment and assumption used to quantify a unit of measure or fix assessment to the feature characteristic being measured. So, this is typically constitutes a measurement system and these various components they contribute to the accuracy of the measurement system.

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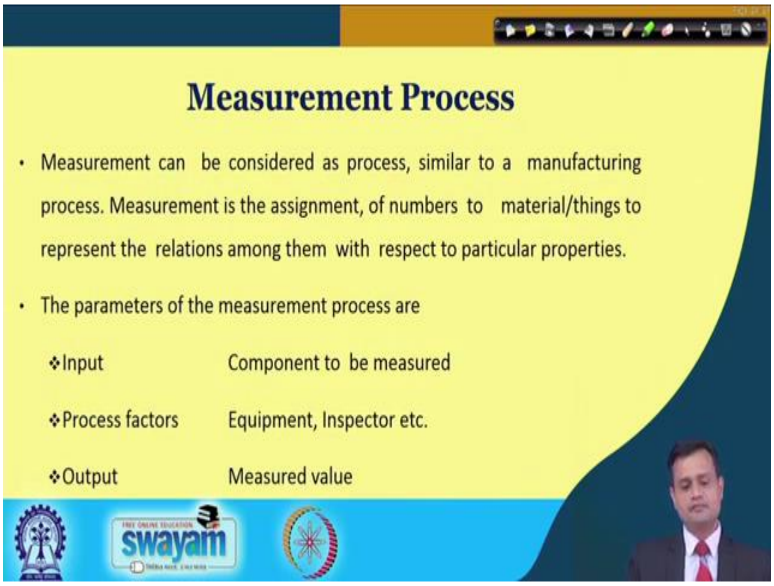

When you see the measurement process, measurement can be considered as a process you have the input may be your parts, components. You have the methodology to measure and as an output you get some desired say measurements data. So, it is a process similar to manufacturing and measurement is the assignment of numbers to material things to represent the relation among them with respect to the particular properties.

You might be measuring the say length, volume, weight, hardness and so on. Input is component to be measured as I said process factor you have equipment, measuring device, inspector, appraiser and output is the measured value.

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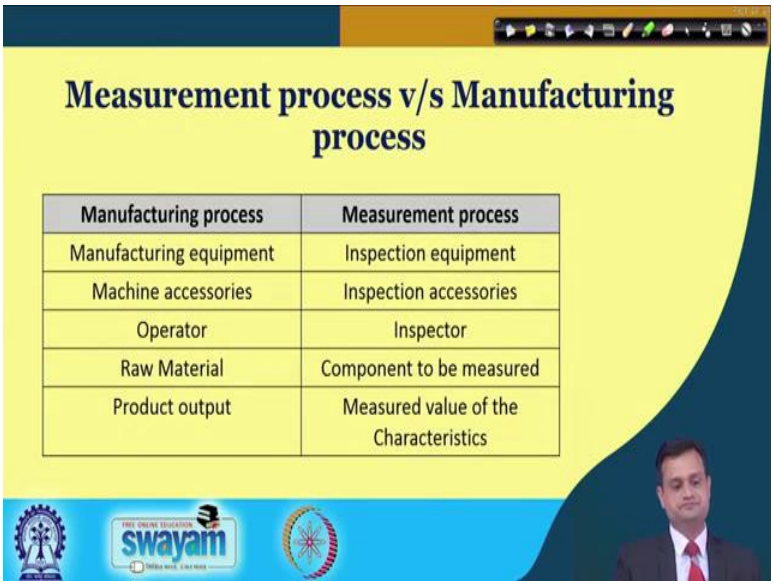

Now, if we compare further manufacturing process and the measurement process. Then in manufacturing process you have manufacturing equipment, in the measurement process you have inspection equipment. In manufacturing process you have machine accessories here you have inspection accessories.

In manufacturing you have operator, here you call the person as inspector or appraiser. Manufacturing you have raw material, here you have manufactured component to be measured. In case of manufacturing your product output and in this case you basically generate the data or the measured value of the characteristic.

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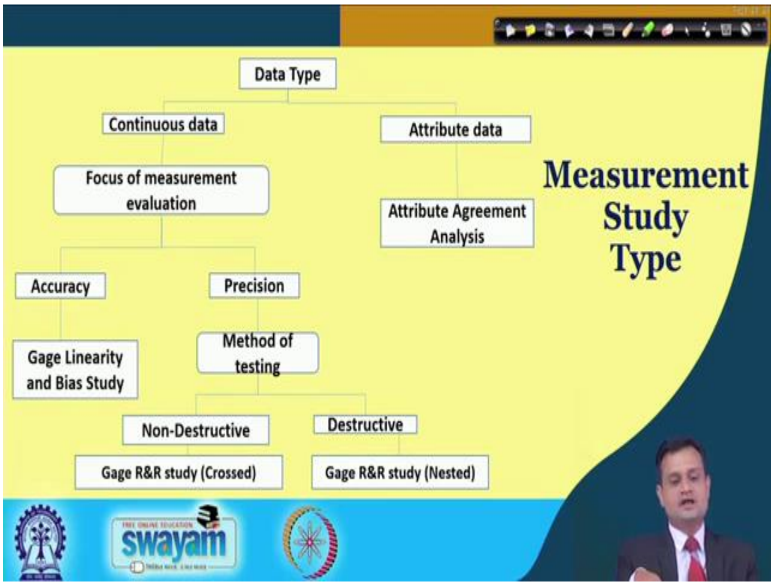

Now, let us try to have the broader understanding of the measurement system study and what type of study we may conduct. So, for that let us try to appreciate that what could be the data type first. So, you can have continuous data and attribute data and continuous data basically you measure in terms of say may be decimal or a discrete value.

And in attribute data you will say that fine this component with respect to the gauge or with respect to the benchmark it is or not. So, continuous data focus of measurement evaluation is accuracy and precision and you have gauge linearity and bias study and method of testing for precision non-destructive and destructive. So, within non-destructive gauge R & R study crossed and gauge R & R study nested within the destructive.

We will mainly focus in this lecture and the next lecture on gauge R & R study crossed I will just try to explain what is the difference between these two. But typically for variable kind of data the issues like accuracy and precision are of utmost important. And for accuracy, you try to check the gauge linearity and bias for precision you have gauge R & R study.

So, once again I am repeating gauge R & R study is for checking the precision. repeatability and reproducibility of my measurement system and you have the attribute data. So, there could be some of the methods or it may be attribute agreement analysis.

But mainly we will focus on the variable kind of data and related study specific to measurement system.

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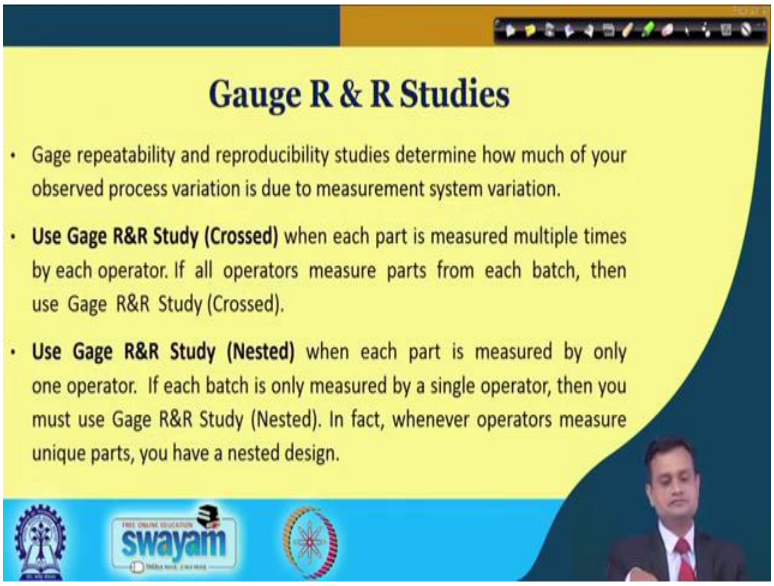

Now, as I mentioned that gauge R & R study it could be of destructive type, non-destructive type it could be crossed and nested. Now if we see the crossed then when each part is measured multiple times by each operator. So, there are number of operators and each operator will measure the each part number of times, multiple times.

If all operator measured parts from each batch then this kind of study is called gauge R & R crossed. If you see the other version nested then each part is measured by only one operator. If each batch is only measured by a single operator then you must go for gauge R & R nested kind of study and operator measures unique parts you have a nested design.

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There are some statistical important properties of the measurement system which are worth noticing. So, the first one is an ideal measurement system will produce only measurements that will always agree with the master value. So, I just explained that what is the master value? You compare it with the say reference gauge value or high end laboratory instrument value and if these are matching then your measurement system is in a good condition. Such measurement system will have the statistical property of zero bias and variance. So, this is very idealistic situation it never happens, but we can say that on the extreme idealistic side. This will have zero valuability and no bias and this kind of zero probability of misclassifying the item exist.

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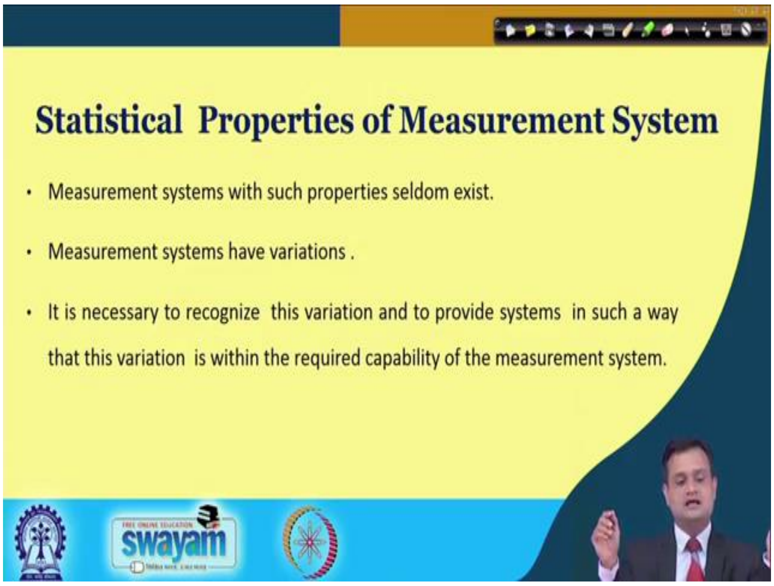

Measurement system with such kind of property as I said seldom exist and measurement system will certainly have variation. So, we are not denying that measurement system cannot have variation. What we want; that these variability should be within the limit and if it is within the acceptable limit then I can rely on my measurement system and hence the measured values. So, it is necessary to recognize this variation and to provide system in such a way that these variation is within the required capability of the measurement system.

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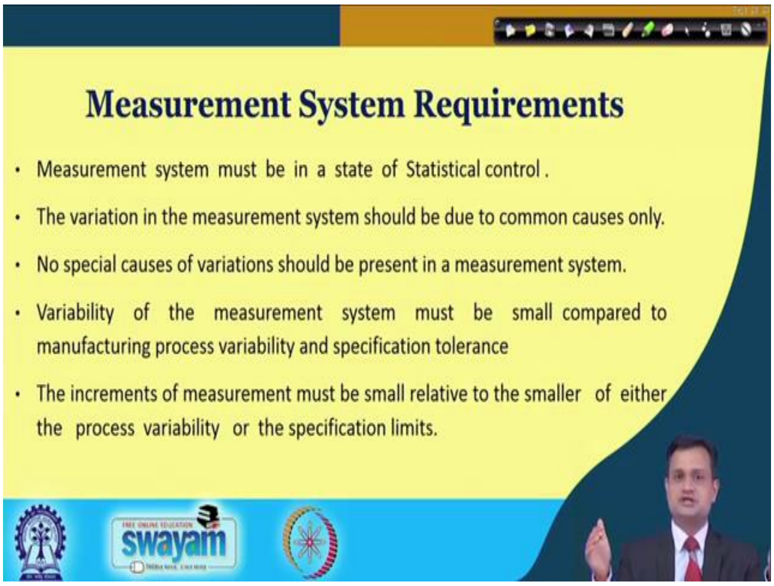

There are certain requirements to be noticed about the measurement system it must be in a state of statistical control. So, we will see the statistical control and the other aspects later on. But over a period of time your measurement system should not go beyond a particular range statistical range. And if it remains in this particular range statistical range then it is within this statistical control.

The variation in the measurement system should be due to common causes or random phenomena only. And no special or assignable cause should be present. Variability of the measurement system must be small as compared to manufacturing process variability and specification tolerance. Suppose for example, as I mentioned you are manufacturing a bearing and you are measuring the OD which is 50 mm.

Now variability permitted because of manufacturing process variation is let us say ±1 mm. And now the variability because of your measurement system is much higher 5 times 10 times then these. Then you will simply be misleading that whether my process is a problem or measurement system is a problem. So, the increments of measurement must be small relative to the smaller of either the process variability or the specification limits. So, this part must be clear that the variability because of measurement system must be extremely small compared to process variability or the specification limits. Otherwise, your input data for the analysis will be faulty and that will lead to the inappropriate actions.

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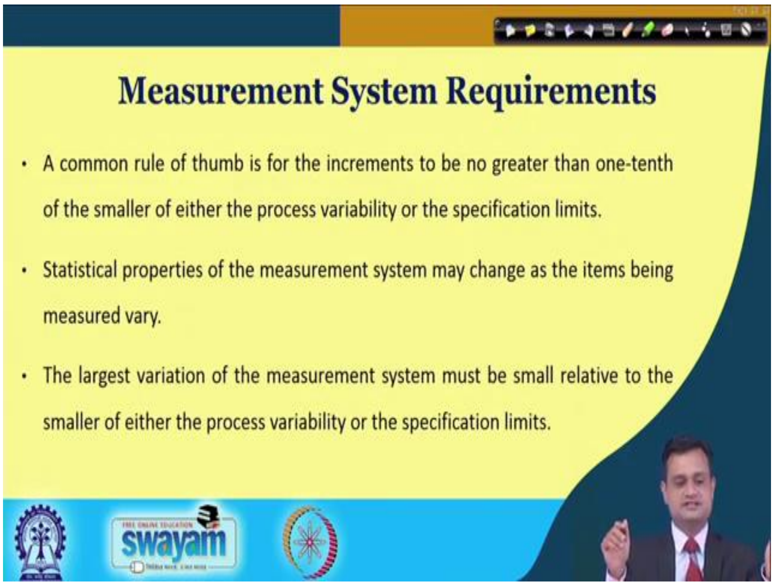

So, a common rule of thumb for increments to be no greater than one tenth of the smaller of either process variability of specification limits. So, it should be one tenth of the smaller value of this and if it is so then I will accept of the variability of my measurement system.

Statistical properties of the measurement system may change as the system being measured vary and the largest variation of the measurement system must be small as I mentioned relative to the smaller value of the process variability or specification limit.

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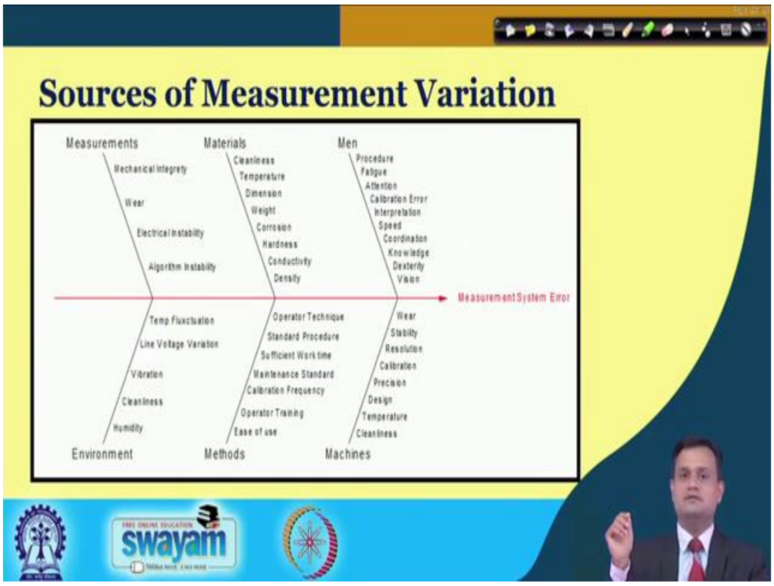

Here I have just jotted down the various reasons that leads to the measurement system error. It could from men, procedure, not fall out properly, fatigue, attention, calibration error, speed, coordination, dexterity, vision, so on. It could because of material; material is not cleaned let us say there is rust there is dusting and then when you take the measurement then it would give you may be higher value.

Temperature, dimension, weight, corrosion, conductivity, there could be reasons because of measurement itself. That is say mechanical integrity, wear, over a period of time it is an instrument and there is wear and tear. Electric instability and algorithm instability your computers interface and the algorithm you are using to capture the data and analyze that may have some error and that lead to measurement error.

You can have environment as I mentioned vibration, cleanliness, humidity, temperature, fluctuations, methods the way operator is measuring, standard procedures are not properly documented or they are not appropriate, calibration frequency, operator timing, and it could be because of machine wear and tear resolution calibration precision design and so on.

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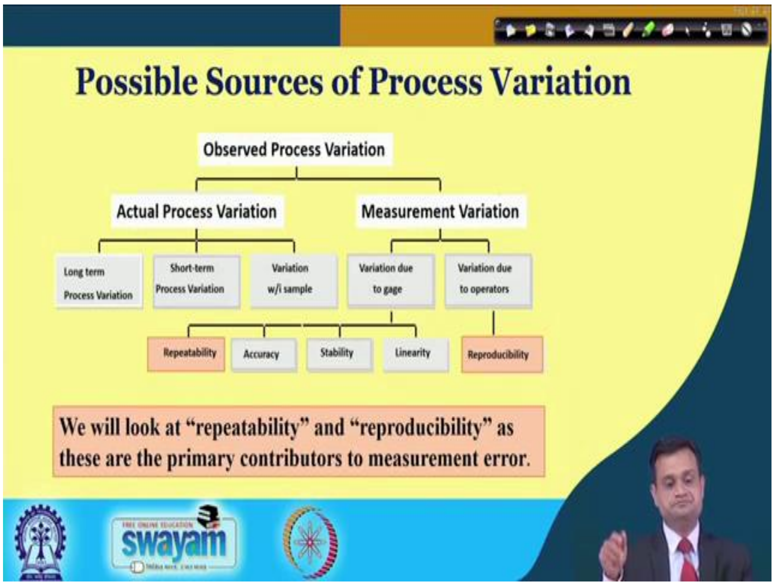

So, if you see and summarize the possible sources of process variation then you have the observed process variation. And this is divided into two part; actual process variation and measurement variation as simple as that. Actual process variation may be long term process variation. Short term process variation variation with respect to your sample or within sample and these are various reasons because of which you encounter the process variation.

When you see the measurement variation it could be variation due to gauge and variation due to operator. Mainly there are two parties involved if we just pick up the main elements then variability because of your gauge measuring instrument and variability because of the operator or inspector or appraiser.

Now, if I see the variability due to gauge further it could be divided into several say issues or factors responsible for that repeatability, accuracies, stability and linearity. We will see all and variation due to operator I will say it is reproducibility. So, I have marked here two terms in red repeatability and reproducibility and these are the primary contributors to the measurement error.

And we will conduct and see study gauge R & R study repeatability and reproducibility study to really check the precision of my measurement system with respect to repeatability and reproducibility.

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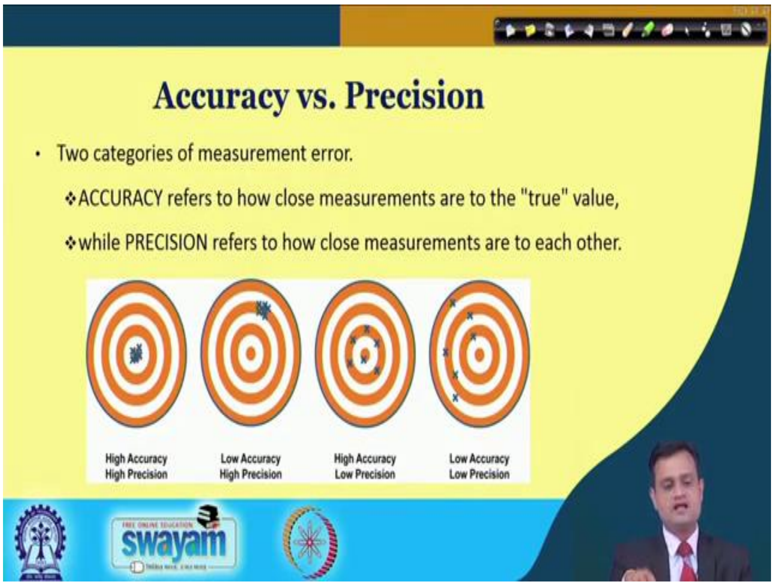

So, just to remind you that the difference between accuracy and precision. If you are close to the target value actual value true value you are accurate. And if you are subsequent readings they are falling in a close proximity then you are precise also. So, the first situation is high accuracy and high precision.

The second one is low accuracy and high precision because you are away from the target, but the readings are falling closer to each other. The third case is high accuracy low precision you have values more or less close to the target, but it is low precision. And the fourth one low accuracy and low precision so here both the dimensions they are affected.

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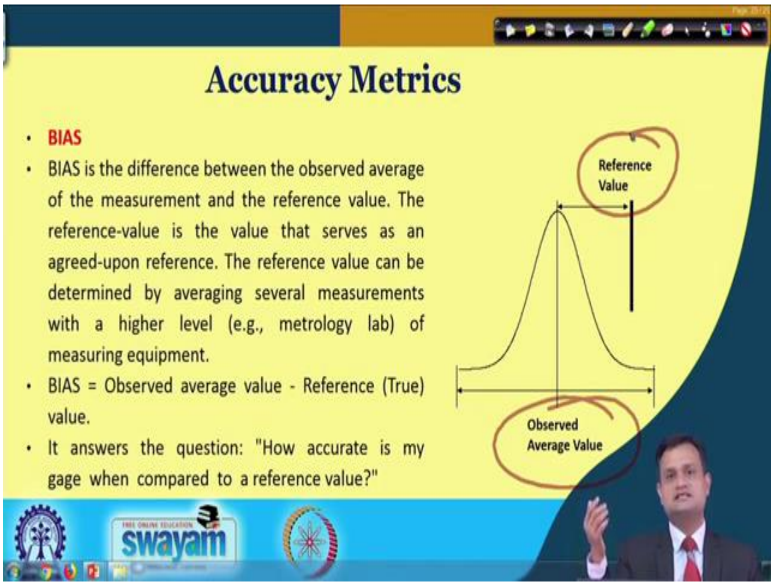

So, now if we just look into couple of matrix the first one is bias. The word is very well known to all of us what is bias. Now let us try to appreciate in terms of measurement system. So, bias typically is the difference between the observed average of the measurement and the reference value.

So, you can see here that you have observed average value; observed average value and you have the reference value. So, there is a variability which is shown as the bell shaped curve. And this variability is because of some random causes may be in the variation variability in the measurement system.

But with respect to observed value and reference value if I see than the difference is called bias. So, it is a difference between observed average value I am repeating and the reference value. The reference value usually we call it as a true value that serves us an agreed upon reference or benchmark and the reference value can be determined by averaging several measurements with a high level metrology lab or very high end instrument. And bias is observed average value minus reference true value. So, typically it answers how accurate is my gauge when compared to a reference value.

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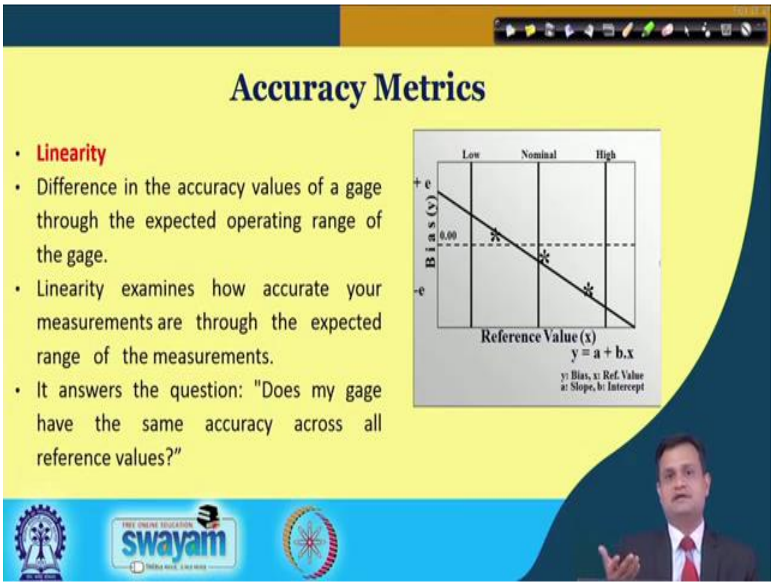

The second one is linearity and you can see the graph that on x axis there is a reference value on y axis I put the bias. And I am trying to set a regression equation simple linear regression $y = a + b.x$. So, y is the bias, x is the reference value, a is the slope and b is the intercept. So, typically linearity means it is a difference in the accuracy values of a gauge through the expected operating range of the gauge.

So, please understand that you have low value, reference value, high reference value, nominal when I take the measurement operate the gauge entire range operating range and then I try to check with respect to bias see the relationship between reference value and the bias, I get an idea whether linearity is present or not.

So, linearity examines basically how accurate your measurements are through the expected range of measurement low to high. And it answers does my gauge have the same accuracy across all reference values. So, I you are interested to see that when I am I am checking 10 degree centigrade temperature and I am checking 90 degree centigrade. Then whether I am getting the same bias or the bias is amplified or there is some difference.

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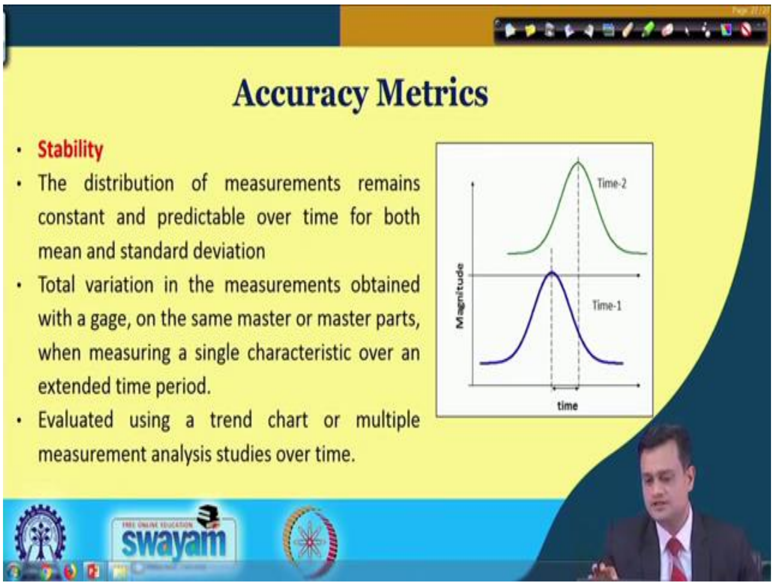

So, over an operating range how my gauge behaves that I am trying to judge through linearity.

The another one is stability you can very well see in this particular say graphs time 1 and time 2. So, typically over a period of time I am just trying to take the reading and see that how my average value as well as with respect to time the variability in the measurement it changes.

So, distribution of measurements remains constant and predictable over time for both mean and standard deviation. And total variability or variation in the measurements obtained with a gauge on the same master or maser parts where measuring is single characteristic over an extended time period. So, this is evaluated using a trend chart or multiple measurement analysis over a period of time.

So, how my system remains stable over a period of time or it ends up with the higher variability shift in the measurement reading and some error. So, that part I am trying to say capture through stability.

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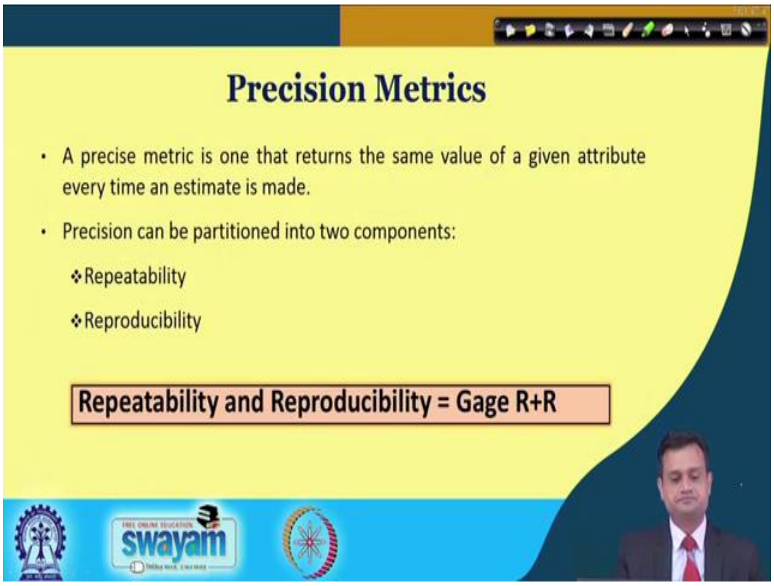

There are certain precision matrix. So, precision matrix as I mentioned previously is the one that returns the same value of a given attribute every time and estimate is made. So, we have two primary and important dimensions to focus on with respect to precision; one is repeatability, other is reproducibility when I am trying to check this two dimension the study is called gauge R+R or gauge R & R gauge repeatability and reproducibility.

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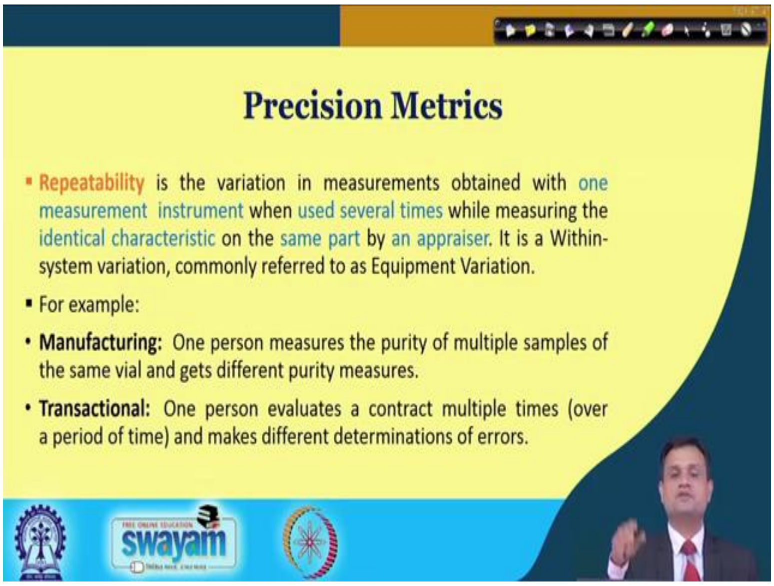

So, I am carefully reading out the definition of repeatability and reproducibility. So, repeatability is the variation in the measurements obtained with one measurement instrument when used several times while measuring the identical characteristics on the same part by an appraiser. So, here I want to check the repeatability in terms of my measurement it is within system variation commonly referred to equipment variation.

Will my equipment give me the same reading? So, we can see the example manufacturing one person or inspector measures the purity of multiple samples of same vial and gets different purity measures. Transactional you can see the example one person evaluates a contract typical contract multiple times over a period of time and makes different determination of errors.

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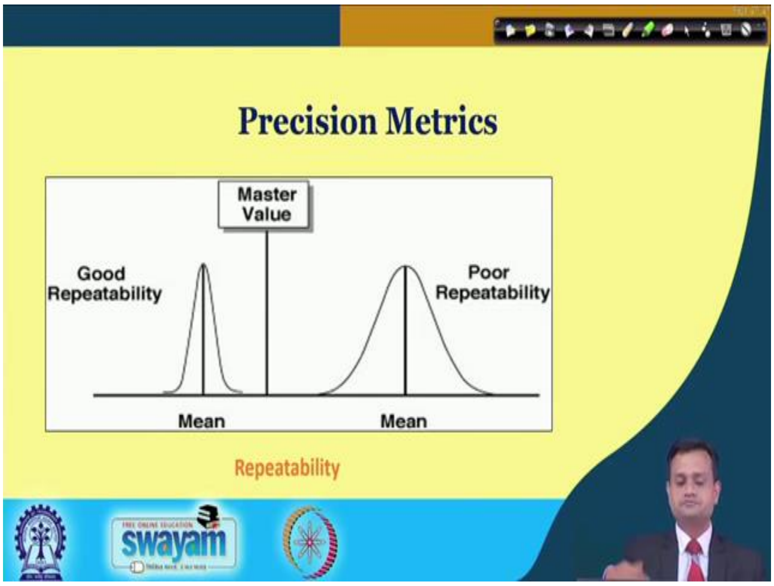

So, this is my repeatability and you can visualize repeatability through this diagram. So, the first one is good repeatability because I am having very less variability and closer to the master value. In the second one you can see that variabilities I am quite away from the master value.

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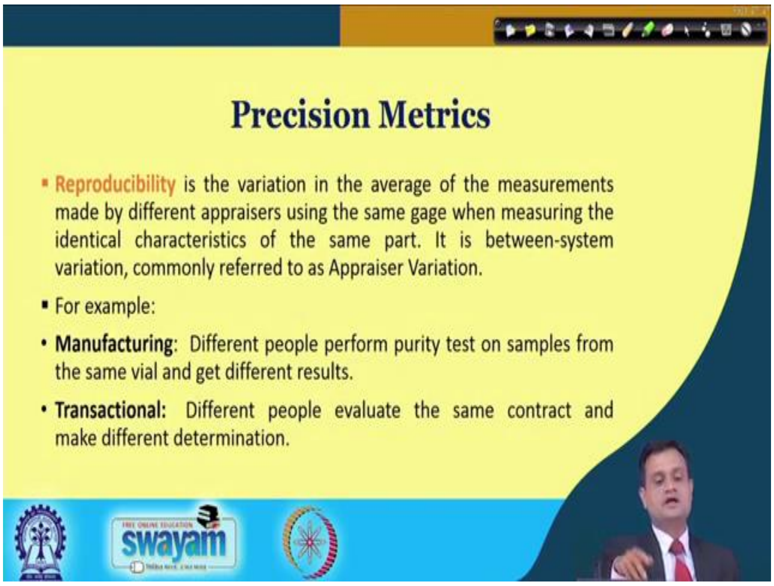

The reproducibility is another important dimension in gauge R & R study. So, it is the variation in the average of the measurements made by different appraiser. So, here I am changing the inspector, I am changing the operator, I am changing the appraiser are they able to reproduce the same reading using the same gauge?

So, there is no change in gauge when measuring the identical characteristic of the same part. Suppose I am measuring the outer diameter of the bearing let it be outer diameter only same part, but different operator will check it. And typically it is between system variation commonly referred to as appraiser variation so, person to person may be I have an inspector in shift one inspector in shift two and I have to consider if there is significant difference in the in the measurement by these two appraiser and when I do it I call it as a reproducibility. So, we can see the example again manufacturing different people perform purity test on sample from the same vial and get different results. Transactional, different people evaluate the same contract and make different determination.

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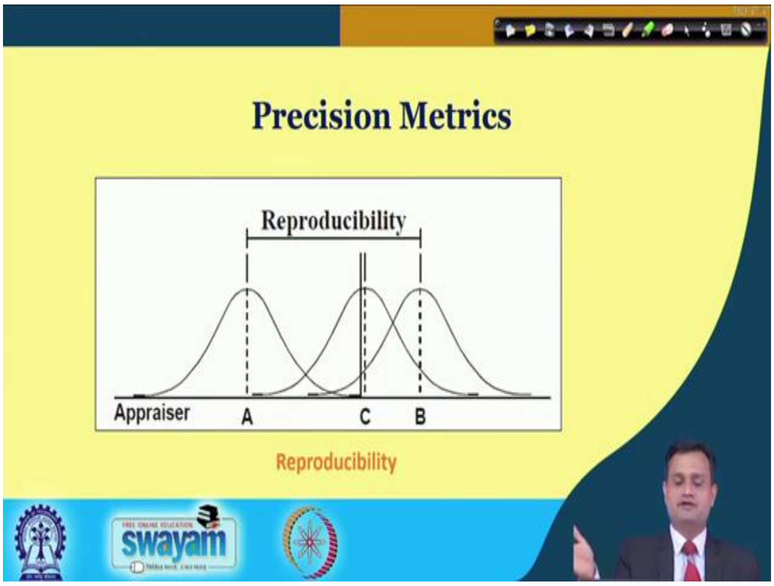

So, you can very well see there are three appraisers ACB or ABC there is a variability. And that is why average value measured value also there is a difference and this refers to the reproducibility.

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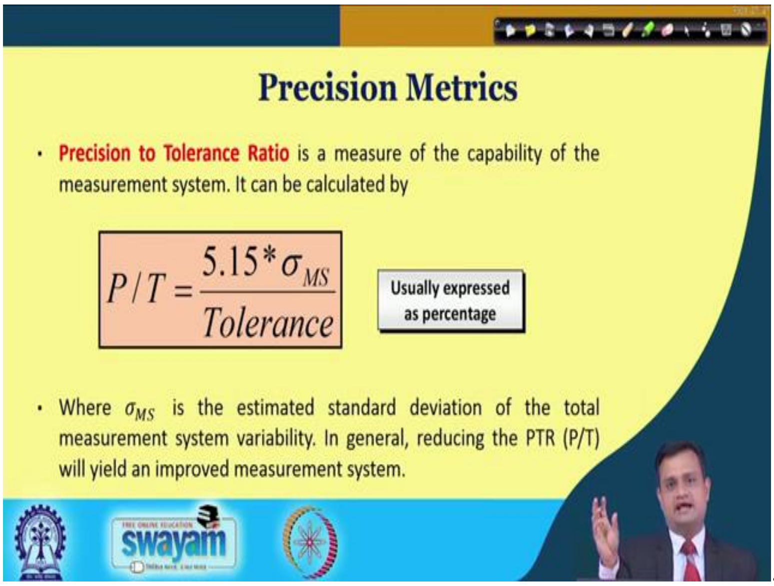

There is a standard matrix which is called P/T precision to tolerance ratio to check the preciseness of my gauge. And P/T the standard equation is $\frac{5.15*\sigma_{MS}\ (\sigma_{MS}\ \text{the estimated standard deviation of the total measurement system})}{\text{Tolerance}}$ and usually this is expressed as percentage.

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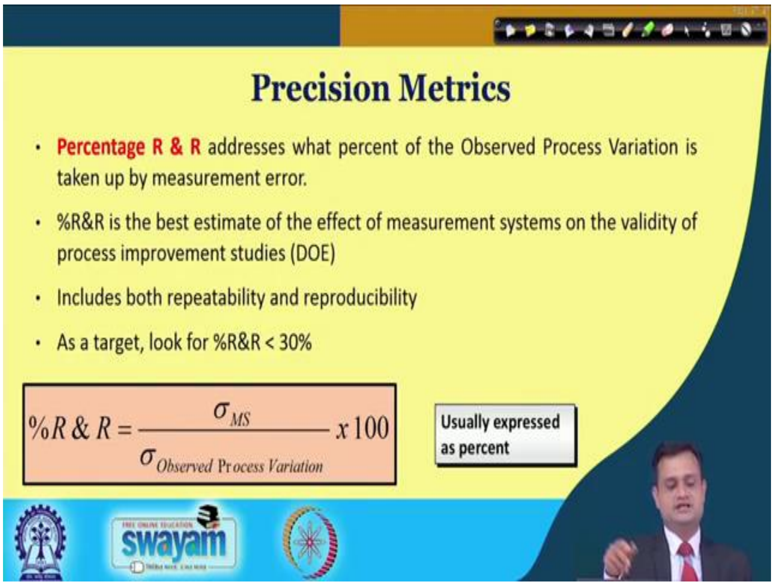

So, here I have some benchmarks and percentage R & R addresses what percent of the observed process variation is taken up by the measurement error. So, again I am reminding you that what percentage of the variation is because of the measurement system I must try to address it. So, percentage R & R is the best estimate and we conduct the design of experiment that we will see in the next lecture.

So, percentage R & R should be less than 30 percent sometimes it could be expected if you want very precise data 10 percent or 20 percent. So, $\%R\&R = \frac{\sigma_{MS}}{\sigma_{Observed\ Process\ Variation}} x\,100$ and expressed as percentage.

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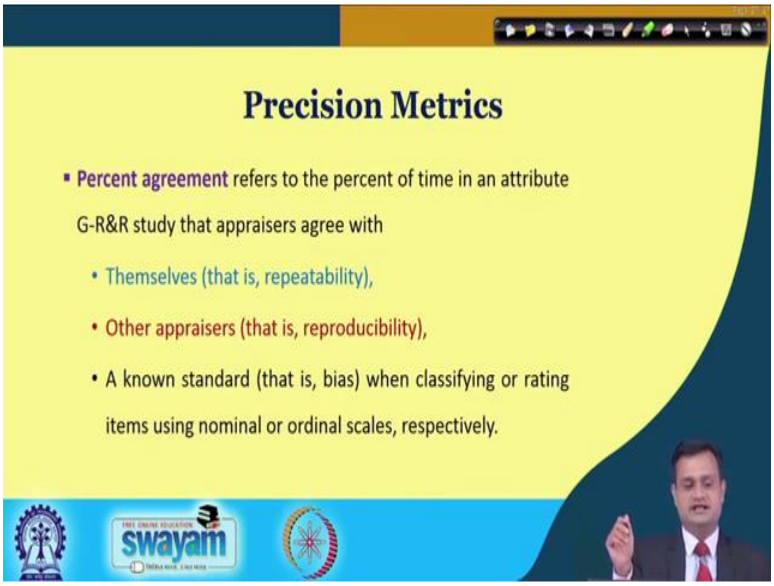

So, percent agreement refers to the percent of time in a attribute gauge R & R study that appraiser agree with themselves, other appraiser and a known standard that is the bias.

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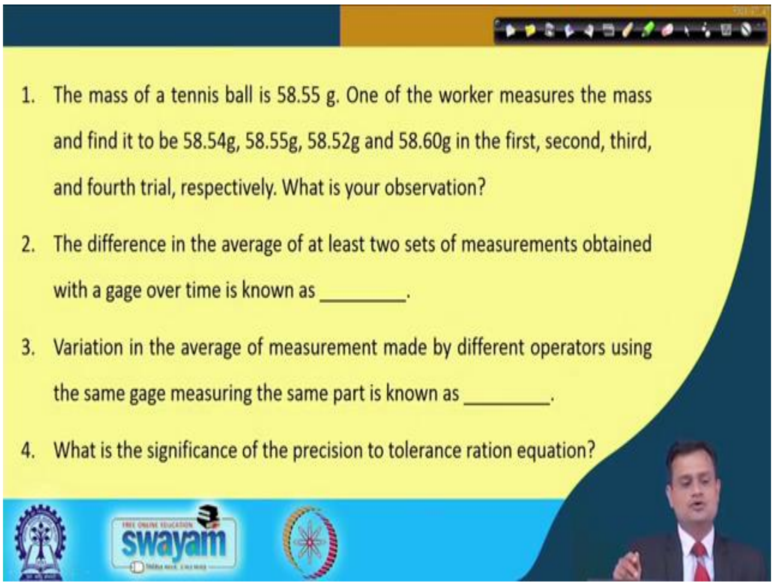

With this we would like to float couple of questions for the introspection and your quick revision of this particular lecture. So, number 1; the mass of tennis ball is 58.55 gram. One of the worker measures the mass and find it to be 58.54 gram, 58.55 gram, 58.52 gram, and 58.60 gram in the first, second, third, and fourth trial, respectively. What is your observation? What do you comment on the measurement system?

2nd; the difference in the average of at least two sets of measurements obtained with a gauge over time is known as fill in the blank. Number 3; variation in the average of measurement made by different operators using the same gauge measuring the same part is known as we have just now discussed. What is the significance of the precision to tolerance ratio equation and what exactly it tries to convey. So, please try to address this questions that would help you to have a quick reason.

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You can further use these references for your personal reading and strengthening the concepts.

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And typically I would like to conclude this session with a note that; measurement system analysis a key step to any process improvement effort. I cannot improve the process unless I have the correct data and based on that I take the appropriate necessary actions. By understanding existing measurement system a team can better understand the data provided by those systems and make better business decisions, manufacturing decisions, or transactional decisions and this can really help the organization.

So thank you very much for your interest in understanding the concepts related to measurement system. We are again to remind you we are in the phase of measure that is the second phase of six sigma, we will continue our discussion on some more issues of the measurement system in the next class. Keep revising, if you have any question or doubt then please note it down refer the text book or you may subsequently say put it on the Google forum and I would be happy to answer. So, be with me, enjoy.