Metrology
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Module-4
Lecture-1
Measurement of straightness, flatness and squareness

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Welcome you for the today's lecture this is module 4 lecture 1.

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Now in this lecture we will be studying about the various geometrical measurement, geometry measurement of the work pieces. Now in the present lecture we will be discussing about the importance of geometric integrity of work pieces also what are the various definitions related to the part geometry measurement and then we will be discussing about the various symbols used to represent the geometric tolerancing.

And also surface plate is most commonly used in workshops for the inspection purpose. So, which is used as a datum surface we will see a brief description of surface plate and then will move on to the meaning of straightness and straightness tolerancing afterwards we will see what are the various straightness measurement methods.

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Importance of geometric integrity of components

- Increasing demand for product reliability and efficiency prominences the geometric integrity of components and assemblies
- The components are to be produced as per designers stringent specifications, so that they function as expected.
- Manufactured components contain deviations from the nominal features and these deviations must be controlled for functional reasons.
- The irregularities on the work pieces are broadly classified into micro and macro irregularities

Now let us understand the importance of geometric integrity of the components there is an increasing demand for product reliability and efficiency which prominences the geometric integrity of components and assemblies. The components are to be produced as per the design is very strict specifications. So, that the function as expected the measured components in variably contain various deviations from the nominal features.

And these deviations must be controlled during manufacturing for functional reasons. The various kinds of irregularities on the work pieces or broadly categorise into micro irregularities and macro irregularities.

- The micro irregularities contain roughness and waviness components. The macro irregularities encompass errors of size and form.
- The deviation from the ideal form referred to as form error (geometrical deviations) is one of the many aspects, affecting the component performance.
- For example, the error of cylindricity affects the performance of **pumps and motors** since the efficiencies of these products change due to cylindricity error.
- In engineering applications we face the problem of measurement of geometrical features such as straightness, squareness, flatness, roundness, cylindricity, parallelism, concentricity, runout, etc.
- In this lecture, we learn the methods used to measure the various geometrical features of engineering components

The micro irregularities contain roughness and waviness on the surface of the components and the macro irregularities encompass the errors of size and form of the components. The deviation from the ideal form normally known as form error or geometrical deviations is one of the many aspects affecting the component performance. For example the errors of cylindricity on the pistons used in hydraulic pistons and hydraulic motors and pumps.

They affect the efficiencies of the product, if there are any deviations like out of roundness out of cylindricity and the pistons. So, they lead to increased friction or increased leakage, so the efficiencies of these will definitely affect. So, it is very essential that we should control the errors while manufacturing and also it is essential that we should measure the various deviations to make to ascertain that the components or within the prescribed tolerance limits.

In engineering applications we face the problem of measurement of geometrical features such as straightness, squareness, flatness, roundness, cylindricity, parallelism, concentricity, run out etc., etc. In this lecture we learn the methods used to measure the various geometrical features of engineering components particularly in this lecture we will be discussing about measurement of straightness.

Definitions
- A **feature** is a general term applied to a physical portion of a part, such as a surface, hole, or a slot.
- Features are generally part surfaces
- A **datum** is a theoretically exact plane, point or axis from which a dimension is measured.
- Inspection equipment such as a surface plate is often used to **simulate a datum**
- A **datum feature** is a **part feature** that contacts a datum
- Since datums are theoretically exact, we use datum features as the origin for measurements

Now let us try to understand the various definitions associated with geometric deviations of the components geometric deviation measurement of the components. So, many times we use the term feature, a feature is a general term applied to a physical portion of a component such as a surface or hole or a slot and these features are generally part surfaces. For example if you have a component like this, so we have this particular surface.

And the feature means whether this particular surface is straight or cylindrical or is there any out of roundness. So, such things are known as feature of a component and a datum is theoretically exact plane or a point or an axis from which a dimension is measured. For example when we want to measure the height, height of this component it is essential that we should take this particular surface as reference.
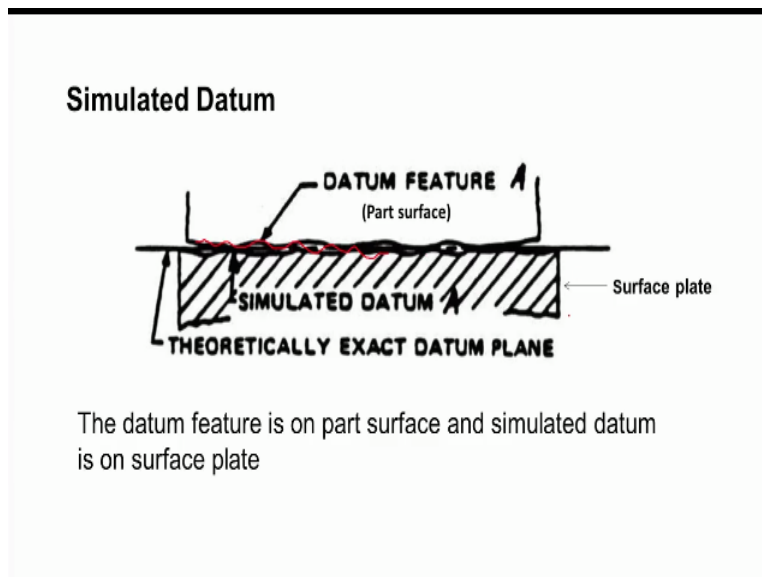
So, normally what we do we keep the component to be measured on the surface plate. So, this is the surface plate and then with reference to this surface we measure the height of this component using appropriate instrumentation. So, this surface plate for a top surface of the surface plate will act as datum. Actually the datum is a theoretically exact plane or it could be point or an axis.

But when we consider the top surface of the surface plate again that will be variation due to manufacturing variations. Now this top surface even though the variations are there in the top surface, now we try to control the deviation of deviations manufacturing errors on the surface

plate and we try to achieve a very flat surface. That means the surface plate is often used to simulate the datum.

So, top surface of the surface plate is used as a datum and that surface is simulated as a datum. Now a datum feature is nothing but a part feature that contacts a datum. Since datums are theoretically exact we use datum features as the origin for measurements.

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Simulated Datum

DATUM FEATURE *A*
(Part surface)

SIMULATED DATUM *A*
Surface plate
THEORETICALLY EXACT DATUM PLANE

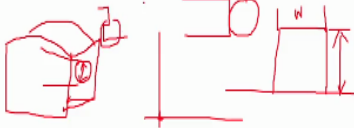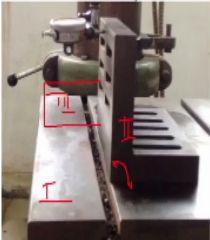The datum feature is on part surface and simulated datum is on surface plate

Now in this diagram we can see this is the surface plate this is the surface plate, and there is a line which is theoretical line which is a theoretically exact datum plane. And then on the surface top surface of the surface plate again there are micro irregularities and we take this top surface as simulated datum surface. And now the datum surface the part surface on the part surface we have the variations like this.

So, the datum that particular surface the datum feature is on the part surface and simulated datum is on surface plate.

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- A **datum reference frame** is a set of three mutually perpendicular datum planes
- How to create a datum reference frame?
- The three planes provide a common reference for the origin and direction of measurement for draftsman, machinist and inspector
- Features on a work piece can be external (ex. shaft diameter) or internal (ex. hole diameter)

Now we should try to understand what is the meaning of datum reference frame it is a set of 3 mutually perpendicular datum planes, now this datum reference frame is very essential in order to measure the component properly. Now 3 mutually perpendicular datum plane means, so this is 1 reference plane and then we can keep another reference plane vertical reference plane perpendicular to this primary reference plane.

This is primary reference plane or reference plane number 1 and this angle should 90 degree, this angle is 90 degree and then perpendicular to these 2 we should provide another surface. So, this is second reference surface and this is third reference surface all the 3 are mutually perpendicular. Now we have to keep the work piece which is to be inspected in this frame and then we should use these 3 reference planes as references or datum surfaces.

And then we should take the measurement, for example when you want to measure the height, so the this horizontal surface is taken as a primary reference. So, when we want to measure this particular distance, so again this plane is taken as reference and then this distance is measured and similarly when we want to measure this distance, now this particular plane is taken as the reference and then measurement is made.

So, this is the datum reference frame but how do we physically create the reference frame. So, that we can use it during physical measurement, now we can see here we have a surface plate.

So, this surface plate can be used as primary reference surface or horizontally horizontal reference surface. Now angle plate, we have to keep on the surface plate, so wherein this inclination is 90 degree.

So, now we have formed the vertical second reference surface, so similarly we can keep one more angle plate here. So, this forms the third reference surface, now we can keep the component within this frame and we can make the measurement. In some cases only one reference may plane maybe required, for example we see we have the surface plate and we want to measure only the height of the object.

In that case we require only one reference plane, in some cases 2 references maybe required, in some cases 3 reference planes maybe required. The 3 planes provide a common reference for the origin and direction of measurement for draftsman, machinist as well as inspector for all these 3 personnel the datum reference frame is required. In order to draw the in order to show the various dimensions.

So, the again the draftsman they will use a particular point as reference with this reference it gives all the dimensions also during the manufacturing in the machines of the operator will use the same reference point and he will measure all the dimensions or give the cuts. And similarly during inspection the same reference frame is used during inspection by the inspector. Now we should understand that features on the work piece can be external or it can be internal features.

For example external feature means the diameter of a shaft, so this diameter is an external feature similarly the height of the object is an external feature, width of the object is an external feature or say we have some work piece with some external feature like this a profile then this also external feature. Similarly if you take an object wherein there is some hole, so we have some hole here.

So this hole diameter becomes the internal feature or maybe inside there is a tapper tapered hole this is the tapered is on their internal feature or say there is a slot like this, so this is some internal feature.

Now we should understand what is the what are the various symbols used in during geometric tolerancing and all these tolerances symbols are as specified by various standards you can see here the different kinds of features are there individual features and you can see type of tolerances form tolerance, profile tolerance, orientation, location, run out. And in the form we have different characteristics like flatness.

So, we have the flatness and this shows how the flatness is indicated on the drawings and when you want to show the straightness a horizontal line is used and whenever we require to show the circularity or roundness, a circle is used and cylindricity is shown by this symbol. Similarly profile of a line can be shown like this, profile of a surface can be shown by using this particular symbol.
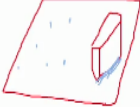
And whenever 2 surfaces are to be made perpendicular and we want to show the perpendicularity aspect then we should use this inverted T symbol and when angularity is to be shown for example we have some angular component like this, then the angularity shown is in this particular symbol and whenever we want to show that 2 lines or 2 surfaces are should be parallel. Then we use this particular similarly for location run out these are the symbols used.

And this is known as feature control frame okay. So, first in the first box we have to write the symbol corresponding to the required characteristic for example here we have use a circle with a + which indicates the position, position characteristic and the tolerance value on the diameter and then this is modifier maximum material control like that and this which is the reference datum for achieving this position, so that is mention in the last box.

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Now in the machine shafts normally surface plates are used as datum surfaces. So, surface plates are mostly rectangular they have rectangular shape having 4:3 length to width ratio. These plates are rigid in design and they are ribbed in the bottom surface. So, that no warping to takes place in heavy loads are place on that. The top surface of the plate is scraped to true flatness lot of care is taken during manufacturing of these surface plates particularly the machining of the top surface of the surface plate.

And many times the straight edges are used to check the flatness of the surface plates. Now you can see here we have this straight edge and we can always use Prussian blue. So, Prussian blue can be applied to this knife edge okay and then the straight edge is moved along the surface of the surface plate wherever they are top peak points Prussian blue gets added to the top peaks and then those peaks can be removed be scripting operations.

Like this we should scrape the surface, so that it is made flat. And for big surface plates levelling screws are provided for adjusting the top surface **to** truly horizontal.

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- The standard available sizes of the plates vary from 100 x 100 mm to 2000 x 1000 mm in 13 ranges.
- The four edges of the plates are finished straight and are square to each other.
- According to IS-2285-1963, the CI surface plates are classified into two grades as GRADE – I and GRADE – II.
- Surface plate is used to provide **datum or a reference surface** for measurement in workshop and laboratories. It is also used to check flatness of any surface.

Now standard available sizes of plates are the sizes vary from 100 by 100 millimetre to 2000 by 100 millimetre in 13 ranges. All the 4 edges of the surface plates are finished straight and aspire to each other according to the Indian standard 2285, the case tolerance surface plates surface plates are made by case tolerance and classified into 2 grades as grade 1 and grade 2 depending upon the requirement if it is for inspection grade for calibration grade we should go for grade 1.

If it is for measurement of flatness or straightness we can go for grade 2. And then surface plate is used to provide datum or a reference surface in most of the measurement activities carried out in the machine shafts.

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Straightness

- A line is said to be straight over a given length, if all points on the line, remain within the two lines, drawn parallel to the general direction of the line in question, separated by a tolerance amount.

- Straightness tolerance can be applied to an **axis**

- It can also be applied to a **surface**

- At many places it is needed that the work surfaces must be perfectly straight

- For Ex. in a lathe, the tool must move in a straight path to generate perfect cylinder. This is possible only when controlling guideways are straight.

Now let us move on to the a geometric feature straightness of the component let us try to understand what is the meaning of straightness we can see here a line is set to be straight over a given length, if all points on the line remain within the 2 lines drawn parallel to the general direction of the line in question, separated by a tolerance amount. For example this is the general direction of the line and now we on this line we have many points or maybe peaks and valleys are there.

Now we have to draw to 2 lines parallel to this general line which are separated by the tolerance amount say this tolerance amount is some point 05 millimetre. Now if all the peaks and valleys on that particular line or well within this range, then we say that line is straight. Now straightness tolerance it can be applied to an axis or it can be applied to a surface. Now we can see when it is applied to an axis, when the tolerance is applied to axis say we have a cylindrical object like this and this is the axis okay.

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Straightness

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- For Ex. in a lathe, the tool must move in a straight path to generate perfect cylinder. This is possible only when controlling guideways are straight.
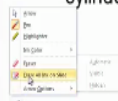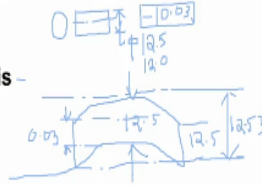
And the size varies diameter varies from 12 to 12.5, so diameter is varying from 12 to 12.5 and then the tolerance is specified like this. So, this is the symbol for straightness and then it is value is 0.03 millimetre and should be straight within this 30 microns. So, what happens is now the size of the component okay. Now this size maximum it can be 12.5 as per the given tolerance on the size. So, minimum is 12 and maximum is 12.5.

And then similarly here at the centre also it is 12.5 now this total distance can go up to 12.53 okay. That means this is the axis and we have another axis here for this particular portion. So, this distance is 0.03 millimetre, so this is diameter tolerance zone. So, this size can be up to 12.53.

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Straightness

- A line is said to be straight over a given length, if all points on the line, remain within the two lines, drawn parallel to the general direction of the line in question, separated by a tolerance amount.

- Straightness tolerance can be applied to an **axis**

- It can also be applied to a **surface**

- At many places it is needed that the work surfaces must be perfectly straight

- For Ex. in a lathe, the tool must move in a straight path to generate perfect cylinder. This is possible only when controlling guideways are straight.
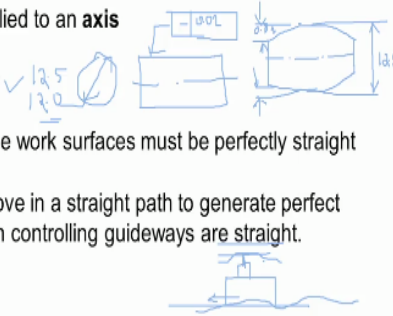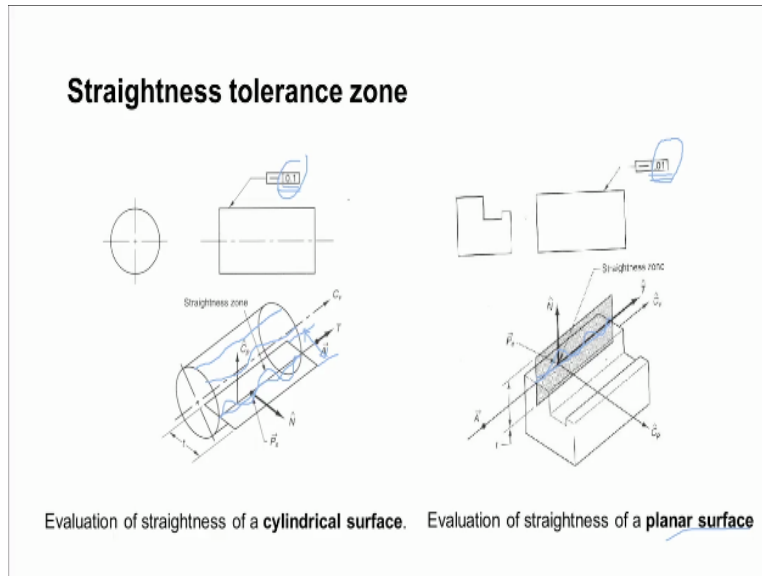
Now when the tolerance straightness tolerance is applied to surface then, so we have this object cylindrical object and so again the size varies from 12 to 12.5, so this is 12 to 12.5 diameter. Now in actual this is the specified tolerance, so when we manufacture the actual component can be like this, so the maximum size it is 12.5 maximum material condition. So, this is 12.5 millimetre as per the given tolerance and so this tolerance on the surface.

So, this is a 0.02 millimetre, now this is the tolerance on the size of the component and this is the tolerance on the feature that is straightness. So, this variation can be up to 0.02 millimetre and similarly here it can be up to 0.02 millimetre okay. At many places it is needed that work surfaces must be perfectly straight. For example in the case of lath the tool must move in a straight path to generate a perfect cylinder.

So, this is possible only when guide ways are straight and the guide ways are straight the carriage will move on this straight guide way. And then the cutting tool will give the cut on the work space and then we get cylinders, if the guide ways are not straight and some error is there. Then the tool will also move in this fashion, so that we do not get the proper cutting we get lot of errors on the work pieces.

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Straightness tolerance zone

Evaluation of straightness of a **cylindrical surface**.   Evaluation of straightness of a **planar surface**

So, now in order to check whether the machine tool guide way is straight or not we use many instruments and methods, so that we will study now. Now we should understand what is the meaning of the straightness tolerance zone we can see here we have a cylindrical object and on this surface the straightness tolerance is given it is 0.1 millimetre. So, what is the meaning of this now we have this cylinder and we take 1 generator, if you take 1 generator on this particular cylinder.

This variation should not exceed this 0.1 millimetre, this is the straightness tolerance. That means this gap is 0.1 millimetre like this we have to consider many generators we have to make measurements on many generators and in all the generators if the error is within 0.1 then the cylinder is said to be straight. Similarly on the flat surfaces planar surfaces again on the surface the straightness tolerance is 0.01.

That means on this surface id you consider a line okay all the variations in the vertical plane should be within this 0.01 millimetre. If that is the case we say this particular surface is straight.

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Measurement methods

- Using straight edge
- Using straight edge and slip gauges
- Using spirit level
- Autocollimator
- Using CMM
- Gap test for rods, bars
- Total indicator readout (TIR) test
- Finger roll test for thin wires and tubes

Now having understood what is the meaning of straightness and straightness tolerance. Now we will move to the measurement of straightness, so various methods and various devices are used to measure the straightness some of the methods are using straight edge we can check the straightness and straight edge along with this slip gauges can be used to access the straightness and we can also use spirit level and autocollimators for checking the straightness.

The spirit level can be used only on the horizontal surfaces whether the a particular line on the horizontal surface is straight or not whereas autocollimator can be used on all different planes. It can be used for checking the straightness along horizontal axis, horizontal planes as well as vertical planes. For example in machine tools say we have vertical guide ways, so whether the vertical guide ways are straight or not that can be checked by using autocollimator.

And the recently with the advancement of CMM and computer aid inspection CMMs are used to check the straightness and there are some methods test as per ASTM like gap test and then the total indicator readout TIR test and then finger roll test for checking the straightness of thin wires and rods and buds. So, we will learn some of these methods.

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Straight Edge

- Straight edge is rectangular or 'I' shaped in section with bevelled edge. Steel straight edges are available up to 2 meter length and CI straight edges are available up to 3 meter length and are widely used for **testing machine tool slide ways.**
- It is used in conjunction with a surface plate for measurement of straightness and flatness of parts.

Slide

Machine Bed
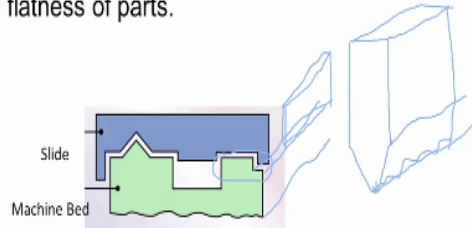
Now using straight edge how to check the straightness, now this straight edge is rectangular or I shaped device with bevelled edge. So, it looks like this, so we have this rectangular shape and then 1 end is bevelled like this with the small radius and this place and then straightness of this particular edge is well within 1 micron depending upon the length.

Now these are made using steel or cast iron and they are available in different length like half meter length or 1 meter, 2 meter, 3 meter for example when you want to measure the straightness of machine tool guide ways. So, this is the slide of the machine tool and this is the machine bed wherein we have the guide ways and say we want to check whether the guide way is straight or not.

So, depending upon the size of the machine this length of the guide way maybe half meter, 1 meter or 2 meter. So, throughout the length whether the guide way straight or not that we want to check. In that case we can use these straight edges and straight edges can be placed on the guide way and then the straightness can be checked. Now you should we can use directly straight edge on the machine tool bed or guide way we can check or sometimes along with surface plate this straight edge can be used for measurement of straightness.

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- According to IS-2220-1962, straight edges are provided in two grades.
- Grade A – for inspection purpose and Grade B – for workshop purpose.
- The straightness of edge of straightedge is less than 1 μm
- By using prussian blue and straight edge, the irregularities on the surface can be found out.

Now according to Indian standard 2220 straight edges are provided in 2 grades. Grade A for inspection purpose and Grade B for workshop purpose by using Prussian blue and straight edge the irregularities on the surface plate can be found as I already explained. So, this photograph shows a I shaped straight edge. So, this is the finish scarped surfaces, the surface is used for checking purpose.

And we different lens are possible to reduce the weight the holes are made here and he can also see some ribbing to increase the rigidity of the straight edges.

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For checking the straightness of a part, the straight edge is placed along the full length of the surface, and the **two are viewed against the bright light.** The absence of the light between straightedge and the surface indicates the straightness of the element.

A quantitative assessment can be made by observing the color of light, due to interference caused by diffraction of light, while passing through the gap.

If the colour is red, it indicates a gap of 1 to 2 μm, and if the colour is blue, the gap is 7 to 8 μm
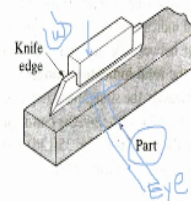
Now for checking the straightness of the components the straight edge is placed along full length of the surface and the two are viewed against the bright light. Now you can see here this is the work piece and we want to measure whether this top surface is straight or not. So, in that case we have to take this straight edge and we have to keep it on the surface and the other side we should keep a light source, bright light source.

And now whether the light is passing between the surface plate top surface and knife edged straight edge. So, that we have to observe light passing in the gap we should observe, if no light is passing then the work piece surface is straight and if there is some light there is it indicates that there is some error, straightness error. A quantitative assessment can be made by observing the colour of the light.

So, due to interference caused by diffraction of light while passing through the gap, the colour of light changes, if the colour is red it indicates the gap of 1 to 2 microns and if the colour is blue the gap is 7 to 8 microns. So, in this way we can check the straightness of the work piece surfaces.

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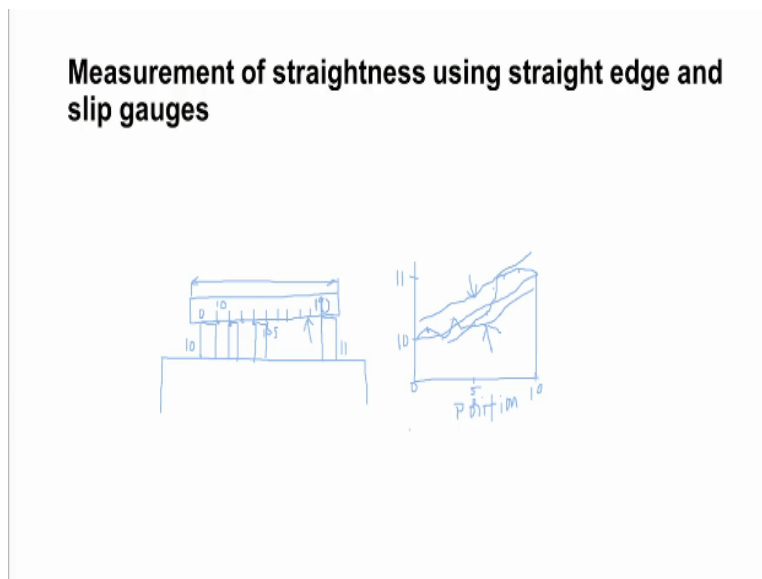
Now along with the straight edge along with slip gauge and straight edge we can check the straightness the procedure is like this we have to use a surface plate a datum and then this is the component the straightness of which is to be checked. So, this could be surface plate or a straight

edge. Now here we have to keep the slip gauge say this is point number 0 and then so we have to mark see this is L.

So, we have to support this length at airy points like this we have to use another set of slip gauges and we have to support like this. So, that this distance airy distance, so that the bending is minimum. Now we have to divide this distance into 1 0equal parts, so this is 1, 2, 3, 4, 5, 6, 7, 8, 9 and 10. So, now the height of this particular slip gauge is 10 millimetre and height this particular set is say 11 millimetre.

So, now we can we know the height of this point number 0 is 10 millimetre and here it is 11 millimetre, height is 11 millimetre point number 10 that height is 11 millimetre okay. So, the theoretical point at this will be 10.1 and here it is 10.2, 10.3, 10.4 and here it is 10.5 this is 10.6, 10.7, 10.8, 10.9 and 11. So, this is height is 11, so this is 10 and this is 11. So, theoretical heights we know.

Now we have to use slip gauges and we have to insert this slip gauges at all these points and actually what is the height we have to measure. And then we can draw the graph, so this is the position on the work piece surface say this is point number 0 and up to 1 at point number 0 the height is 10 millimetre and at point number at this point the height is 11 millimetre.

So, now we can join this means of a straight line, now actual distances actual heights we measure by inserting slip gauges say this is 5. So, at point number 1 say the height is 10.1 something like that and here it is second point, third point, fourth point fifth point, sixth, 8, 9 and this is 10 point. If you join then we get a line like this. Now we have to draw 2 lines, 1 passing through this peak and other passing through this valley.

So, this gap gives us the straightness error of this particular edge. So, this is the edge to be inspected, so what is the error in this particular edge can be obtain by this method.

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Spirit level

- Spirit level consists of a sealed glass tube mounted on a base. The inside surface of the tube is ground to a convex barrel shape having large radius. A scale is engraved on the glass at the top of the tube. The tube is nearly filled with Ether or Alcohol except a small air or vapour bubble.
- The bubble always tries to remain at the highest point of the tube. If the base is placed on horizontal surface, then the bubble rests at the center of the scale.
- If the spirit level is tilted through small angle, the bubble moves and tries to remain at the highest point of the tube.
- They are used for levelling of machines, for measuring small angle or inclination and for **checking straightness** and flatness of surface.

Now other method is a use of spirit level we can check the straightness of the components spirit level consists of sealed glass tube and it is mounted in a base. The inside surface of the tube is ground to a convex barrel as shown here and this radius is large radius and then there is a scale engraved on the glass. And the tube is filled with ether or alcohol and then there is a small air bubble. So, this air bubble it always tries to remain on the top most point.

The base is perfectly then the bubble will be at the centre of the scale. And if it is tilted if the spirit level is tilted then tries to occupy the top most point. It always try to remain at the highest point of the tube. These spirit levels they are used for levelling the machine tools and they are also use to check the straightness of surfaces.

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Test procedure

- Tests for straightness can be carried out by using spirit level or auto-collimator.
- The straightness of any surface could be determined by either of these instruments by measuring the relative angular positions of number of adjacent sections of the surface to be tested.
- So first a straight line is drawn on the surface whose straightness is to be tested.
- Then it is divided into, a number of sections, the length of each section being equal to the length of spirit level base or the plane reflector's base in case of auto-collimator.
- Generally the bases of the spirit level block or reflector are fitted with two feet so that only feet have line contact with the surface and whole of the surface of base does not touch the surface to be tested.

Now the test procedure is like this the test can be carried out by using spirit level or auto-collimator the procedure remains same. This straightness any surface could be determine by either of these instruments by measuring the relative angular positions of number of adjacent sections made on the surface to be tested. So, what we have to do is we have to draw a line on the surface whose straightness is to be inspected like this.

So, this is the surface to be inspected and here we have to draw a straight line and then we have divide this straight line into number of equal parts and distance between 2 adjacent lines being L. So, this distance is L where L is the distance between the base the 2 feet on the spirit level. This is the spirit level and this is the glass tube with the bubble and 2 feet will be provided on the auto-collimator reflector surface or the spirit level.

So, this distance centred distance is equal to L, so by knowing this L we can divide this line into equal number of parts keeping the distance between 2 lines equal to L.

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- This ensures that angular deviation obtained is between the specified two points.
- The spirit level can be used only for the measurement of straightness of horizontal surfaces while auto-collimator can be used on surfaces in any plane.
- In case of spirit level, the block is moved along the line on the surface to be tested in steps equal to the pitch distance between the centre lines of the feet.
- The angular variations are measured by the sensitive level.
- Angular variation can be correlated in terms of the difference of height between two points by knowing the least count of level and length of the base.

Now the spirit level can be used only for the measurement of straightness along horizontal surfaces whereas auto-collimators can be use to check the straightness on vertical and insane surfaces also. In case of spirit level the block is moved along the line on the surface to be tested in steps equal to the pitch distance between the centre lines of the feet. The angular variations are measured by the sensitive level.

That means in the first place in the first position what is the reading of the spirit level that should be noted down and then it is move the second section again what is the bubble reading that should be note. See this bubble in the spirit level reading will change when the straightness the changes. So, angular variations can be correlated in terms of difference of height between 2 points by knowing the least count of level or and length of the base.

Now with this we will conclude this session. In this session we learnt about the importance of geometric tolerancing and what are terms associated with dimension feature measurement and then we also learnt what are the various methods of measuring the straightness and out of those methods we started discussion on the measurement of straightness, using spirit level. So, with this we will conclude, in the next session we will continue the discussion on straightness measurement by various methods. Thank you.