Metrology
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Module-4
Lecture-2
Perpendicularity measurement

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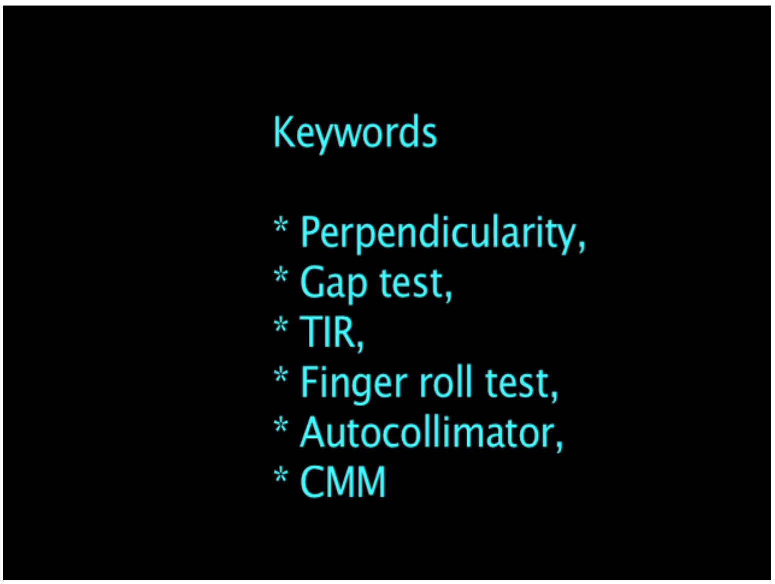

Module4 lecture2 on measurement of geometrical features, In the last class we started discussion on measurement of straightness using spirit level and autocollimator we will continue with the discussion on straightness measurement.

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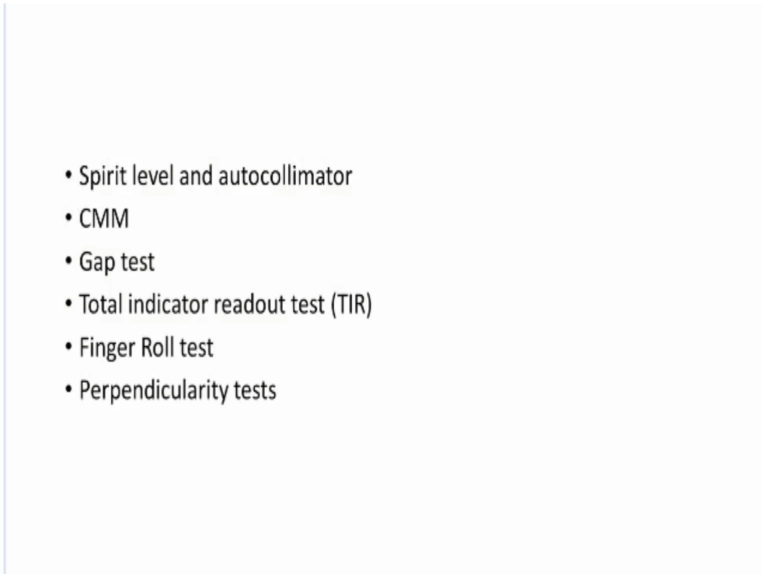

So, in this session we will be discussing about measurement of straightness using spirit level and autocollimator and then we will move on to the measurement of straightness using coordinate measuring machines and we will see the test like gap test and total indicator readout test and finger roll test and after that will move to the measurement of perpendicularity.

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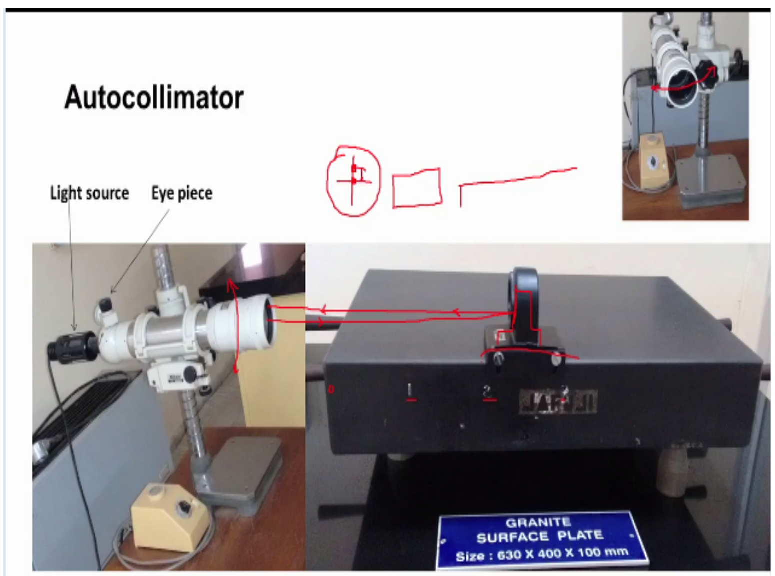

Now we can see some photographs of autocollimator we have the autocollimator and this is the vertical stand to adjust the height of the collimator tube depending upon the work piece height you can see the light source and then this is the power supply for the light source and we have to view the readings through this eyepiece and a micrometer is also attached to the eyepiece. And you can see this is the surface plate whose the straightness is to be tested.

We have this reflector surface the stand with the reflector surface here there is a reflecting mirror. So, light will fall on the mirror, reflecting surface and then it gets reflected back. If there is some inclination, if the surface is like this some uneven is there. Then because of this the mirror is at inclined position, now light will reflect back in this path and then so inside we have view field. So, it looks like this, so when we observe through eye piece the view field is like this we have cross years.

So, when there is no error that means the work piece is perfectly straight then the this is the and this is the reflector ray they will get combined and we get these spot on these in this place. So, if there is any inclination light will get it will move in this path and this spot will move like this. So, this distance we can read using the eyepiece, so like this at different locations different positions we have to keep the reflector.

So, the total length whose total length of the surface is divided into some equal number of parts, this is 0 and you can see this is first position and this is second position, third position like this we have to divide this into equal number of parts and then we have to keep on placing the reflector at different locations and then we should note down the readings. It is very essential that before we start the experiment the surface to be tested is thoroughly cleaned.

If there are some dust particles then the inclination will change the inclination of this reflector stand will change. That will give an error, so it is necessary that surface should be clean properly and then bottom of the reflecting surface also should be thoroughly cleaned. Now see there is arrangement say we have some surface which is inclined like this, inclined surface. So, we can orient the autocollimator tube with respect to this inclined surface.

So, for that this can be moved rotated like this and height can be adjusted depending upon the work piece height. And also we can rotate the autocollimator tube like this in this fashion.

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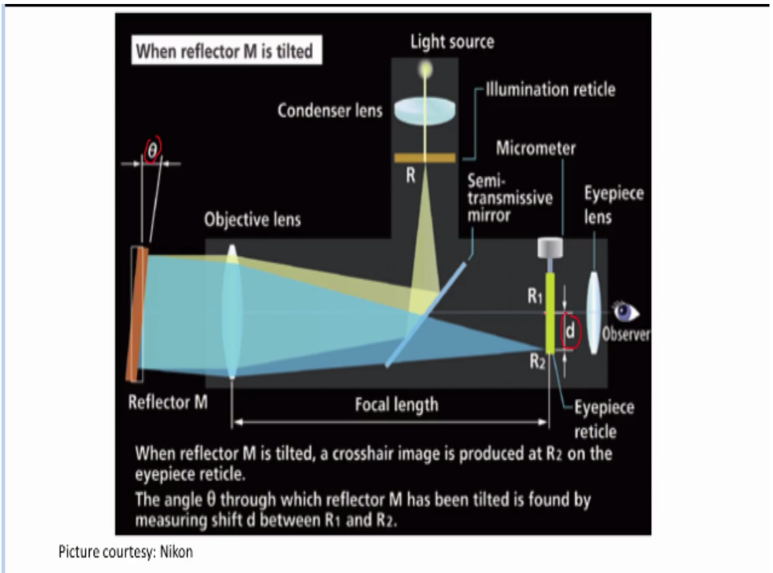

Now this shows the principle of working of autocollimator we can see we have the eyepiece here. This is eyepiece lens and then this is the micrometer okay and the light will fall on the reflector and then if there is some inclination theta then reflected light will move back and it will fall at this position. So, this distance between R1 and R2 that is distance D can be measured using this can be read using the eyepiece.

And the light source is placed here, so light will fall like this and the semi-transmissive mirror is there. So, light will change it will change it is path, it will fall on the reflector and then it will get reflector. If there is no if theta is equal to 0 then R2 will coincide with R1 and there will not be any error.

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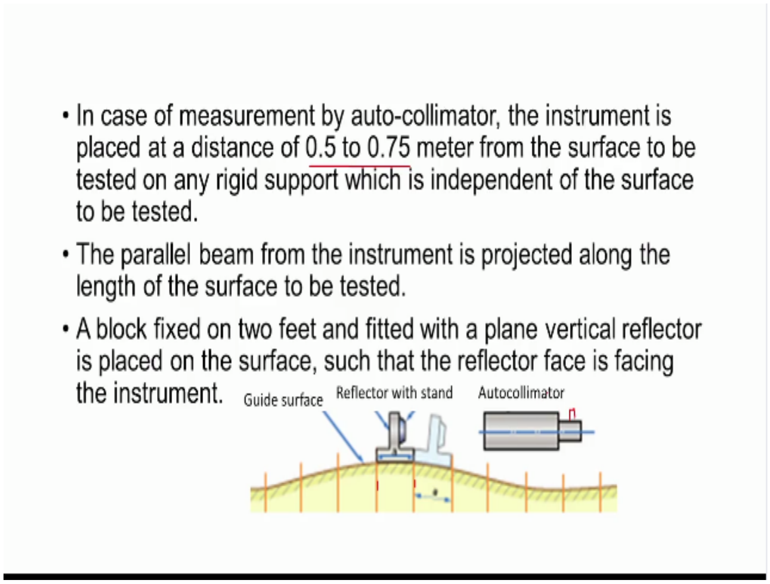

Now whenever we want to take readings we should keep the autocollimator at some distance about half meter to 0.75 meter from the surface to be tested and it is placed on separate stand. It will not be placed on the surface which is to be tested and the parallel beam from the instrument is projected along the length of the surface to be tested. Now you can see here this is the guide surface whose straightness is to be check and we have marked different positions here.

We should keep the reflector with the stand on the guide surface at different locations and then we have to take the readings through the eyepiece.

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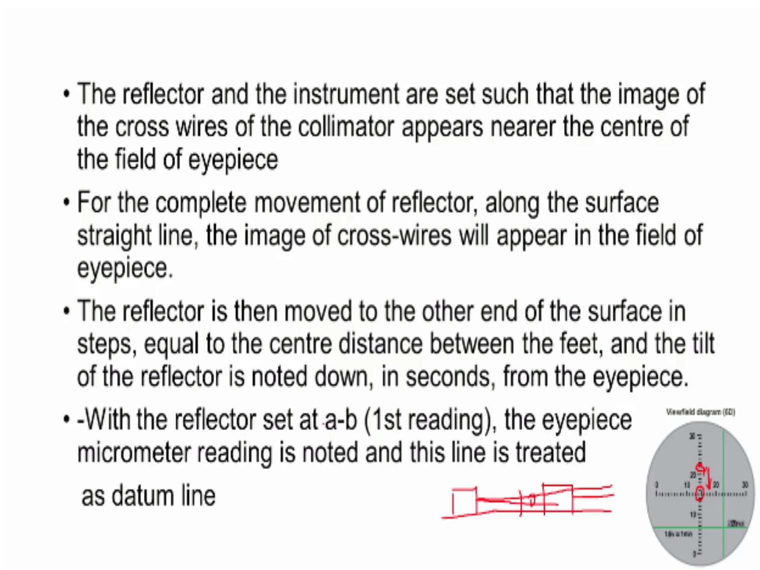

Now inside the view field we have the cross hairs like this and the scale. So, when the work piece is perfectly straight then the incident tray and reflector tray will be on the same line and then there will not be any error, a spot will be at the centre. If there is any error like this, then the this is the incident tray and reflected light will fall again there will be some angle theta. So, light spot we get here and this reading we have to take, so at all locations we have to take this reading.

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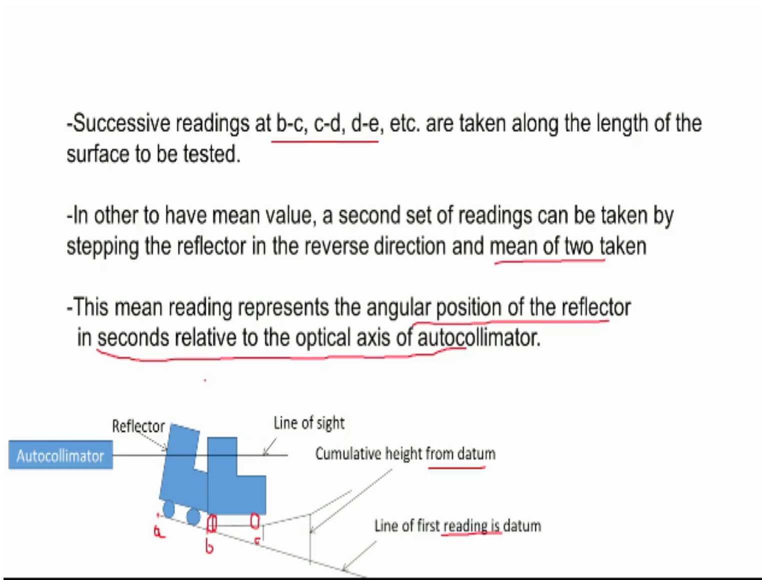

Now you can see here initially this is the surface and this is the location A and this is location B. We have to keep the reflector here and then we should take the reading that is with the reflector set at A-B, this is the first reading, the eyepiece micrometer reading is noted and this line is treated as datum line. So, with respect to this datum line all other readings are taken. Now you can see here this is the first location, so this is a and this is b.

So, this line is taken as datum with respect to this now this is the second position, so this is c. Now b-c, c-d, d-e like this the readings autocollimator micrometer reading should be taken at different locations and all the reading should be added. Then we get cumulative height from the datum. And in the forward direction we should take reading and again in the reverse directions also we should take the readings and then average values we can take mean values we can calculate.

So, this mean reading represents the angular position of the reflector in seconds relative to the optical axis of the autocollimator. This is the optical axis of the autocollimator or line of sight.

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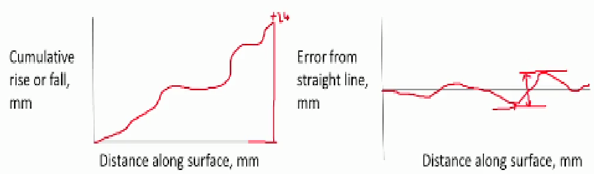
Tabulation of readings

Position	Mean reading of spirit level or autocollimator, sec	Difference from 1st reading , sec	Rise or fall, mm	Cumulative rise or fall, mm	Adjustment to bring both ends to zero, mm	Error from straight line, mm
a	-	-	-	0	0	0
a-b	0					
b-c upto full length	2	2				



Now all the readings are tabulated as shown here, this is the first column shows the position of reflectors. So, starting point is a and then we have position a-b, b-c up to full length we have take readings. So, mean reading of spirit level or so, this is applicable both for spirit level as well as for autocollimator. Now mean readings in the forward direction we are taking the readings and also in the reverse direction we are taking the readings.

And then we have to find the mean values and those mean values in terms of seconds we have to record here. And then difference from the first reading, so that we have to take here. If the say a-b reading is 0 and at b-c say it is 2. Then difference from first reading is 2, so like this we should mark and then we should find whether there is rise or fall and then we have to see the cumulative. We have to add these values to get the cumulative rise or fall in terms of mm.

And then adjustment to bring both ends 0, it is like this distance along the surface in terms of mm and cumulative rise or fall. So, we get the readings like this, this is cumulative rise or fall and then adjustment to bring both ends to 0 say this is the last point and say this valley is some +24. So, we have to add -24, so that this will is brought back to 0 position, the second end is brought back to, in that case we will be getting the line like this.

So, now it is both the ends are at 0 level and then we should find the error from this straight line. So, this is the reference line and then this is the peak value and this is the bottom most point valley and this distance will give us the error from the straight line also we can use least fear method to find out the error.

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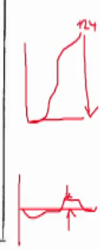
1	2		3	4	5	6	7
Position on Surface	Reading		Difference from 1st Reading (sec)	Rise or Fall in Interval Length (0·001 mm)	Cumulative Rise or Fall (0·001 mm)	Adjustment to bring both ends to Zero (0·001 mm)	Errors from Straight Line (0·001 mm)
	min	sec					
0	2	10	0	0	0	0	0
1	2	10	0	0	0	− 2·0	−2
2	2	12	+2	+1·0	+ 1·0	− 4·0	−3
3	2	15	+5	+2·5	+ 3·5	− 6·0	−2·5
4	2	17	+7	+3·5	+ 7·0	− 8·0	−1·0
5	2	18	+8	+4·0	+11·0	−10·0	+1·0
6	2	17	+7	+3·5	+14·5	−12·0	+2·5
7	2	15	+5	+2·5	+17·0	−14·0	+3·0
8	2	13	+3	+1·5	+18·5	−16·0	+2·5
9	2	9	−1	−0·5	+18·0	−18·0	0
10	2	12	+2	+1·0	+19·0	−20·0	−1·0
11	2	14	+4	+2·0	+21·0	−22·0	−1·0
12	2	16	+6	+3·0	+24·0	−24·0	0

1 sec of arc = 0.0005 mm over the base length



Now we will take a case study, we have taken some readings. So, this is position on the surface that is to be tested 12 positions are there and then reading in minutes and second this is the of spirit level or autocollimator reading. So, the first position the reading is 2 minutes 10 seconds, in the second position also 2 minute 10 seconds like this up to 12 positions we have taken the readings.

And then difference from the first reading, so this is the first reading okay initially we mark it as 0. Because there is no this is the starting point and difference see now this is the second reading difference from this, from the first reading is again 0. And third reading is 2 minutes 12 seconds difference from this first reading okay this is +2 seconds. So, like this we have to find difference from first reading for all the values.

And last reading you can see here, this is 2 minute 16 seconds whereas the first reading is 2 minutes 10 seconds. So, difference is +6 seconds, now we should find rise or fall in interval length in terms of 0.001 millimetre or directly in terms of micrometer. Now first reading is 0, second reading is also 0, now see 1 second of ark is equal to 0.0005 millimetre over the base length, that is if the reflector is like this.

So, we will be having the 2 feet like this, so this is the base length L, so this is can be some 100 millimetre or 120 millimetre like that. So, once one 1 second of ark is equal to 0.0005 millimetre in this case study. So, the rise or fall interval is see difference in seconds is 2, so 2 * 0.0005 millimetre gives us 1 micrometer or 0.001 millimetre.

And then 0.0005 times 5, so this will give us +2.5 micrometer. So, like this we have to find whether the rise or fall in the interval length and then we have to add this values to get the cumulative rise or fall again we values we get in terms of 0.001mm or all these values are in terms of micrometer. So, here this is added to 0 again we get 0 and then this is added to next reading, so we get 1.

So, this value is added to 2.5, so we get 3.5. So, like this we have to get the cumulative values. Now you can see in the last position the reading is +24 micrometers. So, we should bring this to 0, so now the cumulative value is like this it is like this at the last point it is 24, 24 micrometer. So, in order to bring this down to 0 we have to add -24 to this okay adjustment to bring both ends to 0.

So, this end should be brought back to 0, so we have to add -24 then we get 0. So, like this , so we have to add the adjustment values and finally we get errors from straight line in terms of 0.001 millimetre or directly in terms of micrometers. Now we can see here the maximum value is 3 micrometer from the straight line. So, from the straight line that means see we have the reference line like this. So, now the profile is like this, so this is the maximum from the reference line it is 3 micrometer.

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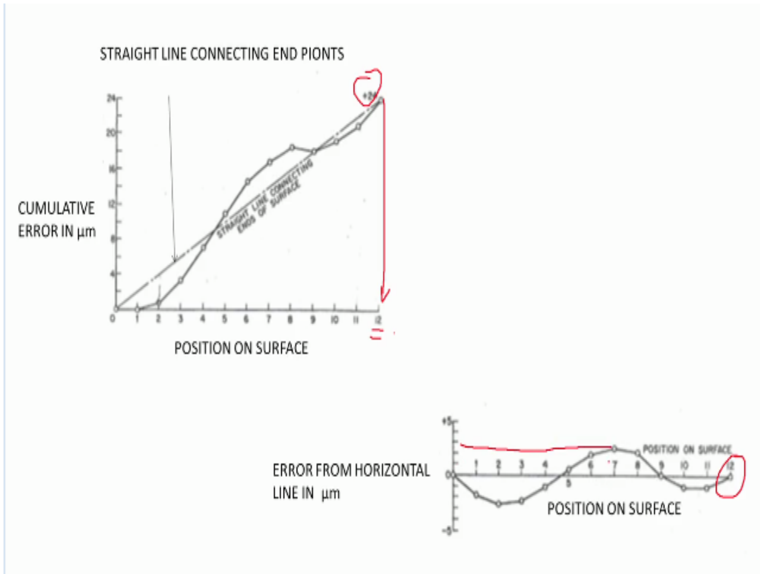

Now we can draw the graphs using those tabulated values. So, x axis on the x axis we have position on the surface we have 12 positions and then cumulative error in microns. That is the column number 5 will give us cumulative rise or fall, so these values we have to take and then we have to plot here okay. So, the cumulative error in terms of microns, now we can see last reading is +24 micron.

Now lease square method we can apply to this and then we can find the error. And another graph we can write this can be brought down to 0 by adding adjustment factor. So, now this is the last position which is brought to 0 and again we can see the graph is plotted here but different positions. Now error from horizontal line, so at this place okay position number 7 we have the error like this it is approximately 3 microns.

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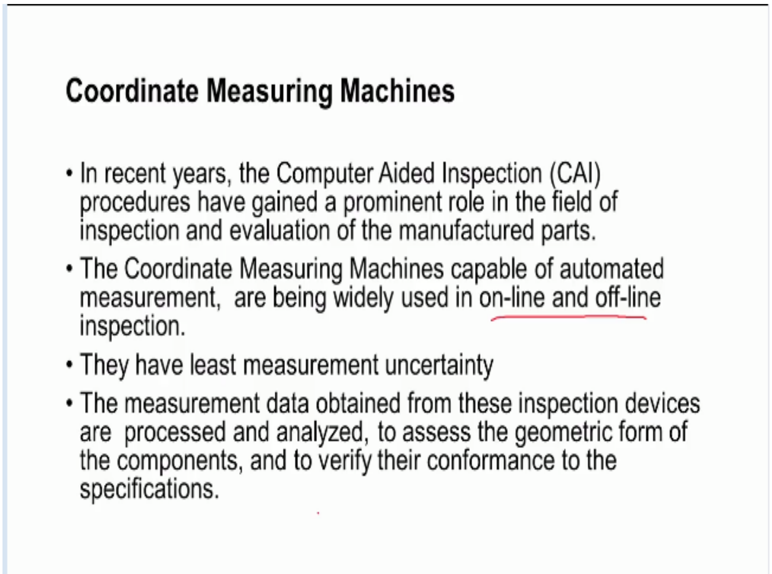

Now, we can use coordinate measuring machines also to check the straightness of given surfaces or line or plane. In the recent years computer aided inspection procedures are used to find out the geometrical features and the CMM Coordinate Measuring Machines it is possible to automate we can these CMMs can be used online or offline inspection after the machining is over we can take out all the work pieces we can clean them properly debur, de-oil etc.,

And then we can load them on to the table of the CMM and we can give the appropriate program for checking the various geometrical features like the straightness or the roundness or parallelism, perpendicularity all those things we can check using coordinate measuring machines. Also online inspection is also possible in the production line itself we can include CMMs and the features can be checked.

If the errors exceed the specified values feedback given feedback can be given to the main computer so, that the changes are made in the programs and errors are brought back within the limits. And the number of points can be taken there are probes attached to the CMMs, those probes can be contact probes or it can be non contact probes like laser spots.

So, number of point we have to take for example we want to check the straightness of a surface.

So, we have take some depending upon the length we may have to take 6 points or 12 or 18 and those data of points are given to the software and software will calculate the straightness or whatever feature is required. And then it will finally tell whether the component is okay or not.

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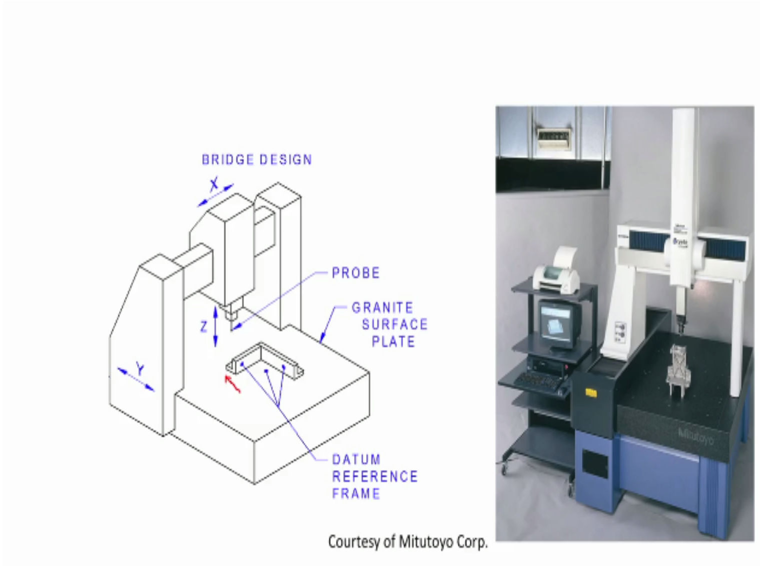

Now these pictures show the commercially available coordinate measuring machine you can see the granite table and then 2 columns are there to support this bridge and then you can see the different axis when the table moves in this fashion it is Y axis and movement in this direction is X axis and vertical movement of the probe is Z axis. So, we have granite surface plate which will act as primary datum surface.

And we can also have secondary or thirstier reference planes as an when needed. So, there is a dedicated computer for analysing the various points and to find out the geometrical form errors.

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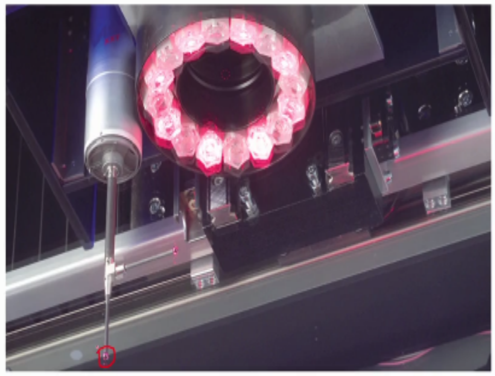
CMM probes



And you can see a photograph of a contact type probe. So, these probes will make contact on the work piece at the specified locations and data points are given to the computer for analysis for processing.

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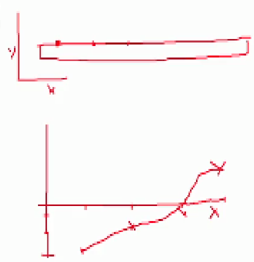
CMM data set and plot

SN	xi in mm	yi in mm
1	0.3956	-0.0033
2	0.6956	-0.0018
3	1.2956	-0.0010
4	1.6656	+0.0017
etc		



-The algorithms for form evaluation based on computational geometric techniques are used.

-Function oriented evaluation can be carried out and the results can presented for straightness.

Now one reading is shown here, so on a particular surface the probe reading, readings beyond by the probes are given here in this table. Basically they give the coordinates with respect to some reference they give the coordinates of all these is x and this y and we have the surface like this. So, what is the coordinate of this particular point, so x and y it will give like this different points it will give the xi values and yi values.

And now these values are given to the computer for processing and finally it tell us, what is the error. So, in this case you can see this is point xx values 0.39 approximately 0.4 and then 0.69 okay, this is 0.8 and this is 1.2 and this is 1.6 millimetre. So, we have 0.39 it is somewhere here y value is negative that is 0.003, so this is say 0.001, 0.002 and 0.003, so the point will be somewhere here.

This is the first point and second point will be somewhere here and third point and fourth point is here. Now we can join them to get the profile and also these data points are processed using algorithms for form evaluation based on computational geometric techniques also functional oriented evaluation can be performed and results can be presented maybe for straightness, flatness, perpendicularity, so all those geometric features can be measured using the coordinate measuring machines.

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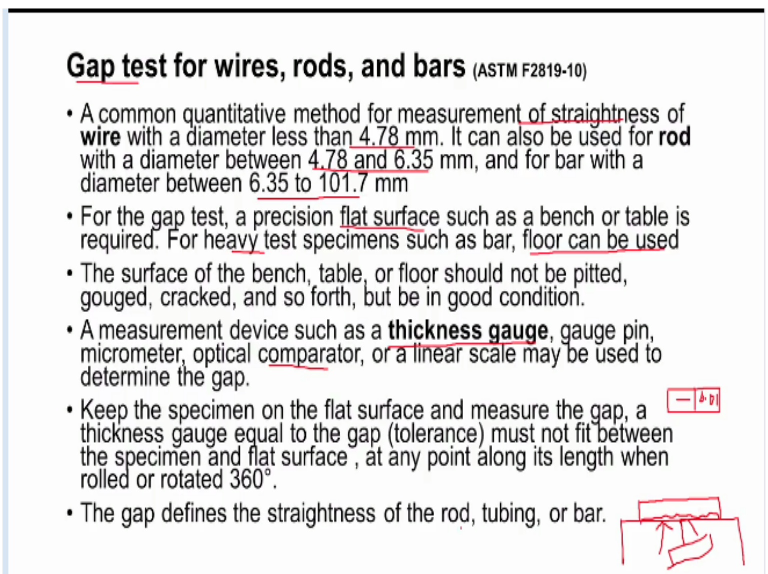

Now, there are some test as specified by ASTM, so they are applicable for wires, rods and bars okay. So, one very common test is gap test okay this is applicable for wires, rods and bars for measurement of straightness okay. So, this is applicable for wires less than 4.78 millimetre. It can also be used to check the straightness of rods within this range 4.78 to 6.35 and for bars with the diameter ranging from 6.35 to 101 millimetre.

Now in order to conduct this gap test a precision flat surface is needed we can use the surface plate as the reference plate. If the work piece is very heavy then floor also very neat clean granite floor can be used for straightness measurement and all the equipment surface plate or floor should be perfectly clean. There should not be any cracks or no pits should be there. The surface should be in very good condition very good cleaned condition.

And we have to use a measurement device such as thickness gauge or gauge pins, micrometers, optical comparators can also be used to measure the gap. So, the procedure is like this we have to keep this specimen on the flat surface okay like this. This is the flat surface or surface plate and then we have to keep the wire or rod or bar horizontally like this. So, this is the specimen, now if there is any error okay.

There will be gap between the datum simulated datum that is surface plate surface and the specimen. So, now we can use thickness gauges now say the straightness that is specified is , so straightness is specified as 0.01 millimetre that is 10 micrometer gap 10 micrometer error is allowed. So, what we have to do we have to take a thickness gauge of 10 micrometer, 10 micrometer thickness gauge and we should try to insert here in the gap.

So, that thickness gauge should be inserted here. So, we have to insert we should try to insert the thickness gauge throughout the length and then we should rotate at different rotation different orientation again we have to check the gap. If the thickness gauge does not enter then we say that wire or rod or bar is okay, it is straight. If the gap enters if the gauge enters then there is an error the straightness error is exceeding the limits, then the work piece is rejected.

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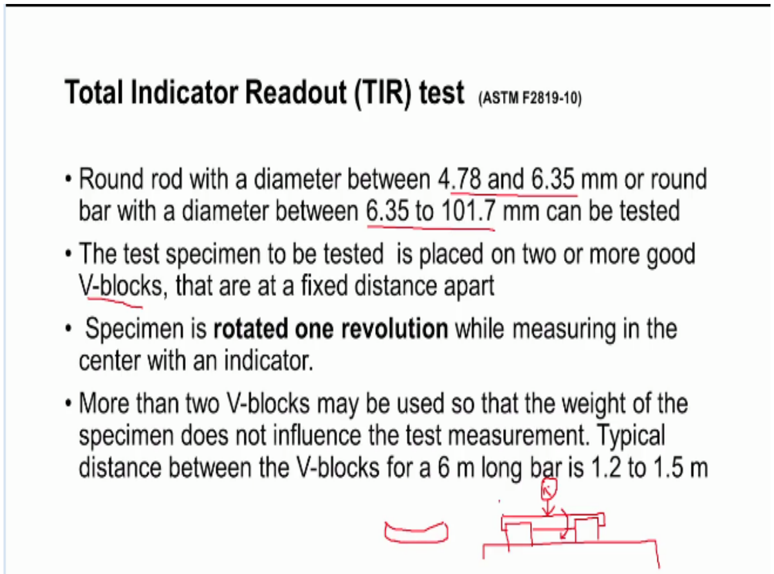

Now there is other test specified by ASTM it is known as total indicator read out test. So, this is applicable for round rods the with the diameter ranging from 4.78 to 6.35 millimetre or round bars with diameter 6.35 to 101 millimetre can be tested with this method. So, we require 2 or more V-blocks in good condition and then a surface plate is required to conduct the test. Now we have to keep the specimen on 2 or more.

V-blocks say this is the surface plate on which we have to keep the V-blocks depending upon the length if the length is length of the rod is 1 meter then we require only 2 if the length is 2 meter, 3 meter then we have to take 3 or more V-blocks to support the rods. Now rod is kept on the V-blocks we have to thoroughly clean the surface of the datum surface as well as the V-blocks. And the rod should be thoroughly clean and then it is placed on the V-block.

Now we have to take a indicator, dial indicator and we have to keep the dial indicator approximately in the middle and then we have to note down the reading. So, we have to take initially adjusted to 0 and now you slowly rotate the rod through one complete revolution and then again you take the reading at different orientations at different rotated position we can take the reading. That mean this will indicate if there is any pending it is indicated by the dial indicator.

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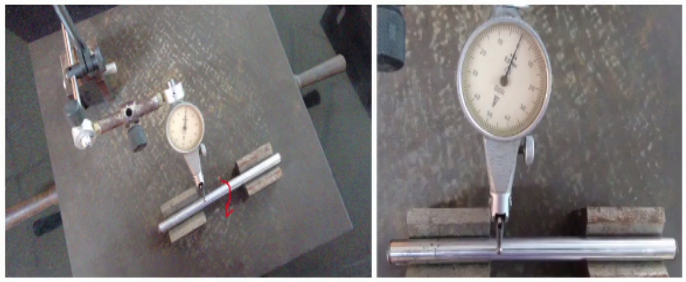

TIR test for straightness- specimen is rotated 1 revolution

Now you can see some photographs how we can these pictures will show how we can conduct the TIR test. Now we have supported the specimen okay specimen length is about 30 centimetre and with diameter of about 12 millimetre and it is supported by 2 cleaned V-blocks at 2 V-blocks are kept on the surface plate and then the rod specimen is placed on the V-blocks and we use the dial indicator or test dial indicator. And then we have to rotate the specimen and we have take the readings.

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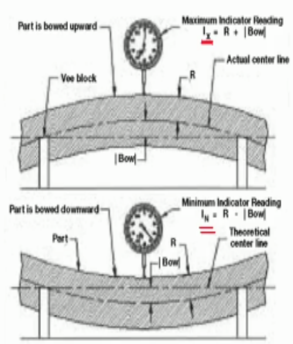
$TIR = I_X - I_N = (R+|Bow|)-(R-|Bow|)=2|Bow|$

where:

R = the radius of the material that is being measured, and

Bow = defined by figure



TIR Method for Measurement of Straightness

And those readings are fed in the expression to get the error, straightness error. So, these 2 are V-blocks this is the specimen and the indicator. So, we have to rotate this and we have to take the reading. So, we can see minimum indicator reading that is IN and then maximum indicator reading IX okay. These values are fed in this hu expression TIR is equal to IX-IN so this and R+ the mode of bow this reading IX reading and –R-mode of this reading IN reading.

So, this will give us the total indicated reading where R is radius of the material that is being measured okay.

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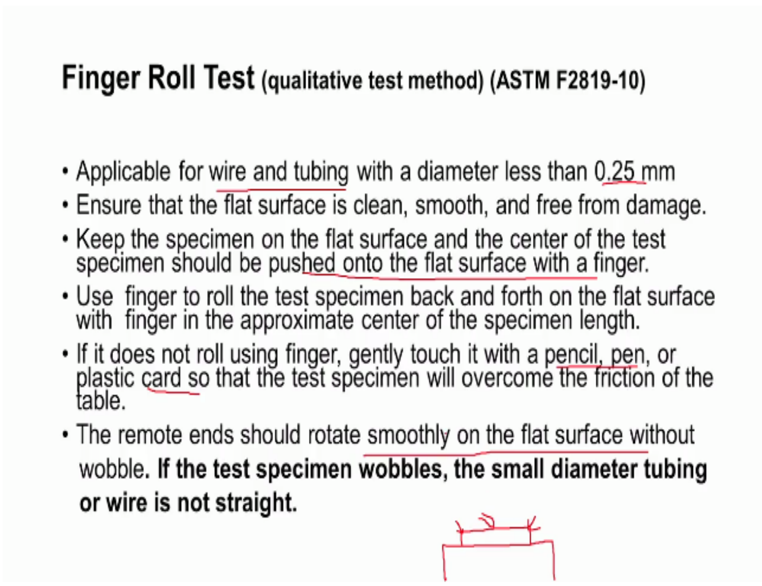

Now there is another test finger roll test specified by ASTM. This is qualitative test method previous 2 methods that is TIR and gap test methods they are quantitative test wherein we get what is the amount of error numerical value we get whereas here this is qualitative test method is will not give any numerical value it will tell whether the wire or tube is straight or not okay. If the diameter is less than 0.25 millimetre then this finger roll test can be used.

So, we should ensure that all the equipment surface plate and the wire is perfectly cleaned and then we should keep the specimen on the flat surface and the centre of the test specimen should be pushed on to the flat surface with the finger that is we have this surface plate and then we have to keep the wire thin wire on the cleaned surface plate and we have to press we have to push this specimen using finger.

So, using finger we should push this and we should move it we should roll it. If it does not roll we can always take the help of pencil or pen or plastic card . So, that the specimen rolls and it overcomes the friction and then starts to roll. Now when we roll the specimen in this fashion the remote ends, this end and this end this remote end should rotate smoothly on the flat surface without any wobbling. If there is any wobbling it indicates that to the specimen is not straight.

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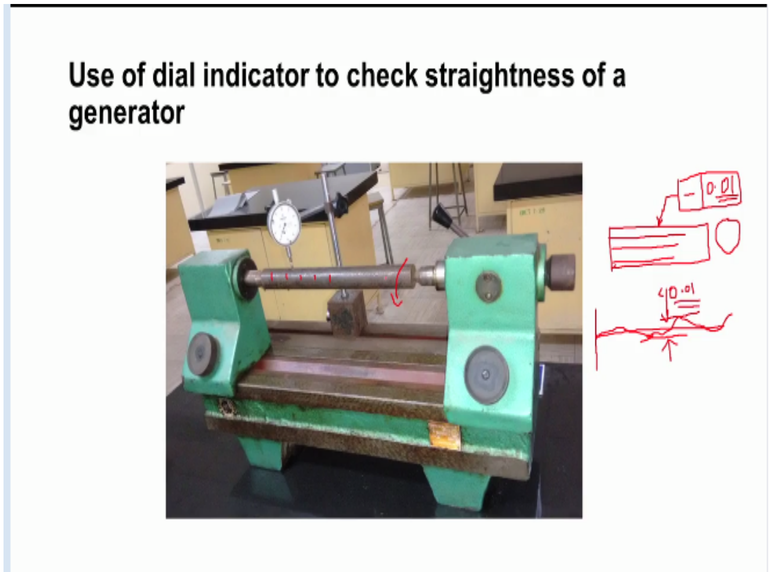

Now we can use a dial indicator or a test dial indicator to check the straightness of the generators on the cylinder. Now say this is the cylinder with some diameter, and the straightness is specified to be say 0.01 millimetre, so this is the specification tolerance, straightness tolerance. Now what we can do we can clean the work piece, a specimen to be tested for straightness and it is mounted between the 2 centres.

And then we can use a dial indicator and we should mount it as shown in this figure, the magnetic stand is placed on the guide ways. And the stylus or probe of indicator is placed on the top most generators. So, that this perpendicular on it is touching the maximum top most generator. So, we should take the reading at this point or we can adjust it to 0 and slowly we can move this indicator to different position.

We can mark the positions like 0, 1, 2, 3 like this, so total length is divided into some equal number of parts and then at these locations we can take the reading. And if you plot depending upon the values we get the profile like this and then we should take the peak value and we should take the valley, peak and valley. So, now we should calculate, what is the gap between this peak and valley.

If this is smaller than the specified value that is 0.01, if this gap is smaller than the specified value then we say the this particular generator is straight. So, similarly we can conduct this experiment on many generators we have to rotate the work piece specimen and a different angles we should take the reading and if in all the angular positions if the error is less than the specified value then we say the cylinder is straight`

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Now that we demonstrate how it can test the straightness of a generator on a cylindrical object you can see we have surface plate and on the surface plate we have kept 2 V-blocks on which the cylindrical object is placed.

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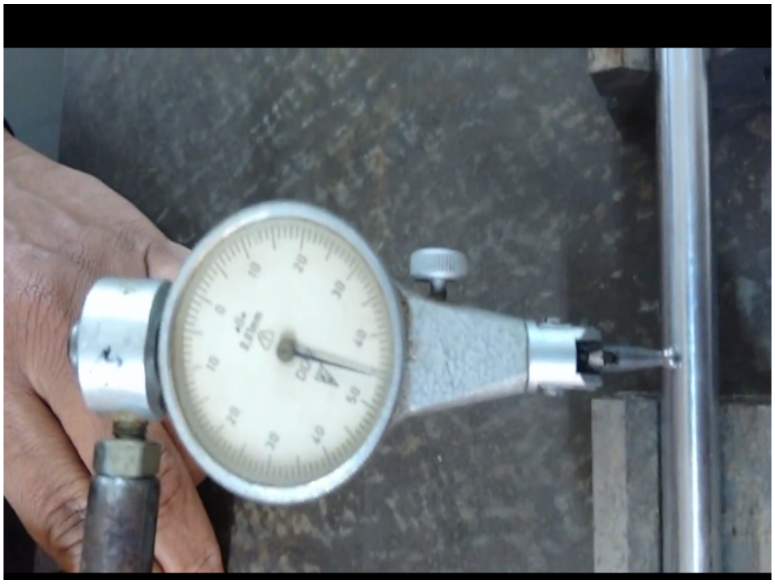

So, we have to clean all the equipment like surface plate, V-block and specimen thoroughly and now at different positions we have to take reading, now you can see using the dial test indicator we are taking the readings.

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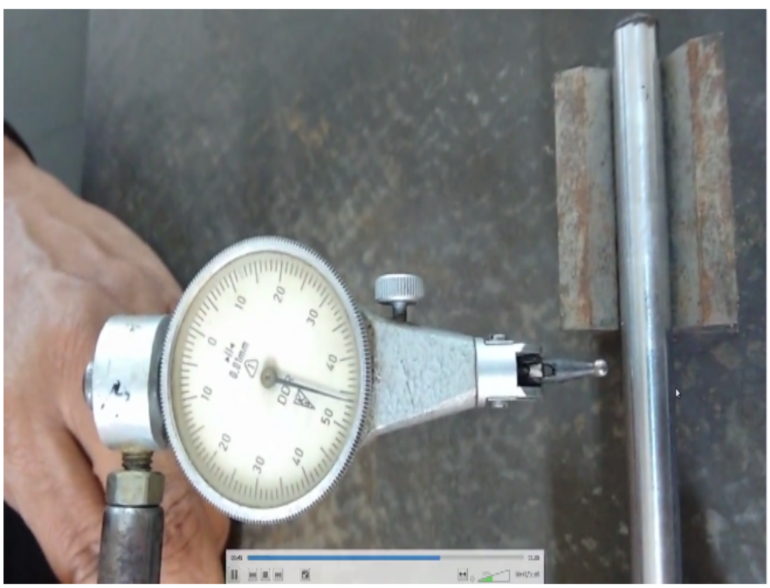

We have to move this stylus over the specimen and the maximum reading we should take. So, we have to see the maximum reading here and then we have to take that reading. Now you can see here it is 0.

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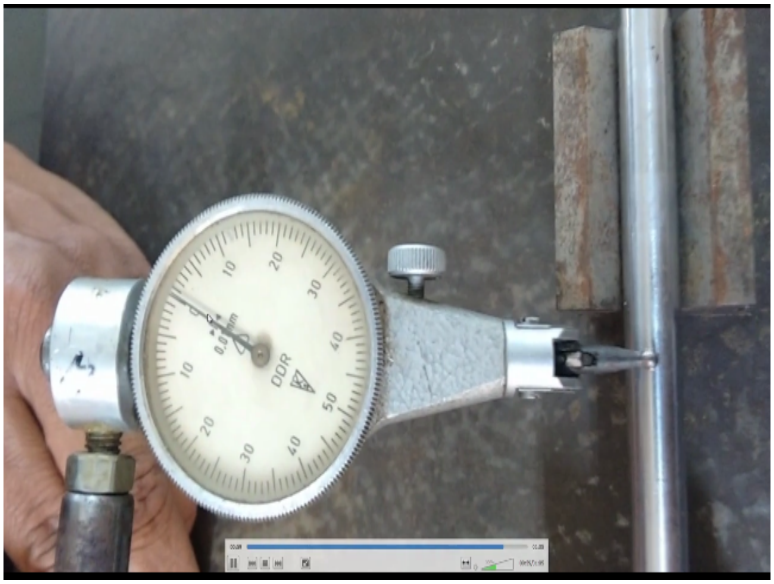

So, like this at different positions we have to take the readings and then we can find, what is the straightness.

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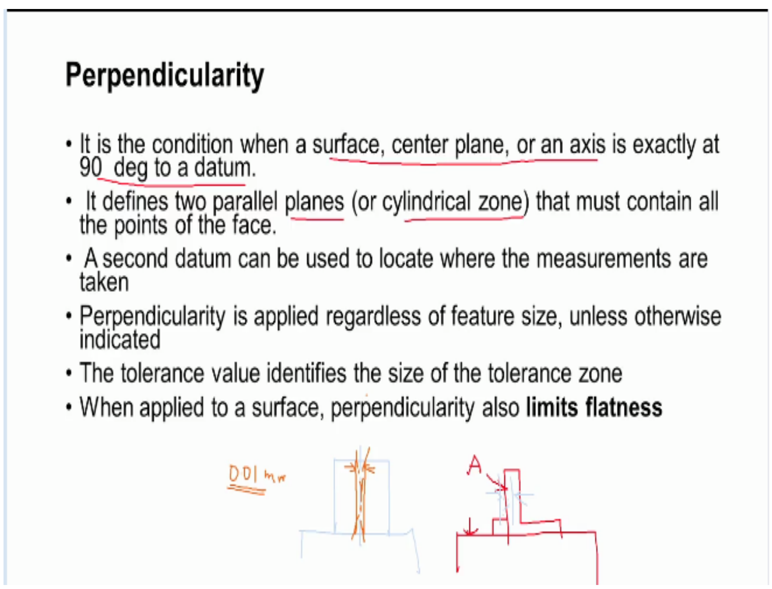

So, now we will move to another geometric form that is perpendicularity. Now it is the condition when the surface or centre plane or an axis is exactly at 90 degrees to the datum. That means we should have a datum and say we have some work piece like this. And this surface, if this surface is exactly at 90 degree then we say this particular surface A is perpendicular to the datum. It basically defines 2 parallel planes or cylindrical zone**.**

That must contain all the points of the phase for example here we have this surface which is to be perpendicular to the datum. Now what we have to do is we have to consider 2 planes like this. So, this is 1 plane and this is another plane if all the points on this particular surface or within these 2 planes. Then we say this surface is perpendicular to the datum surface. And if it is perpendicularity is applied to axis then we have to consider a cylindrical zone.

That is say this is the datum surface and then this is the work piece and we have this axis. So, if the perpendicularity condition is given to the axis say the perpendicularity should be within 0.01 millimetre. Now we have to take is a consider a cylinder here okay. The diameter being 0.01 that is specified value. Now the axis should be within this cylinder it can be like this or it can be in the other direction.

So, axis should be within this cylinder, so that the work piece passes the test.

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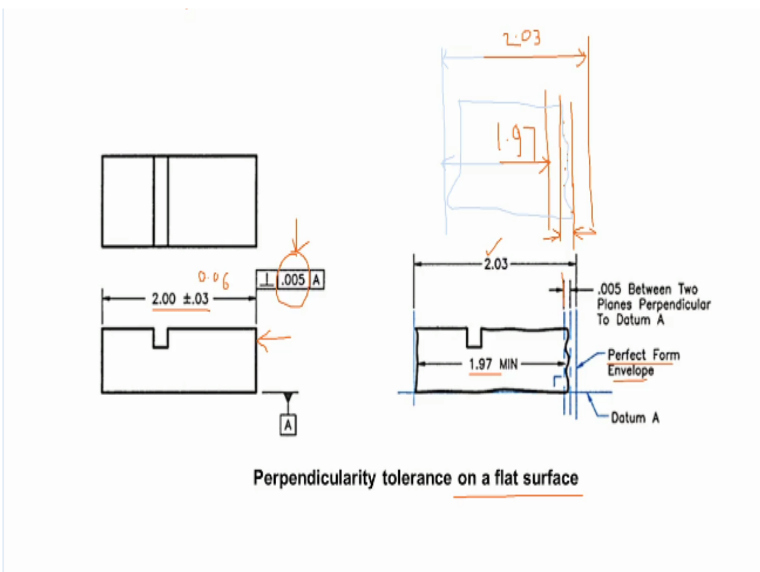

Now this is these picture show the perpendicularity tolerance on a flat surface. This is the work piece and this is the datum reference surface and this is the surface which is to be perpendicular to the datum this surface. And the tolerance that is allowed is 0.005 millimetre that is 5 microns okay. This surface should be perpendicular to this within this allowable deviation. So, the meaning of this is, so we can see we have 2 tolerances 1 is specified for the size of the object.

And, another tolerance for the perpendicularity for deviation perpendicualrity deviation. Now this particular work piece should satisfy both, now we will consider the size tolerance, the maximum width should be below 2.03 okay. This is the maximum size and minimum size is 2-0.03 that is 1.97 millimetre minimum size. So, now this is 2.03 to 1.97 this is the size tolerance and for this we say perfect form envelope, the object should be within this envelope.

Now coming to the perpendicularity tolerance, now you can see here this 1.97 is this line. So, this is 1.97 and this one is 2.03 that means the size tolerance it the total zone is 0.06 millimetre that means 60 micrometer is allowed and now coming to the perpendicularity tolerance it is only 5 microns. So, now let us assume that the work piece is like this, so work piece is like this okay.

Now it is within the limits, so total size is within the limits okay. Now we have to consider this surface to satisfy this perpendicularity tolerance. Now we have to, so this is the one spot we have to draw a line here and this is another spot on the extreme end. So, all the points on the surface on this particular surface should be within 0.005 millimetre. So, in that case this work piece is accepted. That means this particular component should satisfy both size variation as well as form variation.

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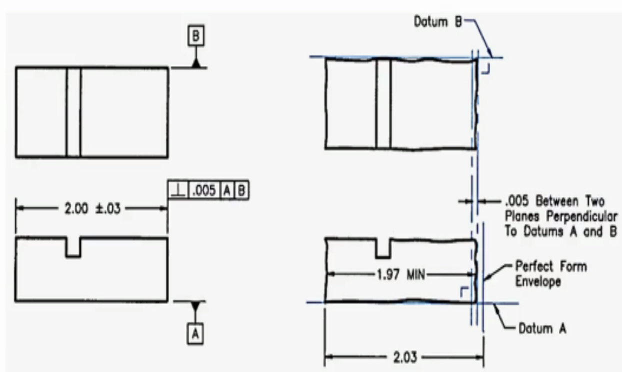

A perpendicularity can be referenced to two datums

And sometimes 2 datums are specified, so in that case this particular surface should be perpendicular to this datum as well as this datum. So, with respect these 2 we should conduct the test.

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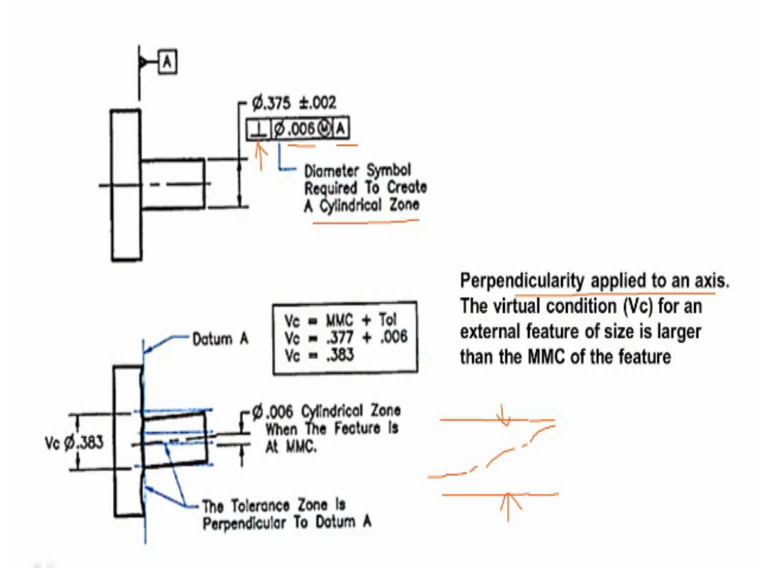

Now perpendicularity applied to an axis, now you can see here this is the work piece and this is the datum surface, reference surface with reference to this the perpendicularity of the axis should be achieved. So, this is the symbol for perpendicularity and the diameter indicates that we have to consider the cylindrical zone. Since the tolerance, perpendicularity tolerance is given to the axis we have to consider cylindrical zone.

And the variation allowed is 0.006 at the maximum material condition and the datum is A with respect to this the axis should be within this value. And the size of this portion cylinder is also mentioned it is 0.375 +/- 0.002 millimetre. Now you can see here the a cylinder is consider here 0.006 cylindrical zone and we can also see, so this is the 0.006 cylindrical tolerance and the axis should be within the specified tolerance. If that is the case then this work piece is accepted.

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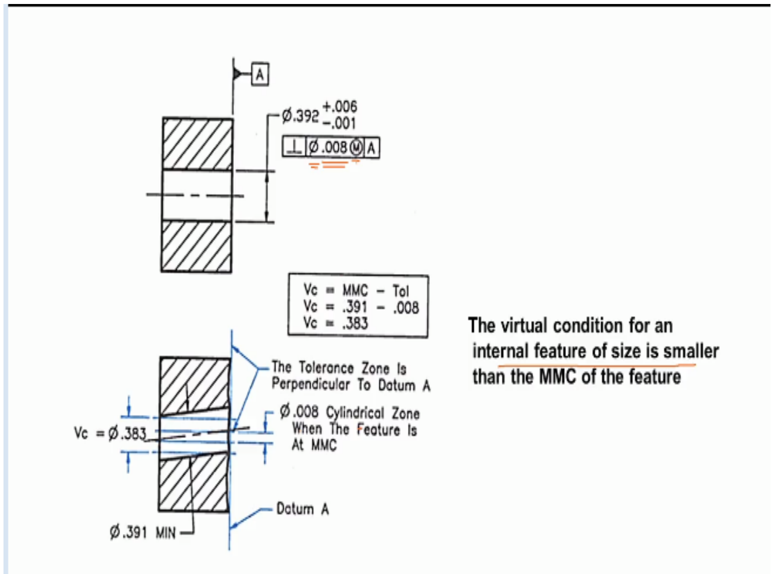

This is the perpendicularity tolerance given for the hole internal feature that is hole. So, this is as specified this is the reference datum for which the axis should be perpendicular to this within this 0.008 tolerance at the amx material condition and since diameter is there and since it is specified perpendicularity is tolerance is given to the axis. We have to consider cylindrical zone.

And again the for the hole the size tolerance is given, you can see here uhh we have considered cylindrical zone with diameter 0.008 millimetre as specified in the drawing. And the axis should be within this cylindrical zone, in that case the work piece is accepted. So, with this we will conclude the session. In this session we discussed about the straightness measurement using spirit level and autocollimator.

We also discussed about the different methods of studying the measuring the straightness that is TIR method, gap test and finger roll test also we discussed about how we can check the straightness of a generator on using the cylinder using dial indicator. Then we started discussion on perpendicularity and what is the meaning of perpendicularity and how we specify the perpendicularity surface and on the axis.

And what is the meaning of those perpendicularity errors tolerance that is specified, so those things we discuss in the next session we will continue the discussion on measurement of perpendicularity thank you.