Metrology
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Module-5
Lecture-2
Surface finish parameters

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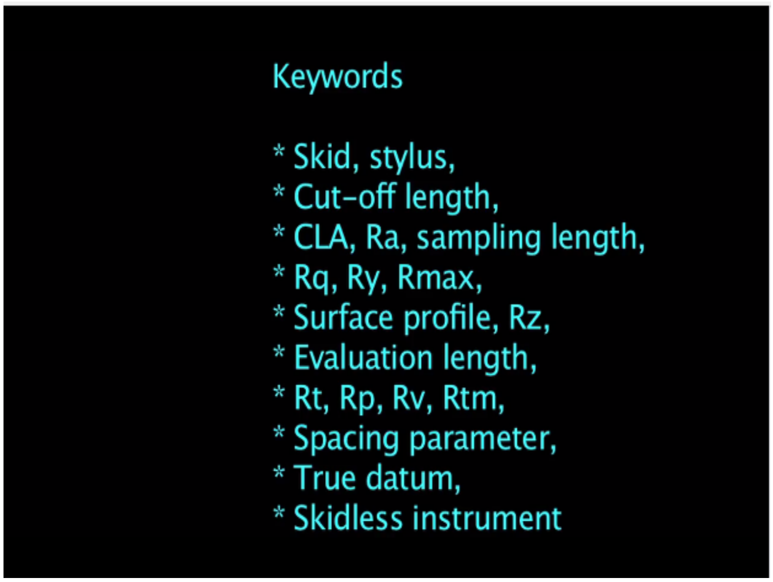

I, welcome for the module 5 lecture 2 in the series of lectures on surface finish measurement, in this lecture we will be discussing about the various parameters which are use to specify the surface roughness and we will also study about the different methods of surface finish measurement like contact methods and non-contact methods. And also will study about the various elements of stylus type instruments.

We will discuss about the types of skids and the design of stylus and the out of phase condition on the skid and then we will also learn how to select the measuring parameters like cut-off length and then finally we will see some experiments.

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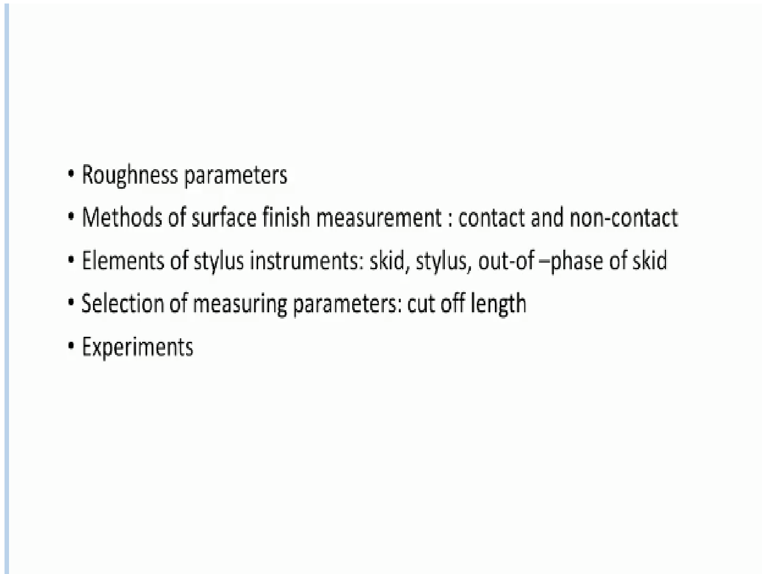

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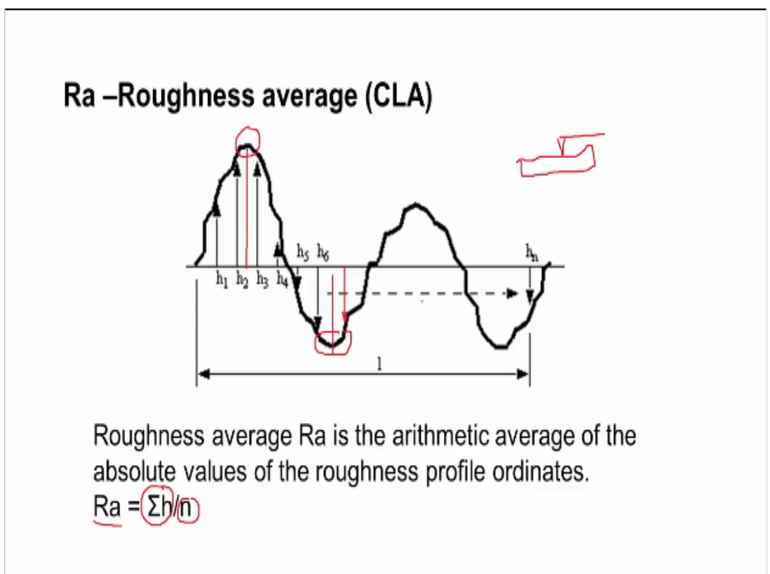

Now we will start with parameters, roughness parameters, so first one Ra roughness average which is also known as centre line average. We can see here after getting the profile the work piece surface is kept on the table of the measuring instrument and the stylus will move on the surface and finally we get the profile as output from the measuring instrument. Now we have to analyse this profile.

In order to analyse this profile you can see at we have to select the length, sampling length L and we have to draw the ordinates h1, h2, h3, h4 up to hn at equal distance. And then we have to measure the heights these ordinates. And then finally we should find the summation of heights like that is h1+h2+h3 up to hn divided by number of ordinates. So, this will give Ra value, if ordinates are measured in terms of micrometers. Then we get Ra value in terms of micrometers.

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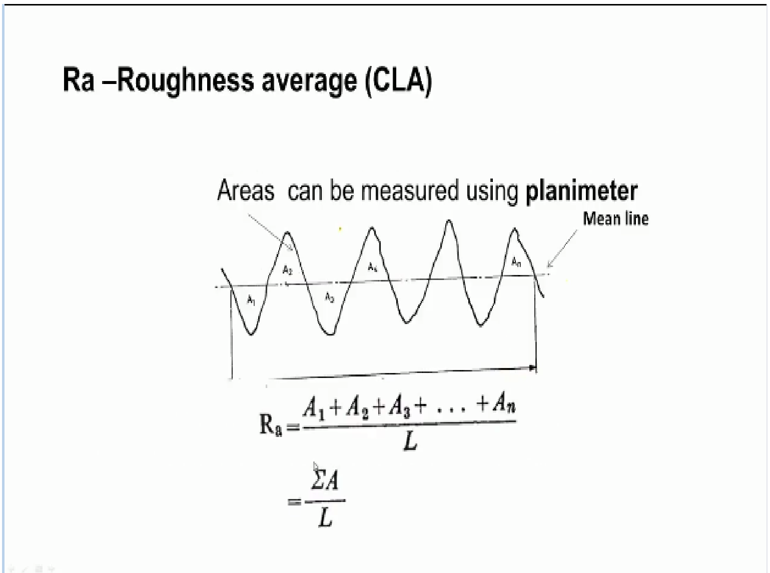

So, another way of see in the previous case you can see here when we select the ordinates at regular intervals now the important ordinates we may miss. For example here we have this peak, so this peak will be losing. Similarly if we draw the h7 here, so we will be losing this valley depth. So, we get a value which is somewhat. So, in order to and also it is difficult to draw too many ordinates at very close spacing and it becomes difficult to measure.

So, we have another parameter we have parameter Ra which can be analysed by means of measuring the area, you can see here we have the main line or centre line and below the centre lone we have areas A1, A3, A5 etc., and above the centre line we have areas A2, A4, A6 up to An. Now these areas can be measured using planimeter. So, that measurement of ordinates is avoided.

So, accurately we can measure the areas using planimeter and then we can measure we can calculate the summation of all the areas divided by the length. So, this will give us Ra value.

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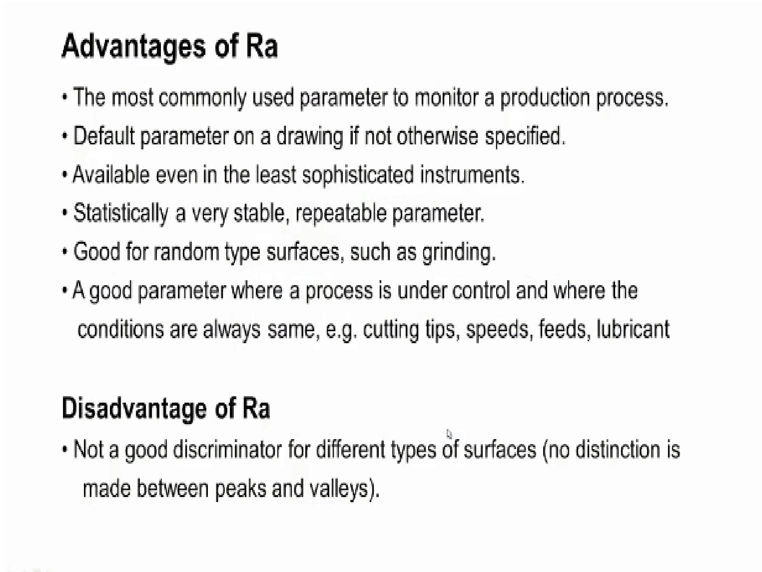

Now what are the advantages of using Ra parameter this is most commonly use parameter to monitor the production processes. This is the default parameter on a drawing if the parameter is not specified. So, this Ra parameter is available in almost all commercially available surface finish measuring instruments. And this is statistically very stable and repeatable parameter and this is very good for random type of surfaces such as grinding ground surface.

A good parameter where process is under control and where the conditions are always same like cutting tips, speeds, feeds etc., or same and then this parameter is better to use. Then disadvantage of Ra is not this is not a good discriminator of different types of surfaces, so no distinction is made between peaks and valleys.

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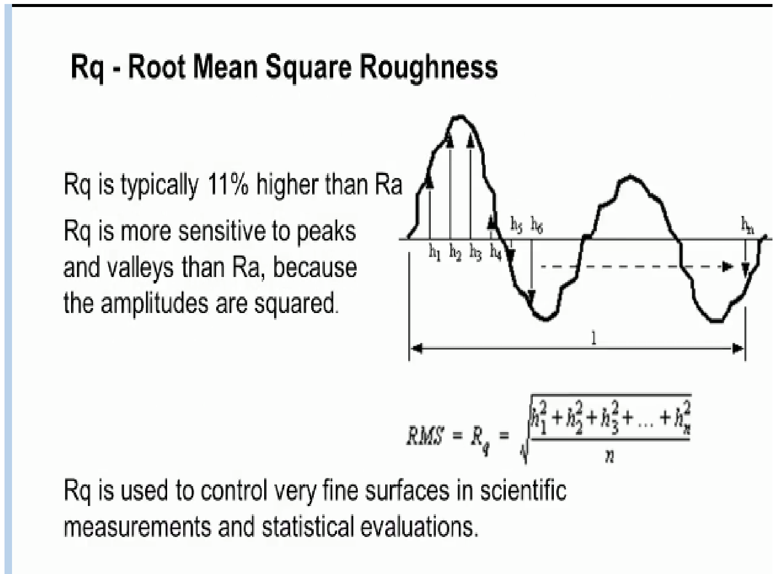

Now another parameter is Rq root mean square roughness, so in this case instead of taking only h1, h2 values this squares of ordinates are taken like this h1 square + h2 square+ h3 square like this divided by number of ordinates under square. So, this will give us Rq, Rq is a typically 15 to 11 to 15 % higher than Ra. And Rq is more sensitive to peaks and valley than Ra because the amplitudes are squared. And this is use to control very fine surfaces in scientific measurements and statistical evaluations.

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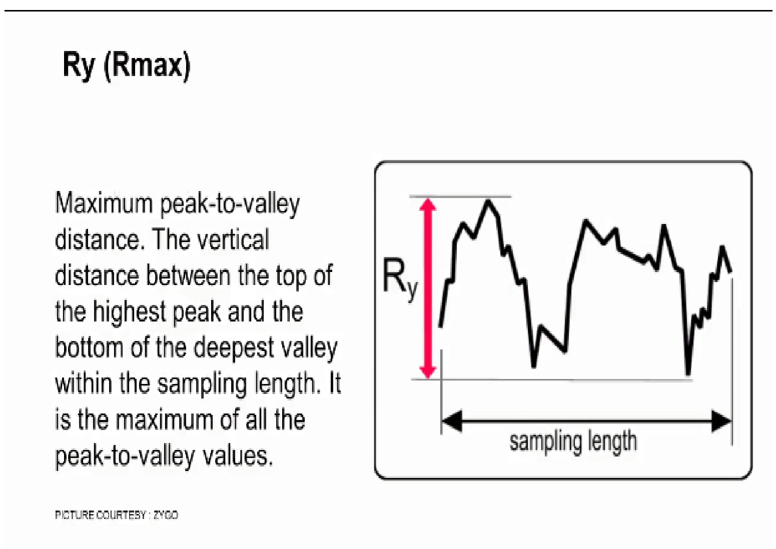

Now next parameter is Ry is this is also known as Rmax you can see here this is the profile that is obtained and over a sampling a particular sampling length. Now the gap between the peak and the valley within the sampling length is termed as Rmax or Ry. So, it is the vertical distance between the top of highest peak and the bottom of deepest valley within the sampling length.

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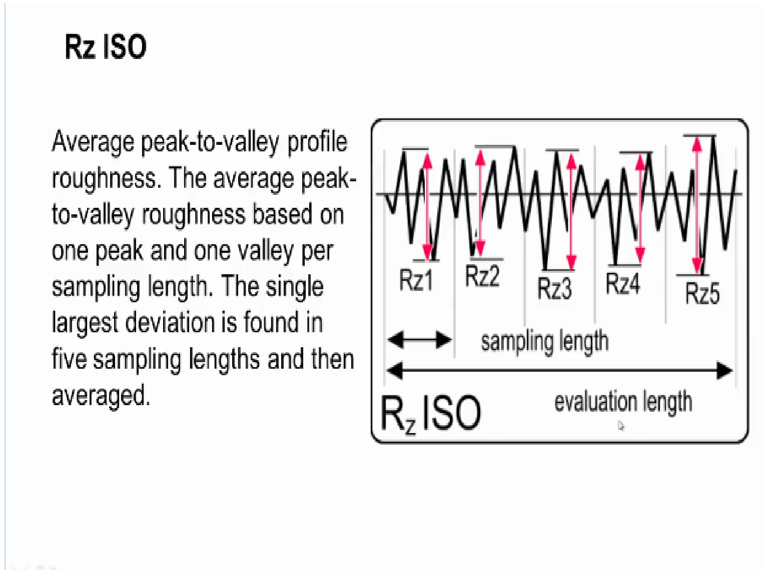

Now this is Rz, so we have the evaluation length which is divided into 5 equal parts. So, we have 5 sampling lengths Rz1, Rz2, Rz3, Rz4 and Rz5 and in each sampling length we have to find the peak to valley distance. Now this is Rz1, similarly peak to valley in the second sampling length that is Rz2, Rz3 like this. Now after finding Rz1, Rz2 up to Rz5 the average peak-to-valley profile is calculated, so that is Rz.

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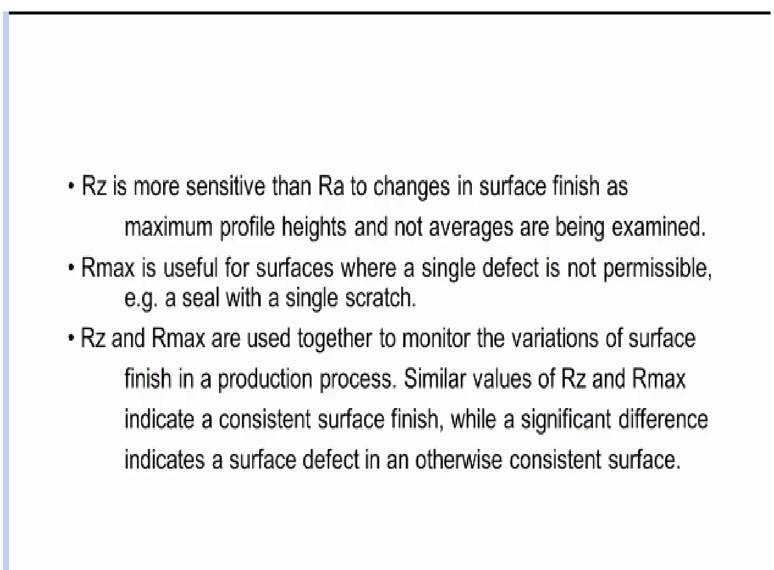

Now this is more sensitive than Ra to changes in surface finish as maximum profile heights and not averages are being examined. Rmax is useful for surfaces where a single defect is not permissible. For example a seal with a single scratch. If there is a scratch and the seal now that also will be considered. So, if it exceeds if the Rmax exceeds certain limit then that particular seal is rejected.

And then Rz and Rmax are use together to monitor the variation of surface finish in production processes. So, similar values of Rz and Rmax indicate consistent surface finish, while a significant difference indicates a surface defect in an otherwise consistent surface.

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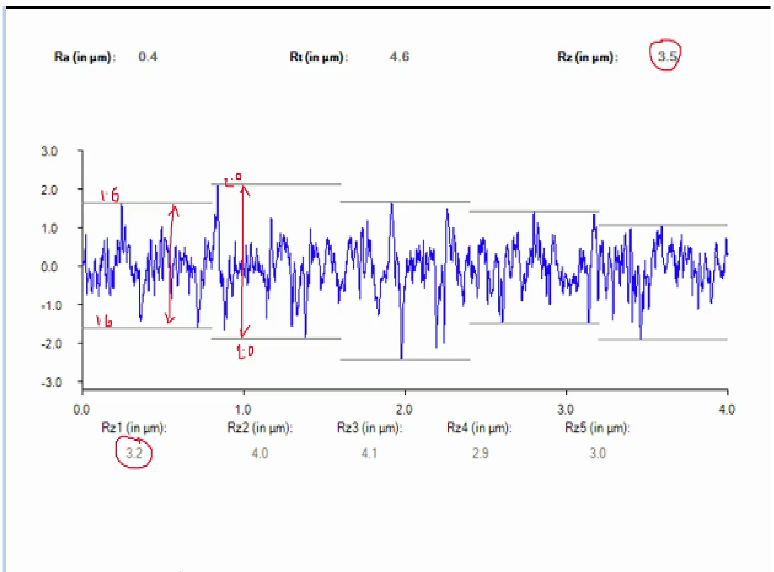

Now here we can see a profile in which we have considered 5 sampling lengths Rz1, Rz2, Rz3, Rz4 and Rz5 we can see here Rz1 value is 3.2 micrometer that we can see here. This is the peak in this particular sampling length and this is the valley, so this distance is this is about 1.6 micrometres and this is about 1.6 micrometers. So, when we add these 2 we get 3.2 micrometer. Similarly the Rz value for this particular sampling length is this one.

So, here this is 2 micrometer and here it is 2 micrometer. So, peak to valley distance is 4 micrometer. Similarly Rz3 is 4.1 and Rz4 is 2.9 and Rz5 is 3, so when we calculate the average of these 5 values we get this Rz of 3.5 micrometer. This is average Rz value.

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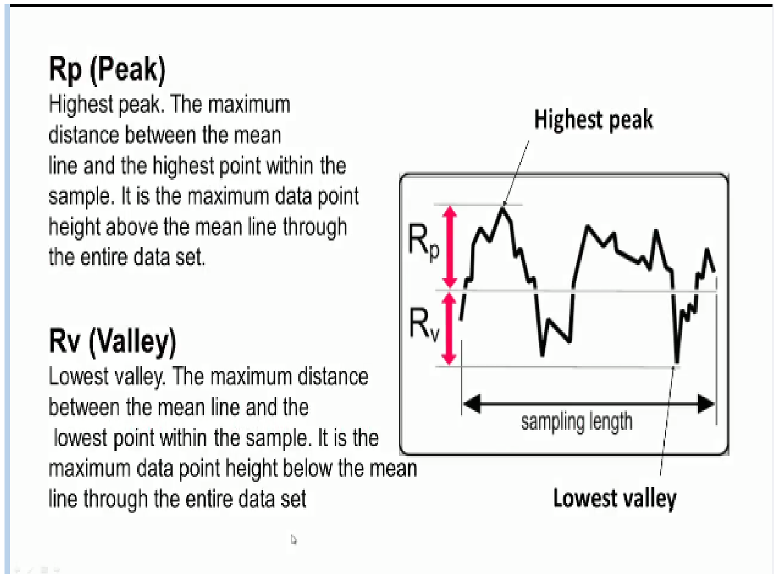

Now coming to the next parameter, this is Rp now this is the gap this is the highest peak the maximum distance between the centre line and the highest peak is termed as Rp within the given sampling length also the distance between the centre line and the lowest valley is known as Rv value.

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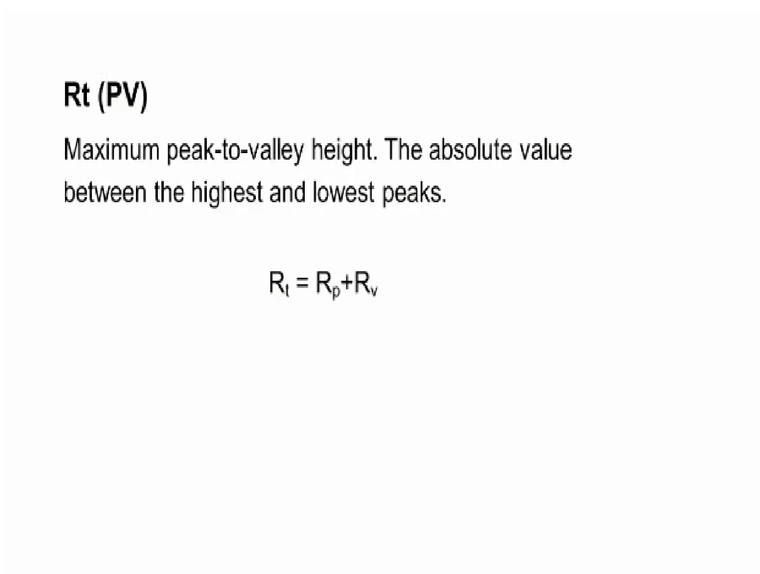

And then Rt this is maximum peak to valley height. The absolute value between the highest and the lowest peaks. So, Rt is equal to Rp+Rv, when we add this 2 we get Rt value.

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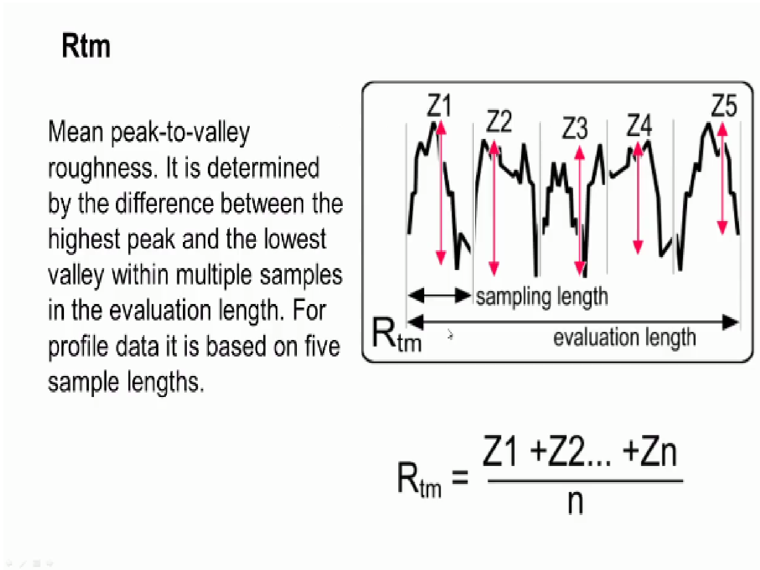

So, next one is Rtm, mean Rt mean peak to valley roughness. Now we can see here we have this evaluation length which is divided into 5 sampling lengths and this is the first sampling length in which we have peak to valley distance it is nothing but Z1. Similarly the second sampling length we have Z2 this is the peak to valley gap, similarly Z3, Z4, Z5. So, when we calculate the average of these 5 values we get Rt mean peak to valley roughness.

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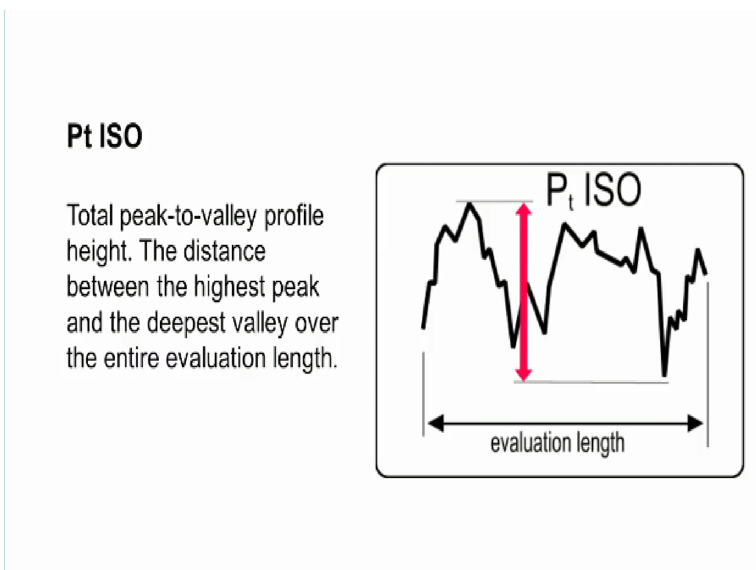

And then this is Pt value total peak to valley profile. So, over the evaluation length the gap between the top most point on the peak and the lowest point and this gap is total peak to valley profile height.

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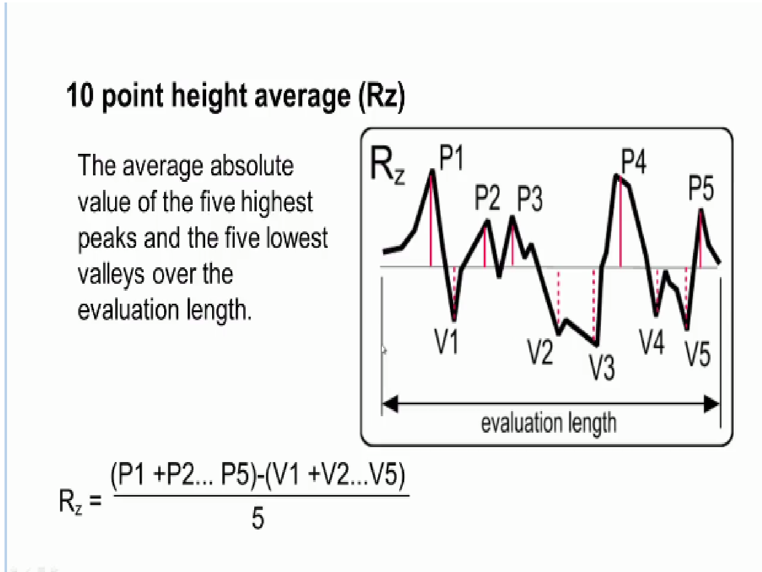

And we have another parameter 10 point average, 10 point height average is also known as Rz parameter. So, again in the evaluation length we have to consider 5 peaks, you can see here in this profile P1, P2, P3, P4 and P5, 5 highest peaks are considered within the evaluation length, similarly 5 lowest valleys are considered you can see here V1, V2, V3, V4 and V5 and now the average absolute value of the 5 highest peaks and the 5 lowest valleys over the evaluation length will give us Rz value.

That means we have to add the ordinates P1, P2, P3, P4, P5 and –the summation of ordinates V1, V2, V3, V4, V5 . Then if we feed this values in this expression we get Rz value 10 point height average value.

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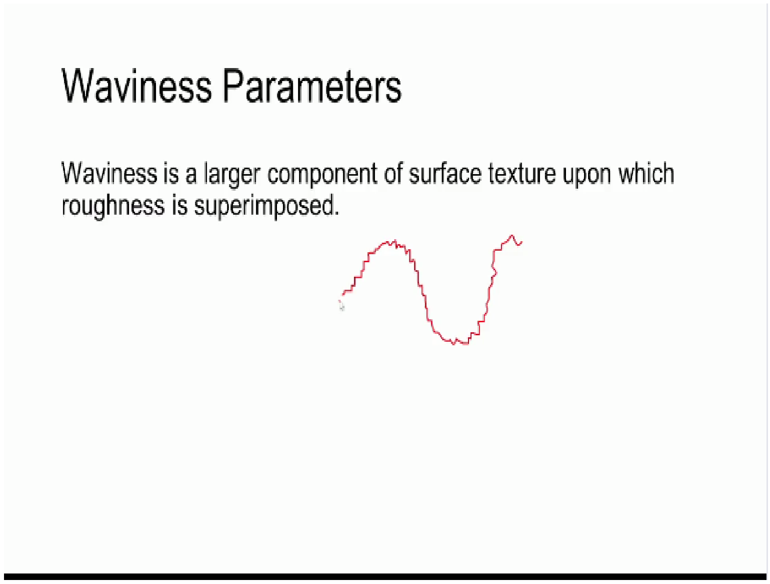

So, now coming to the waviness parameters, so this is waviness is a larger component of surface texture upon which roughness is superimposed like we have the surface roughness and then we have this waviness. So, this profile will give us waviness profile.

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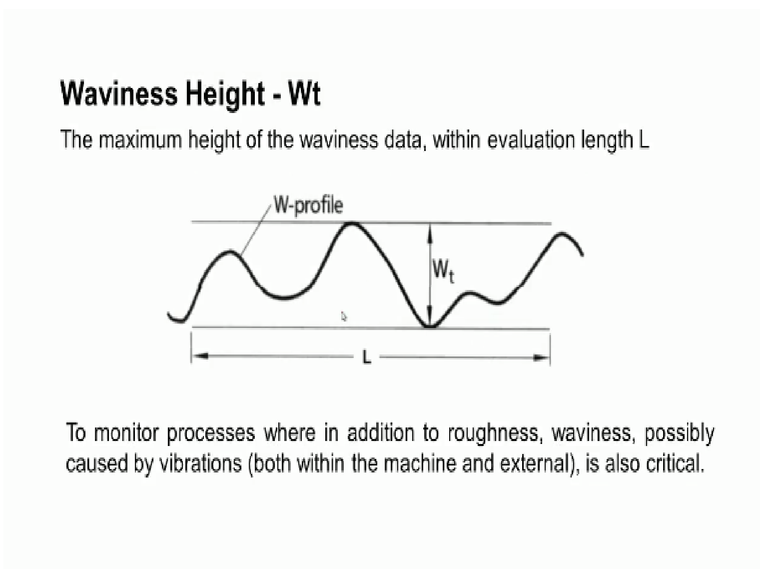

And the parameter that is used to specify this waviness is waviness height that is the maximum height of waviness data within the evaluation length. This is the evaluation length and this is the peak and valley. So, this gap is known as waviness height and it is specified by the symbol Wt. So, this waviness height parameter is used wherein where in addition to roughness waviness is also critical.

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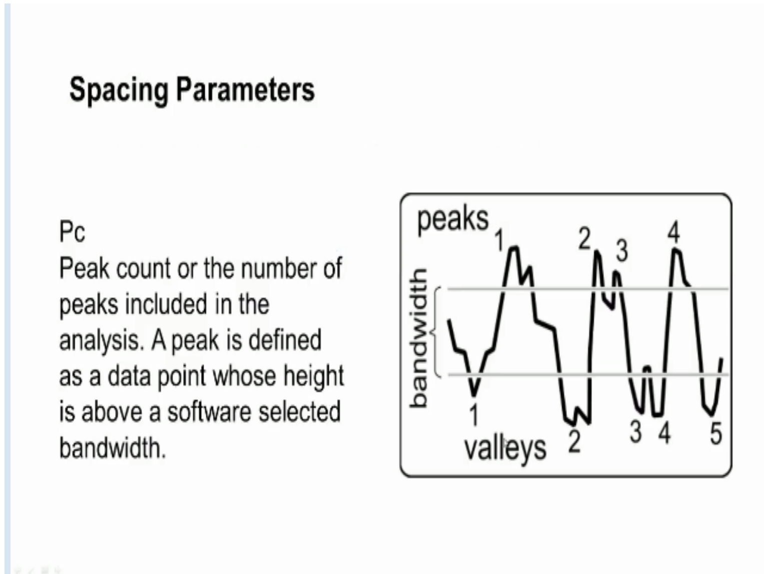

Now moving to the spacing parameters now we have this parameter Pc we have this profile wherein we have peaks 1, 2, 3, 4 etc., and valleys 1, 2, 3, 4, 5 etc., so, this Pc is nothing but peak count or number of peaks included in the analysis of the profile. A peak is defined as a data point whose height is above a software selected bandwidth. This is the software selected bandwidth and we have some peaks above this bandwidth. So, these are considered for the calculating the Pc.

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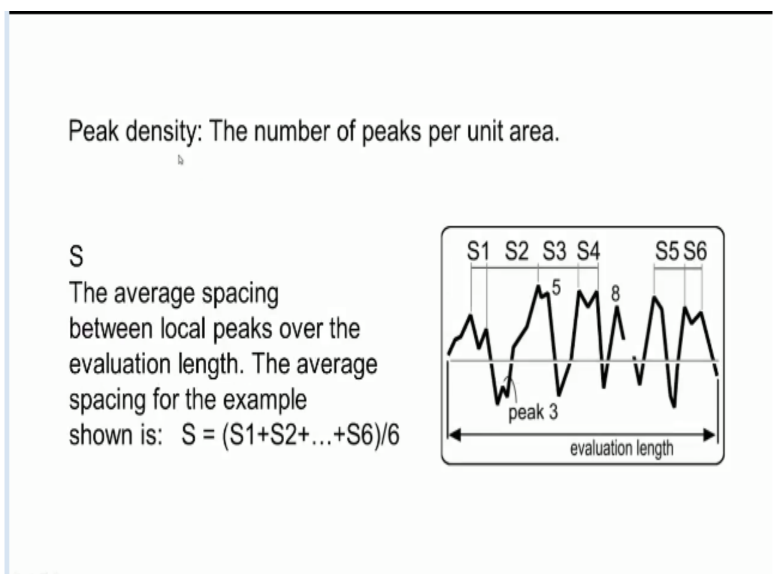

So, if we consider an area of surface then the number of peaks per unit area that is termed as peak density. And another term is S, this is the average spacing between local peaks over the evaluation lengths. Now we can see here this profile we have the evaluation length and we have peaks here one peak and second peak, this is the gap between 2 peaks. Similarly we have considered one more peak here and another peak here.

This distance between this peak and this peak is S2 and similarly distance between and this peak is S3 and so like this . We have to measure the gaps this gaps that is spacing between the peaks and then we should find the average, average spacing using this expression. So, wherein S is equal to (S1+S2 up to S6)/6, if we consider 6 peaks then S1+S2 up to S6 divided by number of peaks considered. So, this will give the average spacing.

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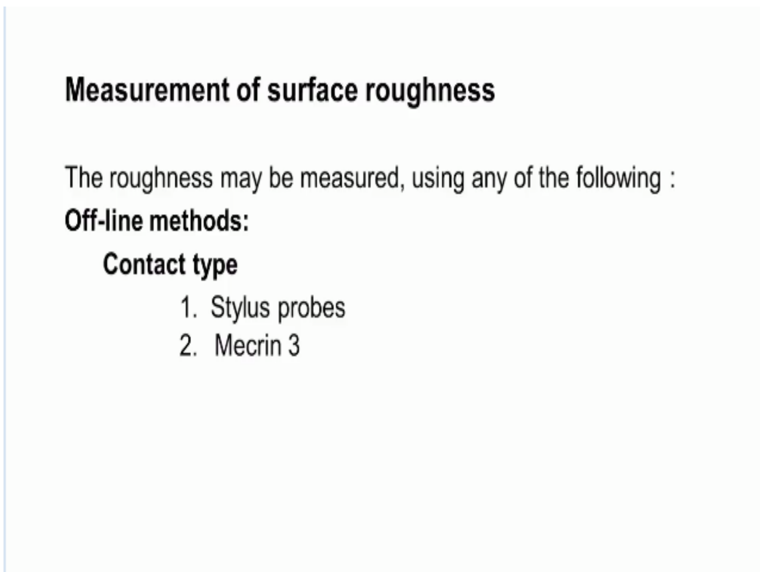

So, now having understood the various parameters used to specify the roughness. We will move to the measurement of surface roughness how we can measure the surface roughness how we can get the various parameter values and what are the kinds of measuring methods used what are the different types of measuring instruments, so those things we will study. So, the roughness maybe measured using anyone of the following methods.

So, we can measure the surface roughness of the component in the offline method that is after the production is over the part is taken out of the machine tool and it is de-oiled and de-bured and then it is kept in the proper atmospheric temperature condition and then appropriate instrument is selected and then the surface is measured to get the various parameters. So, in the offline methods we have different we have contact type and non-contact type measurement methods.

So, in the contact type so we have stylus probe type instrument and Mecrin 3 instrument.

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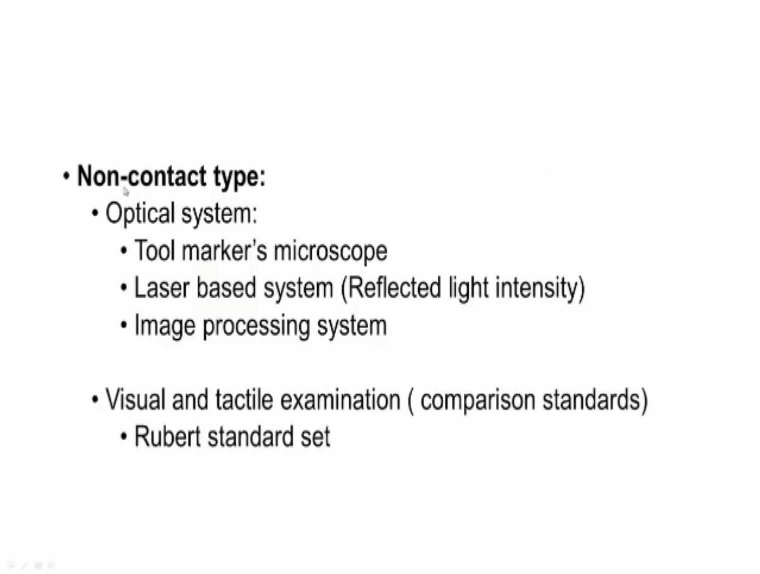

And in the non-contact type offline we have optical **sys** system like tool maker's microscope can be used to analyse the surface and then we have laser based system which works on reflected light intensity method and then image processing systems are also available. And then we can also use some comparison standards using comparison standards we can check the surface under quotient.

So, we can visual examination or tactile examination, so we will also learn about the comparison standards.

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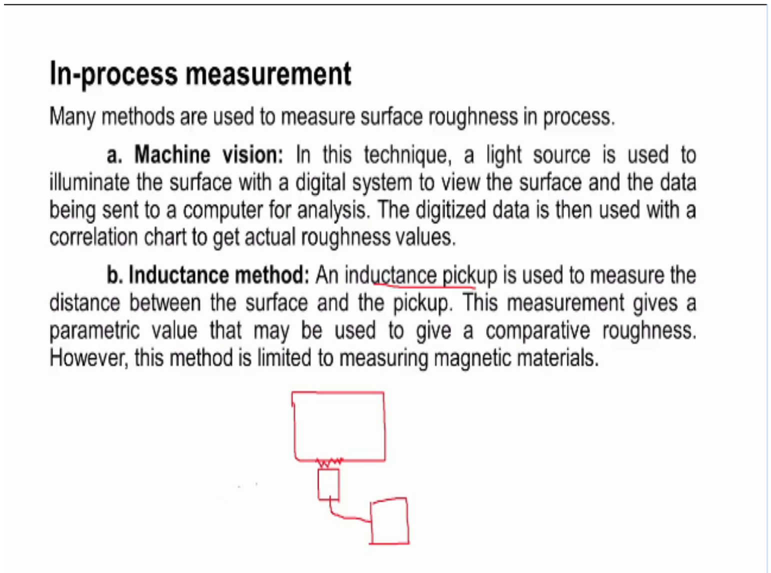

And then there are in-process measurement method that means when the work piece is being machine we can measure the surface finish without unloading the work piece from the machining setup. So, many methods are being used to measure the surface roughness during machining is in process. So, we can use machine vision system or inductance method. In the machine vision the light source is used to illuminate the surface with a digital system to view the surface.

And the data being sent to a computer for analysis, the digitized data is then used with a correlation chart to get the actual roughness values. That means initially we should use some standard specimens whose surface roughness is known and then using those standard specimens we can calibrate the machine vision system. That means for particular surface roughness what is the digital data we get like that we can calibrate.

And then we can use the component for which surface is to be tested we should keep them under mission vision. And then what is the digital system we obtain and then that should be compared with the digital data obtained from the standard specimen. So, that is the measured used in machine vision system and inductance method is also used in which pickup is used, inductance pickup is used to measure the distance between the surface and the pickup.

This measurement give parametric value that maybe use to give a comparative roughness. So, it will be something like this we have the work piece which is being machine and then we can always use an inductance pickup as the surface roughness varies this gap will be varying. So, that gap is stringed and the signal is sent out by the inductance pickup which is supply to the computer for analysing the surface roughness.

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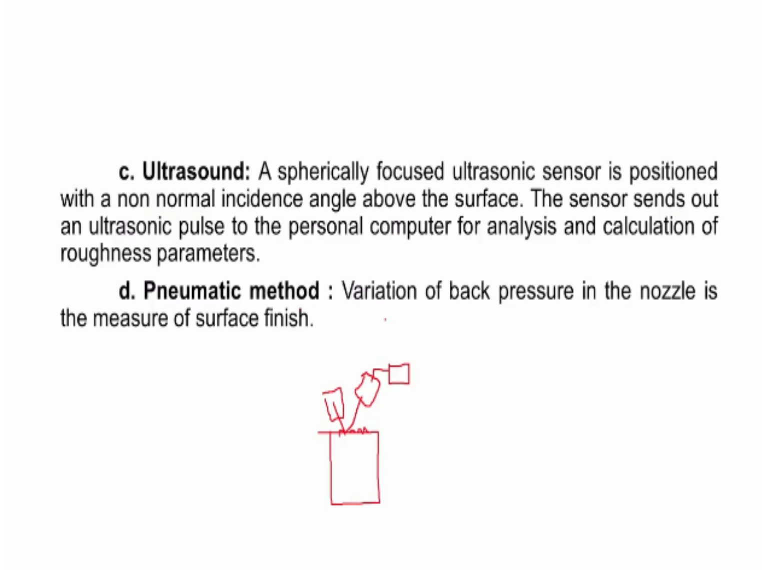

And ultrasound systems are also used a spherically focused ultrasonic sensor is positioned with a non normal incidence angle above the surface. So, it is something like this, so this is the work piece and then ultrasonic sensor is position in non normal incidence angle okay which is not normal to the surface. And then the reflected sound wave is sensed by another receiver and the signal is sent to the computer for analysing the surface.

So, when the due to the reflected sound wave characteristic will change. So, which is use to calculate the surface roughness and then we have pneumatic method. So, this we will study we will discuss after sometime.

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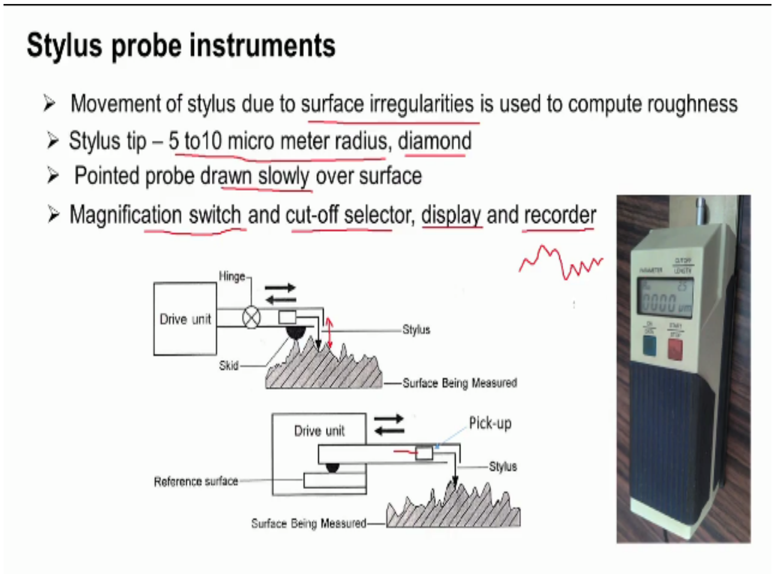

Now let us study some of the stylus probe instruments or the design of a stylus probe and what are the various elements of stylus type instrument. Now you can see here we have the surface being measure we have asperities, peaks and valleys etc., etc., and then we have a stylus here a pointed stylus. So, at pointed stylus is made to move on the surface under quotient. And because of this asperities the stylus will move up and down okay.

And then because of this up and down movement here we have a pickup. So, the design and construction of these pickup we study later. This stylus will move up and down and the pickup will give the signal which is sent to the computer for analysis purpose. This stylus tip it has very small radius of 5 to 10 micrometer and normally it is made out of diamond material to resist the wear.

Now pointed probe is drawn slowly over the surface again the movement is made, probe is made to move at a particular slow speed. And then the variations, due to variations stylus will move and then the signal is digitized and it is sent for the computer, sent to the computer for analysis purpose. In the commercially available instruments there are magnification switches depending upon the surface whether it is rough turn surface or shaped surface or milled surface or ground surface or lapped surface.

So, depending upon the machining process used, so magnification switch magnification can be selected, for lapped surface very high magnification is used whereas for rough turned surface very low magnification is enough. Also we can specify what is the cut-off length or sampling length this is again depending upon the machining process that is selected. If it is grinding process, lapping process, so wherein the we get fine surface cut-off very small cut-off length of less than 0.8 millimetre is used.

So, if it is rough surface, turn surface or milled surface we can use cut-off length of 0.8 or 2.5 like that. So, the cut-off length selection we will discuss again after sometime. The instrument will display the various surface finish parameters like Ra, Rp, Rt etc., etc., that is a display device also we can get the printout of the profile, the profile print we can obtain at different magnification values.

Now here you can see a commercially available instrument. So, you can see the various buttons this is the button to start the instrument to switch on the instrument and then for starting the movement of the stylus and you can see this is the display device and the cut-off length selected is 2.5 millimetre. And you can see it is now it is showing Ra value 0 micrometer. So, different by operating this data point different parameters we can select.

And the value of that particular parameter is displayed here and we can see the probe here, the pickup we can see here. So, which will move on the surface and then the data that is obtained is analysed and then the particular parameter is calculated and then it is displayed. So, in this case there is no printer it is only a display device.

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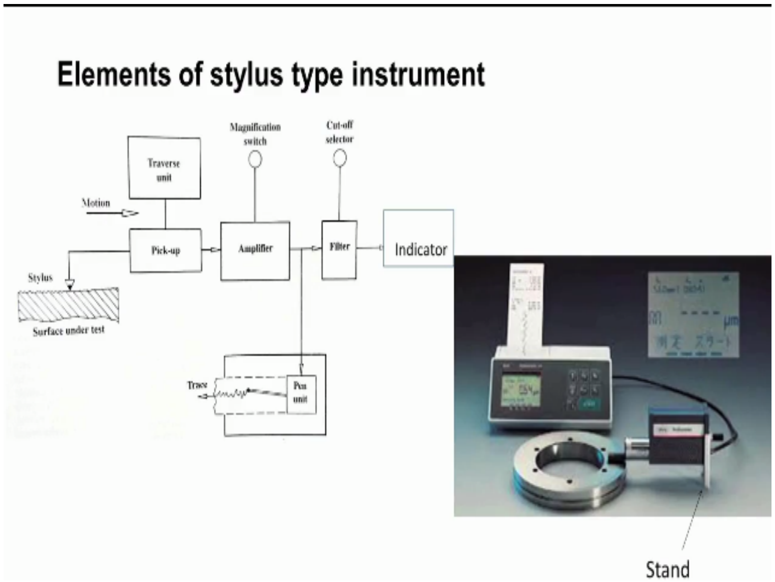

Now what are the various element of a stylus type instrument we can see here this is the surface under quotient which is to be measured and then we have a stylus here a diamond point and then we have a pickup here the details of pickup will study after sometime and there is a traverse unit or in other words drive unit. So, this stylus should be made to move on the surface at predefined speed. So, we need to have a driving unit, so this is the driving unit to move the pickup.

And the signals given by this stylus they are amplified and then appropriate filters are used. For example if you want only waviness that can be indicated here. If you want only the roughness parameter we can filter out the waviness and sometimes we have to eliminate the form error also. So, for such thing different kinds of filters are used and finally we the value is indicated roughness parameter is indicated or waviness parameter is indicated depending upon the requirement.

And here you can see there is a cut-off length selector depending upon the machining process we can select appropriate cut-off length also we have a switch to select the appropriate magnification. So, if the surface is very fine lap surface then we should use very high value of a vertical magnification. If it is rough surface we can lower the vertical magnification and you can see the printer attachment is also there. So, we can get a print of the profile.

Now you can see a commercially available setup here this is the work piece for which surface finish is to be measured. And then this is the instrument stylus type instrument and this is the probe. And now you can see depending upon the height of the work piece we have to adjust the height of this instrument. Otherwise the there will be error in the measured value.

So, for adjusting the height you can see stand is provided, so depending upon the height of the work piece we have to adjust the height of this instrument and then it is connected to a printer and display device. So, here various buttons are there to select the appropriate magnification, cut-off length and what type of what are the various parameters needed etc., can be selected here. And then the value the selected parameter is displayed as well as the profile print we can obtain.

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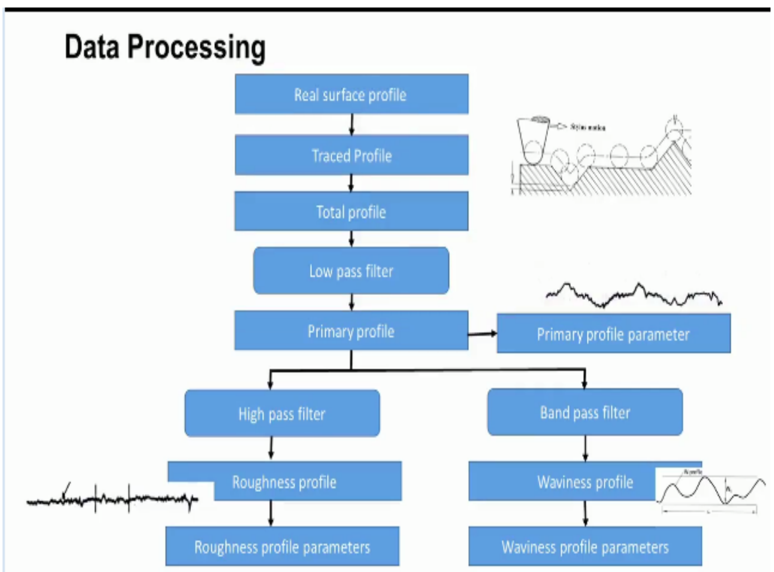

Now how the data is processed, you can see here we have flow chart here, so the real surface profile, now this is the real profile surface which is to be measured which is to be analysed and then we have to trace the profile. That means the stylus of the surface finish measurement instrument will should be moved on the surface to be tested, you can see here we have a conical stylus and then radiused tip. So, this radius will be 2 micrometer or 5 micrometer or 10 micrometer.

And this stylus or probe tip will move on the surface. Now you can see this is the centre of this probe **cur** curved probe and now when we move this stylus. Now you can see this is the locus,

locus of the centre point this point okay. Now you can see the locus we have a sharp point here and here also we have a sharp point. And then we have a peak here, so at this place we can see instead of getting a peak we have a radius here.

So, sort of filtering effect will be there, because of this radius of the stylus probe. So, we get the traced profile like this. So, which consists of the various elements like form, waviness, roughness etc., etc., that means the total profile which is a combination of a form error, waviness and roughness we get and then using appropriate filters, low pass filters and high pass filters different filter gauge and different filters are used to get the required profile.

So, if you pass this data obtained in this total profile via this low pass filter then we get the primary profile okay. You can see here primary profile parameter, so which has waviness as well as the roughness, the form error has been removed and then again this data should through high pass filter. So, that waviness can be removed and now we get the roughness profile you can see here all the waviness has been removed here only roughness parameters we get here.

Roughness profile parameters we can obtain and if you pass this profile data, primary profile data via the band pass filter then we get only waviness profile and we can eliminate the roughness parameters. So, the profile what we get will be something like this. So, roughness element micro irregularities has been removed and we get only waviness profile parameter. So, like this by passing the data obtain via the various filters we can get the required parameters.

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Selection of sampling length

Machining Process	Sampling length, mm
Milling, Boring	0.8, 2.5, 8, 10
Turning	0.8, 2.5
Grinding	0.25, 0.8, 2.5
Planing	2.5, 8, 10, 25

Milling, Ra = 0.8 – 7 μm
Grinding, Ra = 0.025 – 1.6 μm

Periodic Profiles	Non-Periodic Profiles		Cut-off	Sampling Length/ Evaluation Length
Spacing Distance RSm (mm)	Rz (μm)	Ra (μm)	λc (mm)	λc (mm)/L
>0.013-0.04	To 0.1	To 0.02	0.08	0.08/0.4
>0.04-0.13	>0.1-0.5	>0.02-0.1	0.25	0.25/1.25
>0.13-0.4	>0.5-10	>0.1-2	0.8	0.8/4
>0.4-1.3	>10-50	>2-10	2.5	2.5/12.5
>1.3-4.0	>50	>10	8	8/40

Now how do we select the sampling length or a cut-off length. Now we can see here we have listed different machining process milling, boring, turning, grinding, planing etc., and then we have a sampling length for milling we can select 0.8 millimetre sampling length or 2.5 millimetre or 8 millimetre, 10 millimetre again this depends whether the mill surface fine or very rough.

If the mill surface is very rough we can select the cut-off length of 2.5 or 8, if the mill surface is very fine by adjusting the fine machining parameters if we get fine finish then we can go for 0.8 millimetre cut-off length. Similarly we know that we can see here milling in the milling process the normally we get Ra value of 0.8 to 7 micrometer. So, and in the case of grinding we get very fine surface finish that is Ra value of 0.025 up ro 1.6 micrometer.

So, better fine finish we get here, so in the case of grinding we can select lower of lengths like 0.25 millimetre, 0.8 millimetre something like that. Now this is by knowing the machining process we can select appropriate sampling length or if we know roughly what is the surface that is obtain. Then also we can select the cut-off length, for example if you have a surface if we know that the surface roughness on the surface under quotient is a between 0.02 and 0.1.

Then we can select a finer cut-off length of 0.25 millimetre or if the surface finish is in the 2 to 10 micrometer then we can go for a cut-off length of 2.5 millimetre okay. So, by knowing approximate roughness value we can select cut-off length or by knowing the process also we can select the appropriate cut-off length. Now we should know one more thing that ratio sampling length to evaluation length.

Now you can see here normally evaluation length is divided into 5 sampling parts or if we know the sampling length for example say 0.8 millimetre is the sampling length 5 times of this will give us the evaluation. That means 0.8 into 5 that is 4, so 4 is the 4 millimetre is the evaluation length. Similarly if the cut-off length is 8 millimetre 5 times of this is 40 millimetre.

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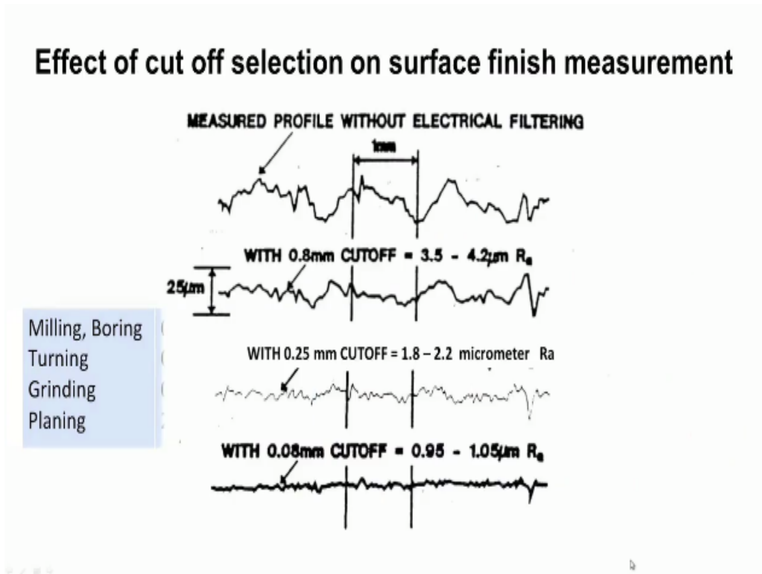

Now what is the effect of cut-off length selection on surface finish measurement, now you can see here this is the profile obtained without any filtering. And then when we select a cut-off of 0.8 millimetre okay, then the finish, surface finish value obtain will be 3.5 to 4.2 micrometer. But instead of selecting 0.8 millimetre cut-off if we select very finer cut-off length of 0.25 millimetre then the roughness value is 1.8 to 2.2 micrometer Ra.

Similarly if you go for very finer surface, finer cut-off length then you can see here this is 0.08 millimetre cut-off is selected then the Ra value obtain will be 0.95 to 1.05 micrometer Ra. That means if you change the cut-off length the Ra value will also change. So, we should exercise lot of care while selecting the appropriate cut-off length. If you select wrong cut-off length then the measurement data that is obtained will be useless.

So, that is why the standards specify different machining process what should be the cut-off length that is to be selected or specified in various standards.

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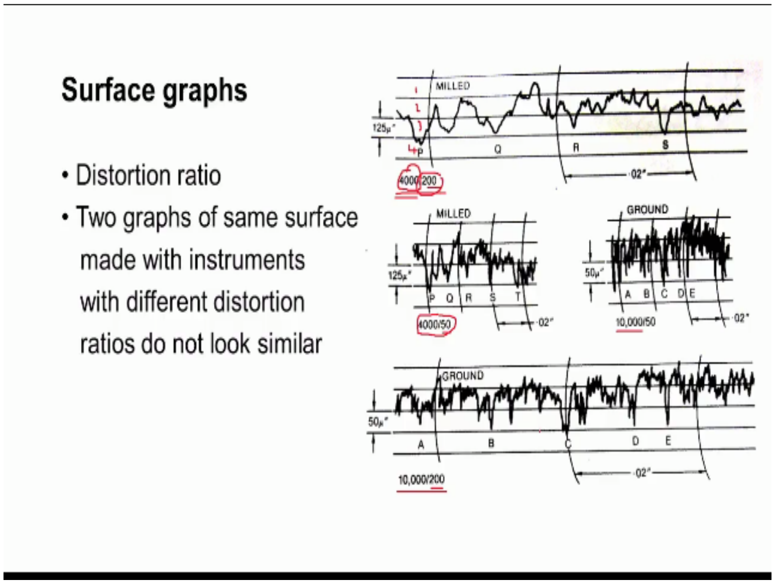

Now we should understand one more thing there is distortion ratio, so you can see here we have 4000/200. So, 4000 is the vertical magnification, so you can see here 4 parts are there this is one and this is second part and this is third and this is fourth part. So, each is having a value of 1000, so total height is 4000 units, so this is the magnification 4000 times the magnification roughness is magnified. So, on the horizontal magnification is 200 times.

Now when we select this particular distortion ratio this is the profile that is obtained. Now if we change the distortion ratio then the profile the surface graph gets distorted, we get a another different kind of surface graph you can see here the distortion ration is 4000/50**.** So, the vertical magnification remains same whereas horizontal magnification has been reduced by 4 times. Here it is for 200 units and here it is 50 unit that means the length is compressed.

So, this profile is compressed, so just by observing the profile graph we cannot say , so if we change the distortion ration and the look of the profile will change the we do not get similar graphs. Similarly we have one more example here, this is the ground surface profile with distortion ratio of 10,000 to 50 you can see here for milled surface okay vertical magnification that is selected is 4000 whereas the ground work piece the magnification selected is 10,000.

Since the surface will be very fine very high magnification we have to select to get the profile. Now the same ground surface when we change the distortion ratio, now you can see vertical magnification is 10,000 only whereas the horizontal magnification is changed to 20. Then we get a profile like this.

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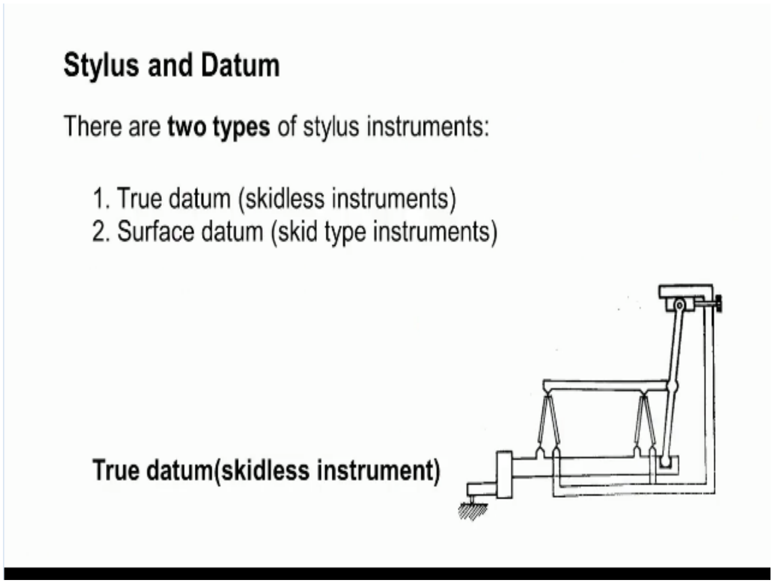

And now let us study about the stylus and datum. So, there are 2 types of stylus instruments one with true datum we say skidless instrument and another with surface datum wherein some skid is provided to establish the reference**.** Now this picture shows true datum as skidless instrument you can see the probe which is moved on the surface and the datum is provided by the instrument external to the surface.

So, the datum is not obtain by the surface itself, it is provided outside. So, that is known as skidless instrument or true datum instrument.

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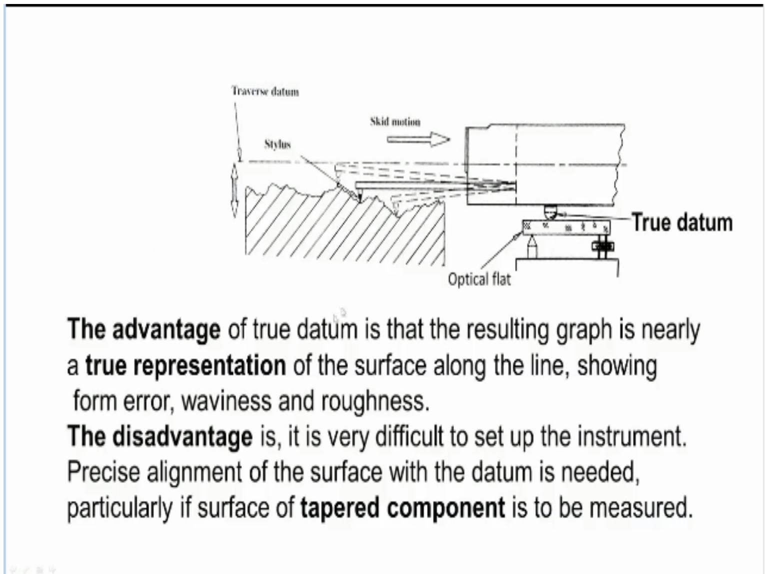

We can see another version of true datum instrument here we have used an optical flat very flat surface is used as true datum. And this is the pickup and this is the stylus unit and when we move the pickup you can see the stylus will move up and down depending upon the surface roughness and waviness. Now the advantage of true datum is that the resulting graph is nearly a true representation of the surface along the line showing form error, waviness and roughness.

So, it gives a total profile, the disadvantage of this system is it is very difficult to setup a instrument. Now you can see here the datum true datum height should be properly adjusted . So, that it is almost parallel and in-line with the surface in quotient. So, very precise alignment of the surface is required particularly if surface of tapered component is to be measured.

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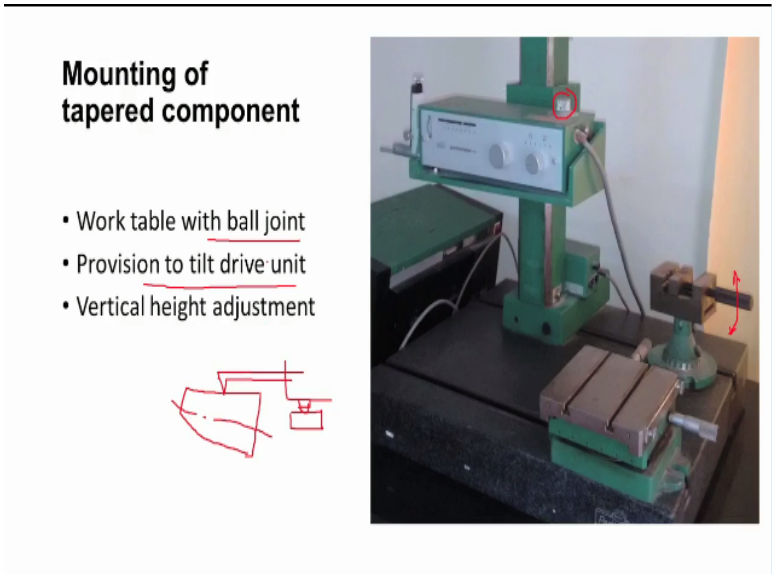

Now you can see the mounting of tapered component when tapered components are to be measured how do we adjust the datum in the case of true datum system. So, you can always use a work table with a ball joint we can see here a work table with a ball joint, so depending upon the taperness we can always align this you can change inclination of this table. So, that the surface becomes parallel to the stylus movement of the probe the movement like this.

So, say we can tapered component like this and then we have the stylus and then externally we have the datum. So, the movement of the stylus should be parallel to this datum, so in that case this line should be made this generator should be made parallel to this datum. So, in such cases we can use the work table with ball joint we can tilt the work table. So, the generator becomes parallel to the movement.

Also other provision is we can tilt the drive unit itself you can see here there is a knob here for adjusting the height of this. That means to change the inclination of the movement and also there is provision for moving the total drive unit up and down for vertical height adjustment. Now let us conclude this lecture, in this lecture we studied the various parameters which are used to specify the roughness like roughness parameters, waviness parameters and spacing parameters.

And also we learned about the different methods of measurement of surface finish also we started discussion on stylus type instrument. We discussed about this skid and then the stylus and then tip radius of the stylus etc., now we will conclude this session in the next class we will continue the discussion of the stylus type instruments thank you.