Technology of Surface Coating
Prof. A. K. Chattopadhyay
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur
Lecture 37
Assessment of Surface Roughness and Thickness of Coating

Assessment of Surface Roughness and Thickness of Coating, now these are two outcome of a deposition process that means with passage of time we expect certain growth of the coating and at the same time, the surface feature of the coating, it can be either very rough or it can be very smooth or it can have different morphology with non-uniform unevenness in the surface and that may happen because of various reasons.

Now let us look into that what is the requirement of measurement of this surface roughness, at least we understand that when this coating is mechanically functional that means in that case the frictional characteristics or frictional aspect becomes one of the prime issue and in that case the roughness of the coating can have an overriding influence on overall performance of the coating or the coated part. As such the material can be a very good tribological material having one of the best tribological property.

However, since it is not very smooth and in that case the surface roughness can have an overriding influence in escalating the friction to a very high value. So in that case the chemical inertness of the material that will become less significant and more important will become the roughness of the coating and this roughness of the coating.

This roughness of the coating, at least one can understand the frictional aspect, the wear of the component, the power requirement to drive the device or the machine with all those coated component. So this is one important area to be dealt with and at the same time what we see, the thickness of the coating, now this thickness of the coating, now what should be the order of thickness, whether it is just 1 to 2 micron or several tens of micron or several hundreds of micron.

Now this has to be judged considering the substrate coating, relation, their interface, deposition condition, particularly the deposition temperature, interfacial, stress, then interfacial reaction layer and all these and there are many other issues which actually decides what should be the order of coating, but applying our common sense, we understand that when it is a wear resistance coating that durability and thickness, they have some kind of co-relation.

That means thicker the coating if it is kept there, retained there and does not have any kind of premature descaling, delamination sort of thing in that case and if the coating simply undergoes normal wear process which happens to be idle one, then one can imagine that thicker the coating, durable will be its, I mean the durability will be more, that means thicker the coating, more will be its durability. So in that respect thickness of the coating is also another important area of research and investigation.

However if we consider a particular process definitely we have to look in the yield characteristics of this process that means what is the growth rate of this one and each process has its own limitation in the growth rate and there it is just a process of coating plus the coating material, that means material being deposited and also the process parameters and their combined effort, individual effect and combined effect and all these things taken together finally we get one value, what is the growth rate and then what will be the thickness of the coating .

So after conducting a deposition, one has to look in what is the order of thickness and what is the time rate of growth that means the growth rate of coating, for that also this measurement or assessment of thickness of the coating that is found out to be quite relevant. So roughness of coating and thickness of coating just like various responses of this coating process one has to pay attention to these that means this roughness of the coating and thickness of the coating.

Now Influence of Substrate Surface Roughness, now when we give importance to this measurement or assessment of roughness of the coating, in that case also we find that roughness of the substrate is equally important, it is important in that particularly considering one particular coating process, say for example if it is a PVD coating for a particular material we like to have one kind of surface roughness, if it is a CVD coating that requirement may be little liberal and we need not hold that tight tolerance on this surface roughness requirement.

If it is a particulate deposition coating like plasma spraying and all those, then substrate also need to be roughen and that scale of roughening of that substrate which is going to receive this sprayed layer and the substrate surface which is going to be a receptor of PVD coating, their requirement may not be the same so influence of surface roughness that affects the coating, however one has to also specify the roughness of this substrate and for that also measurement of surface roughness is equally important.

So we understand it is not only the roughness of the coating after condensation of this deposit but it is also that before the deposition starts, what is the characteristics of this substrate surface, at least its morphological characteristics that can be well recognized and well documented by this surface roughness assessment or measurement.

Surface Roughness Morphological Feature of a Coated Surface, that means what we understand here, that means surface roughness is just, it is a reflection of morphological feature of a coated surface. And there what we find, factors influencing the roughness of coating, this is important because roughness is the outcome and the input variables are the process parameters.

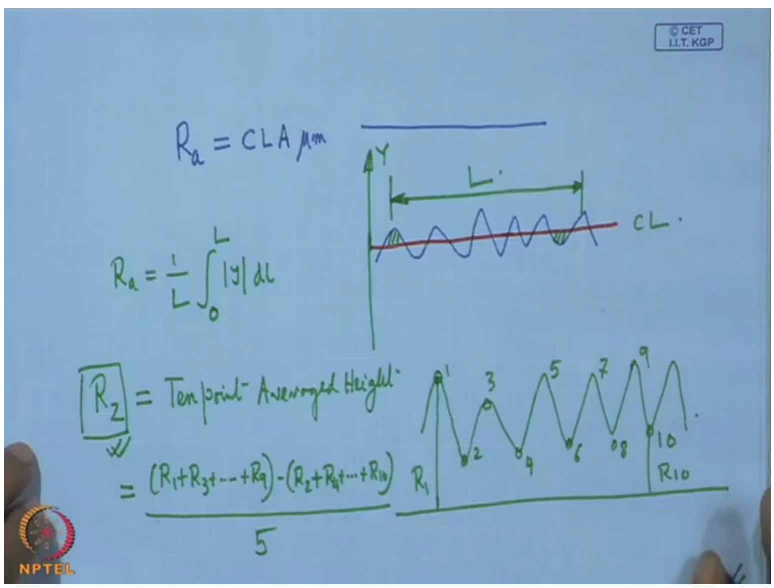
So here proper monitoring, measurement, assessment of the roughness and then co-relating this roughness with the process variable is important in order that the process parameter specification can be made and it will become almost a reproducible thing in nature so that the roughness value which will be of immediate interest considering the functional requirement and that surface roughness can be co-related to the input variable like all sort of process parameters, maybe gas pressure in PVD or maybe in CVD, the temperature of the substrate, then there are flow rate of various gaseous product.

So all this things are taken into consideration and their joint influence or joint effect will be reflected in surface roughness of the coating. So process variables, then substrate, chemistry of the substrate, then comes also the roughness factors influencing the surface roughness that means here also we should pay attention to that nucleation density that means the moment the coating starts, what is the nucleation density and how this coating is building up, what is the size of individual grain, large grain with small in number or small grains with high density, then uniformity of the grain size, there can be some pin hole or there can be some outgrowth. So all this things finally they are going to influence very strongly the surface roughness of the coating and this will definitely affect the performance of the coating in actual field.

Numerical Assessment of Roughness, so this is actually one important step how to quantify this surface roughness, we can have an qualitative filling or impression about the surface, it is smooth or rough, but quantification is necessary in order that a co-relation is established between the input variables, the substrate, the preparation, chemistry of the substrate, cleanliness of the substrate, all, I mean related issues can be properly addressed if we can quantify or numerically assess the surface roughness.

Now for this assessment of surface roughness, we have apparatus for measuring which can be contact type or non-contact type, but most important thing what we are going to measure and then accordingly the instrument can follow the instruction. So what is going to be measured that we have to specify or that has to be standardize. So at least as far international recommendation there are three parameters for any surface. It can be a process surface without coating, machine surface, ground surface, powdered metallurgically developed surface, whatever may be the surface.

(Refer Slide Time: 13:31)



We have actually three parameters that has to be specified. Number one, what we call and it is the RA that is the symbol that is called center line average, center line average and which is expressed in micron, micrometer and this we can explain actually surface is not just like an optically flat planer surface.

We have there waves so this may be irregular, so this if this be the surface then what we can look here that for this surface, first of all it is center line average, we must find out where is the center line, how does it appear or where it is located, so it is actually a line drawn in such a manner so that the area under the curve above and below are numerically same. That means, this is for example area above this main line and this is the area below the main line and that is called the central line and here we have to consider what we call a sampling length.

A sampling length, so say this is the sampling length and over this length, this RA value that is given as numerically as 1 upon L with this mod of Y into DL and integration, what is the significance of this one, it is actually it shows the departure what we have shown by this blue line that is the departure of the blue line above this red one which is center line and it is defined so that equalization of this area above and below that is properly done and here actually it is the arithmetic average of the total departure of this actual surface from the mean line and that is given by this equation.

So here we only consider that means this is actually the Y direction so we consider only the magnitude so from there we can get the average deviation from the mean line, so this is one of the parameter which is expressed to define the surface roughness. Then comes another one what we call RZ that is called Ten Point Averaged Height, averaged height between the peaks and valleys.

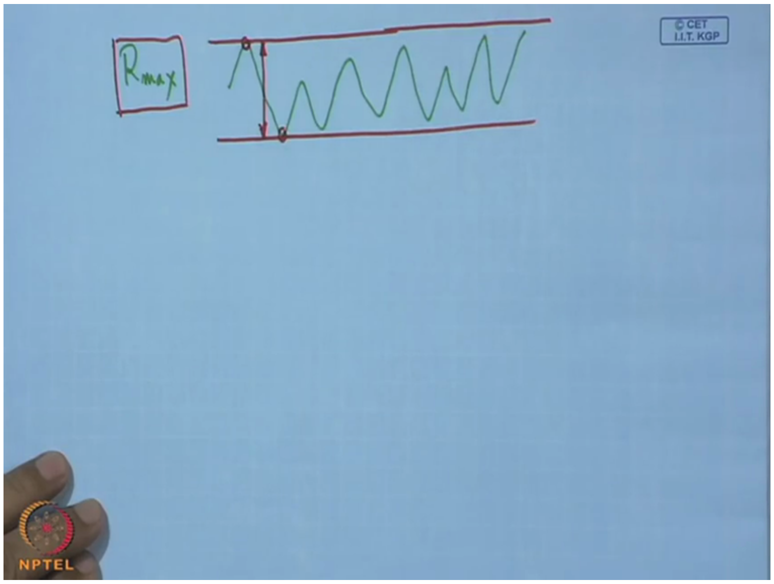
Now say, here we have such a profile and what we can find out that a datum like this, this can be arbitrary and over the sampling length we can find out this way, points. So we can find out ten points and over these ten points we can find out the height of this peaks, of this hill, say this is R1 and this is R10 obviously so we have R2, R3, R4 and so on. So it is a ten point average.

So what we can do it is actually the arithmetic average of the height of the peaks, that means R1, R3 to R9 minus R2, R4 to R10. So this is actually the summation of heights of this hill top and this is the valley and that is divided by 5, so this is actually the pairs so we consider ten points and these heights are considered and what is the difference between these two, here we find out the difference between, height difference between the hill top and the valley that means peak and valley are considered.

But in CLA, center line average, we are not considering from peak to valley, it is actually the arithmetic average of the departure of the whole profile from the mean line so from this actually what we get, we get actually the idea about the surface roughness that means what is the depth of this group, say 5 to 6, that is a depth of group, 1 to 2 that is a depth of group, or say from 3 to 4, something like that 9 to 10, but this is quite missing. So this is from engineering point of view, this is more relevant, so one can get some idea about the surface roughness and possible effect in friction.

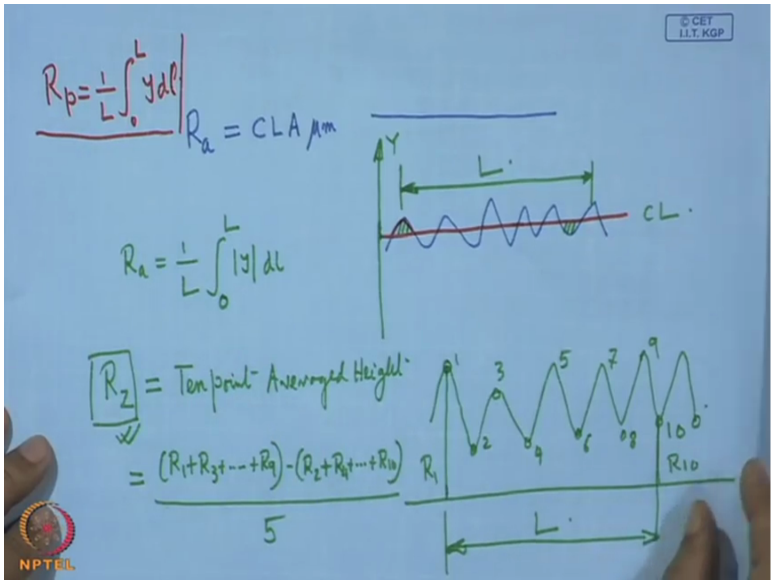
So there is another term what we call R Max, that means the maximum, so this is also a sampling length that means over this sampling length, over this sampling length we have to find out highest, five highest peaks and five lowest valleys, so five highest points and five lowest point and then this formulation is possible.

(Refer Slide Time: 20:35)



Now in this, what is mean by R Max, that means if this is the profile then we can find out something like this, so if we just draw two parallel line parallel to this center line like this we can draw one line through this highest peak and we can draw another line through this lowest valley that means that is the highest out of all peaks and that is the lowest out of all valleys in that case this height difference that we call R Max. That means for characterization of a surface we have to define all this RA, RZ and R Max.

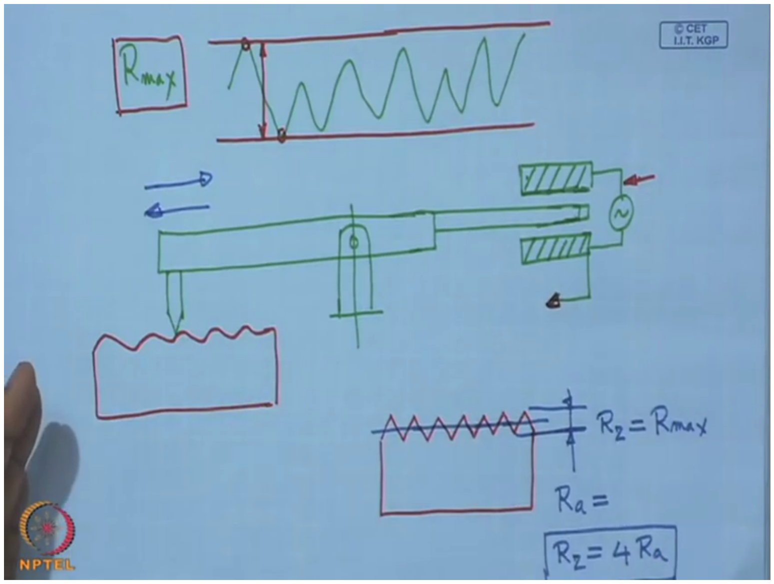
(Refer Slide Time: 21:45)



Sometimes also, it is also interesting to define instead of here we have considered this CLA value considering both plus and minus but sometimes what we call, that means this is called RP that is given by 1 upon L and in this case it is L into 0 YDL, that means this is only considering only the plus sign, that means only this plus part those are considered in this integration process and it is just not the magnitude so it is actually the average of height of the points which are above the center line and their height, average height from the center line and that is defined by this symbol RP.

Now here we need apparatus and this apparatus are useful, very handy and this can be used for all routine activities for measurement of surface roughness and we can have both, contact type and non-contact type, so contact type means there we have to use one stylus and this stylus is in direct contact with the surface to be examined and depending upon the position or the profile, this stylus will have some upward movement and accordingly this vertical displacement of the stylus which follows the geometry of the surface accordingly this vertical displacement will convert or will be converted into some electrical signal and then that will be processed, that will be captured, filtered that can be recorded. So this is the basic hardware of the instrument and the basic principle is here that this is actually conversion of a mechanical displacement into some electrical signal.

(Refer Slide Time: 24:29)



Now one such instrument, the basic principle we can show like this, this is basically one horizontal arm of that instrument, and this arm it is actually pivoted at this point, this is the pivot and here we have the stylus and this is mostly a diamond stylus and on this side what we see here it is actually one capacitance it is a capacity transducer.

So it is a parallel plate capacity transducer, so this air gap, so this is actually the capacitor, so it is a parallel plate capacitor and here we have to give one AC input and from that we can expect a output, voltage output and here what we see. So depending upon the geometrical location of the stylus which is in contact with this surface naturally this extension of this lever or the arm that will change its position with respect to this plates and as a result of that for a given input here we can expect a variable output.

Now these are all processed and then it can be given as a readout or it can be stored. So these are all the peripheral thing, one issue is important here that calibration of this instrument and for that we have a masterpiece and this is exactly a triangular profile which is precisely made and with this triangular profile we have, it is just a triangular profile with highest possible precision that is cut and over that naturally here what we see this is peak to valley that is RZ which is actually R Max because all the triangles are of identical geometry so RZ is equal to R Max.

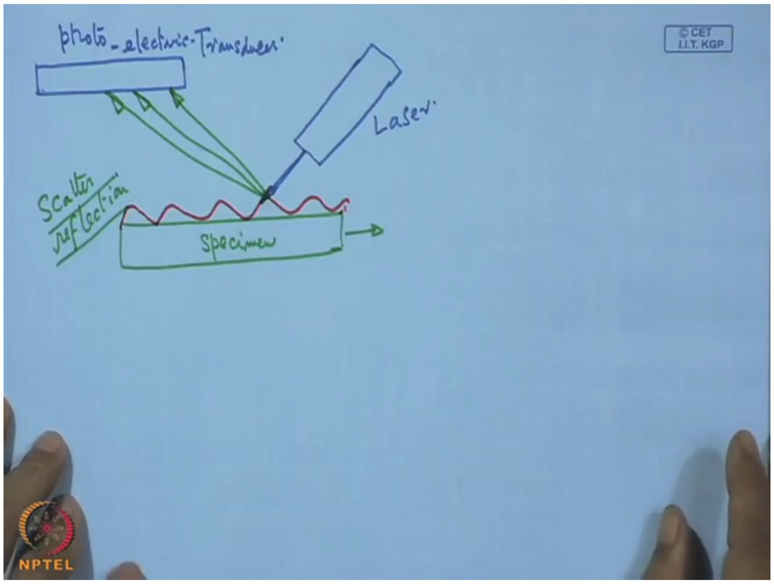
And at the same time, we can have a center line and locating the center line is not difficult because it is a symmetrical so it will be just go through the mid-section, so in this case what we find that this RA is RA value that is given for this material for this master gauge, master piece and then RZ so this RZ is equal to about 4 RA, geometrically it comes out to be four times. So these values are given and accordingly this instrument depending upon this read out, its amplification factor or sensitivity factor can be adjusted according to this value which is already given.

So this instrument is ready and that can be used for routing measurement of surface roughness. Now is it just free of any weakness or limitation? Certainly not. Number one problem is that, this scanning that means this has to scan and in that scanning process is not too fast, so it has to scan in this direction and then backtracking to its original position, so it has to scan over a well specified sampling length, this is number one.

And number two is that when the surface is not so hard or it is actually as diamond stylus even with a small load fine scratches can be clearly visible on this coated surface or any surface of interest. So naturally one has to look into this aspect of micro scratching of the surface by this diamond stylus and if somebody is interested to make several runs of this surface measurement then one would expect so many scratch lines on this surface. So this is also limitation number two.

And number three is also limitation on the tip radius of the stylus. So micro detailing, detailing in micro meter level or in nanometer level, if this surface has so many sharp corners and micro detail in that case that stylus may be limited in recording all those micro detail and those will be rounded off. However for comparison of two surfaces just for assessing whether it is a rough surface or a smooth surface with reasonable accuracy and quantification from that point of view, these machines are quite convenient and quite reliable for use, for all sort of engineering application.

(Refer Slide Time: 31:09)



Now Non-Contact type Using Laser Refection, now in this case what happens, a laser beam will fall on this surface under examination. So this is the surface and here we have irregularities something, it may be a coated surface and then what we have, here we have a photo-electric transducer, so this is a photo-electric, so this is the laser beam, laser source, so this is the incident beam and from that what is going to happen, there will be a pattern, it will be a scattering of refection that means from this we can have such kind of scattering and it follows certain pattern, well defined distinct pattern and from that with proper assessment, proper standardization, it will be possible to record the surface roughness as this sample specimen moves.

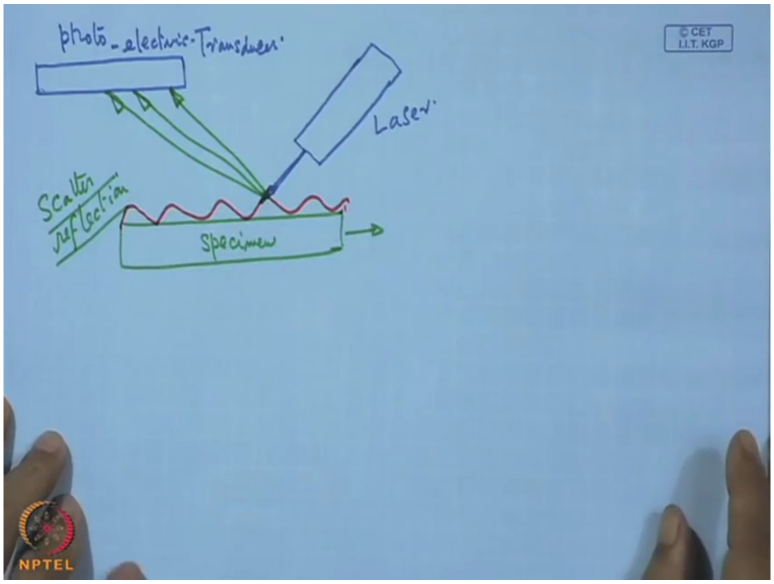
And this will have scattering of reflection, that means scatter reflection, so this is another way it is non-contact type. However it has both, each system has its merits and demerits, in this case non-contact means that radius of the stylus tip, that part that should not be a limitation in this case, it is rather high speed operation, process is faster, this is also number two, large area can be assessed rather quickly and also say for example the parts which are coated in a steel mill, steel plant, galvanized part where it is of immediate interest to assess the surface roughness. This is just one example that this laser beam reflection that is going to be one of the best candidate, there we cannot use a contact type detector for assessment of the surface roughness.

But the limitation is that when the surface is too rough in that case this distinct scattering that is no more possible and that does not occur. So in that case what we see it is mostly diffused scatter reflection that is diffused and in that case one cannot distinguish between the reflected beam which should correspond to a particular surface roughness or surface orientation and that becomes one of the difficulty in this case.

However for weak assessment of the surface roughness over a larger area and where the coating, coated surface does not allow or does not allow use of a direct contact type sensor or a stylus in that case this laser non-contact reflection type apparatus is found to be most suitable.

Now Atomic Force Microscope, this is very recent development and in this case actually when it is a surface coating and with fineness of all coating technology with refinement of all the processes, one can also go to characterize that surface in the atomic level, that means just to have detail about the top layer atomic arrangement and that is also a kind of surface morphology study or surface irregularity study, that arrangement of the atom.

(Refer Slide Time: 36:26)



So in that case we can also have a probe something like this but in this case the probe is very sharp so for this consideration one can imagine that this size of this probe almost equal to that of one atom and here what we can see that if it is the atomic arrangement, the top layer, so this is actually the probe and this probe can be used for recording the detailing on the surface in the atomic scale.

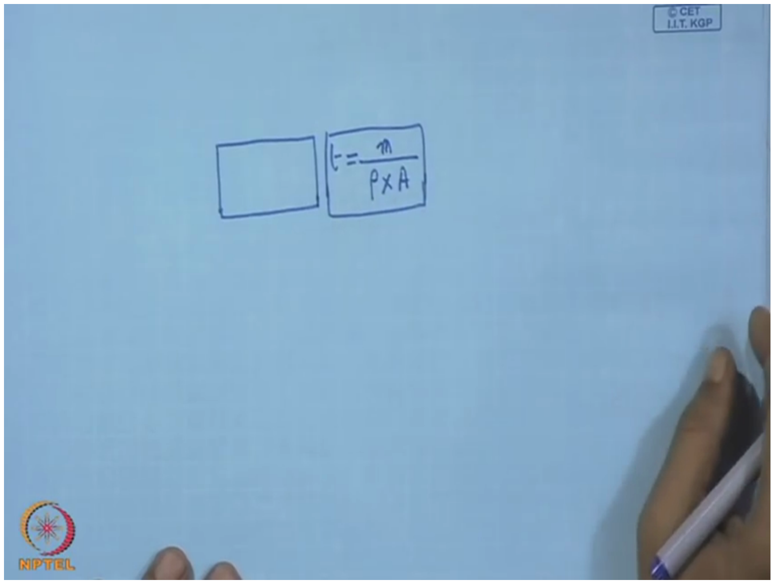
Now this is the top surface of a coated specimen and this coated specimen maybe like this and just beneath it we have the specimen holder and this is going to be a specimen holder and these are the top layer of atom and that is the tip of the probe and it is very sharp, it can be compared with that of size of the atom. Now what is done here we have to receive some signal from this atomic arrangement which will be followed by this probe that means this is actually the specimen holder, this is the specimen holder and that will be driven by one actuator and this is going to be one actuator and this is actually a piezoelectric actuator.

Now in this piezoelectric actuator what is given that if we apply a voltage in this direction, that is the input voltage then we expect a displacement, mechanic displacement, displacement microscopic, very small amount of displacement, microscopic displacement and with that and there will be a flexible I mean there is like a leaf spring and which will be held here that specimen holder, so there is the probe and this probe is actually provided with a transducer for recording the displacement and the force, force and displacement, force and displacement in the vertical direction.

It can also record the force and displacement in the horizontal direction, so that means here we have force and displacement recording both in vertical and in horizontal direction, so as this thing moves, naturally depending upon the location of particular atom, so this stylus, the tip of the stylus will adjust its position depending upon the local arrangement of a particular atom and then there can be a vertical displacement in upward direction on downward direction as this specimen is moved by this microscopic displacement given by this input voltage to this piezoelectric crystal.

So this way it is possible to record the minute detail on the surface of the coated surface and where one expect that the detailing in the atomic level to examine because now the coating process can allow the fineness of the structure in that level that this kind of atomic force microscope will be one of the best candidate to make proper diagnosis and investigation on this surface to have all sort of minute details in that atomic level.

(Refer Slide Time: 41:54)



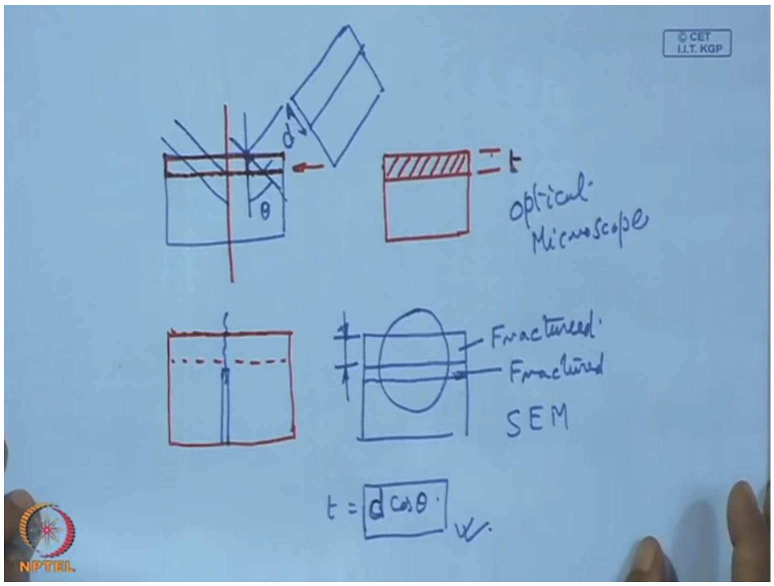
Now we see the Assessment of Coating Thickness, now we already mentioned why this assessment of coating thickness is required. Now how this assessment can be made, one can be very easy way very simple Gravimetric Method and in this case we can have a coated surface and then because of this coating there will be some increase in mass or weight, then that can be divided so that is the increase in mass divided by density and divided by the area, so from that we get average bulk thickness of the coating but this is good for coating of those surfaces which are quite large and where we are more interested in the average value of the coating thickness rather than the coating thickness on a particular corner or particular geometry of a part.

What I mean that in a device or in a component we can have geometrical complexity, so in that case chances are quite high that in all geometrical places, geometrically complicated areas or zone which are geometrically difficult to reach by this coating and there the thickness may be not that high, however the places where the coating is easily (())(43:57) by the substrate surface, there this thickness may be quite high.

This is also one issue, plus depending upon when there is electrically assisted coating just like electroplating what is going to happen in the sharp or corner and sharp point, we have larger growth rate of the coating because of higher ion current density. So in those cases it is not reasonable and not acceptable just to give a bulk value because depending upon the geometrical complexity of the whole substrate.

The thickness may vary from point to point and there attention has to be paid and this uniformity of coating throughout the surface that means a microscopic examination of this coated surface is more important rather than just finding out the average thickness of the coating from this increase in mass. So this can be possible just by Micrography or by Fractrography.

(Refer Slide Time: 45:15)



Micrography means in this case what we can show, this is just on the top we have the coating, so this was the substrate, original substrate and on that a coating is deposited. Now this coating can be visualized by microscopic examination, so one has to take a section of this one and then looking from this side, that means this is the cross-section which appear to be like this and this can be well measured under a microscope this thickness and here it is actually a metallograph.

So polishing with proper care so that this edge rounding does not take place so all this thing should be handled with adequate care and precision so that the enter coating bandwidth can be revealed under the microscope. So this way one can also find out the thickness of the coating. However this can be also done instead of just cutting this thing what we can do also say this is the coated surface, this is the coated surface and this is the boundary between the coating and the substrate which is not visible.

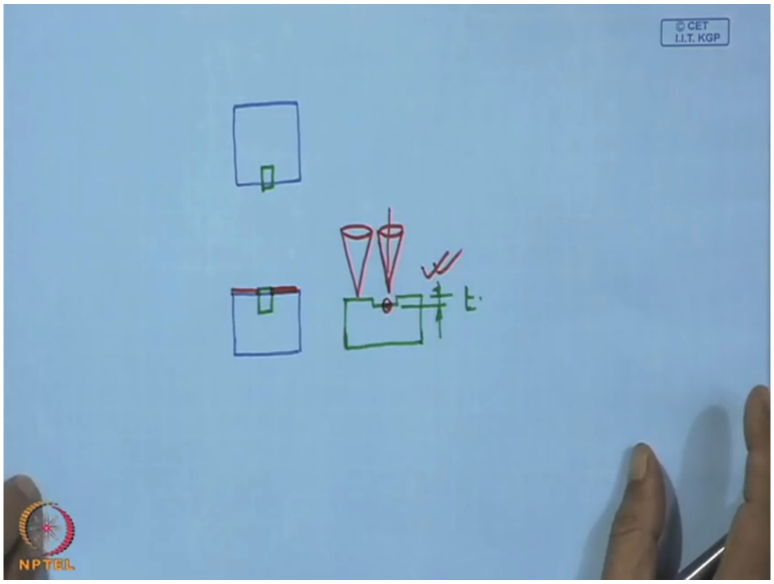
So one can also do something like that slitting to create a narrow slit upto this point and after that breaking this surface, so after breaking this surface what we can see here definitely, this is the surface and upto this point it is actually the fracture surface. So the coated surface is also a fractured surface and this part of the substrate that is also a fractured surface.

So that means the sample is intentionally fractured at this point and this picture one can record in scanning electron microscope and this is just optical microscope. So from this we can also get clear idea about this thickness of the coating and other important issue concerning the morphology of the coating. Now here what we can add that this coating, if this coating is shallow then to facilitate assessment or measurement of the coating what we can do, that this is actually this way we can also keep or we can inclined this way, that means here this is going to be the band.

So what we can see, this is going to be the band of the coating and this band, that means if this angle is theta between this normal and this inclined surface then the band what we can measure here if this is D and if this included angle is theta then we know that T is equal to actually D cos theta, so this D we can measure because it is now little bit enlarge so the error in measurement, relative error in measurement that will be less and we can measure by knowing this angle of inclination.

That means this polishing has to be done in an inclined manner which is done in this case at right angle to this coated surface but here it is done in an oblige manner to get a better value of this bandwidth and then by co-relation we can find out this one.

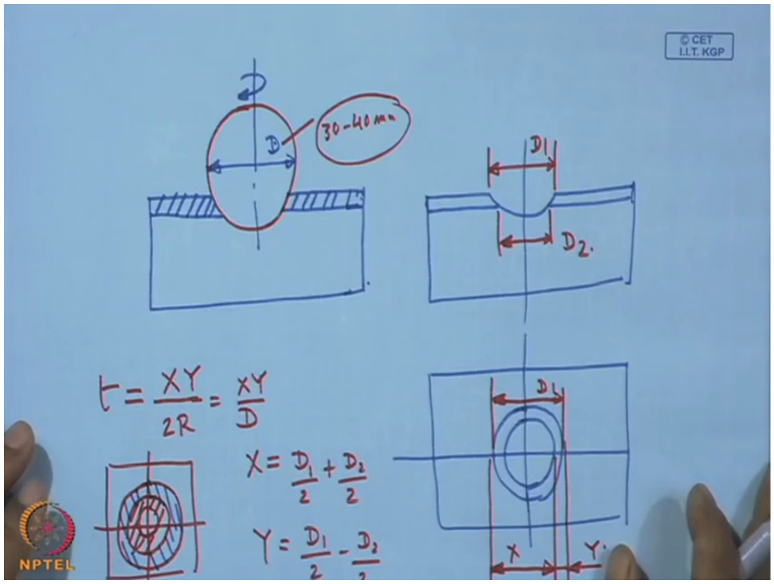
(Refer Slide Time: 49:59)



Now what we see, micrograph and fractrograph, masking a portion of the substrate, say for example this is actually the top view of the substrate and this is the front view. So what we can do, so what we can do here that we can mask this surface, so this is actually the mask and over this mask, what we can do, we can put the coating and in this case, this may be the coating and then the mask is removed so after that what we are left with, it is actually this area which is not coated or covered by coating so by use of a instrument like a profilometer or telestep, we can find out the depth of this step, that means the depth of this step that can be also find out by a contact type instrument or by depth focusing.

It is also possible to have a lens of a microscope which can focus at this point and then it can be shifted here and it can be shifted at this point so this is the point here and then we can lower this lens of this microscope to have the focal point, transferring the focal point here on this surface and from that it is also possible to assess the thickness of the coating. So this is either by masking, either by using a telestep or by using this depth focusing lens.

(Refer Slide Time: 52:31)



Now comes Ball Erosion Tester, now with ball erosion tester what we see here that when we use this ball erosion tester, that means it is a ball and which is going to erode a surface and this is actually coated surface. So it rotates about this axis, so this is going to be the coating and after a passage of time we expect a crater formation, that means after elapse of this time we expect a crater formation on this surface and that is the diameter of the ball, that is actually the diameter of the ball.

And then what we see further to this here on the top view, we get actually two ring, so the outer one, the outer circle comes for this diameter, this is D1, so this actually D1 and the inner one this comes from this, this is actually D2, so this is a diamond impregnated ball and this diamond impregnated ball it can have a diameter of 30 to 40 millimeter, so that can be used with this load and then we expect this crater to form.

Now from this, we can find out two dimensions, this is one dimension, this is X and this is actually Y, X and Y actually, actually X is equal to D1 plus 2 and D2 by 2, so that is actually X and what is Y, that is D1 by 2 minus D2 by 2, so this D1 and D2 we can measure clearly under the microscope and capitally D is the diameter of the ball, so from there we can have this relation which can be geometrically also deduced, it is actually this by 2 R or this is XY by D, so 2 R means radius of the ball and D is the diameter of this ball which causes actually this cratering.

So from this we can with fair accuracy, we can also determine this thing, this value, so this way we can also determine and that is well practiced in all tool manufacturing industry where routinely tools are coated and tools are quality controlled is routinely check and this is one way of doing the thing. Now instead of a monolayer coating if we have two distinct multilayer in that case also it is possible to have just instead of two circles, we can have three circles.

So in the central zone the coating is exposed and we have one coating here and we have another coating in the outermost ring. So from there it is also possible by having respective value of X and Y, we can determine this value of T1 and T2 for this two rings. Now this thing can be also extended for a surface, coated surface which is circular, say for example the coating on the balls instead of a flat surface so only here this formula is little bit modified but the basic principle of working and measurement will remain same.

So with that we can summarize todays discussion that surface roughness reflects morphological features of a coated surface and is strongly influenced by the coating process, material of the coating and that of the substrate. Through numerical assessment of the surface roughness either by contact or non-contact method one can judge suitability of a coating process for producing smooth coating. Similarly yield of a coating process and role of various process variables can be conveniently assessed by measurement of coating thickness with available measuring techniques.