Roughness Measurement
A Guide V2

The Proscan 2000 software is a powerful software application designed for shape analysis, object digitisation and accurate surface analysis. This manual will guide you through each of the functions available within this software.

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1.0 Surface Texture – General Information

1.1. What is surface texture?

Every surface has some form of texture that takes the form of a series of peaks and valleys. These peaks and valleys vary in height and spacing and have properties that are a result of the way the surface was produced. For example, surfaces produced by cutting tools tend to have uniform spacing with defined cutting directions whilst those produced by grinding have random spacing.

In surface texture there are many factors that, when combined, characterise a surface's profile. For example:

the microstructure of the material
the action of the cutting tool
the instability of the cutting tool on the material
errors in the machine tool guideways
deformations due to stress patterns in the component

1.2. What is the difference between roughness, waviness and form?

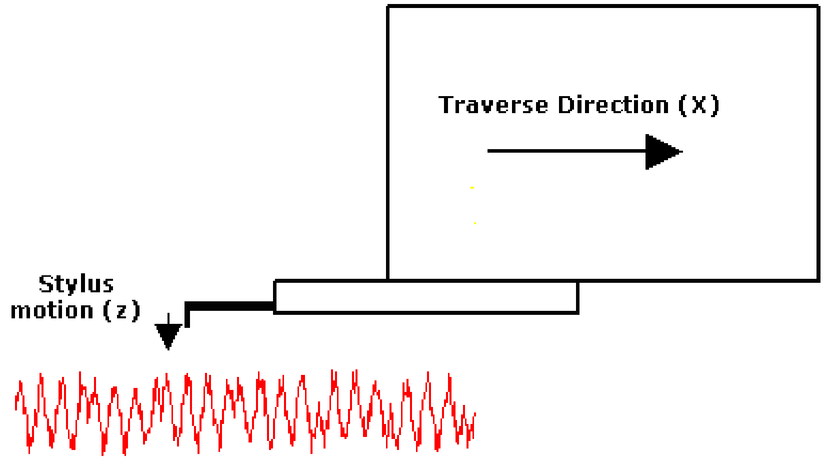
We analyse three main elements of surface texture - roughness, waviness and form.
Roughness – this is usually the process marks or witness marks produced by the action of the cutting tool or machining process, but may include other factors such as the structure of the material.
Waviness – this is usually produced by instabilities in the machining process, such as an imbalance in a grinding wheel, or by deliberate actions in the machining process. Waviness has a longer wavelength than roughness which is superimposed on the waviness.
Form – this is the general shape of the surface, ignoring variations due to roughness and waviness. Deviations from the desired form can be caused by many factors. For example:
the part being held too firmly or not firmly enough
inaccuracies of slides or guideways of machines
stress patterns in the component
Surface, Waviness and Form are rarely found in isolation. Most surfaces are a combination of all three and it is usual to assess them separately.

Please note: There is no set point at which roughness becomes waviness or vice versa as this depends on the size and nature of the application. For example, the waviness element on an optical lens may be considered as roughness on an automotive part.

1.3. How do we measure surface texture?

In the past surface texture has been assessed by the judgement of the inspector either by eye or even fingernail. In order to put a number to the surface texture, we need to use a more accurate means of measurement. A traditional surface measuring instrument will consist of a stylus with a small tip (fingernail), a gauge or transducer, a traverse datum and a processor. The surface is measured by moving the stylus across the surface. As the stylus moves up and down along the surface, the transducer converts this movement into a signal which is then exported to a processor which converts this into a number and usually a visual profile.

For correct data collection, the gauge needs to pass over the surface in a straight line such that only the stylus tip follows the surface under test. This is done using a straightness datum. This can consist of some form of datum bar that is usually lapped or precision ground to a high straightness tolerance. On small portable instruments this is not always a good option and can add to the expense of the instrument. In these cases, it is possible to use an alternative means of datum. This is a skid



Over time, technology has advanced and there have been a number of developments in the measurement of surface texture. Optical non-contact techniques have been developed which provide significant advantages over the traditional stylus approach. The very fact that the more modern methods do not touch or change the studied surface in any way, makes the analysis of surface texture simpler, faster, more accurate, and more reliable

1.4.Key concepts

In most traditional methods, a single measurement will be made on the surface in order to assess the texture. This measurement must be representative of the surface and appropriate to the purpose of the measurement (e.g. measuring normal to the lay of the surface, or in the indicated direction). The most important concept is to know what you are dealing with. From a knowledge of the roughness amplitude and wavelength values expected from the surface, it is possible to select the appropriate instrument settings for a reliable roughness measurement. The most important factors will be the selection of stylus tip (or measurement step) and the roughness filters

With more modern methods, it is possible to take multiple measurement lines in a reliable and repeatable fashion. This opens the door to the study of roughness on large amounts of two dimensional data (providing far more statistically reliable information), and the potential analysis of three dimensional functions. Three dimensional functions are still somewhat new and have yet to be formalised or standardised. Hence, two dimensional functions are only available to ISO standards

1.5.How do we separate Roughness, Waviness and Form?

In order to separate the three elements, we use filters. On most surface texture measuring instruments we can select either Roughness or Waviness Filters.

Selecting a Roughness Filter will remove waviness elements, leaving the roughness profile for evaluation. Selecting a Waviness Filter will remove roughness elements, leaving the waviness profile for evaluation. Separating the roughness and waviness is achieved by using filter cut-offs.

1.6. What are filters?

Electronic or mathematical methods or algorithms which separate out different wavelengths and allow us to see only the wavelengths we are interested in.

1.7. What is a cut-off?

In basic terms, a cut-off is a filter and is used as a means of separating or filtering the wavelengths of a component. Cut-offs have a numerical value that when selected will reduce or remove the unwanted wavelengths on the surface. For example, a roughness filter cut-off with a numeric value of 0.8mm will allow wavelengths below 0.8mm to be assessed with wavelengths above 0.8mm being reduced in amplitude; the greater the wavelength, the more severe the reduction. For a waviness filter cut-off with a numeric value of 0.8mm, wavelengths above 0.8mm will be assessed with wavelengths below 0.8mm being reduced in amplitude

1.8. What measurement length should I make?

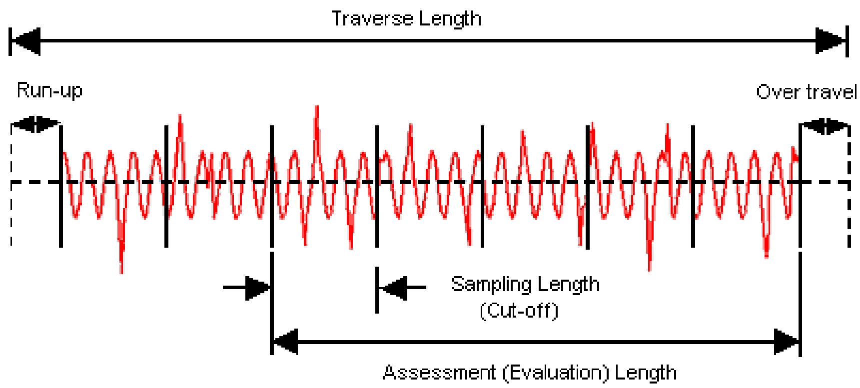
The measurement length is dictated by the numerical value of the cut-off, which itself is dictated by the type of surface under inspection.

Typically, a measurement may consist of a traverse of 6-7 times the cut-off selected. Foe example, 7 cut-offs at 0.8mm = 5.6mm. One or two cut-offs will then be removed according to the filter type and the remaining cut-offs used for assessment. This only applies when measuring roughness.

For measuring waviness or primary profiles, the data length is chosen according to application and the nature of the surface. In general, the data length needs to be sufficient to give a true representation of the texture of the surface.

1.9. What is a sample length?

After the data has been filtered with a cut –off, we then sample it. Sampling is done by breaking the data into equal sample lengths. The sample lengths have the same numeric value as the cut-off. In other words, if you use a 0.8mm cut-off, then the filtered data will be broken down into 0.8mm sample lengths. These sample lengths are chosen in such a way that a good statistical analysis can be made of the surface. In most cases, five sample lengths are used for analysis.



1.10. Which cut-off should I use?

In general, you select a roughness cut-off in order to assess the characteristics of the surface you require. These are usually the process marks or witness marks produced by the machining process. To produce a good statistical analysis of these process marks, you would normally select a cut-off in the order of 10 times the wavelengths under consideration. These wavelengths may be the turning marks on the component. Warning; cut-offs should be determined by the nature of the component and not by the length of the component. Choosing the wrong cut-off will in some cases severely effect the outcome of the result. ISO 4288-1996 makes the following recommendations on cut-offs and evaluation lengths, it should be noted that these are recommendations, not requirements

RECOMMENDED CUT-OFF ISO 4288-1996				
Periodic profiles	Non-Periodic profiles		Cut-offs	Sampling length/ Evaluation length
Spacing Distance	Rz	Ra	(mm)	Cut-off/(mm)
Sm(mm)	(µm)	(µm)		
>0.013 to 0.04	(0.025) to 0.1	(0.006) to 0.02	0.08	0.08/0.4
>0.04 to 0.13	>0.1 to 0.5	>0.02 to 0.1	0.25	0.25/1.25
>0.13 to 0.4	>0.5 to 10	>0.1 to 2	0.8	0.8/4
>0.4 to 1.3	>10 to 50	>2 to 10	2.5	2.5/12.5
>1.3 to 4	>50 to 200	>10 to 80	8	8/40

1.11. Selecting the appropriate roughness filter bandwidth.

Surface roughness is deemed to be separated from waviness by means of a filter that rejects wavelengths longer than a specified cut-off wavelength, λc. In the late 1990's, in order to improve the comparability of surface roughness measurements, ISO introduced the concept of "bandwidth" into roughness analysis. Under this regime the shorter wavelengths used in the analysis are constrained by a short wavelength filter whose cut-off is denoted as λs. The roughness filter bandwidth is specified as the ratio between the lengths of these two cut-off values.

The choice of λc filter will depend on the process being assessed. There are a number of guidelines available to help with the choice of filters. As an example ISO 4288:1996 shows tables of sampling lengths for expected surface finish amplitude and spacing parameters. The λc filter is chosen from the available recommended cut-offs (e.g. 2.5mm, 0.8mm, 0.25mm, 0.08mm etc).

Selecting the λs filter is slightly more complicated. The ISO recommendation is to use a bandwidth of 300:1 wherever possible. The λs filter value is selected out of a similar list to the λc filter. The smallest λs available will be dependent on the data spacing available in the raw profile (data taken from the data acquisition system). The λs filter should be chosen so that it does not attenuate wavelengths that are likely to be introduced by the machining process. The recommended combinations of λc, λs and stylus tip radius are shown in ISO 3274:1996. There is no recommendation made for methodologies other than stylus type instruments. However, on a sampled system, we can simply select a sample rate (or step size) which will act as a λs filter. Alternatively, stating the λc filter used, and the sample step use will adequately define the data bandwidth used

The filters, together with the number of cut-offs used for the analysis, should be specified whenever surface roughness is being quoted. If they are not given, then under the ISO standards certain defaults will be assumed (5 cut-offs, 0.8mm, 300:1 bandwidth). Unless the cut-off and bandwidth are the same between measurements, you cannot rely on being able to obtain comparable results.

1.12. Summary

In summary, control of the overall bandwidth of the system is essential for ensuring comparability of results. The right choice of filter cut-offs (and therefore bandwidth) should be determined from knowledge of the machining process and the expected surface finish amplitudes and wavelengths.

When quoting roughness values, it is useful to include filter cut-off, number of cut-offs and bandwidth whenever these values deviate from the ISO recommendations. All of these parameters are likely to affect the measurement result.

2.0 Measuring Surface Roughness With The Proscan 2000

2.1. Available Parameters

The standard Proscan 2000 software supports a large number of two dimensional roughness parameters as follows. Please see the Proscan software manual for detailed instructions on how to select the required parameters for analysis

2.1.1. (ISO) Am

The arithmetic mean of the point heights

2.1.2. (ISO) Ra

Ra is the universally recognised and most used international parameter of roughness. It is the arithmetic mean of the absolute departures of the roughness profile from the mean line

2.1.3. (ISO) Rz

The Rz (also known as the ISO 10 point height parameter) is the average height difference between the five highest peaks and the five lowest valleys within the sampled length

2.1.4. (DIN) Rz

This Rz is the average height difference between the highest and lowest point that are contained within the five equal parts of the sample length.

2.1.5. 10Ln (DIN) Rz

10Ln Rz is an average of ten Rz lines in both X and Y direction. The ten Rz lines are spaced equally across the scan.

2.1.6. (ISO) Rmax

This function if activated allows the user to accurately calculate the maximum peak-to-valley height within one section. Rmax is an indication of the max defect height (peak or valley) within the assessment area.

2.1.7. (ISO) Rp

This function, when selected, will find the Root Mean Square of the profile height

2.1.8. (ISO) Rm

This function, when selected, will find the minimum valley depth over the entire scan line

2.1.9. (ISO) Rq

Rq is the square root of the average of the square of the deviation of the scan from the mean line

2.1.10. (ISO) S

This function calculates the peak profile density of the scan

2.1.11. (ISO) Sm

This function calculates the average peak spacing over an area of the scan

2.1.12. (ISO) R3z

The vertical mean from the third highest peak to the third lowest valley in a sample length

2.1.13. (ISO) Wt

The waviness of the profile over the assessment length

2.1.14. (ISO) Nr

Normalised peak count

2.1.15. (ISO) D

Peak count over the assessment length

2.1.16. (ISO) Rv

The maximum depth of the profile below the meanline within the sample length

2.2.2D Analysis

Traditional surface analysis methods have relied on a single, two dimensional line of data to define the surface under consideration. Proscan software supports this methodology via the 2d profile function. The user is first prompted to select the required line of data via the graphical interface, the selected line of data is then displayed in a new window which is aimed at supporting standard surface analysis functions and methods

2.2.1. Autolevel

This function is provided to enable the data to be levelled prior to analysis. It calculates the straight line of best fit to the data, subtracts this line from the original data and displays the modified information, ready for further analysis

2.2.2. Waviness Filter

This filter allows you to view the general form of a surface by removing most of the surface texture or roughness from the data set. It is equivalent to the warpage filter, expressed in distance, or cut-off terms, and works in the following way

Warpage/Waviness Filter – This filter is used to remove the texture on the profile leaving only the waviness or form. A filter size in numeric units is input by the operator, which defines the amount of texure removed. For this example a filter of 0.2mm on a scan with measurements every 0.1mm will look as follows:

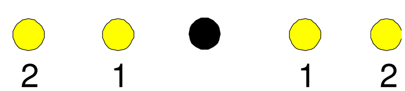
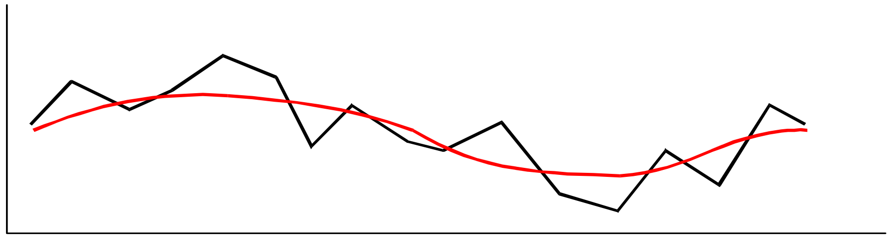


Fig 1.

Each circle in Fig 1 represents a point of measurement. When applying a filter size of 0.2mm the software automatically calculates an average of the height for all measurements within the defined cut-off either side of a central point. This average is then placed in the central position (shown as black above). The algorithm is then repeated for the neighbouring point until all points have had this averaging applied to them. The effect of doing this can be seen in Fig 2. It should be noted that the filter only becomes effective after ½ of the applied cut-off at each end of the scan line.



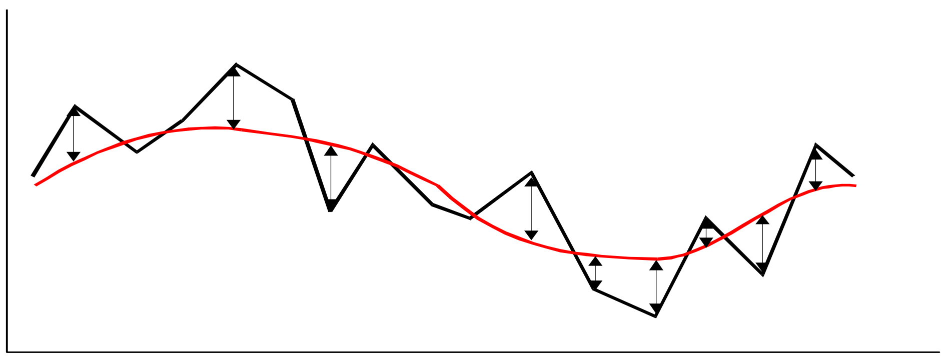
Profile before warpage filter has been applied

Profile with warpage filter applied

2.2.3. Roughness Filter

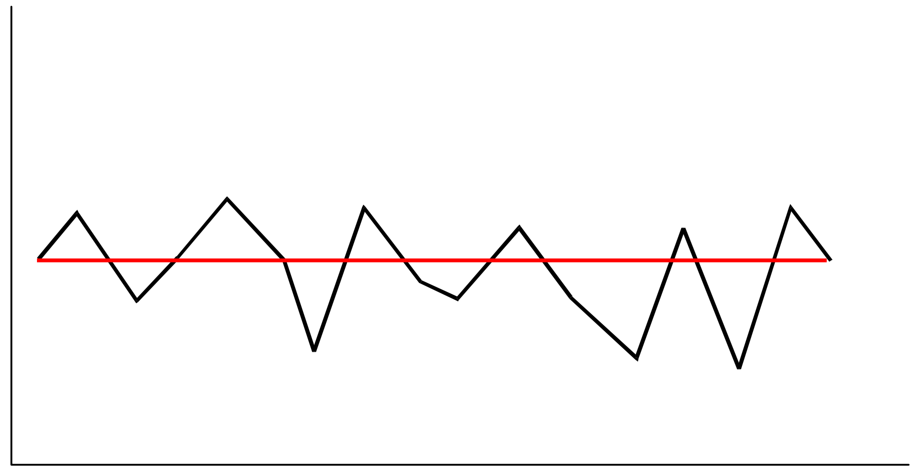
The roughness filter is used to remove the general form of the surface, and leave the surface roughness. It is equivalent to the surface filter, expressed in distance, or cut-off terms, and works in the following way

Surface Filter – This filter is used to remove the form of the profile leaving only the texture.



This filter works in the same general way as with the warpage filter, with the software using the rolling average (based on the cut-off applied by the operator) and calculating a smoothing effect through the entire scan.

Once the software has calculated this, it subtracts the smooth profile from the original scanned data, removing the underlying form, to leave only the texture. Once again, the filter only becomes effective after ½ of the applied cut-off distance at each end of the scan line



2.2.4. 2D Profile Analysis Results

Continuously updated results of the selected mathematical calculations are displayed in this window. It is important to note that, to assist in the application/discovery of appropriate filter values, cut-off sections of data are not discarded according to ISO recommendations, so care must be taken when using these calculated results. They should be used for guidance purposes only

2.3.3D Analysis

The traditional stylus method for calculating surface roughness, uses a single line of data to characterise a surface. One of the greatest advantages of using a three dimensional scanning instrument, such as the Proscan, is the ability to easily and rapidly acquire large amounts of data over an area. This means that it is possible to apply statistical methods to standard ISO roughness calculations and thereby obtain more accurate and repeatable information

We have already discussed the application of waviness and roughness filters to raw data. When looking at 3D surfaces we need to revert to the usage of the surface filter, to bring out the roughness information. The surface filter itself works on a point by point basis (as the data consists of a number of discrete measurements). In order to convert our calculations into ISO recognisable terms, we need to apply ISO 4288-1996 recommendations. See the following example

2.3.1. Defining Bandwidth

We wish to look at a surface with an expected Ra of around 0.05 microns (non periodic profile). The ISO recommendations on this are that you use a cut-off filter of 0.25 mm, with a sampling length/evaluation length of 0.25/1.25 mm. One of the concerns of the ISO standard is that the bandwidth of the data be restricted, ideally with a ratio of 300:1. Our intention is to apply a roughness filter of 0.25 mm, we can restrict the bandwidth of our data by selecting an appropriate step size, in this case 0.25mm/300 = 0.0008 mm, or 0.8 microns. The nearest available step size in this instance is the lowest available step on the Proscan system, that is 1 micron. We also need an evaluation length of 1.25mm, therefore the number of steps that we require is 1.25 mm/0.001 mm = 1250 steps per line

NOTE In order to comply with ISO recommendations, we can take a single scan line, and perform the required calculation on that data line. Alternatively, we can take any number of scan lines, and perform the same analysis on each line. This improves the credibility of the accumulated data, and provides a far sounder basis from which to draw conclusions

2.3.2. Calculating Filter Value

Once we have collected our scan data, we need to process the information. Firstly, we need to present the data in a form which is as level as possible. The Proscan software offers a number of ways in which this can be achieved (please see the Proscan 2000 software manual). These include datum plane levelling, three point levelling and auto levelling (where the plane of best fit is calculated, and the data levelled accordingly). Once the data has been levelled, we need to apply a suitable filter to remove the underlying form of the surface, and leave us with only the roughness information. In this case, we have already seen that the recommended cut-off filter is 0.25 mm. To convert this into surface filter terms we perform the following calculation

(Cut-off filter in mm / 2) / step size in mm = Surface Filter

Or, for this case (0.25 / 2) / 0.001 = 125

The Surface filter allows values from 1 to 99 to be entered. 99 Is the least aggressive surface filter, and should be adequate for applications which indicate a higher value. We now have an appropriately filtered data set, but before we can calculate the surface roughness information, we need to discard the filter affected data at each end of the scan line (or lines), that is the first 1.25 and the last 1.25 mm. We can do this within the Proscan software, by using the zoom function, (see the Proscan software manual), and then loading the area. This newly loaded area is now ready for analysis which is performed by simply clicking on the analysis icon on the Proscan software toolbar

2.3.3. Analysing Data

A 'Profile Analysis' window will now come up in the software, this window will show the results for the selected calculations, in both the X and the Y direction. By default, these calculations will be performed on the lines of data highlighted by the crosshairs in the main software window

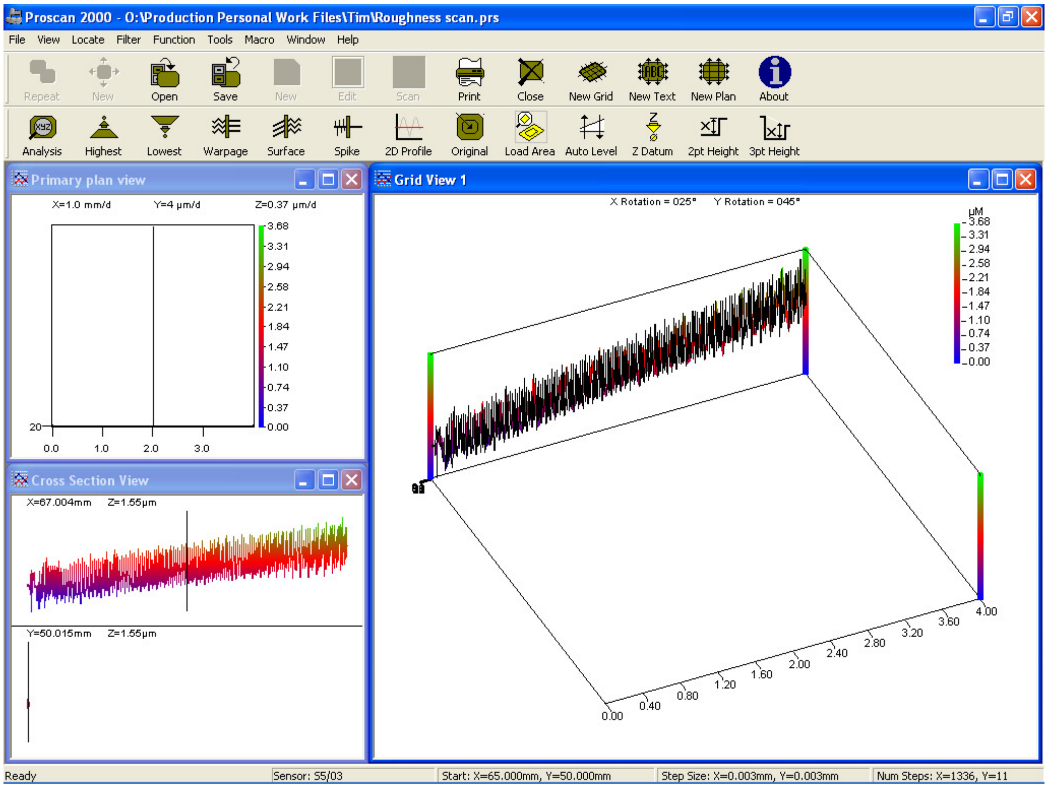
Alternatively, fuller use of the Proscans 3D data collection capabilities can be made by selecting the 'Zoomed Area' box. Calculations will then be made on each line of data in both the X and the Y direction, the profile analysis window will display the minimum, the maximum, and the arithmetic mean of the calculations

2.3.4. Roughness – An Example

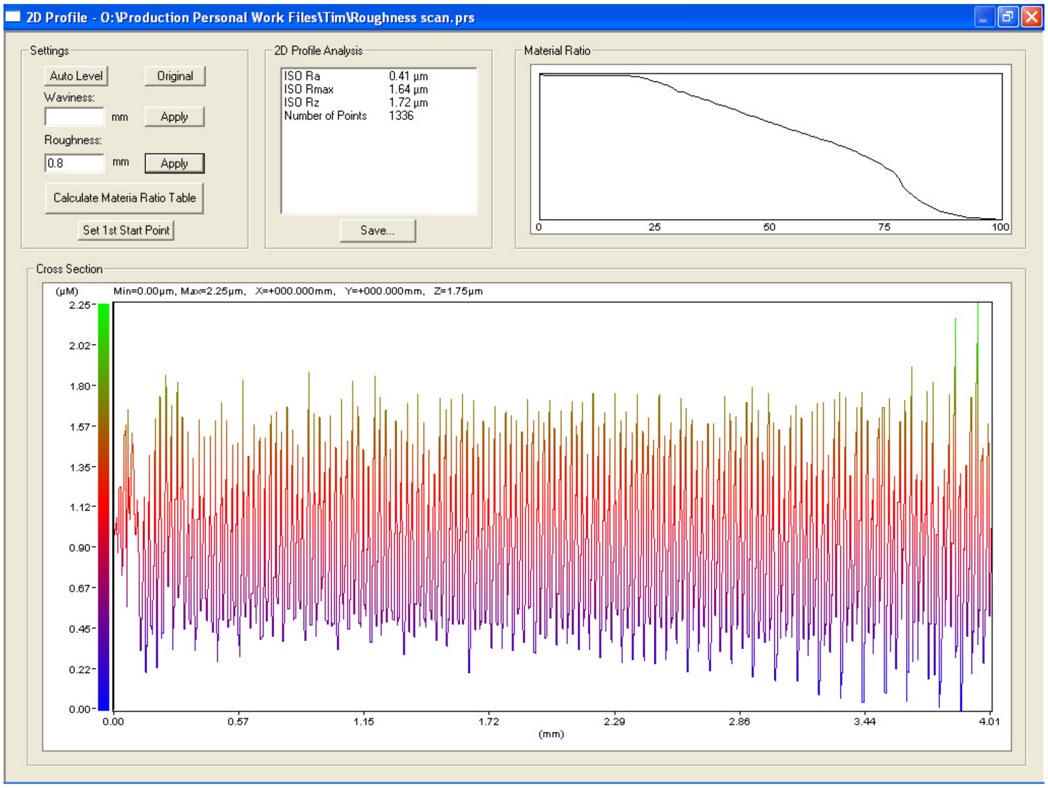
We have a sample with an expected Ra value in the region of 0.4 micron

If we look at ISO recommendations, we can see that, for this type of surface, the recommendations are that we use a cut-off of 0.8 mm with a sampling length/evaluation length of 0.8/4.0 mm. The general rule within ISO is that we use a default bandwidth of 300:1 for calculations, therefore the step size that we should apply is 0.8 mm / 300 = 2.7 E -3 mm, or, in Proscan terms, approximately 3 microns. We need to scan a length of 4 mm which means that we require (4 mm / 0.003 mm (step size)) steps, or approximately 1,335 steps

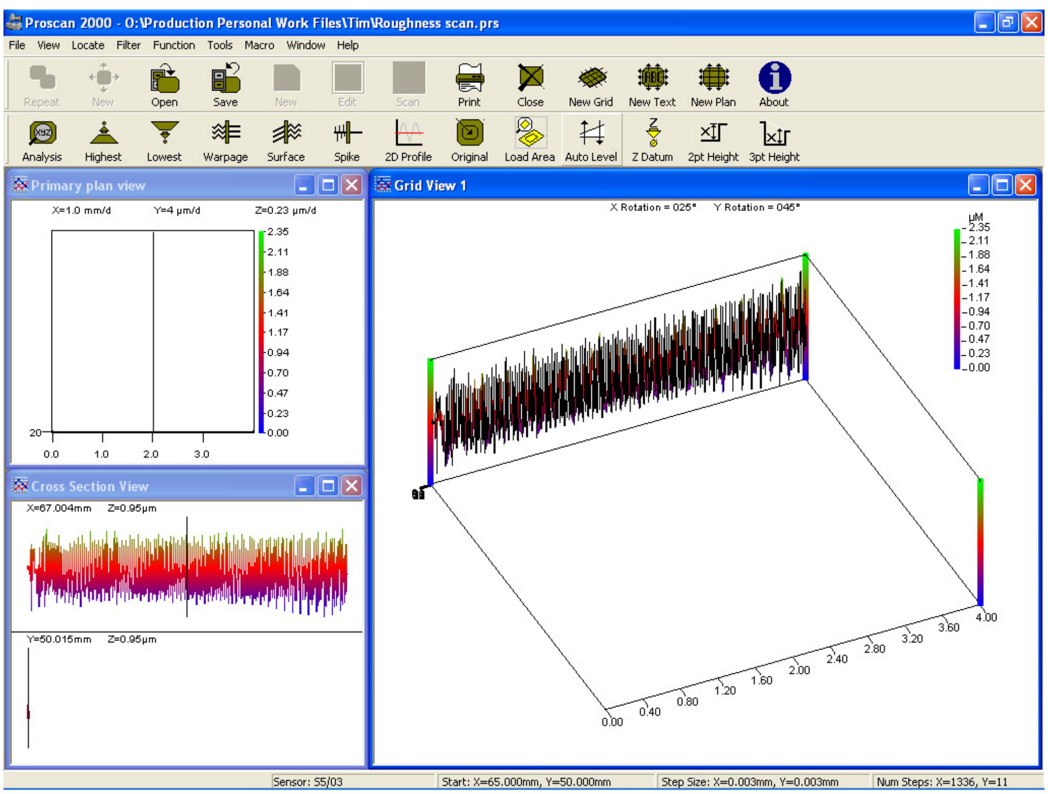
For purposes of speed, we input 10 steps into the number of lines scanned, and scan in the X axis. The results are as follows



We can perform a simple check on the data (to confirm that we are using the right parameters). Using the 2D Profile Tool, Auto Levelling the data, and applying the 0.8 mm Roughness filter, we get the results shown in the following screen, where the indicated Ra is 0.41 microns. This result indicates that we are in the right ball park, and can continue with the analysis. If the result had fallen within a different region on the ISO recommended cut-off table, we could have re-evaluated the scan parameters, and rescanned the sample with the new settings



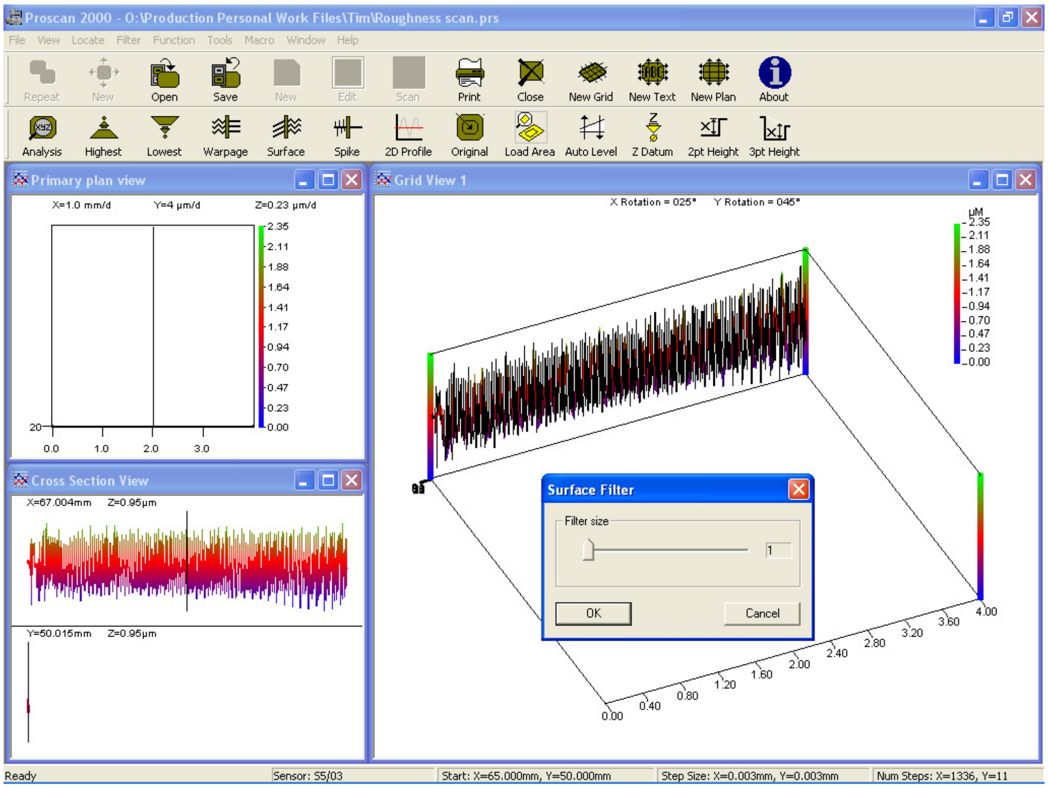
We can now go back to the original data screen and apply 'Auto Level' to the data, which leads to the following screen of levelled data



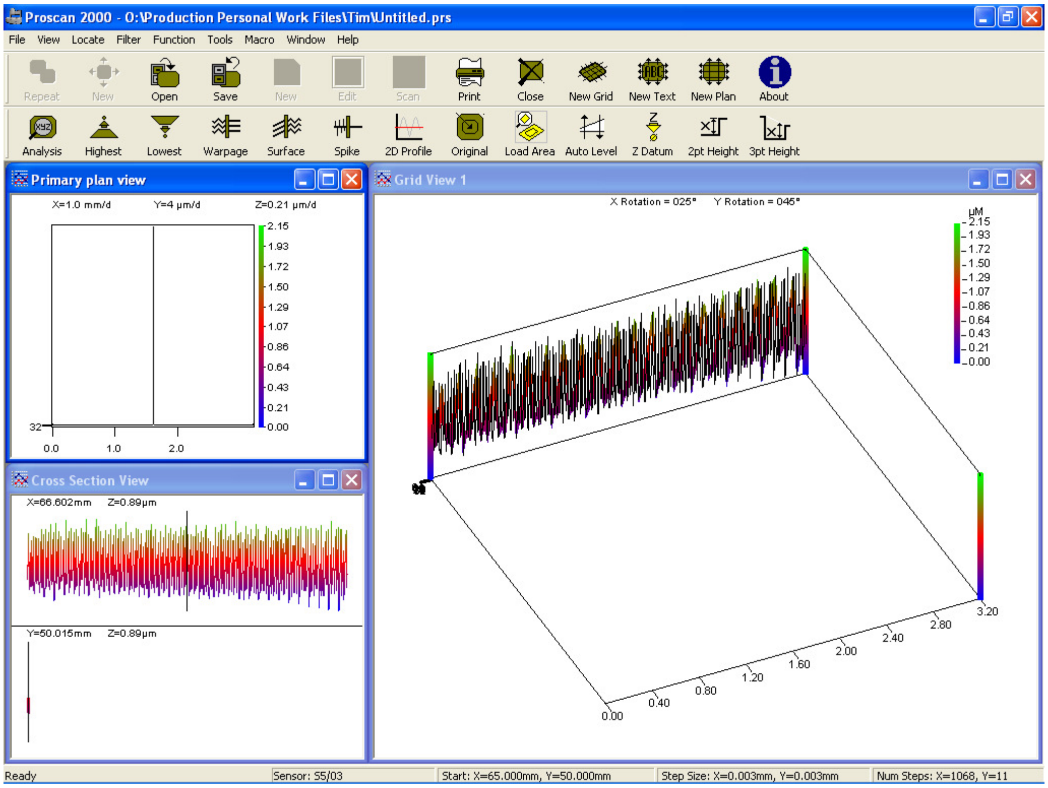
It is now time to apply the cut-off filter. Firstly we need to calculate the correct 'Surface Filter' to use. The calculation for this is :-

(Cut-off filter in mm / 2) / step size in mm = Surface Filter
(0.8 mm / 20) / 0.003 mm = 133

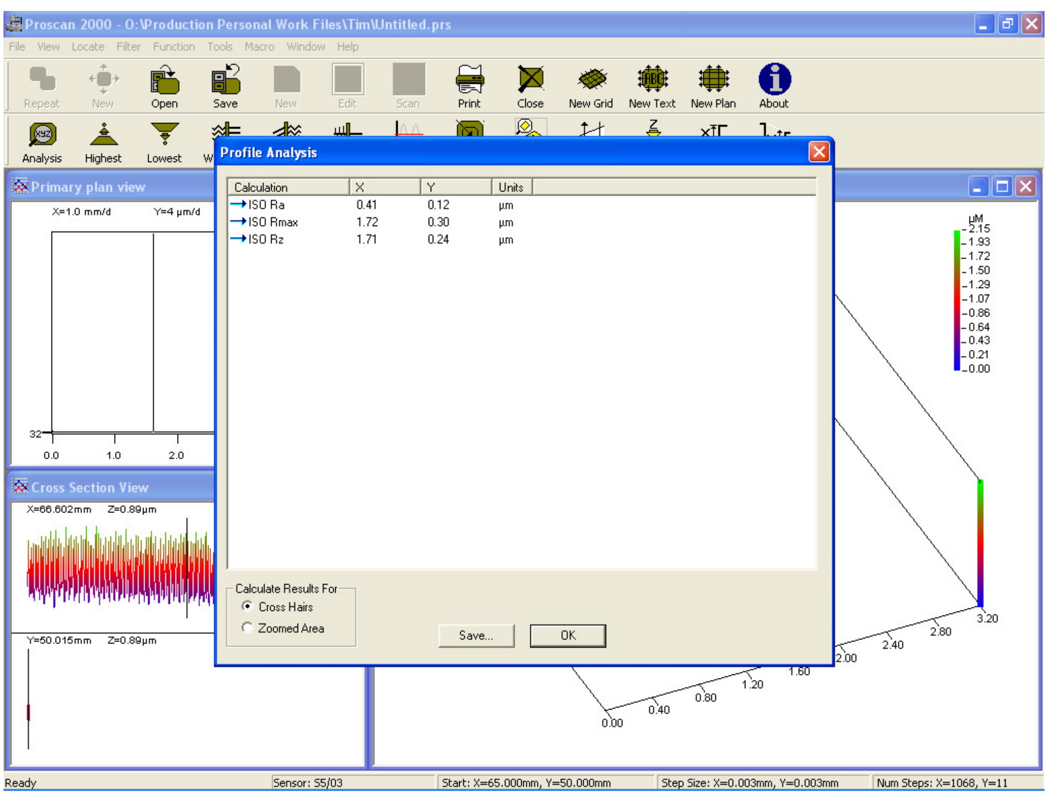
Hence we apply a 'Surface Filter' of 99. The result is as follows



It is now time to discard the unwanted filter affected data, which is the first and last 0.4 mm. We do this by carefully zooming into the required area, and then clicking on the 'Load Area' icon. As follows

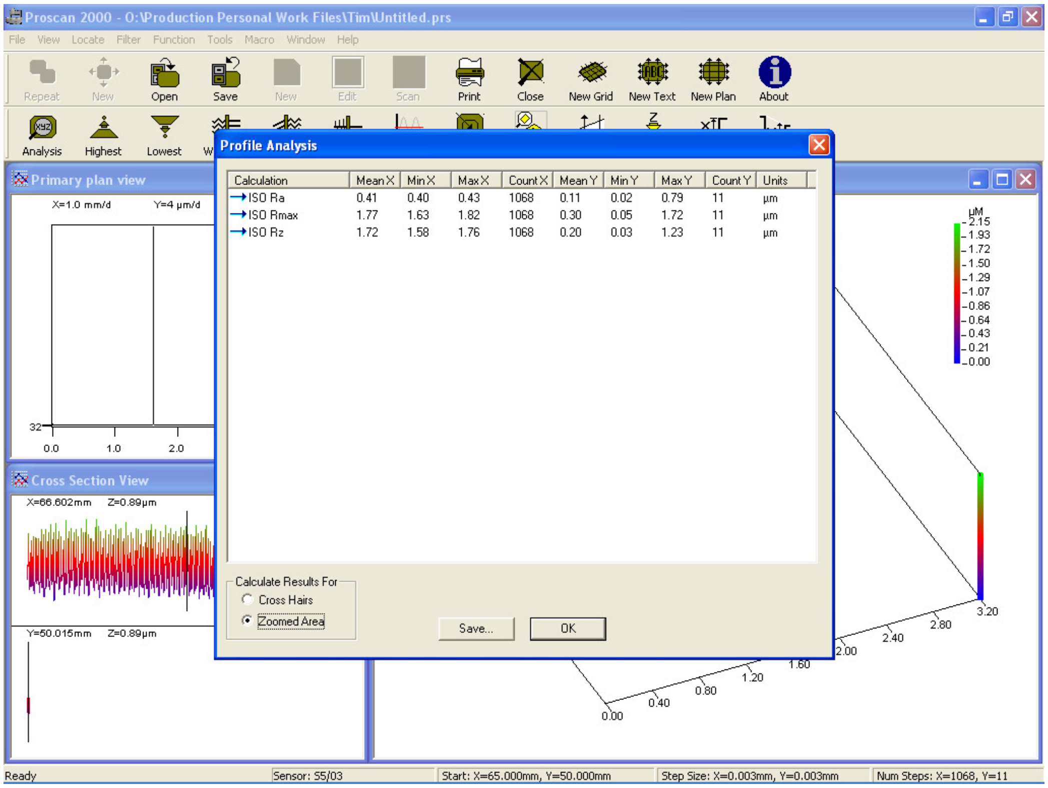


We can now analyse the surface by clicking the 'Analysis' icon. The following screen is displayed. This shows the analysis information for the cross section marked out by the cross hairs. We can look at a different line by clicking the 'OK' button, moving the cross hairs with either the mouse, or the arrow keys, and reselecting the 'Analysis' icon



Alternatively, we can readily access more statistical information by clicking on the 'Zoomed Area' button. The software will immediately recalculate the results on a line by line basis and will present the following screen, data can then be saved to a '_____.csv' file for further analysis

NOTE:- Very large data sets may take some time to perform the required calculations



2.3.5. Summary

ISO guidelines are recommendations only, and are primarily aimed at providing uniformity of methodology amongst the users of roughness information. It is not possible for such guidelines to keep abreast of measurement technologies or requirements, and as such, they are not always as applicable as would be ideal

It is entirely possible to measure a single roughness by two different methods, and obtain different results. Following ISO methods will not always give the best, or the most appropriate answers. When quoting roughness information, it is always best to provide as full information as possible regarding the measurement method, the tools used, and the parameters applied