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TECH BRIEF: SURFACE ROUGHNESS MEASUREMENTS

by Charles D. Dern, P.E.

Introduction

Surface finish is a critical issue to those involved in pharmaceutical process equipment. Thus, one must understand the various means used to measure surface roughness. Many familiar nomenclatures such as "Number 4 Polish" or "180 Grit" have given way to far more precise units of measurements such as R_a or R_z. To help in the understanding of these terms, this paper outlines the means most commonly used to define the quality of surface finish.

Definitions

µ - is the Greek letter *mu* (pronounced "mew"). It is used in both English and metric systems to denote "one millionth of" and means the same thing as the prefix *micro-*. Thus *µ"* means one millionth of an inch or a microinch, *µm* denotes one millionth of a meter or a micrometer. It is also common to use *µ* by itself to designate micro- meters.

Microinch vs. Micrometer - By definition there are .0254 meters to an inch. Thus, there are .0254 micrometers to a microinch. To convert microinches to micrometers, one multiplies microinches by .0254. To convert micrometers to microinches, one divides micrometers by .0254. All surface roughness parameters can be measured in either microinches or micrometers depending upon the system with which the user is familiar.

Average Roughness Height Parameters - (Such as R_a) specify the average of all height within a given length.

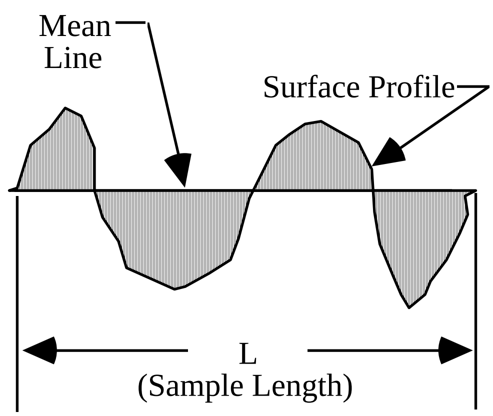
Averaged Extreme Value Roughness Parameters - (such as R_z) specify the average of a set of peaks and valleys (i.e. the difference between the highest and the lowest) within a given length.

Extreme Value Roughness Parameters - (such as R_t) specify the difference between extreme heights in a surface profile.

R_a

R_a is the *arithmetic average roughness height.* It was formerly known as the Arithmetic Average (AA) in the United States and as the Centre Line Average (CLA) in England. Referring to the sketch below, if one added the lengths of all the vertical lines, considering all the lengths as positive regardless of whether they are above or below the mean line, and then divide by the number of lines, one would have a good approximation of R_a. Mathematically this would look like:

$$R_a = \frac{\text{Sum of Absolute Line Lengths}}{\text{Number of Lines}}$$



Obviously, the more lines that one includes, the more accurate one's result. Therefore, if one could sum an infinite amount of lines, that is, calculate the actual shaded area; one would have a perfect result for the sample area. The mathematics of calculus allows one to do just this. The equation for this process is:

$$R_a = \int \left| \frac{\text{line heights}}{L} \right| dx$$

R_a is the area between the surface profile and the mean height divided by the sample length.

The advantages of R_a are several. First, it is one of the most standardized parameters in the world and is specified for about 90% of all surface parameters. Second,

R_a is useful for the detection of general roughness height variations and for the quality control of various manufacturing processes. R_a, however, cannot detect infrequently occurring "spikes" of abnormally high or low surface variations. If this is a concern, it must be supplemented with another method such as R_z.

R_q

Before moving on to R_z it will be helpful to quickly examine R_q, also known as RMS or "Root Mean Square," because this was the industry standard until several years ago. Mathematically, the equation for R_q is:

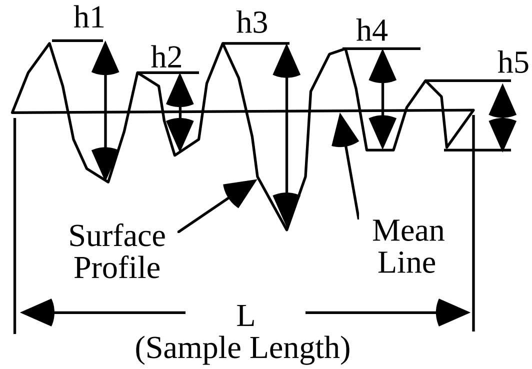
$$R_q = \sqrt{\frac{f(\text{line heights})^2\, dx}{L}}$$

Though R_q is similar to R_a, the squaring of the "line heights" gives more "weight" to the larger heights. Thus, R_q is actually the "standard deviation" of the line heights, that is, the height of which 67% of the surface aberration is equal to or less than. There is no advantage/ disadvantage to R_q other than that R_a is more widely used. Note also that some time ago, the term "RMS" was used in surface measurement to denote something slightly different (due to the limitations of surface measuring devices at that time). For accuracy, however, the symbol R_q should be used instead of RMS.

R_z

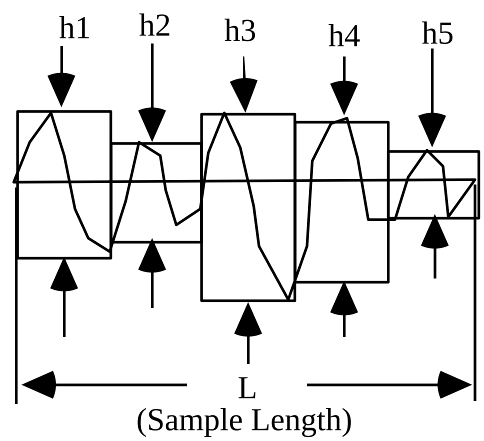
There are, unfortunately, several accepted definitions of R_z. We only consider the two most widely used. The International Standards Organization definition of $R_{z(ISO)}$ is the "Ten Point Roughness Height" and is the average height of the five highest peaks and the five lowest valleys found in a given length.

$R_{z(ISO)}$ is useful for evaluating surfaces where the presence of high peaks and/or deep valleys is of critical importance. Examples of such surfaces are small valve seats and o-ring grooves. The problem with $R_{z(ISO)}$ is that there may not be five definable peaks or valleys within the sampling length. Measuring devices account for this problem in different ways, but by definition, the answer given regardless of how it is handled is inaccurate. A measuring instrument in this situation should give a warning signal that there is not enough data.



$$R_{z(ISO)} = \frac{h1 + h2 + h3 + h4 + h5}{5}$$

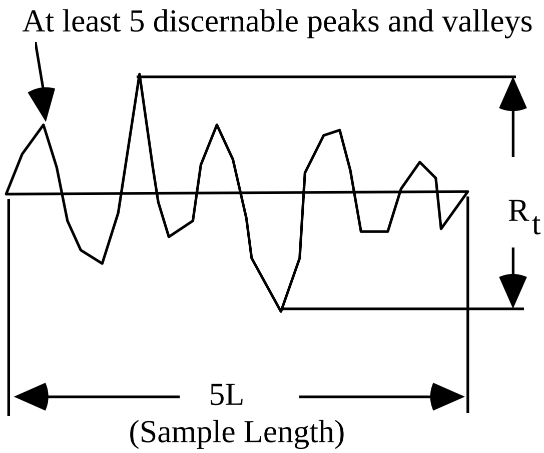
The German DIN standard 4768/1 assigns the symbol R_z to what ISO assigns the symbol R_{tm}. $R_{z(DIN)}$ is known as the "mean peak to valley height." It divides the sample length into five equal lengths and then measures and averages the difference between the highest and lowest point in each of the five segments. $R_{z(DIN)}$ has an advantage over $R_{z(ISO)}$ in that regardless of the peak and valley profile of the surface, $R_{z(DIN)}$ takes the highest and lowest point of each segment.



$$R_{z(DIN)} = \frac{h1 + h2 + h3 + h4 + h5}{5}$$

R_y and R_t

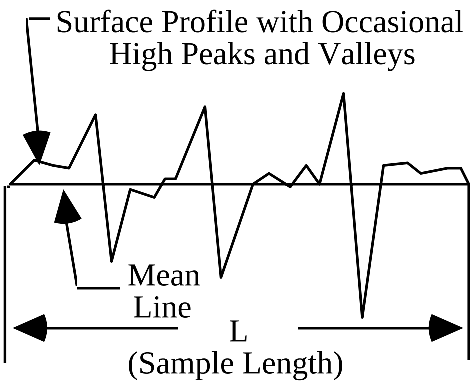
R_y (formerly called R_{max}) is simply the difference between the highest peak and the lowest valley of a given sample length. The problem with R_y is that even with the most highly polished surfaces, maximum peaks and valleys can vary widely between measurements taken just millimeters apart on a given surface. R_t attempts to compensate for this problem. R_t is the "Maximum Roughness Height in Five Cutoffs." Although background literature is not very clear on this point, apparently R_t varies from R_y in that a measurement can only be taken when there are five distinguishable peaks and valleys. Therefore, as in the case of $R_{z(ISO)}$, an instrument measuring R_t should signal the operator that there is insufficient data if five distinct peaks and valleys cannot be found.



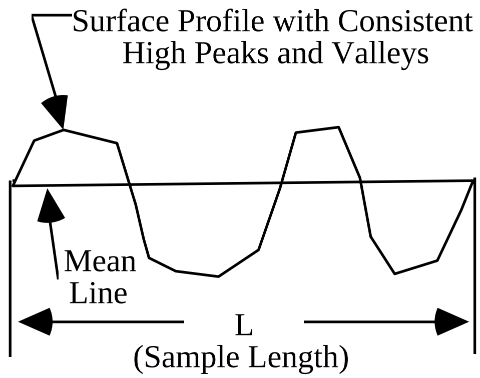
As seen in the diagram, R_t tends to give less variance in readings because it takes the highest peak and lowest valley out of five peaks and valleys. On the other hand, no less than five different R_y readings could be obtained from the above surface.

Comparison of Surface Parameters

By definition, there is no direct mathematical conversion from one parameter to another. The cases of R_a and R_z provide good examples. The diagrams below show how it is possible to have approximately the same R_z while seeing variations in R_a.



Small R_a with Large R_z



Large R_a with Large R_z

Results vary widely depending upon the material that one is polishing as well as the polishing method used. However, if the materials and polishing method are consistent, there should be a statistical correlation between the two, that is, certain R_a's should have a corresponding range of R_z's that tend to occur with them. By gathering data of R_a's and the corresponding R_z's, it is possible to do a statistical correlation by linear regression. Research performed at the Hull Company found values of m in the range of 5.5 to 7.3 and values of y in the range of 15 to 40 for the equation $R_z = m \times R_a + y$ where all units are in microinches.

Highly polished surfaces show a tighter correlation between R_a and R_z while rough finishes as measured by R_a show a greater variance in corresponding R_z's. This is because the aim of polishing is to remove peaks and valleys from a given surface. The more peaks and valleys that are removed, that is, the more consistent a surface profile is, the more correspondence that should occur between surface parameters.

The same holds true when comparing R_t or R_y to R_a or R_z. As the maximum peaks and valleys are removed by the polishing process, the differences between various R_t or R_y readings will decrease and the statistical correlation between the Maximum Roughness Height and the Average Roughness Height should converge.

Other Surface Finish Specifications.

Despite readily available surface profilometers that quickly and easily measure any of the aforementioned parameters, one often comes across terms such as "Number 4 Polish," "Satin Finish" and "Foundry Finish." Even more common is the use of the term "Grit" preceded by a number such as 180 or 240.

First, the use of general terms is imprecise. As the table below shows, both result a general range of surface polish rather than an exact finish. For instance, a Number 4 Polish approximates a 30 to 35 microinch Rq roughness. Because there are no strict guidelines, the question remains as to whether a 36 or 37 microinch R_q finish still qualifies as a Number 4 Polish.

Second, grit refers to the size of the polishing medium of a new cloth or belt. Although using certain grits *tends* to yield certain finishes, one is still left with a range of surface roughness as opposed to a specific criterion to be met. Any one of the surface roughness parameters described above provides a much better definition of required finish than the use of terms or grit.

Third, the above issues raise difficulties during the validation process. Validation demands repeatable and quantifiable data. Specifications such as Grit or "Satin Finish" offer virtually no benchmark against which to measure the conformance or non-conformance of a particular surface finish. On the other hand, measurement methods such as Ra are readily quantifiable.

Conclusion

The question remains as to which surface roughness parameter is best. As with most things, the answer depends upon one's intention. If one needs to know the overall finish of a surface, the advantages and disadvantages of R_a vs. $R_{z(DIN)}$ are clear. R_a is more universally recognized and provides the most useful way for detecting general variations in a surface, but it cannot detect the presence of occasional extreme peaks and valleys as does R_z.

R_t and R_y are, of course, valuable for those who need even more information on the extreme conditions of a surface. The problem with these parameters, as was mentioned above, that readings can vary widely and that many readings are necessary to obtain a true picture of the surface condition.

Regardless, the use of terms such as "Satin Finish" or specifications of "grit" are to be avoided because there is no objective method of measurement.

Because of its ease of measurement, widespread use within the pharmaceutical community and suitability for the purpose, Hull Company uses the Ra measurement for all surface finishes. These measurements are taken with a semi-automatic profilometer. Results are supplied with available Installation Qualification (IQ) documentation.

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Charles Dern is a Project Engineer for SP Industries.

Table 1: Statistical Comparison of Surface Roughness Finish Specifications.

Ra micro inches	Rq (RMS) micro inches	Rz micro meters	Grit	Other Names
145-154	170-180	21-30*		
125	140-150	18-24*		
71	80-85.2	8-13	80	Foundry Finish
62.5	75	7.6-10		
60	72	7.5-9.9		Satin Finish
52	58	6.7-9.1	120	
50	60	6.5-8.9		
42	47	5.8-8.2	150	
39.2	47	5.6-8		
36	39.6	5.2-7.6		
32	36-38	5.1-6.5*	150-180	#4 Polish
30.9	35	5.3-6.3	150-180	#4 Polish
30.4	33.4	5.2-6.2	150-180	#4 Polish
30	34	5.1-6.1	150-180	#4 Polish
28.8	34.5	5-6	150-180	#4 Polish
27.3	30	4.7-5.7	150-180	#4 Polish
24.8	27.3	4.3-5.3		#7 Polish
22.7	25		180	#7 Polish
19.2	21.1	3.3-4.3	180	#7 Polish
18.2	20		180-240	#7 Polish
15	17	2.5-3.5	240	#7 Polish
14	15.4	2.4-3.4	240	#7 Polish
12	14	2-3	320	#7 Polish
9.4	11	1.8-2.8	320	#7 Polish
7.7	9	no data	320	#8 Polish
2-8	3-5	no data		#8 Polish

**Extrapolated: assumes linear correlation with smaller Ra's and Rz's*

Notes:

1) All Correlations are statistical. Data from one column will only have a "tendency" to approximate data in another column.
2) Italicized Numbers in Ra column are interpolated from Rq column.
3) Hull data is given with the range of one standard deviation.

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