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Computer Aided Predicting of Surface Finishes before Machining

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Abstract

The profile of a machined surface depends on at least three processes; the kinematics or motions in the machining process, dynamic behavior or vibrations of the machine-tool-work system and the material deformation process as the chip is formed. The surface produced due to the feed motion (kinematics) of the cutter along the workpiecce will be considered in this paper.

A turning data base system is prepared in order to determine feeds from machining data for a number of different materials. The other step in this work is to develop a computer program for predicting surface finish for turned parts. The importance of work results is to automate the process of finding estimated values of surface roughness before machining. So it is a helpful indicator when choosing cutting conditions to machine a part within certain surface finish.

أستخدام الحاسوب في تخمين الخشونة السطحية قبل أجراء عملية التشغيل

الخلاصة

ان هيئة السطح المشغل تعتمد على ثلاث عمليات على الاقل وهي كل من الأنتقال او الحركة خلال عملية التشغيل والسلوك الديناميكي أو الأهتزازات في منظومة ماكنة التشغيل وعملية تشكيل النحاتة للمادة المشغلة. في هذا البحث سيتم أعتماد السطح الناتج عن حركة التغذية للأداة نسبة الى المشغولة.

تم أعداد نظام لبيانات عملية الخراطة من اجل حساب مقدار التغذية ولعدد من المواد المختلفة. اما الخطوة الاخرى للبحث فهي اعداد برنامج حاسوبي لتخمين مقدار الانهاء السطحي للقطع المشغلة بعملية الخراطة. ان اهمية نتائج البحث هي في أتمتة عملية أيجاد قيم تخمينية للخشونة السطحية وذلك قبل أجراء عملية التشغيل. لذا فان النتائج تعتبر كمؤشر يساعد في اختيار ظروف القطع لتشغيل قطعة معينة وبأنهاء سطحي معين.

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1-Introduction:

Surface finish is an apparent witness of tool marks or – lack of same – on the machined surface. The design engineer is usually the person that decides what the surface finish of a work piece should be. He bases his decision on what the work piece is supposed to do. Where good surface finishes achieve high efficiency by decreasing friction; e.g., a piston engine may give high hoarse power with less friction of the connecting rod, crank, and piston. Also good surface finishes increase wear resistance between moving pieces in an assembly part. Good surface finishes are the norm in several industries, as in the micro processor industry [1]. When designing or using a part, its performance is expected to depend on part surface characteristics. For example, axel shafts are subjected to alternating stresses as the axel rotates and fatigue failure should be of concern. So, it is important to avoid local, sharp features on the shaft since these are usually initiation sites for fatigue failure. One problem is to decide on how to describe or characterize the surface. The surface finish will be measured during part production but is intended to be useful for describing surface behavior in use. The machine tool power and rigidity also affects surface finish of the part, where improving the way system of a turning machine; for example succeeded to largely improve surface finish [2]. The basic definitions that related with this research can be seen in appendix (A).

2. Surface finish in machining [1]:

Since machining is often the manufacturing process that determines the final geometry and dimensions of the part, it is also the process that determines the part's surface texture. The ability to achieve a certain tolerance or surface is a function of the manufacturing process. This process determines surface finish and surface integrity. Some processes are inherently capable of producing better surfaces than others. In general, processing cost increases with improvement in surface finish as shown in figure (1). This is because additional operations and more time are usually required to obtain increasingly better surfaces.

Figure (2) indicates the usual surface roughness that can be expected from various machining processes. The data represent surface finishes that may be readily achievable by modern, well - maintained machine tools.

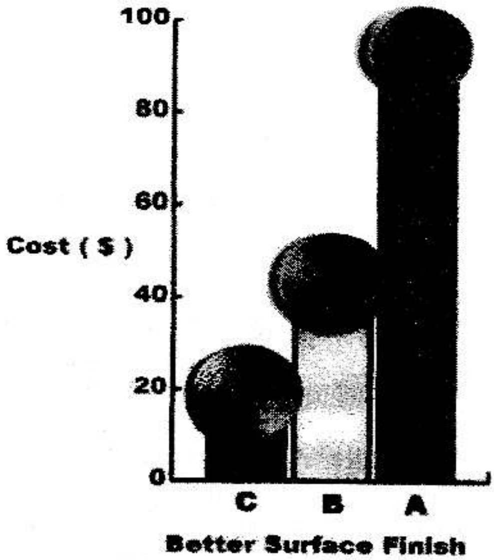

Figure (1) Relation between cost and surface finish [1].

Item	Machining process	Typical surface finish	Range of roughness
1	Turning	Good	(0.5-6) micrometer
2	Drilling	Medium	(1.5-6) micrometer
3	Milling	Good	(1-6) micrometer
4	Planning	Medium	(1.5-12) micrometer
5	Reaming	Good	(1-3) micrometer
6	Shaping	Medium	(1.5-12) micrometer
7	Sawing	Poor	(3-25) micrometer
8	Boring	Good	(0.5-6) micrometer

Figure (2)
Surface roughness produced by various machining processes [3].

The roughness of a machined surface depends on many factors that can be grouped as follows:

a) Geometric Factors: these include; type of machining operation, cutting tool geometry, most importantly nose radius, and feed. The surface geometry that would result from these factors is referred to as the ideal or theoretical surface roughness, which is the finish that would be obtained in the absence of work material, vibration, and machine tool factors.

Tool geometry and feed combine to form the geometry of the surface. In tool geometry, the shape of the tool point is the important factor. The effects can be seen for a single-point tool in figure (3). With the same feed, a large nose radius causes the feed marks to be less pronounced, thus leading to a better finish.

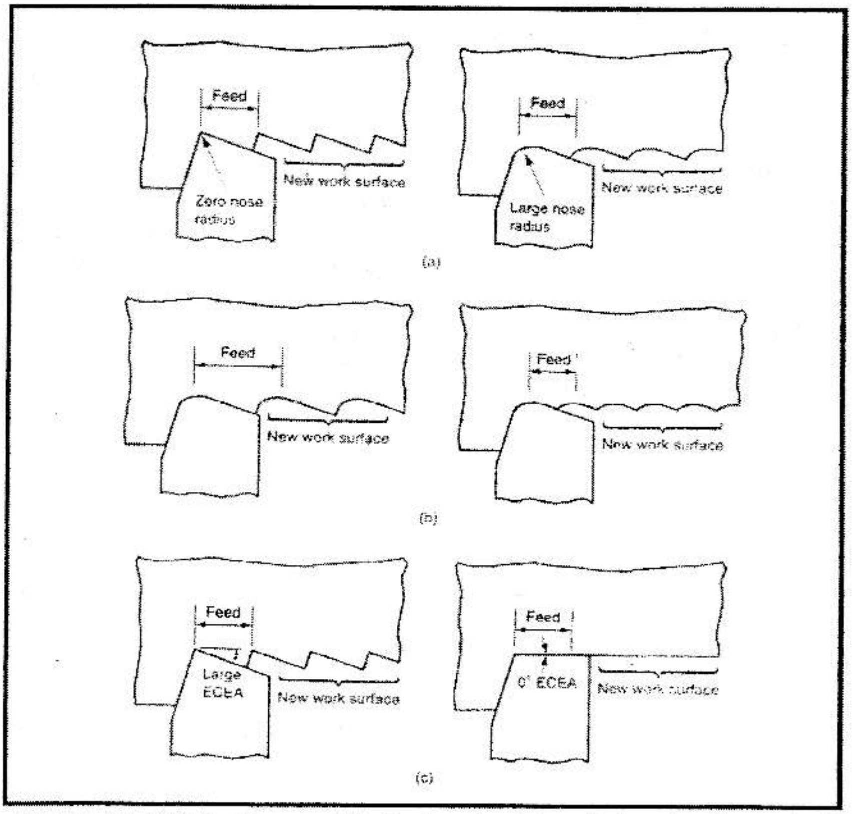

Figure (3) Effect of geometric factors in determining the theoretical finish [3]. (a) Effect of nose radius. (b) Effect of feed. (c) Effect of end cutting edge angle.

The effect of nose radius and feed can be combined in an equation to predict the ideal arithmetic average roughness for a surface produced by a single-point tool. The equation applies to turning [3]:

$$R_i = \frac{f^2}{32NR} \quad \dots\dots\dots\dots\dots (1)$$

Where R_i=theoretical arithmetic average surface roughness, micrometers

f = feed, mm; and NR = nose radius on the tool point, mm

b) Work Material Factors: these include; built-up edge effects, damage to the surface caused by the chip curling back into the work, tearing of the work surface during chip formation when machining ductile materials, cracks in the surface caused by discontinuous chip formation when machining brittle materials, and friction between the tool flank and newly generated work surface. These factors are influenced by cutting speed and rake angle, such that an increase in cutting speed or rake angle generally improves surface finish. These factors usually cause the actual surface finish to be worse than the ideal. An empirical ratio can be developed to convert the ideal roughness value into an estimate of the actual surface roughness. Figure (4) shows the ratio of actual to ideal surface roughness as a function of speed for several classes of work material.

c) Vibration and Machine Tool Factors: these include; chatter or vibration in the machine tool or cutting tool; deflections in the fixturing, often resulting in vibration; and backlash in the feed mechanism, particularly on older machine tools.

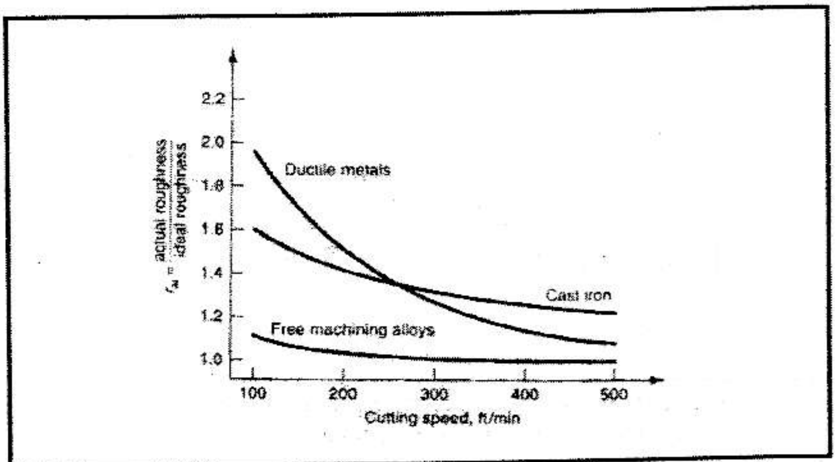

Figure (4) Ratio of actual to ideal surface roughness [3].

The effect of vibration can be considered on four main points:

(1) The effect of vibration on the machine tools,
(2) The effect of vibration on the cutting condition,
(3) The effect of vibration on the work piece,
(4) The effect of vibration on the tool life.

The major effect of vibration on the work piece is worsened surface finish. When vibration becomes then dimensional accuracy of the job may also be affected.

Figure (5) shows a typical surface profile and chatter marks shown in a magnified way in the cutting and feed direction.

The chatter frequency in cycles/minute can be determined from equation (2) using the correspondence of figure (6).

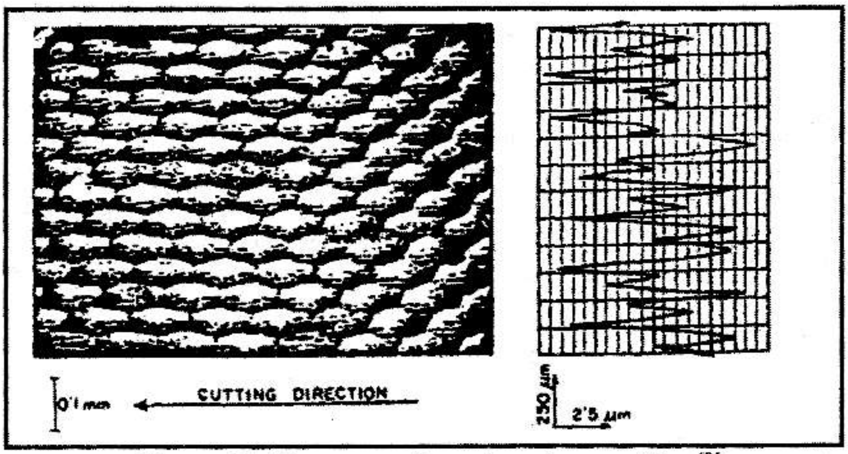

Figure (5) Chatter marks and surface profiles [8].

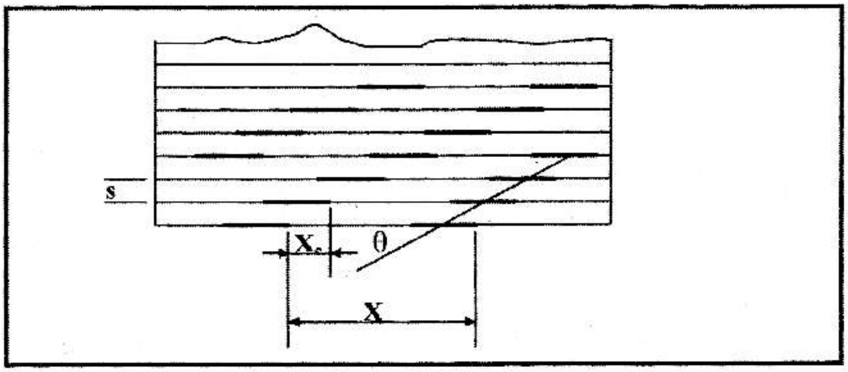

Figure (6) Chatter displacement on surface [8].

As, $cot\ \theta = X_C / s$; $X_C = NX - \pi D$, and $Xv = \pi Dn$.
Therefore,

$$v = \frac{Nn}{\{1 + (s/\pi D)\cot\vartheta\}} \quad \dots (2)$$

Where N= number of spirals
n= spindle r.p.m
s= feed mm/revolution
D=diameter mm
θ = angle of inclination.

Peters [9] has shown that there is a close correlation between vibration values and roughness values. This conclusion has been derived from the results of experiments performed on five different lathes which is indicated in table (1) below.

Table (1) Vibration – Roughness Correlation

Test No.	Vibration values	Roughness values
1	1.13	1.29
2	0.36	0.40
3	0.52	0.50
4	1.25	1.36
5	0.59	0.43

3. Turning database:

The first part of practical work in this paper is devoted to make a data base system for turning operation. This system includes the suitable cutting conditions of turning that are available in machining handbooks [10]. When running the program it asks for input values of depth of cut and material properties. The output is feed and speed values as shown in tables 2, 3, and 4. Speed values are employed in determining (rai) ratio from figure (4). The graph is translated to numerical data so as to be used in this paper within the computer program shown in figure (7).

4.Surface finish determination:

Results from previous step are used in another computer program to compute the surface finish of a part. Both feed value and (rai) ratio are input to the program in order to get ideal surface roughness and actual surface roughness according to the equation above. Tables 2, 3, and 4 give the results where three values of nose radius are supposed. Sample graph in figure (8) is plotted for the first material in each table (steel) to show the relation between nose radius and surface roughness for three feed numbers. The plot is adequately write and agrees with theory. Where the type of tooling used for any machining process can better the surface finish if care is taken. Typically the larger the radius, the better the surface finish. As a tool nose moves away from pointed toward rounded, the depth of the profile decreases, producing a better finish.

Table (2) results for (0.5) nose radius.

Item	Work Piece Material	Cutting Depth (mm)	Feed (mm)	Speed (ft/min)	Ratio, Rai	Ideal Roughness, Ri (mm)	Actual Roughness, Ra (mm)
1	Non-alloyed carbon steel, structural steel	0.5	0.1	221.4	1.445	6.25×10^{-4}	9.03×10^{-4}
		3	0.5	188.6	1.545	1.56×10^{-2}	2.41×10^{-2}
		6	1	139.4	1.745	6.25×10^{-2}	10.9×10^{-2}
2	Non-alloyed carbon steel, tool steel, cast steel	0.5	0.1	196.8	1.522	6.25×10^{-4}	9.51×10^{-4}
		3	0.5	131.2	1.79	1.5×10^{-2}	2.79×10^{-2}
		6	1	98.4	1.955	6.25×10^{-2}	12.21×10^{-2}
3	Free cutting steel	0.5	0.1	246	1.39	6.25×10^{-4}	8.68×10^{-4}
		3	0.5	20	1.522	1.562×10^{-2}	2.37×10^{-2}
		6	0.6	147.6	1.7	2.25×10^{-2}	3.82×10^{-2}
4	Gray cast iron, med, hard	0.5	0.1	118	1.567	6.25×10^{-4}	9.79×10^{-4}
		3	0.3	90.2	1.63	5.62×10^{-3}	9.16×10^{-3}
		6	0.6	62.3	1.667	2.25×10^{-2}	3.7×10^{-2}
5	Bronze, brass alloy	0.5	0.1	393.6	1.0	6.25×10^{-4}	6.25×10^{-4}
		3	0.3	328	1.22	5.6×10^{-3}	6.86×10^{-3}
		6	0.6	260	1.22	2.25×10^{-2}	2.74×10^{-2}
6	Aluminum alloy	6	0.6	>400	1.0	2.25×10^{-2}	2.25×10^{-2}
7	Duro-Plast thermoplast	3	0.2	>400	1.0	2.25×10^{-3}	2.25×10^{-3}

Table (3) results for (0.3) nose radius.

Item	Work Piece Material	Cutting Depth (mm)	Feed (mm)	Speed (ft/min)	Ratio, Rai	Ideal Roughness, Ri (mm)	Actual Roughness, Ra (mm)
1	Non-alloyed carbon steel, structural steel	0.5	0.1	221.4	1.445	1.04×10^{-3}	1.5×10^{-3}
		3	0.5	188.6	1.545	2.6×10^{-2}	4.02×10^{-2}
		6	1	139.4	1.745	1.04×10^{-1}	1.81×10^{-1}
2	Non-alloyed carbon steel, tool steel, cast steel	0.5	0.1	196.8	1.522	1.04×10^{-3}	1.58×10^{-3}
		3	0.5	131.2	1.79	2.6×10^{-2}	4.66×10^{-2}
		6	1	98.4	1.955	1.04×10^{-1}	2.03×10^{-1}
3	Free cutting steel	0.5	0.1	246	1.39	1.04×10^{-3}	1.44×10^{-3}
		3	0.5	20	1.522	2.6×10^{-2}	3.96×10^{-2}
		6	0.6	147.6	1.7	3.75×10^{-2}	6.37×10^{-2}
4	Gray cast iron, med, hard	0.5	0.1	118	1.567	1.04×10^{-3}	1.63×10^{-3}
		3	0.3	90.2	1.63	9.37×10^{-3}	1.52×10^{-2}
		6	0.6	62.3	1.667	3.75×10^{-2}	6.25×10^{-2}
5	Bronze, brass alloy	0.5	0.1	393.6	1.0	1.04×10^{-3}	1.04×10^{-3}
		3	0.3	328	1.22	9.37×10^{-3}	11.43×10^{-3}
		6	0.6	260	1.22	3.75×10^{-2}	4.57×10^{-2}
6	Aluminum alloy	6	0.6	>400	1.0	3.75×10^{-2}	3.75×10^{-2}
7	Duro-Plast thermoplast	3	0.2	>400	1.0	4.16×10^{-3}	4.16×10^{-3}

Table (4) results for (0.1) nose radius.

Item	Work Piece Material	Cutting Depth (mm)	Feed (mm)	Speed (ft/min)	Ratio, Rai	Ideal Roughness, Ri (mm)	Actual Roughness, Ra (mm)
1	Non-alloyed carbon steel, structural steel	0.5	0.1	221.4	1.445	3.1×10^{-3}	4.5×10^{-3}
		3	0.5	188.6	1.545	7.8×10^{-2}	12.01×10^{-2}
		6	1	139.4	1.745	3.1×10^{-1}	5.45×10^{-1}
2	Non-alloyed carbon steel, tool steel, cast steel	0.5	0.1	196.8	1.522	3.1×10^{-3}	4.75×10^{-3}
		3	0.5	131.2	1.79	7.8×10^{-2}	13.98×10^{-2}
		6	1	98.4	1.955	3.1×10^{-1}	6.1×10^{-1}
3	Free cutting steel	0.5	0.1	246	1.39	3.1×10^{-3}	4.34×10^{-3}
		3	0.5	20	1.522	7.8×10^{-2}	11.89×10^{-2}
		6	0.6	147.6	1.7	11.25×10^{-2}	19.12×10^{-2}
4	Gray cast iron, med, hard	0.5	0.1	118	1.567	3.1×10^{-3}	4.89×10^{-3}
		3	0.3	90.2	1.63	2.8×10^{-2}	4.58×10^{-2}
		6	0.6	62.3	1.667	11.25×10^{-2}	18.75×10^{-2}
5	Bronze, brass alloy	0.5	0.1	393.6	1.0	3.1×10^{-3}	3.12×10^{-3}
		3	0.3	328	1.22	2.81×10^{-2}	3.43×10^{-2}
		6	0.6	260	1.22	11.25×10^{-2}	13.72×10^{-2}
6	Aluminum alloy	6	0.6	>400	1.0	11.25×10^{-2}	11.25×10^{-2}
7	Duro-Plast thermoplast	3	0.2	>400	1.0	1.25×10^{-2}	1.25×10^{-2}

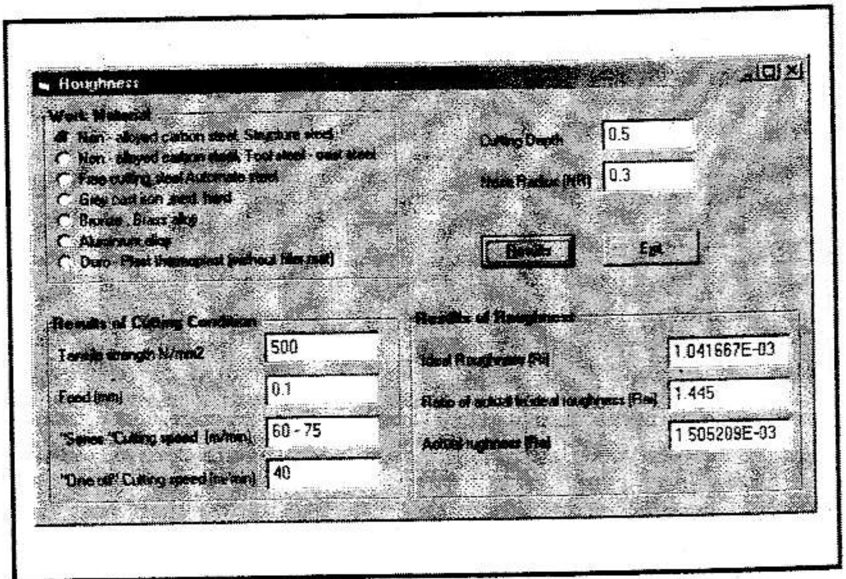

Figure (7) Turning data base system.

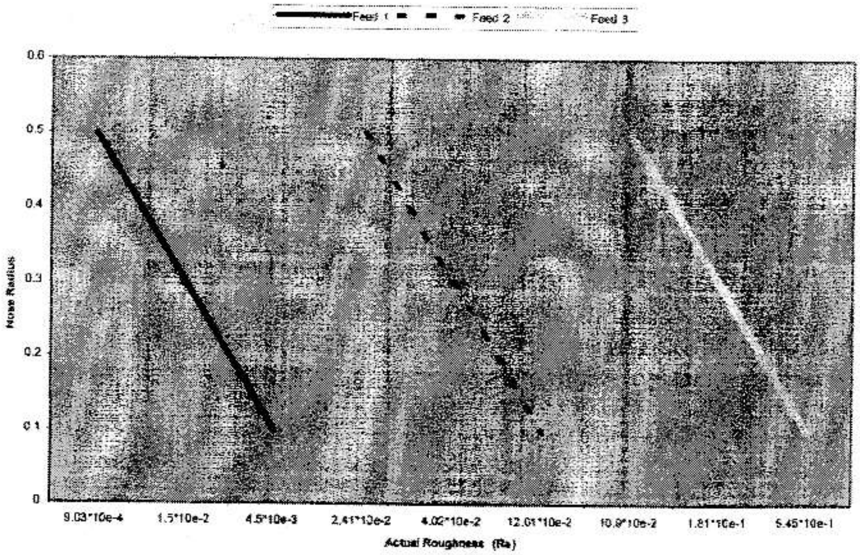

Figure (8) Sample results of the relation between tool nose radius and surface roughness for non-alloyed carbon steel at three different feed values

5. Conclusion:

The prediction of surface finish for any designed part is useful to be done before machining. That is to assure that the industrial engineer will choose the proper machine tool produce the part. Also he can decide about machine tool accuracy that is capable to achieve the specified surface roughness. This paper is conceders a good guide to perform the mentioned task. It give the engineer a computerized turning data base in order to select the suitable cutting conditions and offers to him a program to determined surface roughness automatically.

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Appendix (A)
Basic Definitions

The following paragraphs give essential definitions for related terms and concepts to the subject of this work.

a.1. Characteristics of surfaces [3]:

A microscopic view of a part's surface would reveal that it is less perfect. The features of a typical surface are illustrated in the highly magnified cross section of the surface of a metal part in figure (1-a).

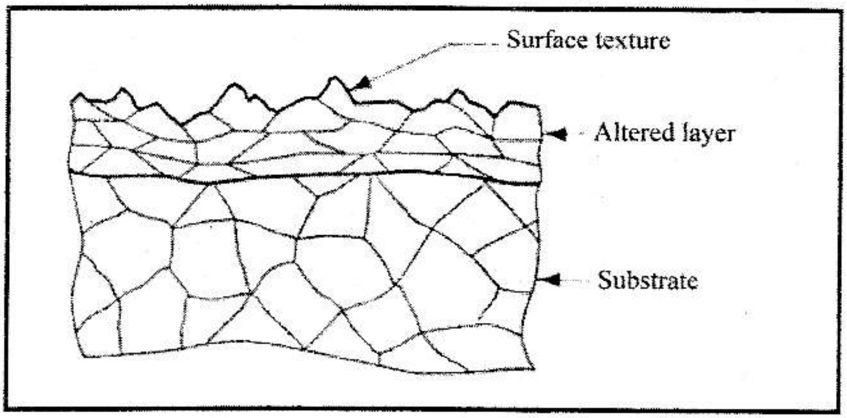


Figure (1-a) Characteristics of surfaces [3].

a.2. Surface texture [3]:

It consists of the repetitive and/or random deviations from the nominal surface of an object; it is defined by four elements: roughness, waviness, lay, and flaws. These features are illustrated in figure (2-a).

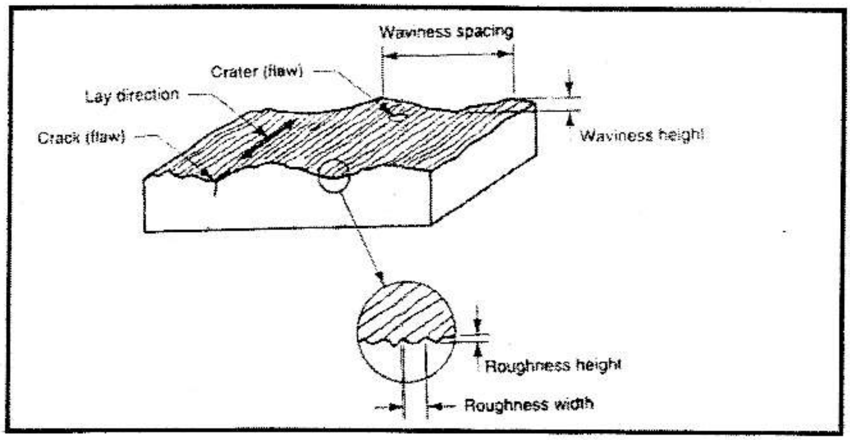
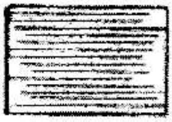
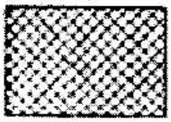
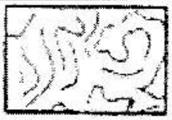
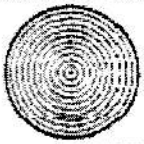
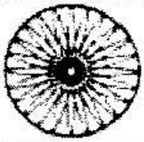


Fig. (2-a) Surface texture [3,4].

Roughness: refers to the small, finely spaced deviations from the nominal surface that are determined by the material characteristics and the process that formed the surface.

Waviness: is defined as the deviations of much larger spacing; they occur due to work deflection, vibration, heat treatment, and similar factors. Roughness is superimposed on waviness.

Lay: is the predominant direction or pattern of the surface texture. It is determined by the manufacturing method used to create the surface, usually from the action of a cutting tool. Figure (3-a) presents most of the possible lays a surface can take, together with the symbols used by a designer to specify them.

Lay symbol	Surface pattern	Description
=		Lay is parallel to line representing surface to which symbol is applied.
⊥		Lay is perpendicular to line representing surface to which symbol is applied.
×		Lay is angular in both directions to line representing surface to which symbol is applied.
M		Lay is multidirectional.
C		Lay is circular relative to center of surface to which symbol is applied.
R		Lay is approximately redial relative to the center of surface to which symbol is applied.
P		Lay is particulate, nondirectional, or protuberant.

Flaws: are irregularities that occur occasionally on the surface; these include cracks, scratches, inclusions, and similar defects in the surface. Although some of the flaws relate to surface texture, they also affect surface integrity.

a.3. Surface integrity [5]:

Surface texture alone does not completely describe a surface. There may be metallurgical or other changes in the altered layer beneath the surface that can have a significant effect on the material's mechanical properties. Surface integrity is the study and control of this subsurface layer and the changes in it that occur during processing that may influence the performance of the finished part or product.

a.4. Surface Roughness and Surface Finish [6]:

There are two terms included within the scope of surface texture. Surface Roughness is a measurable characteristic based on the roughness deviations. Surface finish is a more subjective term denoting smoothness and general quality of a surface. In popular usage, surface finish is often used as a synonym for surface roughness. The most commonly used measure of surface texture is surface roughness. With respect to figure (4-a), surface roughness can be defined as the average of the vertical deviations from the nominal surface over a specified surface length.

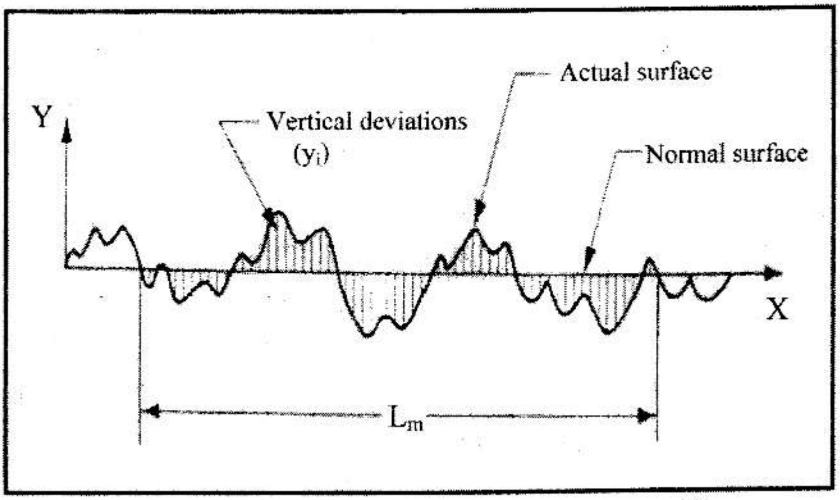


Figure (4-a) Definitions of surface roughness [6].

An arithmetic average (AA) is generally used, based on the absolute values of the deviations, and this roughness value is referred to by the name "average roughness". In equation form [6]:

$$R_a = \int_0^{L_m} \frac{|y|}{L_m} dx ......or...... R_a = \sum_{i=1}^{n} \frac{|y_i|}{n}$$

Where:

R_a = arithmetic mean value of roughness, micrometers

y = the vertical deviation from the nominal surface (absolute), micrometers

L_m = the specified distance over which the surface deviations are measured.

n = the number of deviations included L_m. And $y = y_i$

An alternative to the AA method is the "root-mean-square" (rms) average, which is the square root of the mean of the squared deviations over the measuring length.

a.5. Symbols for Surface Texture [7]:

Designers specify surface texture on an engineering drawing by means of symbols as in figure (5-a).

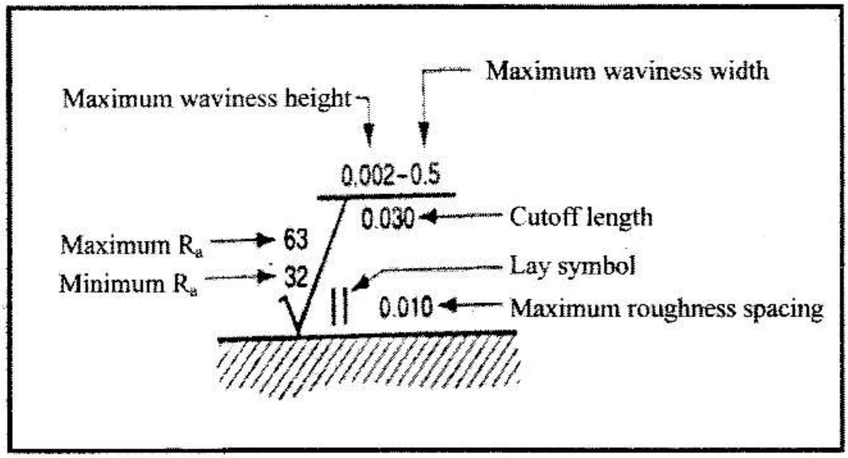


Figure (5-a) Design symbols for surface texture [7].