Fractal Simulation on Machined Surfaces

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Abstract: The characterization of machined surfaces is a very important activity in any manufacturing process. There are instruments that characterize the surface and its roughness using scale dependent statistical parameters such as variation of height, slope and its curvature. However it has been found that these parameters are strongly dependent on the resolution of roughness measuring instrument. Consequently, instruments with different resolutions and scan lengths yield different values of these statistical parameters for the same surface. The conventional methods of characterization are therefore fraught with inconsistencies. The underlying problem is that although rough surfaces contain roughness at a large number of length scales, the characterization parameters depend only on a few particular length scales, such as the instrument resolution or the sampling length. A logical solution to this problem is to use scale-invariant parameters to characterize rough surfaces. Fractal geometry is a potential tool for characterizing this type of random patterns observed in nature and hence its suitability for surface finish measurements and studying the effect of operating conditions and tool geometry in the finish obtained on a machined surface and simulate the pattern using of fractals. Thus this study can be extended to predict the surface pattern when machining conditions.

***Index Terms* - Turning, Surface Roughness, Fractals, Feed and Cutting speed**

I. INTRODUCTION

Surface roughness is commonly encountered problem in machined surfaces. It is defined as finer irregularities of surface texture, which results from the inherent action of the production process. Consequently, surface roughness has a great influence on product quality, and the part functional properties such as lubricant retentivity, void volume, load bearing area, and frictional properties. Furthermore a good quality machined surface significantly improves fatigue strength, corrosion resistance, and creep life. Surface roughness is consisting of a multitude of apparently random peaks and valleys. When two rough surfaces are brought to be in contact, it is occurred in smaller area, which is called the real area of contact. This area is not only a function of the surface topography but also on the study of interfacial phenomena, such as friction and wears[3]

The form of each roughness profile after finish turning strictly depends on the shape of the tool nose, cutting parameters and mechanical properties of the workpiece material used. It is obviously known that turning generates a broad spectrum of surface profiles and their features change from periodic to aperiodic.

The objective of the present work is to develop the fractal models can develop from the computer programs (“C” language). The fractal geometry approach will be utilized for characterizing each machined surface by two scale-independent parameters “D” and “G”. These parameters are used for simulating the measured surface roughness profile by using Weierstrass-Mandelbrot fractal function.

II. Fractal geometry

Almost all geometric forms used for building manmade objects belong to the Euclidean geometry. They are comprised of lines, planes, rectangular volumes, an integer dimension, 1, 2, or 3. This concept can be described both intuitively and mathematically.

A more mathematical description of dimension is based on how the “size” of an object as the linear dimension increases. In one dimension, consider a line segment. If the linear dimension of the line segment is doubled then obviously the length of the line is doubled. In two dimension, if the linear dimensions of the rectangle for example are doubled then the characteristic size, the area, increases by a factor of 4.This relationship between dimension D, linear scaling L and the resulting increases in size S can be generalized and written as,[15]

$$S = L^{D} \qquad (1)$$

Mandelbrot (1967) founded fractal geometry when he showed that for decreasing unit of measurement, the length of a natural coastline does not converge but instead increases monotonically. On plotting the length L as a function of the unit measurement m on a log-log plot, he found numerous applications in characterizing and describing disordered phenomena in science and engineering. In order to understand the relevance of this new field of mathematics to rough surfaces, it is necessary to have a formal background of fractal geometry. The profile of a rough surface Z(x), typically obtained from stylus measurements, is assumed to be continuous even at small atomic scales. Although the assumption breaks down at atomic scales, for engineering studies the continuum is assumed to exist down to the limit of zero length scale. Therefore, since even finer levels of detail emerge under repeated magnification, the tangent at any point cannot be defined. Thus the curve has the mathematical properties of being continuous everywhere but non-differentiable at all points. Surface profiles are also known to be self-affine in roughness structure. The Weirstrass-Mandelbrot fractal function satisfies the property of continuity, non- differentiability and self-affinity is therefore used to simulate and characterize such profiles.[3-6]

The Weirstrass-Mandelbrot (W-M) fractal function is,

$$\mathbf{Z(x) = G^{D-1}\ {}_{n=n1}\sum^{\alpha} \cos(2\pi\, \gamma^{n}\, x)/\gamma^{(2-d)n}} \qquad \mathbf{;\ 1<d<2,\ \gamma>1.5} \qquad (2)$$

Where,

G is a scaling constant,
D is the fractal dimension,
n_1 is the lower cut-off frequency,
γ is the spectral frequency corresponding to 1.5 in a Brownian process,
Z(x) is the roughness function.

2.1 CONCEPT OF FRACTALS

The fractal dimension as a concept is used to bestow some order in a system, which exists in a state of chaos. The concept allows us to look into nature through a whole new perspective to understand interpret and represent images efficiently. Fractals are used for modeling non-linear systems. The fractal offers a way of seeing order and pattern where formerly the random and the erratic had been observed. When we are interested in the structural forms, which a chaotic process leaves in its wake, then we use the terminology of fractal geometry, which is really the geometry whose structure are gives order to chaos [12-14].

In some sense, fractal geometry is first and foremost a new language used to describe, model and analyze the complex forms found in nature. However, while the elements of traditional language the familiar Euclidean geometry are basic visible forms such as lines, circles and shapes, those of the new language do not lend themselves to direct observation. They are namely algorithms, which can be transferred into shapes and structures only with the help of computers. Once this language has been mastered, we can describe the form of surface roughness as easily and precisely as an architect can describe a house using the language of traditional geometry.

We develop fractal models and methodology for data taking the form of surfaces. An advantage of fractal analysis of fractals is that it partitions roughness characteristics of surface into a scale –free component

2.2 FRACTAL CHARACTERIZATION

Most rough surfaces including machining ones and corresponding profiles are multiscale in nature. This multiscale property is better expressed as self-similarity or self-affinity in fractal geometry implying that when the surface or the profile is magnified more and more details emerge and the magnified image is statistically similar to the original topography. Statistical self-similarity means that the probability distribution of a small part of a profile will be congruent with the probability distribution of the whole profile if the small part is magnified equally in all directions[5]. However, self-affinity implies unequal scaling in different directions. The qualitative description of statistical self-affinity for a surface profile is shown in Fig. 1. The property of self-affinity can be characterized by the profile fractal dimension D ($1< D <2$).

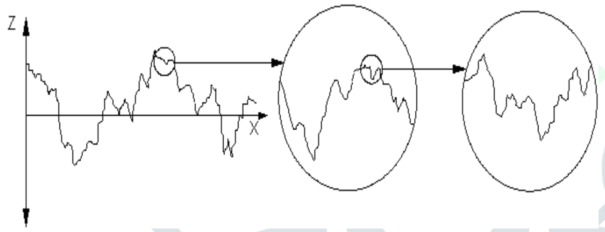

Fig 2.1 Qualitative description of statistical self-affinity for surface profile

In order understand the non integer dimension of fractal objects, it is important to review some forms of classical fractals. The von Koch curve shown in the fig is constructed by removing the middle third of line segment of a unit length and replacing it by two segments of equal lengths. In subsequent stages each segment is broken into three parts and the middle portion of each segment is replaced by two parts. If this process is repeated infinite times the Koch curve is obtained. The fractal dimension "D" of the Koch curve can be calculated from[2].

$$D = \frac{\text{Log } N}{\text{Log } (1/m)} \quad (3)$$

Where N is the number of equal parts (N=4), and m is the magnification factor value (m=3). Fractal objects have the following properties, first they are continuous but not differentiable anywhere. Secondly the curve is exactly self-similar. Thirdly, although the curve contains roughness at a large number of scales, the dimension of the curve remains constant at all scales. This scale invariance of the dimension is an important property, which will be utilized to characterize rough surfaces. However, because rough surfaces are self-affine objects could not be used for characterizing the fractal dimension of rough surfaces.

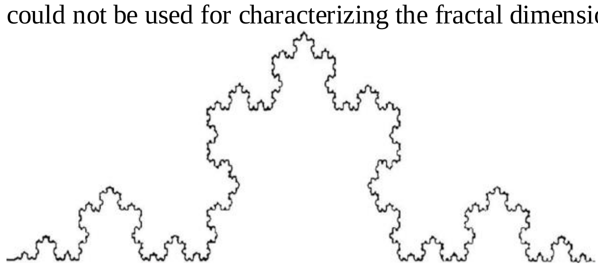

Fig 2.2 construction of the Von Koch curve at different iterations

III. EXPERIMENTAL WORK

The experimental work is planned to obtain the input-output patterns for developing the Fractal models that can simulate the machining process in plain turning operations. The input measured surface profiles to develop the Fractal Models were; the cutting conditions (speed, feed, depth of cut, nose radius), and the machine tool vibrations. The corresponding output patterns are the fractal parameters of the measured profiles of all machined profiles of all machined specimens.

Table 1 Cutting parameters employed for tools

Tool	High speed steel				Brazed carbide				Coated carbide			
Feed (mm/min)	0.4	1	2	2.8	0.4	1	2	2.8	0.4	1	2	2.8
Nose radius (mm)	0.4				0.5				1			
Depth of cut(mm)	0.5				0.5				0.5			
Cutting speed (m/min)	0.56				0.56				0.56			
Machine	PSG A 100				PSG A 100				PSG A 100			
Operation	Turning				Turning				Turning			
Work piece size	30 X 100				30 X 100				30 X 100			
Material	Mild steel				Mild steel				Mild steel			

3.1 PROFILE MEASUREMENT

The registration of surface profiles and measurement of surface roughness parameters were performed by means of profilometer with the assistance of PC software. The sample lengths were set to 50 and 40mm respectively. For every sample, 4 individual measurements were carried out and based on these data; the mean values of roughness parameters were calculated. Surface roughness was analyzed using horizontal and vertical roughness parameters as well as fractal dimension. And also the measured profile is compared to the fractal profiles.

IV. RESULTS AND DISCUSSIONS

4.1 DISCUSSION ON PROFILES SIMULATED USING FRACTALS

The profiles are simulated by three methods namely, Brownian motion, Koch curve and W-M function. The profiles are developed for a single operation condition. The same method can be extended to other cases also. The profiles developed using Brownian motion and Koch curves Fig2.1 and Fig2.2 are not very elegant solutions. It is difficult to include randomness in the profiles they work on a systematic algorithm.

In the W-M function, parameters from the actual profile can be included. This parameter is bix-counting dimension of the profile generated by operating the program developed on the profile. The results obtained are shown in fig4.1 shows the actual profile (HSS tool) and simulated profile by W-M function. The surface roughness parameters R_a/R_{max} are calculated by a program. It is evident that R_a/R_{max} values tally closely. The use of box counting dimension proves that the simulated profiles closely tally with the actual profiles. The profiles are also geometrically similar. Similarly fig4.2 is represent the profiles obtained with brazed carbide tool, and ground surface in fig4.3

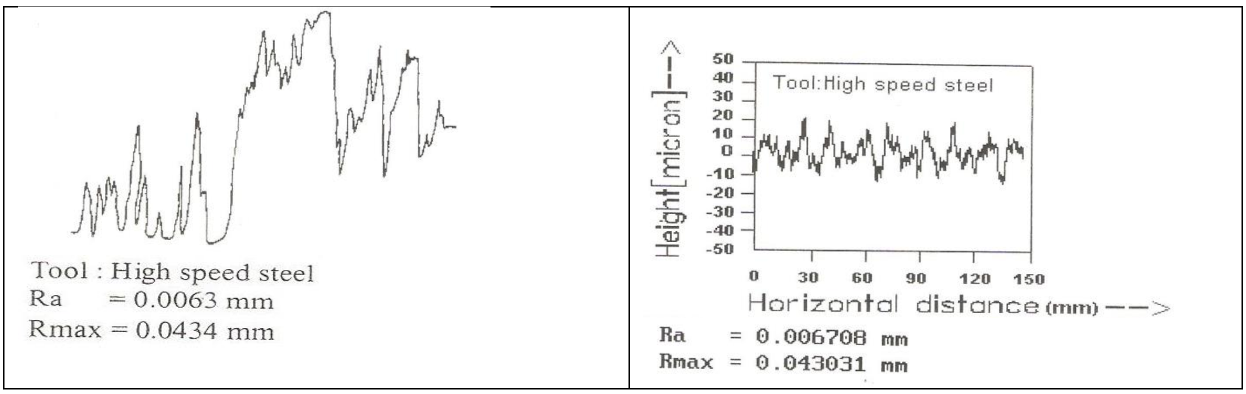

Fig 4.1 Measured and simulated Profiles for HSS tool

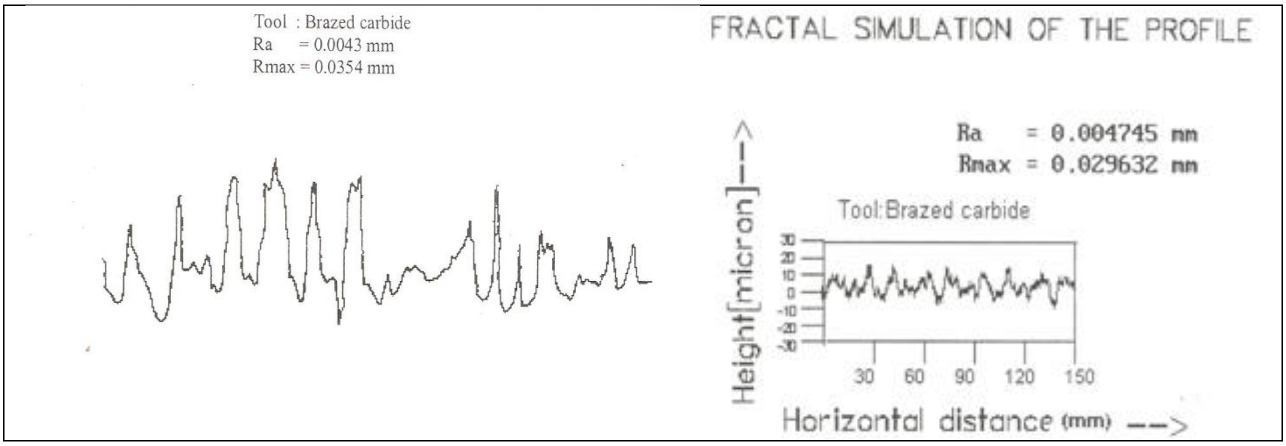

Fig 4.2 Measured and simulated Profiles for Brazed carbide tool

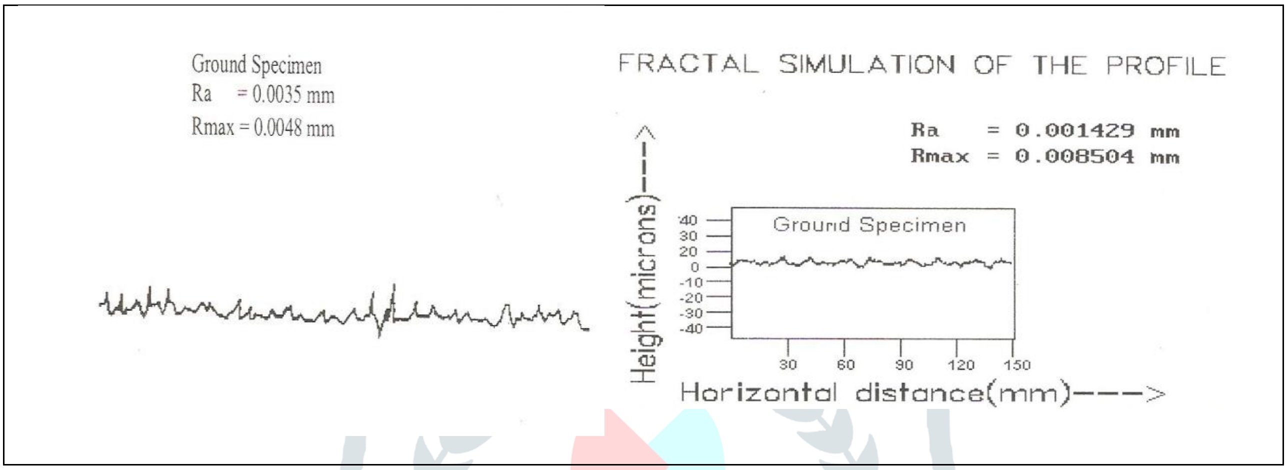

Fig 4.3 Measured and simulated Profiles for grounded specimen

V. CONCLUSION

In this work, the fractals are created using C program and they utilized for simulating the machined surface. From that, the appearance of actual surface shown so that the user can have an idea about the surface.

1. Analytical models are limited in applications by their complex nature and randomness in the machining operations. Random nature arises from material in homogeneity, tool orientation, and excitation of machine tool and temperature variations. Such situations can handle by fractals especially using the W-M function. The actual profiles when processed using a program can simulate a theoretical and calculate the parameters of interest.
2. The fractal geometry approach was successfully used in characterizing the machined surfaces by two parameters "D" and "G", which are unique and scale – invariant.

VI. FUTURE WORK

This work can further extended to determine the relation between fractal dimension and machining conditions. From that the fractal parameters can be used to the W-M fractal function in order to generate an artificially fractal predicted profiles. These models can help to manufactures to know the appropriate cutting conditions to achieve the required surface roughness profiles on the manufacturing parts and the tribological performance.

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