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Factors influencing the generation of a machined surface. Application to turned pieces

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ABSTRACT

The final shape of the surface of a workpiece is determined by three main groups of factors: (i) the type of machining, the cutting parameters and the geometry of the tool; (ii) the vibration of the tool; (iii) a whole range of influences or factors such as the fracturing of material, deposits and/or adhesions of material, elastic recoveries, plastic deformations or tool wear. In this work, a procedure is developed to obtain three different surfaces: the real surface; the surface generated by the tool through its geometry, its vibration, and the cutting parameters; and the surface generated by the rest of the phenomena involved in machining.

This procedure enables in depth to be carried out on the relations between the irregularities of the surface of the workpiece and the various factors that generate these irregularities. Not only will it be possible to improve the reliability of the formulations that relate parameters of surface roughness with vibration and cutting parameters, but it will also be possible to study, in greater detail, the rest of the phenomena that, together with the vibration, influence the final result of the machining.

1. Introduction

The surface quality requirements constitute a common factor in manufacturing processes. The obtained surface is primarily determined by the process of machining. However, once the type of process has been chosen, the vibration of the tool and machining parameters become essential factors. Other factors that affect the surface may include phenomena such as fractures, adhesions or material deposits, elastic and plastic deformations, and aspects that affect the tool, such as wear. Surface quality plays a vital role in the field of manufacturing engineering: among other factors it affects the functionality of the parts, their manufacturing cost, their maintenance cost, the service life of the piece and the fatigue strength of the material. It encompasses the macrogeometry, the microgeometry and the physical and chemical properties. Exact knowledge of the surface obtained by the manufacturing process enables the degree of adaptation to be ascertained between the workpiece and the use to which it will assigned, which can reduce process times and improve competitiveness.

The first step to establish the surface quality is to measure the surface of the workpiece with an appropriate instrument. The first devices for measurement of workpiece surfaces appeared in the 1930s. However, the major boom in their development occurred in the 1960s. The next impulse was produced in the 1990s through advances in microelectronics and data processing techniques.

A first classification of these devices can be made in accordance with whether contact with the surface of the workpiece is necessary. This group includes devices whose measurement is performed by means of a stylus. Their main advantages include extensive experience in their use and the existence of regulations governing their use. Their main drawbacks are: low reading speed from the surface, the need for measurement in the absence of any vibration, and the disadvantages of contact between stylus and surface, for example, the effect called *stylus convolution*. This effect arises since the dimension of the stylus incorporates a smoothing of the surface due to the size of the tip. Any wavelength shorter than the dimension of the tip is effectively removed from the frequency spectrum. Another effect is the so-called *tip flight*. The tip of the stylus can be separated from the surface of the workpiece by an excessive reading speed, and by the presence of steep slopes and/or angles. Tian et al. (2009) define a critical scanning speed to avoid this effect. Another reading error can be generated by the point of contact between the stylus and the surface whereby the stylus fails to touch the workpiece with its lower end but instead makes contact via a lateral

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Nomenclature

a	acceleration (m/s^2)
R	Value of the accelerometer reading (V or mV)
k	Constant; 1000 for readings in V, and 1 for readings in mV
S	sensitivity (mV/g)
G	gain
F	Fourier fast transform
jw	vector of frequencies of the signal f
fs	sampling frequency of the signal f
fc	*cut-off* frequency
n	Number of readings of the signal f
M	Length or order of an FIR filter
B_k	element k of the coefficient of a filter

point. To avoid this effect Wang and Whitehouse (1995) report an approach to the reconstruction of the surface by means of Neural Networks (NN). Finally, all data acquisition systems introduce a small distortion in the reported data. This background noise should be removed with a suitable filter.

The group of devices that have no contact with the piece encompasses the devices that are based on optical microscopy and electron microscopy. Optical instruments do not need any contact with the workpiece, they have a greater ability to read a variety of surfaces, they have a faster reading speed, and they generate a high content of information. However, their drawbacks include: dependence on certain properties (such as the reflection of light), and reading errors originating from false reflections. Electron microscopy-based techniques can be used for the study of smaller surfaces using, for example, scanning electron microscopes (SEM), and scanning probe microscopes (SPM). Scanning probe microscopes can also differ, as shown by the scanning tunnelling microscope (STM), for conductive materials, and the atomic force microscope (AFM) for conductive, and non-conductive materials. Other techniques, such as those presented by Liao et al. (2010) with the use of holography laser, by Natarajan et al. (2012) with the analysis using an FFT-2D of the images obtained by a camera, or by Xiao et al. (2013) and the use of scanning deflectometry with rotation stage, remain in the current field of research.

Once the surface of the workpiece is measured, it is necessary to establish a set of parameters which characterize the surface. These parameters are established on the basis of the distance of each of the points reported on a line or plane medium. Parameters related to 2D and 3D profiles are collected in various national and international standards. However, there are many studies that question the suitability of these parameters. Dong et al. (1992, 1994) show the surface is not adequately described by them, there is no relationship with these parameters and the possible uses of the workpiece, there is great variability depending on the chosen area, and there is a lack of concordance between the different standards. The parameters associated to profiles change drastically depending on the direction of measurement, and even within the same direction, depending on the chosen alignment. Variations of up to 50% can be registered.

As an alternative to the description of the surface through statistical parameters, two procedures for the simulation of surfaces are used to improve the knowledge of this surface. In the first procedure, machining parameters, the tool geometry, and its vibration are employed to attain the theoretical surface that the tool would leave on the workpiece. In the second procedure, surfaces that do not accurately match the real surface are obtained. However, these surfaces share some statistical parameters. The most commonly used parameters are the skewness and the kurtosis.

In the first group, Kim et al. (2002) propose a simulation of a turning perpendicular to the longitudinal axis of the piece. This type is found more commonly than turning parallel to the longitudinal axis such as that proposed by Boryczko (2011). It is more common to use exclusively the main frequency of vibration over a broad set of these frequencies. The common practice is to use only one of the three components of the acceleration: that perpendicular to the surface. On extremely rare occasions, non-circular geometry at the end of the tool is used, for example, the elliptical form such as that proposed by Qu and Shih (2003).

In the second group, fast Fourier transform (FFT) is the most widely used technique when real surfaces are studied. However, it is unusual to use FFT in the simulation of profiles. One option would be to study the complete frequency spectrum of real profiles through the use of NN. This spectrum of frequencies would be obtained from a set of profiles made with various cutting parameters. Once the NN is trained, the probable frequency spectrum would be obtained for a particular combination of feed, depth of cut and speed. As well, through the inverse of the FFT, the profile could be obtained. This technique is used by Lu et al. (2010). Other option is introduced by Chui et al. (2013). They generate a surface with circular cosine-exponent autocorrelation function (ACF) based on FFT. However, for the modelling or simulation of surfaces, regressive analysis are normally used, such us, autoregressive moving average models (ARMA). The goal is not finding surfaces that reproduce the real surfaces, but to find surfaces that share certain preset statistical parameters, normally the skewness and the kurtosis. There are several variants: Hong and Ehmann (1995) use the mixture of differential equations and linear autoregressive models; Wu (2000) uses the autocorrelation function and the spectral power density of a set of longitudinal profiles; Wu (2004), the simultaneous use of FFT and the Johnson translator system; Uchidate et al. (2011), the generation of 3D random surfaces via Autoregressive modelling; or Luo et al. (2013), the Pearson translator system.

Neither of the two alternatives (statistical parameters or simulations) explains the origin of alterations of the surface. A first attempt in this direction would be to separate the surface profile irregularity into classifications of roughness, waviness and shape components along the measured length. The usual procedure is the analysis through FFT and in some specific cases, as demonstrated Yuan et al. (2005), through the wavelet transform (WT). The slender workpieces possess special features added to the previous classification. Slender workpieces, as well as microgeometric deviations, experience macrogeometric deviations. According to Rahman et al. (2013), these macrogeometric deviations are affected by cutting parameters, the rigidity of the workpiece, and the rigidity of the machine.

There are other factors that alter the surface of the workpiece. Examples include the elastic recovery appearing in the piece after the passage of the tool, and the plastic deformations. Another effect is produced when very small cutting depth values are used. Liu and Melkote (2006) analyze this case. The tool rubs the surface of the workpiece and deforms the material but there is no cutting of the material. This material moves to the sides of the tool. This phenomenon is known as plastic side flow. Cheung and Lee (2001) show a similar situation in the case of very small feeds. All these phenomena are greatly influenced by the isotropy and anisotropy of the material and the crystallographic orientation.

The evolution in the wear of the tool is another aspect which alters the surface of the workpiece. Datta et al. (2013) formulate a progress in the techniques of analysis by image allows us to delve into the on-line control of tool wear and into its influence on the surface. One aspect that modifies the wear experienced by the tool is the type of cutting. Sreejith (2008) studies the effect of dry cutting, with minimum quantity of lubricant, and under flooded coolant conditions with respect to the cutting forces, surface