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Portability study of surface roughness models in milling

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Abstract

In spite of the huge number of research studies around empirical surface roughness models, there is no methodology applied in industry to model and adapt accurately the surface roughness in machining operations. Any change of the process with respect to the initial conditions where the experiments were conducted implies an additional estimation error which difficulties the use of the model in the current process. This paper studies the portability of empirical models for surface roughness prediction in face milling operations. As portability problem, we refer to how a proper surface roughness model obtained from theoretical/experimental data under specific conditions decreases its performance when it is applied in a different environment. The work gives some guidance for future design of more robust surface roughness models.

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Keywords: Machining; Design of Experiments; Surface Roughness; Model Error; Model Portability.

1. Introduction

In machining processes, the surface roughness of the machined parts is one of the most significant product quality characteristic. It is a key factor in evaluating the quality of a product and has a great importance on manufacturing costs and functional behavior of the machined parts in exploitation such as assemblability. The surface roughness also influences the tribological characteristics, the fatigue strength, the corrosion resistance and the aesthetic appearance of the machined parts. For instance, in aerospace industry high pressure hydraulic systems and fuel

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injections systems in particular require high quality surfaces and precisely defined features, such as o-ring grooves in order to maintain system integrity [1]. Therefore, the lack of good surface quality fails to satisfy one of the most important technical requirements for mechanical products, while extremely high level of surface quality causes higher production costs and lower overall productivity of cutting operations [2].

Surface quality is directly related to cutting conditions and thus, it is of great importance to quantify the relationship between surface roughness and cutting parameters such as cutting speed, feed rate and depth of cut. However, surface roughness is not only influenced by these cutting parameters but also by a large number of factors such as cutting-tool wear, material characteristics, tool geometry, stability and stiffness of the machine tool - cutting tool - workpiece system, built-up edge, cutting fluid, etc [3] .

Surface roughness is composed of two components: the first is the ideal or geometric finish, which is defined as the finish that would result from the geometry and kinematic motions of the tool and, the second is the natural (or inherent) finish, which results from tool wear, vibration and dynamics of the cutting process, work material effects such as residual stresses, inhomogeneity, built-up edge formation (BUE), and rupture at low cutting speeds. The ideal roughness can be calculated from the feed rate per tooth, the tool nose radius, and the tool lead angle and it is usually the predominant component of the finish in operations in which tool wear and cutting forces are low, for example, when machining aluminum alloys with diamond tools. Unlike the ideal finish, the natural component is difficult to predict in general and it is often the predominant component of the finish when machining steels and other hard materials with carbide tooling, or when machining inhomogeneous materials such as cast iron or powder metals [3]. Therefore, the ideal surface quality is not generally achieved even in the ideal cutting conditions and the prediction of surface roughness is usually not reliable in industrial practices.

A large number of research studies have tried to model surface roughness according to these factors in order to predict surface roughness and optimize cutting parameters. The effect of axial and radial runout and its modelisation was described in Franco et al. [4] and later they expanded their study to analyze the back cutting effect on surface roughness [5]. The effect of machine-tool rigidity on the surface roughness generation was also investigated in [6] where it was observed that a good surface roughness for slender tools can be achieved provided the tooth passing frequency used in the milling process (and its harmonics) does not produce high frequency response values.

Tool wear is probably the most common factor studied when surface roughness is critical. According to [7], higher roughness values are observed especially at the very early stage where the inserts are rather new. Afterwards due to the friction these inserts become wear and the radiuses of tool edges increases, therefore, the heights of feed marks decreases. However, in most operations when the tool wear value exceeds certain value, surface roughness tends to increase considerably [3].

The effect of coating layers and tool material on surface roughness was also studied in [8,9]. Nalbant et al. [8] analysed the effects of uncoated, PVD- and CVD-coated cemented carbide inserts and cutting parameters on surface roughness in CNC turning. In the experimentation it was observed that increasing the number of coating layers decreases the friction coefficient and parallely decreases the average surface roughness value of the workpiece. In [9] two types of inserts with the same geometry and substrate but different coating layers were used to evaluate the effects of two coating layers as well as the cutting parameters onto the surface roughness. In this research the authors found out that surface roughness values were significant lower when employing PVD coated (TiAlN) inserts instead of CVD coated (TiCN+Al2O3+TiN).

It is also well-known that the cutting-tool geometry such as lead angle, relief angle, rake angle, nose radius, tool facet or wiper geometry are well-known parameters that may influence on surface roughness generation as it is shown in several technical data [10,11]. Some of these parameters have been also considered by researchers in order to analyze and model surface roughness under different cutting conditions. For instance, Grzesik [12] studied the effect of different shaped ceramic tools on surface roughness in hard turning, and Ozel et al. [13] also analysed the cutting edge geometry (honed edges) effect on surface roughness.

The cutting parameters and their effect on surface roughness is also well-known and it is reported in machining handbooks and technical data from vendors [10,11]. In [9] it is shown how increasing cutting speed improves surface quality since it reduces cutting forces together with the effect on natural frequency and vibration. Furthermore, too low cutting speeds may produce material adhesion at the inserts (built up edge) increasing surface quality [14]. A critical aspect in cutting parameters is the feed rate and its relation on the minimum undeformed chip thickness. Surface profile presents more fluctuations as feed decreases, which can be explained by the influence of the