Multivariate Optimization of the Cutting Parameters when Turning Slender Components

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ABSTRACT

The geometric features of the work piece and the cutting parameters considerably affect the quality of a finished part subjected to any machining operation owing to the imposed elastic and plastic deformations, especially when slender components are produced. This work is focused on the influence of the work piece slenderness ratio and cutting parameters on the quality of the machined part, assessed in terms of surface roughness and both geometric (run-out) and dimensional (diameter) deviations. Turning tests with coated tungsten carbide tools were performed using AISI 1045 medium carbon steel as work material. Differently from the published literature, a statistical analysis based on the multivariate one-way analysis of variance (MANOVA) was applied to the data obtained using a Box-Behnken experimental design. In order to identify the combination of parameters (slenderness ratio, cutting speed, feed rate and depth of cut) levels which simultaneously optimize the responses of interest (surface roughness, run-out and diameter deviation), a multivariate optimization method based on principal component analysis (PCA) and generalized reduced gradient (GRG) was employed.

Keywords: Dimensional Deviation, Roughness, Roundness, Slenderness Ratio, Turning

1. INTRODUCTION

The selection of the most appropriate machine tool for the manufacture of a determined component depends mainly on the size and shape of the part and on the power required to remove material. For instance, turning may be carried out on parts ranging in size from those used in watches to propeller shafts as long as 25 m, in addition to aluminium parts over 3 m in diameter (ASM, 1995).
Turning of long and slender components, such as automotive spindles, axles and drive shafts, is usually undertaken with either a steady rest (clamped directly on the ways of the machine tool) or a follow rest (clamped on the carriage) used to support the part during cutting, thus avoiding deflection due to machining forces. Nevertheless, the majority of research works reported is conducted without the above mentioned devices in order to maximize workpiece deflection and simplify modelling.

Surface roughness and dimensional deviation (diameter error) are the principal concern with regard to the quality of turned components; whereas geometric deviations are seldom taken into account. This work addresses this subject matter from a different point of view, i.e., it presents a statistical analysis on the influence of the slenderness ratio and machining parameters (cutting speed, feed rate and depth of cut) on the quality of medium carbon steel shafts subject to turning with coated carbide inserts. In addition to surface roughness and run-out deviation, the quality of the machined component is assessed in terms of dimensional deviation. Finally, the influence of the measuring position is also considered.

2. LITERATURE REVIEW

The influence of the follow rest and cutting parameters on the deviations induced after turning slender bars was investigated by Jianliang and Rongdi (2006), who stated that workpiece deflection is the principal factor affecting dimensional deviations of shafts with high slenderness ratios, whereas deflections of the workpiece clamping system and tool holder are the major source of dimensional errors induced in bulky shafts, therefore, when turning slender bars, the deflection of the tool holder can be neglected. Not surprisingly, the experimental work indicated that the smallest deflection was obtained near the chuck, where the workpiece is firmly held by the jaws, followed by the tailstock. Highest deflection was recorded in the region between the centre of the workpiece and the tailstock. Finally, the dimensional deviation (diameter error) increased drastically with feed rate and depth of cut owing to the machining forces elevation and decreased slightly as cutting speed was increased.

According to Hinduja et al. (2003), the principal sources of geometric errors on machined components are the machine tool, cutting force induced errors, thermal errors and tool wear. These authors used a combination of linear and rotational springs to model force-induced errors when turning. The experimental validation indicated that the magnitudes of the force-induced and thermal errors are comparable.

Liu and Venuvinod (1999) report that error compensation strategies are not widely employed in the shop floor owing to fact that they require a large amount of data from each machine tool using specific equipment (such as laser interferometers) while the machine tool is idle. An error compensation strategy based on the dimensional assessment of previously machined components is proposed and the authors claim that a maximum diameter error of 5 μm is obtained, in contrast to 70 μm when the program is not used.

A comprehensive investigation undertaken by Rivin (2000) suggests that with the recent advances on both tool materials technology and machine tools design, the tooling structure has become the weakest link in the machining system, leading to excessive deflection and low accuracy, in addition to forced and self-induced vibrations, which impair the machined surface finish. According to Quintana and Ciurana (2011), regenerative chatter is regarded as the most frequent form of self-excited vibration. It promotes variations in chip thickness and cutting force, thus resulting in a wavy machined surface. A method for suppressing regenerative chatter and its deleterious consequences to the quality of the machined part is proposed by Ma et al. (2011) by means of ultrasonic elliptical vibration of the cutting tool. The authors claim that using this technique the tool is periodically separated from the chip and workpiece and that the direction of the frictional force is reversed.
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