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High Speed Milling of Hardened Steel Convex Surface

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Abstract

This paper presents a contribution to hardened tool steel milling studies. High speed milling is largely utilized to substitute some EDM and polishing operations, mainly in hardened tool steel finishing. Tool path strategy may either enable good surface finish or contributes to generate high roughness values and poor surface finish. Tool inclination (angle between tool axis and workpiece surface) influences the system response to vibration. In this work, several milling experiments were performed in a circular convex AISI D6 hardened steel workpiece, having as input variables feed direction (upward and downward the circle) and tilt angle (tool inclination). The main results indicate that upward tool path presented mostly high roughness values which were also influenced by tool inclination. Downward tool path presented low roughness values and was less influenced by tool inclination. Upward tool path and positive tool inclination should be avoided because they presented roughness values incompatible to EDM process substitution.

Keywords: High speed milling, Hardened steel, Tool path, High speed machining, Cutting force, Vibration

1 Introduction

High speed milling of hardened materials enables the use of milling instead of EDM and polishing processes in finish machining of molds and dies, when the substitution is possible, mainly in complex surfaces in four or five axis machining centers (Altintas et al, 2014; Arnone, 1998; Childs et al, 2004). In this process, the contact angle between cutting edge and the material, the radial depth and the axial depth of cut are low and spindle rotation is high, which leads to high values of cutting speed. Chip removal rate in high speed milling is low compared to conventional milling, but it is higher than EDM chip removal rate. Low chip thickness increases the specific cutting force (K_s) and should be avoided by the use of the highest possible feed rate, which reduces time production. On the other hand, high values of feed per tooth increases workpiece surface roughness (Diniz et al, 2010; Sandvik, 2015a; Sandvik, 2015b; Sandvik, 2000; Souza et al, 2014).

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Vibration in high speed milling process influences workpiece surface roughness and tool life and must be controlled for operator, machine and process safety. However, this process is very prone to tool vibration, since the tool, several times, must be long, to cut deep cavities of the molds and dies, and with small diameter, in order to copy the typical small diameters of the corners of these components. Among the several ways to reduce vibration in this process, as the use of sensors, analytical and finite elements models, lobe diagrams construction and analysis, it can be cited the choice of different values of cutting parameters and cutting strategies. In milling process, vibration occurs due to the chip formation and to the variation of cutting force caused the chip thickness variation. Milling process might also present chatter or self-excited vibration. Chatter may produce very poor surface finish in workpiece, reduced tool life, tool damage and breakage, damage of the machining center structure and risks to operator security. Chatter occurrence in conventional milling process is rare due to the low spindle speed used, but in HSM it is important, because high spindle speed is able to reach frequencies similar to those where chatter occurs (Altintas et al, 2014; Arnone, 1998; Beak and Fox-Rabinovich, 2014; Koshy et al, 2002; Lacalle and Lamikiz, 2009; Sandvik, 2015a; Sandvik; 2015b; Sandvik, 2000; Urbanski et al, 2000).

Cutting strategies are important factors to reduce vibration and workpiece surface roughness and to decrease production time. To choose a cutting strategy means to choose the tool path direction and trajectroy and tool axis inclination related to the milled surface. The choice of a suitable tool path strategy is able to reduce tool vibration and to produce good surface finish, suitable to be used in dies and moulds, resulting in lower process costs (Souza et al, 2014). The angles which define tool inclination are tilt angle and lead angle. Tilt angle is the angle between cross feed direction and tool axis and lead angle is the angle between feed direction and tool axis (Ozturk et al, 2009; Sandvik, 2015a; Sandvik, 2015b; Sandvik, 2000).

Souza et al (2014) analyzed tool path strategies for convex semi sphere milling made of AISI P20. The utilized tool was a 6 mm diameter ball nose coated with TiAlN carbide mill. The authors tested five spiral strategies: i) radial contour from the material base to top; ii) radial contour from the top to the material base; iii) parallel contour from the material base to the top; iv) parallel contour from the top to the material base; v) the tool followed the convex semi-circle, with parallel passes. They concluded that the real process time was longer than estimated process time, according to software simulation, mainly for the non-spiral strategies. The roughness values were the lowest and adequate for EDM process substitution, for the radial tool path from base of material to top.

Cutting strategies may minimize chatter effect. Kull Neto et all. (2016a) performed high speed milling tests in a convex quarter of cylinder of 27 mm radius made of hardened AISI D6 steel. The tool trajectory used was linear following the cylinder axis. The input variables were the spindle rotation (to produce different tool edge entrance frequencies), the direction of the tool passes (downward and upward) and the tool overhang (97 and 112 mm). The tool used was a 12mm ball nose carbide tool coated with TiAlN. They concluded that cutting strategy was more influent than tool edge entrance frequency, even when this frequency was a resonance frequency of the system. Downward cut (when the tool pass goes down in the cylinder in the subsequent passes) produced lower vibration and lower roughness values than the ones produced by upward cut, regardless the tool overhang used.

Kull Neto et al (2016b) analyzed the milling of the same quarter of cylinder used in the previous work, but now the tool trajectory was linear. The subsequent tool passes followed the workpiece radius. The input variables were the tool inclination (called tilt angle -16°, 0° and 16°) and feed direction (downward and upward). Radial force values observed with tilt angle 16° and downward cut were higher than other cutting conditions tested and which made the roughness values in this condition to be the highest among all the tests. The condition which produced the lowest roughness values, tilt angle 0° in upward cut, produced low values of radial force.

The main objective of this analysis is to find the influence of tool inclination tilt angle and tool feed direction in the surface finish of a quarter circle convex surface of a hardened AISI D6 steel workpiece, milled using HSM technique, with the tool describing a quarter of circle in each tool path.