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Optimization of Turn-milling Processes

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Abstract

Turn-milling is a relatively new machining process technology offering important advantages such as increased productivity, reduced tool wear and better surface finish. Because two conventional cutting processes turning and milling are combined in turn-milling, there are many parameters that affect the process making their optimal selection challenging. Optimization studies performed on turn-milling processes are very limited and consider one objective at a time. In this work, orthogonal turn-milling is considered where spindle and work rotational speeds, tool-work eccentricity, depth of cut and feed per revolution are selected as process parameters. The effects of each parameter on tool wear, surface roughness, circularity, material removal rate (MRR) and cutting forces were investigated through process model based simulations and experiments carried out on a multi-tasking CNC machine tool. The results are used to select process parameters through multi-objective optimization.

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Keywords: Multiobjective optimization; turn-milling; material removal rate (MRR)

1. Introduction

Turn-milling is a promising method for machining of cylindrical and non-coaxial (eccentric) parts with improved productivity. This method consists of turning and milling operations. Essentially it is a turning operation carried out using a milling cutter. In turn-milling cutting tool and work piece rotate around their own axes simultaneously. Due to these special aspects of the turn-milling offers several advantages. First of all, due to rotational movements of both tool and work piece, high cutting speed can be achieved in turn-milling operations. This is an important advantage particularly for parts with large diameter which cannot be rotated at high speeds. Furthermore, because of the interrupted cutting in turn milling, chips are broken and cutting temperature reduces which in turn decreases tool wear and increases tool life. Additionally high surface quality and low cutting forces are obtained due to lower cutting temperatures which make higher cutting speeds possible and produce smaller chips [1, 2].

At the end of the 1800s Tilghman [3] used milling cutter instead of turning tool to reduce temperature at the contact zone. Academic studies on turn-milling, on the other hand, started in 1990s. Schulz et al. [4] stated that by integrating conventional turning and milling machine tools with each other in the creation of new machine tools, in particular setup time is reduced and it is possible to shorten production time and reduce costs. Schulz [5] divided turn-milling operations into two groups: orthogonal and co-axial. In the study, plain bearing half liners are machined and it is showed that better surface roughness is achieved in comparison to turning operation. In another study of Schulz [6] kinematic conditions and its influence on the tool wear and surface roughness are handled.

Recent studies on turn-milling have mostly focused on experimental investigation of the surface quality. Kopac and Pogacnik [7] investigated effects of tool position according to the work piece and vibrations on the surface quality. In same study, they indicated eccentricity effect on surface roughness in orthogonal turn-milling. Choudhury et al. [8] studied effects of spindle speed and feed rate for different work piece materials for orthogonal turn-milling and compared the surface roughness with those obtained by conventional turning. They claim that 10 times better surface quality can be achieved by turn-milling compared to turning. In a later study,

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Choudhury et al. [9] continued their work on the surface roughness in orthogonal turn-milling this time including effects of work piece rotational speed, cutter diameter and depth of cut. They indicated that the surface roughness in turn-milling is also better than the conventional milling. Neagu et al. [10] researched the kinematics of orthogonal turn-milling based on circularity, cutting speed and tool geometry. As a conclusion they claimed that turn-milling can achieve up to 20 times higher productivity than turning. Savas and Ozay [11] investigated effects of cutting parameters on the surface roughness in tangential turn-milling developing a new method. As a result of their studies, they observed that the obtained surface roughness is close to the grinding quality. Filho [12] studied orthogonal turn-milling by using a five axis machining center to measure cutting forces and compared them with the analytical model predictions. Cai et al. [13] carried out orthogonal turn-milling experiments with different machining parameters and obtained conclusions about cutter wear and work piece roughness. Zhu et al. [14] described surface topography in orthogonal turn-milling, and proposed mathematical models to describe theoretical surface roughness and topography of rotationally symmetrical work piece.

Optimization studies on turn-milling started with Pogacnik and Kopac [15]. This experimental study presents guidelines on how to avoid dynamic instability by using optimum entry-exit conditions which can be achieved through a proper set-up of the process parameters. As a result, they proposed a decision diagram. Savas and Ozay [16] performed a study of cutting parameter optimization to minimize surface roughness in tangential turn-milling process using genetic algorithm based on experimental results.

The objective of the present study is determination of optimal orthogonal turn-milling (Fig. 1) parameters by using multi-objective optimization. Spindle and work rotational speed, eccentricity, depth of cut and axial feed are selected as process parameters. In order to optimize these parameters, minimum surface roughness and cutting force and maximum tool life, circularity and material removal rate (MRR) are selected as the objectives. Values of optimum objective functions and parameters for each generation were found. Different cases are investigated for making comparison.

In the analysis, tool life and machined part quality are formulated including eccentricity effects with the aid of experiments. Finally, suggestions on selection of optimal turn-milling process conditions are summarized.

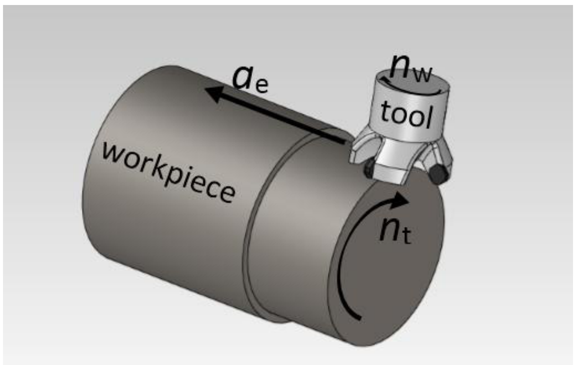

Fig. 1. Orthogonal turn-milling operation.

2. Process geometry and parameters

Turn-milling has a complex geometry due to rotational motions of both cutting tool and work piece. Fig. 2 illustrates the geometry of orthogonal turn-milling and the parameters in the process. As shown in Fig. 1 tool and work piece rotate with speeds of n_t and n_w respectively where their ratio, n_t/n_w, is defined as r_n. In addition, there are two different feeds in turn-milling; f_z is the feed per tooth which is in the circumferential direction whereas a_e is the feed per revolution in the axial direction as can be seen in Fig. 2.

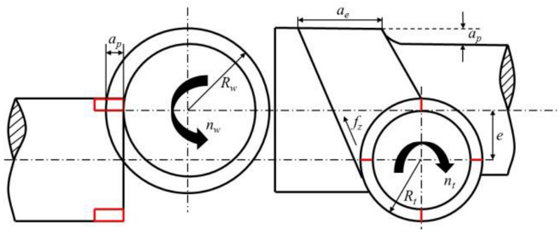

Fig. 2. Process geometry and parameters in orthogonal turn-milling.

Eccentricity is one of the special parameters in orthogonal turn-milling. Fig. 3 shows concentric and eccentric forms of orthogonal turn milling. Eccentricity in orthogonal turn-milling causes changes in chip formation whereas eccentricity increases only side of the cutting tool is involved in the chip formation.

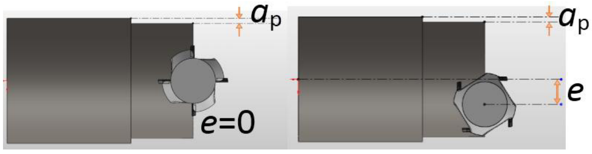

Fig. 3. Eccentricity in orthogonal turn-milling.

3. Objectives of the process

In this section objectives to be optimized are defined and their mathematical expressions are shown.

3.1. Tool wear and tool life

Tool life T, improvement is crucial to reduce the cost of production. Cutting tools have a limited life due to inevitable wear and consequent failure, and ways must be found to increase tool life. Cutting tools fail either by gradual or progressive wear on cutting edges or due to chipping or plastic deformation [17]. Generally a tool wear criteria is defined as a threshold value of the tool life.

Parameters, which affect the rate of tool wear in turn-milling are as follows [2];

- cutting conditions (cutting speed V, eccentricity e, and depth of cut a_p)
- cutting tool geometry