Hybrid Modelling and Optimization of the Oblique Cutting of AISI 1045 Steel

Iván La Fé Perdomo, Study Centre on Advanced and Sustainable Manufacturing, University of Matanzas, Matanzas, Cuba
Ramón Quiza, Study Centre on Advanced and Sustainable Manufacturing, University of Matanzas, Matanzas, Cuba
Marcelino Rivas, Study Centre on Advanced and Sustainable Manufacturing, University of Matanzas, Matanzas, Cuba
Veena Ramtahalsing, Fuescon, Wanica, Suriname

ABSTRACT

Optimization is a very important issue in mechanical industry, especially in machining processes, where different aspects must be considered. Thus, selecting the most proper cutting conditions plays a key role for obtaining efficient and competitive products. This article proposes a hybrid approach for modelling and optimizing the oblique turning processes. Analytical modelling and statistical regressions are combined for predicting the values of the most important parameters involved in the oblique cutting process. The predictions of the model were validated by using experimental data, showing coincidence for a 95%-confidence level. Then, an a posteriori multi-objective optimization is carried out by using a genetic algorithm. Two important and conflicting objectives are simultaneously considered: unit cutting time and tool wear rate, which describe the productivity and tool waste, respectively. The outcome of the optimization process is a set of non-dominated solutions, which are optimal in the wide sense that no other solution in the search space can improve one objective without worsen the other one. Finally, the decision-maker chooses the most convenient solution depending on the actual workshop conditions.

KEYWORDS

Modelling, Oblique Cutting, Optimization, Productivity, Tool Wear Rate, Unit Cutting Time

1. INTRODUCTION

Optimization is a very important issue in mechanical industry. Specially, in machining processes, where different aspects must be considered, selecting the most proper cutting conditions plays a key role for obtaining efficient and competitive products.

From the first published cutting processes optimization work (Taylor, 1907), to the most current literature (Rao & Kalyankar, 2014), a big amount of research has been expended on this topic. Nevertheless, a general robust solution, which can be applied to any cutting process, has not been obtained (Umer, Qudeiri, Hussein, Khan, & Al-Ahmari, 2014). This is caused by two main reasons. On one hand, the high complexity of the phenomena involved on the cutting processes makes it very hard to obtain reliable accurate models for describing the behaviour of the involved variables.

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Most of the optimization approaches use empirical models which cannot be applied outside the data intervals used for fitting these models. Moreover, obtaining experimental data from cutting processes is expensive and time consuming.

Other approaches have been proposed for modelling the cutting processes, such as finite element method (Abouridouane, Klocke, & Döbbeler, 2016; Amrita, Surjya, & Arun, 2011; Bartarya & Choudhury, 2011; Markopoulos, Kantzavelos, Galanis, & Manolakos, 2011; Umer, 2016; Umer et al., 2014; Weng, Zhuang, Chen, Guo, & Ding, 2017) and mechanistic approaches (Abouridouane et al., 2016; Bai, Sun, Roy, & Silberschmidt, 2017; BaoHai, Di, Xiaodong, Dinghua, & Kai, 2016; D’Acuntoa, Le Cozb, Moufkib, & Dudzinski, 2017; Fu, Chen, Mao, & Xiong, 2017; Gao, Sun, & Leopold, 2018; Vinogradov, 2014; Weng, Zhuang, Zhu, Guo, & Ding, 2018; Zhang & Guo, 2015). Both offer reasonable accuracy with few experimental data, but requires a lot of time for computing the outcomes (especially, the finite element method).

On the other hand, due to the complex nature of these models, the objectives functions and constraints do not fulfil the conditions of continuity, differentiability and unimodality, required for most of the optimization tools (Quiza, López-Armas, & Davim, 2012). Therefore, heuristics techniques have been applied for solving these problems. They include genetic algorithms (Batish, Bhattacharya, Kaur, & Cheema, 2014; Ganesan & Mohankumar, 2013; Kübler, Böhner, & Steinhilper, 2015), simulated annealing (Baseri, 2011; Wang, Wong, Rahman, & Sun, 2006), particle swarm optimization (Marko et al., 2014) and ant colony optimization (Vijayakumar, Prabhaharan, Asokan, & Saravanan, 2003), but all of them rely on the accuracy and reliability of the underlying models. Furthermore, the use of a single objective model is not enough for depicting the complex nature of the cutting processes (Kovačević, Madić, Radovanović, & Rančić, 2014; Saha & Majumder, 2016). Neither the a priori multi-objective optimization, which combines the different goals into a single one, can solve this problem (Quiza, Beruvides, & Davim, 2014).

The present paper proposes a hybrid approach for modelling and optimizing oblique cutting processes, which combines analytic, empirical and heuristic techniques. This method avoids the use of large and expensive amount of experimental work and allows carrying out the optimization with accuracy and flexibility.

The paper is structured in six sections. After this introduction, the general framework of the proposed approach is outlined. The third section presents the mechanistic model of the oblique cutting process. Section four depicted the optimization strategy. The fifth section presents a study case exemplifying the proposed methodology, including an experimental validation. Finally, conclusions are exposed at the sixth section.

2. GENERAL FRAMEWORK OF THE HYBRID MODELLING AND OPTIMIZATION APPROACH

The proposed hybrid approach (see Figure 1) is aimed to optimize, simultaneously, the unit cutting time, \( t_{oc} \) (which is defined as the time required for removing a volumetric unit of material, i.e., the inverse of the material removal rate) and the initial tool wear rate, \( \xi \). The decision variables are the cutting parameters: cutting speed, \( V \); feed, \( f \); and depth of cut, \( a_p \).

The tool wear rate will be computed by using the Usui’s model, from the parameters at the tool-chip interface: sliding velocity, \( V_s \); normal pressure, \( \sigma_n \); and temperature, \( T_{int} \). These variables are computed by an analytical model, from the cutting parameters. Nevertheless, as the computation speed of the analytical model is low, it cannot be directly used in the optimization process (as optimization heuristics require evaluating a lot of times the objectives functions and constraints). Therefore, an empirical model is fitted from the analytical outcomes, relating the tool wear rate to the cutting parameters. If this relationship is simple enough, a statistical regression can be used. On the contrary, some artificial intelligence modeling tool (such as neural networks or fuzzy logic) can be selected.
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