A study on an analytic optimization of variable pitch broaching

Zsolt Iklodi* and Zoltan Dombovari *

*MTA-BME Lendület Machine Tool Vibration Research Group, Department of Applied Mechanics, Budapest University of Technology and Economics, Budapest H-1521, Hungary

Abstract. An analytic technique for the optimization of tooth distances in variable pitch broaching is presented, by solving the vaguely equivalent variable pitch milling problem using zeroth order approximation of the anyway periodic coefficients of arising parametric excitation. To achieve the highest possible material removal rate on the prescribed cutting speed range of the workpiece material, the phase of the regenerative delayed terms is tuned to cancel the undesirable self-excited (chatter) vibrations of the broaching tool, based on the vibration (chatter) frequencies obtained from the analysis of Hopf-bifurcations type stability loss of the cutting operation.

Introduction

As a multiple stage subtractive manufacturing process, broaching is subject to the same regenerative effects as other conventional machining techniques such as milling or turning, and thus prone to the self-excited vibrations, also known as chatter [1]. Avoiding these harmful vibrations is crucial for fulfilling the generally high surface quality and integrity requirements of such high precision operations. However, scientific research on the dynamic stability analysis of broaching is remarkably scarce. Most studies concerning broaching focus on process monitoring or cutting edge geometry optimization, employing empirical and finite element techniques [2]. This study is motivated by two main goals. First, conducting a stability analysis of broaching operations through the formulation of a simplified mechanical model, which is presented on Figure 1.(a), and second, optimizing the tooth distribution of broaching tools, to achieve the highest possible material removal rates on a given cutting speed, while guaranteeing chatter free operation.

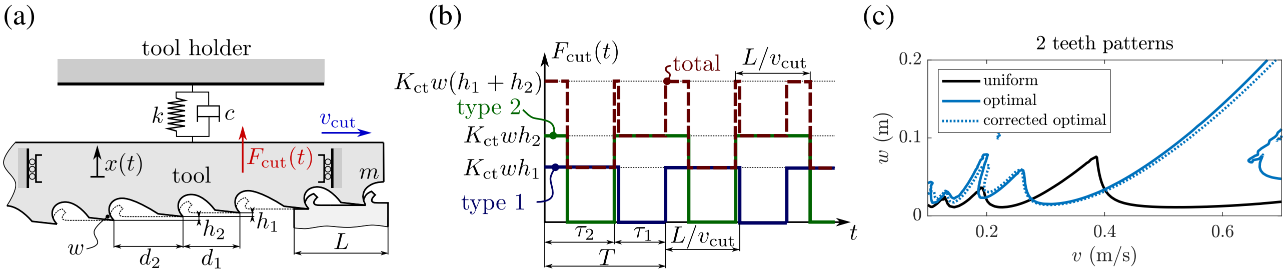

Figure 1: Panel (a): one degree of freedom mechanical model of variable pitch broaching. Panel (b): periodic forcing in variable pitch broaching with a two-teeth repeating pattern. Panel (c): stability map of broaching with uniform pitch and with phase optimized two-teeth repeating pattern.

Results and discussion

Even though broaching is generally regarded as a time limited operation, through transient simulations, it has been shown, that optimizing the tool geometry based on stability analysis of periodic orbits of infinitely long broaching operations can produce favourable and reliable results. After formulating a zeroth order approximation the periodic cutting force terms illustrated on Figure 1.(b), the optimization of tooth distances in infinitely long variable pitch broaching becomes equivalent with the optimization of pitch angles in variable pitch milling. Consequently, the optimization process followed the same steps that were employed in [3], by tuning the phase delay of regenerative terms to completely cancel out self excited vibrations on a given chatter frequency, which can be calculated either analytically for uniform, or numerically for variable pitch cases. The result of this optimization technique for two teeth repeating patterns is demonstrated on the stability map shown on Figure 1.(c). Here several cutting speed ranges can be found where the acquired variable pitch broaching tool provides higher resistance to chatter, an enables machining with higher material removal rates.

Acknowledgement

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No. 958357, and it is an initiative of the FoF Public Private Partnership.

References

[1] Axinte D. (2007) An experimental analysis of damped coupled vibrations in broaching. *International Journal of Machine Tools and Manufacture* **47**:2182-2188.

[2] Arrazola, P. J., Rech, J., M'saoubi, R., & Axinte, D. (2020) Broaching: Cutting tools and machine tools for manufacturing high quality features in components. *CIRP Annals* **69**:554-577.

[3] Budak, E. (2003) An analytical design method for milling cutters with nonconstant pitch to increase stability, part I: theory. *J. Manuf. Sci. Eng.*, **125**:29-34.