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Optimization of surface roughness in broaching

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ABSTRACT

The broaching process is used to generate high quality surfaces in very short times. In order to improve the understanding of the evolution of surface quality in broaching, a sensitivity study of the influence on the surface roughness of several broaching parameters dealing with the tool design, the cutting conditions or the workpiece material was performed. Forces and chip formation have also been analyzed so as to highlight the surface roughness generation. This paper shows how the process parameters (such as cutting speed or lubrication), tool design (rise per tooth, tooth angles, substrate material), and workpiece material affects the surface roughness.

Introduction

The broaching process is commonly used since the 19th century to generate complex and accurate surfaces in a limited time. Even if broaching is commonly used in aeronautical and automotive industries, a few researches have been achieved on this process compared with turning, milling or drilling processes.

The cutting forces and specific forces obtained in broaching applications have been well studied [1–3]. Those results are used to predict the broaching forces in an industrial context, depending on cutting tool geometries, process parameters and workpiece material. It can be used to design the cutting tool (main parameters of this tool are presented in Fig. 1) or the broaching machine, and smooth the forces variation in a broaching operation.

As broaching is used to finish functional surfaces, the impact of this process on surface integrity was also the subject of several studies. The influence of broaching on deformed layer thickness [4,5], on hardness [6,7] and residual stresses [8,9] has been analyzed.

Roughness is also a key quality criterion to take into account in high added-value sectors such as aeronautical or energy industries. An ANOVA achieved by Mo [10] on the impact of coolant, rake angle, cutting speed and rise per tooth (RPT usually noted h) showed that mean roughness (Ra) is more dependent on rake angle and coolant, and that cutting speed does not almost affect Ra. The maximum cutting speed studied was 10 m/min while new broaching applications usually raise this cutting speed up to 50 m/min.

Mean roughness value in broaching was also studied by Schulze on a fixed RPT value of 0.06 mm [8]. Obtained results show no significant variation of surface roughness when cutting speed varies from 7 to 50 m/min on a case hardening steel SAE 5120.

All these papers have investigated a limited number of parameters, in a limited range of value variation.

The case study presented in this work consists in the optimization of surface roughness in broaching of an X12Cr13 stainless steel with High Speed Steel (HSS) tool, and straight oil lubrication. The strategy of optimization is based on an end-user point-of-view (Fig. 2). When facing a poor surface roughness after broaching, what is the easiest parameter to vary? The cutting speed is the single parameter that can be modified when the machine, the tool and the lubrication have been selected. That is why the influence of cutting speed has been investigated first in this research work.

Then if the optimization induced by the change of cutting speed is not satisfying for the end user, the design of another cutting tool can be considered by varying the rise-per-tooth, the rake angle, the flank angle, the substrate, the coating, etc. Of course this is more costly (some k€) and time consuming as end-users have to wait several weeks for the delivery of the new tool. So in order to make the right design quickly, we have investigated broach parameters.

Then, if the new broach is not fully satisfactory in terms of generated surface roughness, it is possible to modify the lubricant. This is always an uncertain work, since it is very difficult to know the composition of lubricants available on the market. Even if the composition is well known, the interaction between their components, the workpiece and cutting tool materials is hardly

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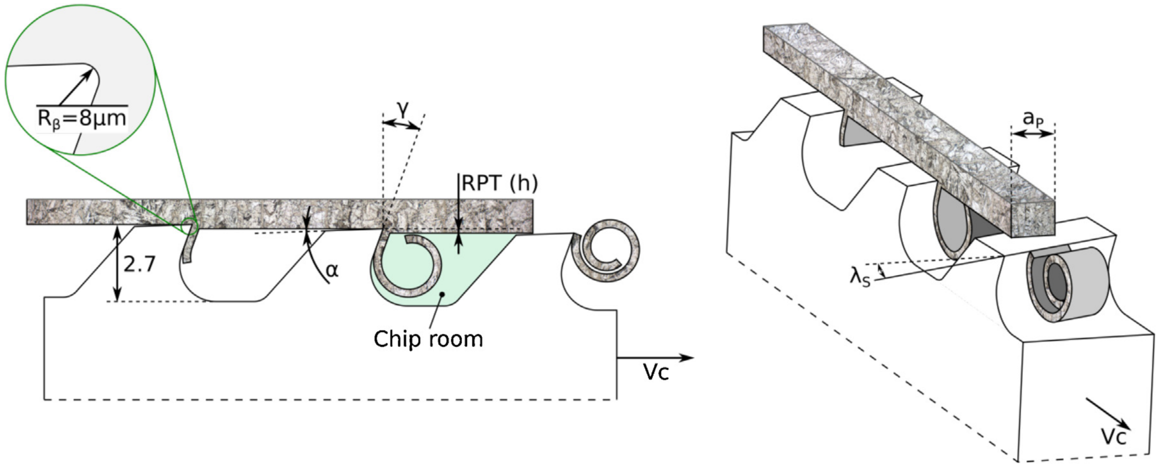

Fig. 1. Schematic representation of broaching parameters.

predictable. Moreover, it is also a tough work since the new oil has to be validated by the machine builder and the health authority of the company, which is a long and expensive procedure. So a sensitivity study on a large number of lubricants has been made in order to evaluate the interest of this solution to improve surface roughness.

At this point, if the modification of lubricant is not satisfactory, the stiffness of the clamping system and of the whole machine can be investigated. The redesign of the mechanical structure is also a long and costly problem. This parameter has not been investigated in this work.

Finally, the last solution consists in modifying the material of the workpiece. This is also a very complex task since it has to be discussed with the designer of the part. This is only possible if the potential financial gain is substantial and if a large number of parts are planned to be produced. So, it has been decided to investigate the sensitivity to the workpiece material.

The structure of the study is presented in Fig. 2.

Note that the influence of the machine structure was not properly studied in this work, even if its influence can be observed on some broaching tests as discussed below.

Experimental setup

The experimental setup developed for this study is presented in Fig. 3. A 4 axis machining center with a horizontal spindle was exploited to carry out broaching experiments. The spindle was equipped with a specially designed workpiece holder, and a clamping system mounted on a 6 axis dynamometer maintains the broaching tool. In order to limit the disturbances induced by the entry/exit of broaching tool teeth, tests were carried out with a single tooth cutting tool.

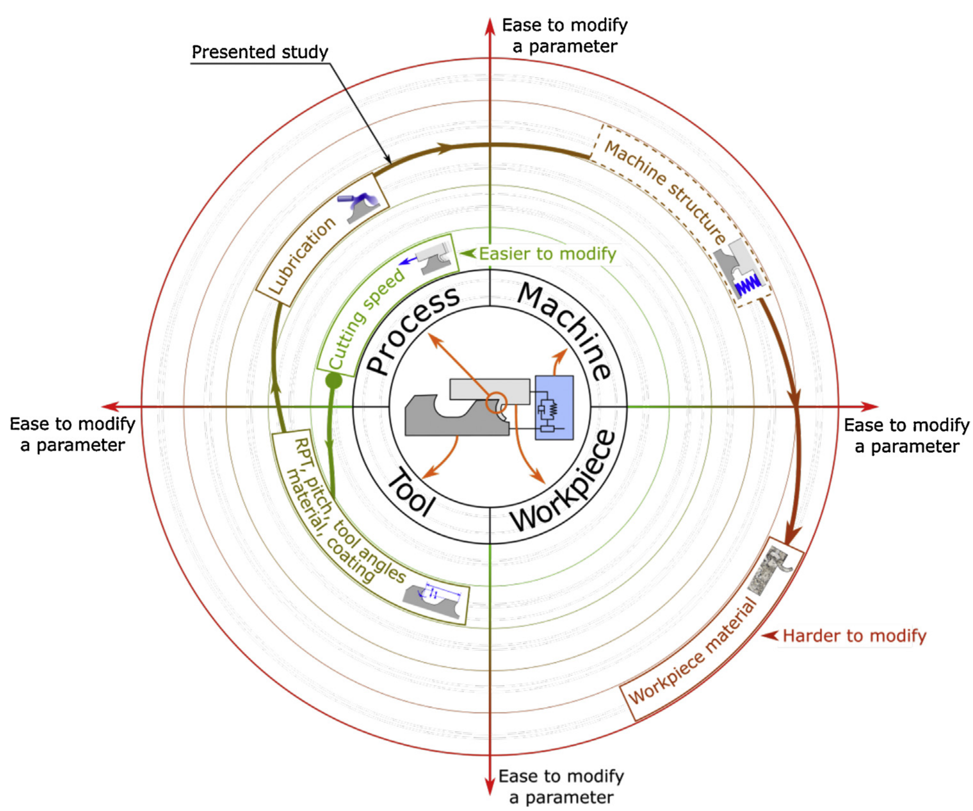

Fig. 2. Study of surface roughness; from the easier to the harder modifiable parameter.