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Development of an intelligent chuck system for the improved manufacturing of thin walled parts

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Abstract

The manufacturing of thin walled and overhanging structures represents a special challenge in milling due to self-excited and forced vibrations and thus associated chattering during the cutting process. Adjustment of the cutting process parameters may mitigate the occurrence of chatter and its resulting effects, however the machine productivity is reduced as well.

The approach presented in this work deviates from the mentioned traditional one in the sense that there are no changes in the machining itself but in the workpiece holder to achieve a maximal metal removal rate combined with an enhanced surface quality. In this paper an intelligent chuck system is presented. The developed chuck system is an active workpiece holder for the detection and suppression of undesired vibrations. Besides the developed sensor system and the used actuators, the focus will be on the processing of the measured data and the actuation strategy as well. Furthermore the experimental set-ups which were built up to verify the assumptions made during the investigation will be shown.

Keywords: intelligent chuck, chatter suppression, piezo actuated fixture

1. Introduction

Unstable process conditions in milling of thin walled parts can lead to poor surface quality and an increased tool wear [1]. Especially in manufacturing of impellers or blisks (blade integrated disks), where the efficiency in the final application of the parts depends on the surface and where long and slender tools are necessary, this issue is a limiting factor for the productivity of the manufacturing process. Due to the complex geometry and used materials, a post-treatment of defective parts is usually unprofitable even in small series production.

Various methods have been proposed to mitigate and suppress the occurrence of chatter without affecting the productivity. In [2] Stoferle proposed a sinusoidal spindle speed variation that necessitates communication with the machine control. The influence of irregular tooth pitch on the process stability has been described, e.g. by Slavicek [3]. A special milling tool geometry and therefore also an intervention in the milling strategy are required. Also, vibration absorbers which are mounted directly to the machine structure can compensate unwanted chatter as Sims [4] showed. Will [5] utilized active movement of the spindle and, thus, of the milling tool for the avoidance of unstable processes. The costly and elaborate implementation of this method might be a reason why it has not been spread widely in industrial environment so far. In [6–9] not the actuation of the tool but of the workpiece is in focus of research. The outcomes of these efforts are piezo actuated workpiece holders in which a translational high dynamic movement of the workpiece can be applied in two directions. To realise this two actuators are necessary.

The approach presented in this paper consists in an autonomous intelligent chuck system based on rotational actuation and integrated chatter detection. Following this strategy, only one actuator is required which is directly related with savings in costs and space in the working area of the milling machine. The manufacturing of an impeller shall be the sample application.

The main sections of the paper describe the two development steps of the intelligent chuck system. At first, the paper summarises the investigation results which were achieved with a basic prototype. This includes the kinematics structure, the choice of an actuator and a suitable sensor concept. In the following section, the rotational chuck is introduced. This contains further development features and suggestions for the control strategy. Results of an experimental validation are followed by a summary and conclusion of the analyses presented in this paper.

2. First prototype

In figure 1 a first test rig is shown including all components of the targeted chuck system but here in a simplified stage of development.

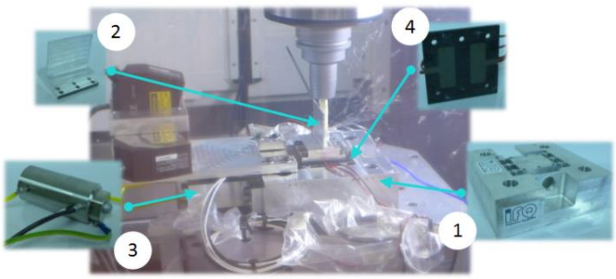

Figure 1. Prototype during milling process and highlighted components; (1) - frame, (2) - impeller blade, (3) - actuator, (4) - sensor system

The structure (1) consists of a stiff frame connected via flexure hinges with an inner table which can be moved translationally in one degree of freedom by a piezo actuator (3). On the table a conventionalized impeller blade (2) is mounted. The detection of vibration during the process is realised with piezo patches, which are integrated in a CFRP plate (4) between table and blade. Eddy current sensors and laser triangulation sensors allow the monitoring of the crucial system behaviour [10].

3. Rotational chuck

The aim of the final prototype is to provide an autonomous chuck for the detection and mitigation of chatter which can be easily integrated in common milling machines. In figure 2, the chuck is mounted on a pallet. Also shown is the three-armed sensor system in the upper right and a more detailed presentation of the system structure on the left.

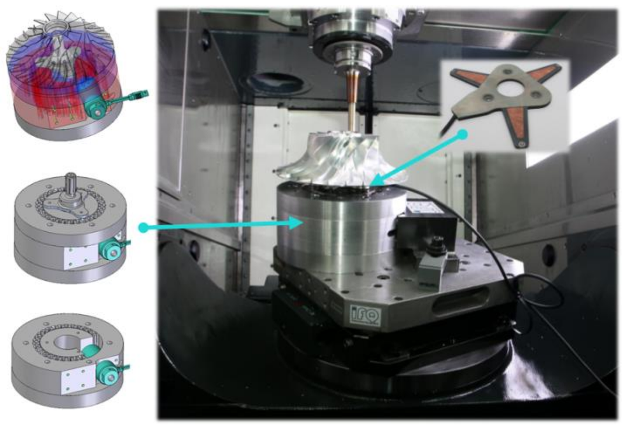

Figure 2. Rotational intelligent chuck system.

The rotational chuck involves an excited core which is guided by flexure hinges in order to carry out concentric vibrations driven by a single piezo actuator. The core integrates a clamping mandrel for fixation of the workpiece. The excitation of this system aims in disturbing the regenerative chatter effect at the contact point between tool and workpiece. The system control is supported by results of previous simulations [11] of the milling process. Due to the continuously changing control path, an adaptive control is considered.

4. Results

The effect of milling with active actuation of the prototype test rig is one of the main results and is presented in figure 3 on the right. The left side represents the surface of the milled blade without any actuation. The targeted outcome is a 25 percent increase in productivity of the whole process, so this presented result is an important sub-step which shows the usability.

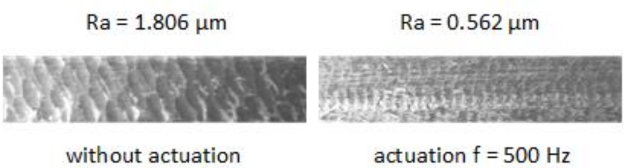

Figure 3. Surface quality without actuation and with an active excitation of 500 Hz.

5. Summary and conclusion

In this paper the development of an intelligent rotational chuck system is presented. The application possibilities and limits of the structure, actuator and sensor system are shown in different stages of development. Different control strategies are tested and evaluated. Methods for the detection of unstable process conditions are implemented and tested. It is shown, that the active excitation of the workpiece can result in a better surface quality.

The outcome of this paper demonstrates the possibilities of an intelligent chuck system. Unwanted behaviour during milling could be detected and suppressed. The presented solution with only one actuator enables a cost-effective and space-saving way for increased productivity in the manufacturing of low rigidity thin walled parts like impellers or blisks. Due to the fact that such a system could be mounted in usual milling machines, even small businesses could benefit.

5. Future work

Future efforts will focus on enhanced control strategies towards adaptive control. It should be also considered that further applications with higher masses or other material of the workpiece are of interest. Finally, the system has to be adapted for the daily use in industrial environment.

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