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Intelligent Fixtures for High Performance Machining

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Abstract

Fixtures are an essential element of the machining system, being part of the precision path and force flux between process and machine tool. Intelligent fixtures enable the identification of critical process conditions, a compensation of error influences and the minimization of defective parts. At first, this contribution presents a study in which the influence of the clamping setup and of the workpiece characteristics at various steps of the machining process is analyzed. Experimental and theoretical results regarding the dynamic process behavior reveal the relevance of these influences with respect to machining performance and workpiece quality. Secondly, the European research project INTEFIX is introduced. Representative approaches of intelligent fixtures, reducing workpiece vibrations and distortions, and improving workpiece alignment, are described and prototypes are shown. In a third part, two examples of intelligent fixtures are presented and discussed more in detail. The first example concerns a fixture for the identification and active mitigation of chatter in milling of thin walled workpieces. The second example is related to the compensation of workpiece distortions which occur in machining of large thin walled structural parts.

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1. Introduction

Fixtures and clamping devices are an essential part of machining systems for material removal processes. But their importance is often neglected or underestimated during the layout of manufacturing machinery and processing solutions. The relevance of fixtures regarding productivity, efficiency and quality is mostly not considered properly, e.g. with respect to the planning of production systems and related costs. Main tasks of fixtures and clamping systems are [1,2]:

- to define the location (position and orientation) of a clamped workpiece in the workspace of the machine tool
- to maintain this defined location even under the influence of static and dynamic mechanical and thermal loads
- and to guide these loads as an integral element of the machine structure inside the force flux

For automation purposes, the integration of an energy supply (hydraulics, pneumatics, electric power) and related interfaces is necessary. Furthermore, fixtures and clamping elements with integrated sensors for monitoring tasks are available [3-7]. Conventionally, fixtures should avoid any changes of the clamping point locations during the machining process. Flexible fixtures allow an adaptation of the clamping interfaces to the workpiece geometry [8-11]. Active fixtures enable an actuated movement of clamping points, e.g. for adaptation to distorting workpiece shapes [12,13], or to excite the workpiece in order to improve process conditions [14,15].

The accuracy, performance and reliability of a clamping scenario involving workpiece and fixture depends on the number, distribution and configuration of clamping devices and contact points including support pins or referencing elements. The layout of a fixture and the arrangement of clamps is a challenging task which can be accomplished by

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means of computer aided methods [16-18]. Since fixtures are part of the accuracy path of the machining system, their tolerances affect the quality of the processing result [19-21]. Fixture design can be supported by numerical calculation and simulation [22-24]. An essential aspect is the avoidance of workpiece deformations which can be caused by the clamping system itself [25]. In order to properly calculate and analyze the static and dynamic behavior of workpieces which are clamped in a fixture, an accurate modeling of the contact between the workpiece and the clamping element is important [26-28]. Testing of contact interfaces is necessary in order to parameterize and validate the calculation approaches [29-32]. Furthermore, the process-workpiece-fixture interaction has to be considered in assessing the performance of the fixture and to estimate the influence of a fixture layout on the machining process [33-35]. For compliant and thin-walled workpieces, the dynamic behavior of the machining process has to be analyzed carefully [36,37]. Modelling of the process-workpiece-fixture system allows the implementation of optimization strategies for attaining a suitable fixture layout [38-41]. A significant number of studies therefore aim in automated fixture configuration systems [42-46]. However, fixture design is dominated by the experience and knowledge of the designing engineer. Some approaches incorporate this knowledge into computer aided layout strategies [47,48]. Design methodologies for fixtures can be regarded as an ongoing topic, especially in view of intelligent fixtures [49].

In the following, a study is presented that reveals the relevance of the fixture layout with respect to the dynamic process-workpiece-fixture interaction. Afterwards, an overview of an ongoing European research project is given, which aims for the development of sensor and actuator integrated fixtures for thin walled and compliant workpieces. A final goal of this project is to provide design methods for such intelligent fixtures. Two examples for the simulation aided layout of intelligent fixtures are introduced in detail.

2. Relevance of fixtures

Since fixtures are located in the force flux of a machining system, their static, dynamic and also thermal behavior directly affects the quality and performance of the process. Regarding productivity and material removal rates, the vibration properties of the workpiece-fixture sub-system limit the range of stable process conditions. Consequently, fixtures are mostly over-dimensioned in order to provide sufficient stiffness and damping. However, this over-dimensioning leads to high costs and resource consumption.

For an improved fixture layout, basic analyses are necessary to gain a detailed knowledge of the dynamic behavior of the workpieces which are clamped in the fixtures. Furthermore, calculation and simulation approaches are necessary which allow an assessment of the performance of a designed fixture in a virtual environment during the layout procedure prior to the final hardware realization.

With the aim to reveal the influence of the fixture setup on the process stability in exemplary milling operations, a re-configurable test fixture was realized in cooperation with the company Roemheld (Fig. 1 and Fig. 2). The initial fixture setup incorporated three clamping points (equipped with supporting pins and swing clamps) and stoppers for referencing of the workpiece (Fig. 1a). This setup intentionally exhibits a certain dynamic weakness in less supported areas of the workpiece in order to enhance the visibility of vibration effects during the process. In further configurations, the locations and number of clamping points and additional supports vary (Fig. 1b).

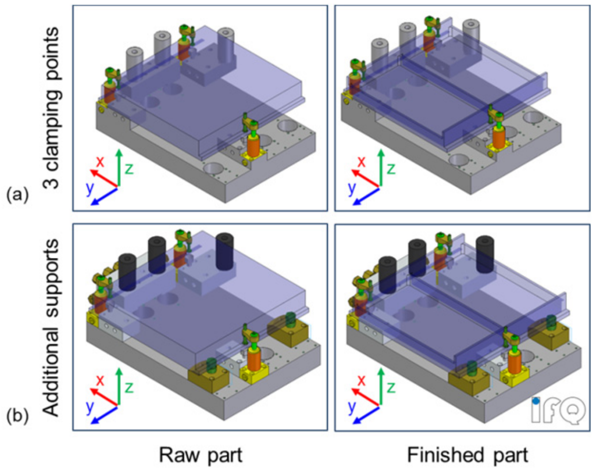

Fig. 1. Re-configurable test fixture for exemplary machining experiments; (a) initial fixture setup with three clamping points, (b) configuration with two additional hydraulic supports

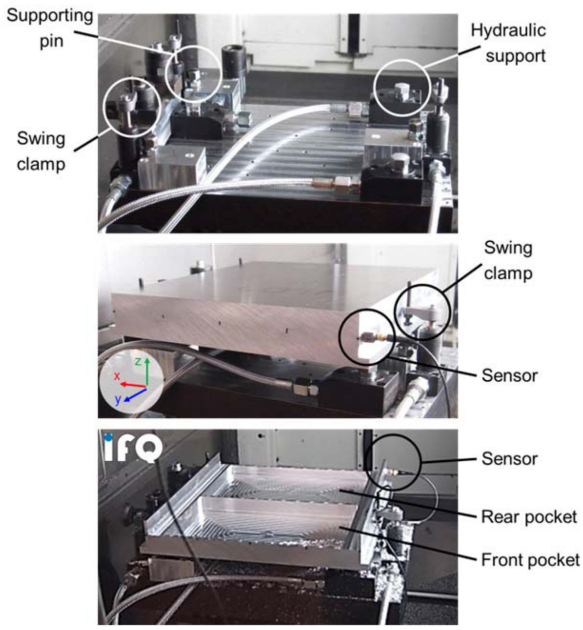

Fig. 2. Realized test fixture without and with clamped workpiece

The chosen milling test scenario consisted of a face milling of the top surface of the clamped raw material block and two pocket milling cycles with a circular strategy. Thus, the final workpiece has a ribbed and thin-walled structure. The workpiece material was Al7075. A coated 12 mm carbide tool