euspen's 18th International Conference & Exhibition, Venice, IT, June 2018
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Increasing the Accuracy of an Intelligent Milling Tool with Integrated Sensors

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Abstract

In an industrial research project, the Institute for Machine Tools in cooperation with a German company developed an intelligent milling tool with indexable inserts, which can diagnose and indicate the wear condition to the user, and assembled a prototype. When developing the intelligent tool, there were challenges to be surmounted regarding the selection, the design and the calibration of the integrated sensors. This paper describes the development steps for the design, electronic and IT features of the cyber-physical tool.
The main emphasis of this paper is on the methods for calibrating the sensors in order to be able to generate reproducible measuring results for the planned usage of the tool sensors, i.e. the intelligent monitoring of the indexable inserts' wear condition. Measured quantities and disturbance variables during machining, such as e.g. constantly varying force effects and transient temperature gradients, do not occur singularly in the machine tool but as multiphysical phenomena influencing each other. For the calibration, the physical phenomena were separately considered at first before analysing and recording an overlapping between the multiphysical domains. Hence, the interdependences between the measured physical quantities were known and could be taken into account when developing the intelligent changing routine for indexable inserts.

Machine Tool, Sensor, Cutting, Calibration

1. Introduction

Cyber-physical systems in industry have been the development trend of this decade. The milling tool presented in this paper makes it possible that the necessary change of the cutting edge in a tool with indexable inserts can be carried out without visual inspection thanks to integrated electronics and sensor technology as well as an intelligent logic. The goal of this project, initiated by industry, is to create a self-sufficient system consisting of a tool with integrated sensors, an intelligent tool changer for indexable inserts and an indicating device, which informs the user about required changes of indexable inserts (Figure1).
The focus of this paper is on the arrangement and the necessary calibration of the sensors, as this intelligent tool makes it possible for the first time to specifically change only single indexable inserts as well.

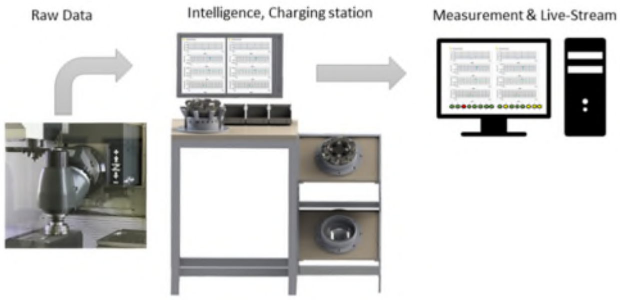


Figure 1. Information chain - milling tool and loading station

The following sensors are integrated into the intelligent tool:

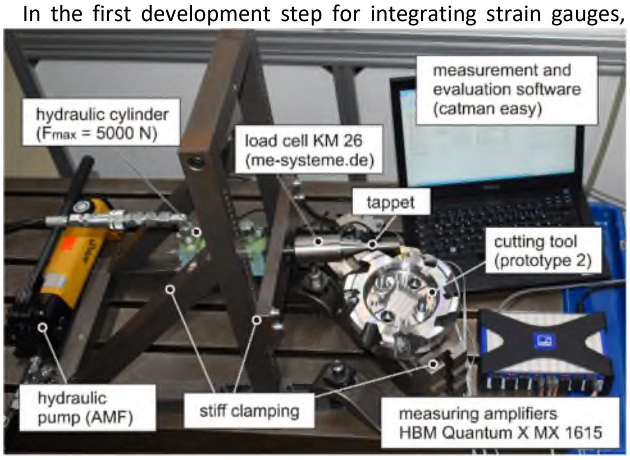
- Accelerometer/gyrometer: on and off switching function of the tool (sleep/wake-up function), detection of impacts and vibrations
- Strain gauges for establishing the resultant force on the cutting edge
- Temperature sensors on the cutting edge for determining the cutting temperature.

As the strain gauges measured only the deformation of the cutting tooth by the force acting on the tool, they were calibrated after their integration and converted into a resultant force on the cutting edge.

2. Tests and calibration of the sensors

2.1. Calibration with a measuring system

In the first development step for integrating strain gauges,



different positions of strain gauges were tested on the milling tool. The two most suitable positions were chosen for a further test.

Figure 2. Measuring set-up for calibrating the resultant force of the milling tool

Figure 2 shows the test set-up for calibrating the strain gauges on the milling tool by using a force applied via a hydraulic system. The prototype of the milling tool was clamped tightly on a solid test bed and loaded with a force of up to 5000N on the insert via a piston. A measuring amplifier HBM Quantum and a load cell KM26 by me-systeme, which was calibrated with weights before, were used as reference measuring system.

Figure 3 shows the test results for calibrating the strain gauges with a stepped increase and decrease of the applied force. It can be clearly seen that the deformation follows the stepped course, although there are differences between the two integrated strain gauges. Owing to the smaller differences between the applied force and the measured deformation, the position of the strain gauge 2 was chosen for the further design of the prototype and the further experimental tests.

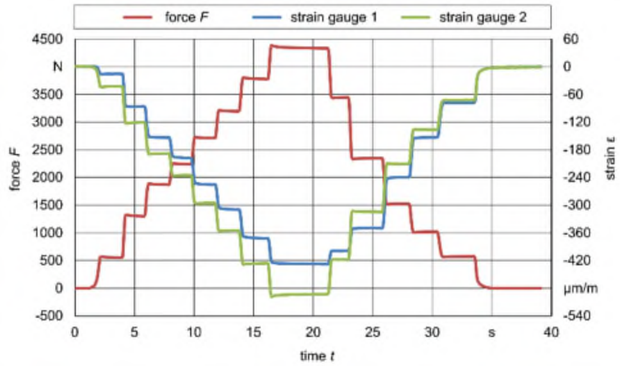


Figure 3. Force applied in steps (red) on the primary abscissa compared with the measured deformation curves (green and blue) on the cutter teeth via integrated strain gauges (secondary abscissa)

2.2 Calibration with the first prototype electronics

Electronics with a microcontroller ATMEGA328P was used for the first prototype of the intelligent tool. The deformation was measured with the strain gauge using an HX711 with an analogue-digital converter. Via a GPIO (General Purpose Input Output), it supplied the microcontroller with the measured values in the form of digits, which must be converted into a measured force then.

To record, represent and save the data measured in the tool, a conversion factor x must be determined. Regarding the integrated strain gauge 2, an average conversion factor of x = F/Digits = 0.007643 N/Digits was established from several calibration measurements. Figure 4 presents the comparison between the measured digits (blue), the applied force as well as the force measured on the milling tool, taking account of the average conversion factor.

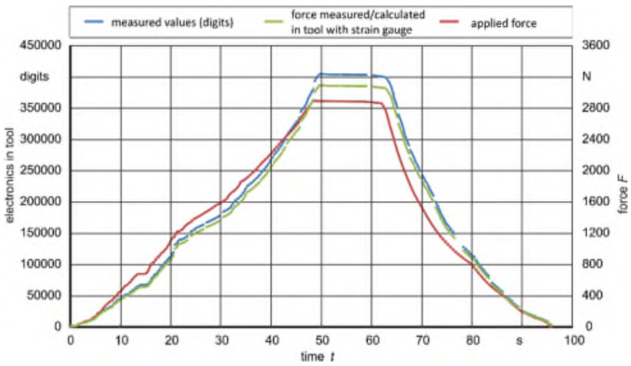


Figure 4. Digits measured with HX711 (blue, on the primary abscissa) vs applied force (red) in comparison to the measured and calculated forces (green), both on the secondary abscissa

The graph clearly shows that the applied force (red) is higher than the force established on the strain gauge or rather is ahead of the curve in the phase of increasing force. At the maximum, the force on the strain gauge (green) is, however, higher than the applied force. This was also confirmed for other load profiles and in further tests. This could be caused by friction effects between the tappet and the load cell, which was built into a metal casing. With decreasing force, the deformation at the strain gauge (green) decreases more slowly than the applied force. To sum up, both the strain gauge and the used electronics of the milling tool proved to be suitable for measuring the forces on the indexable insert of milling tools.

2.3 Test of temperature influence

However, as the indexable insert in the machine tool warms up intensely during the milling process, the influence of an increasing cutting edge temperature was examined in the subsequent test. Taking the tests presented above into consideration, it therefore became necessary to develop the test set-up further. A heating spiral was made to simulate a heating source directly on the cutting edge. With this heat source, it was possible to locally apply heat to the indexable insert in the tool via a thrust piece, comparable to the heat arising in cutting processes.

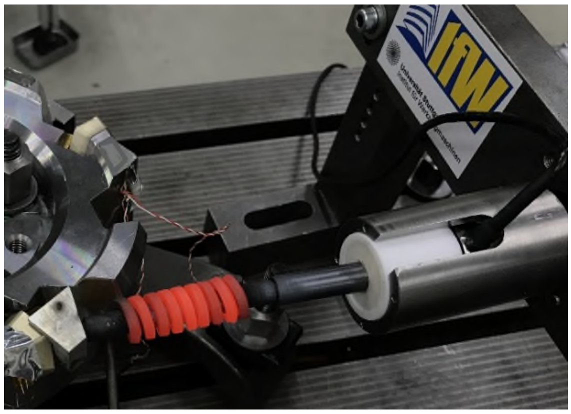


Figure 5. Test set-up for examining the heat influence

In order to reduce not only the friction between the metal housing of the load cell and the tappet but also the heating of the load cell, a pressure piston out of Teflon was developed. The tappet, connected to the pressure piston, as well as the adjusted thrust piece for the indexable insert were manufactured out of invar steel to keep the thermally induced expansion of the thrust unit small. Figure 5 shows the test set-up for examining the deformations under the influence of heat.

The complete paper will show the results of the tests for examining the heat influence and how to increase the accuracy by using an improved circuit.

3. Conclusion

The measuring results presented in this paper were used for a further development step of an intelligent milling tool with integrated monitoring of resultant force and cutting temperature. The first prototype could monitor the cutting edge of an indexable insert with moderate accuracy. Then a possibility was developed for measuring the resultant force with good accuracy via the deformation. Thanks to the increased application effort, the final milling tool will be equipped with eight force measuring points on eight indexable inserts. Opposite indexable inserts will be interconnected to a full bridge via a measuring amplifier. The cutting temperatures will also be established behind every indexable insert. By using intelligent analysis routines of which the development has only just begun, it will be possible for the user of these tools to detect the condition of the inserts during the milling process.

Literature will be added in the complete paper