Optimized Chipping Processes with a New Mechatronic Tool System
Application of Strain Gauge Sensors and Piezoelectric Actuators

Franz Haas[1], Elke Nuspl[2] and Manfred Pauritsch[1]
[1]*Department of Automation Technology, FH CAMPUS 02, Körblergasse 126, A-8010 Graz, Austria*
[2]*TCM International Tool Consulting & Management GmbH, Technologiepark 3, A-8510 Stainz, Austria*

Keywords: Chipping Technology, Mechatronic Tool System, Condition Monitoring, Piezoelectric Actuators.

Abstract: The paper introduces a new measurement device which allows collecting the chipping force in three directions and additionally the process temperature. The apparatus consists of a specially designed tool holder with integrated strain gauges, the electronic measuring equipment and the evaluation software. During the first period a new device for research and development purposes has been designed, experiments on innovative materials are presented including the comparison with simulation results. The next step of the project incorporates the product development based on the previous experience with targets accuracy, cost effectiveness, reliability and the possibility of active damping of tool vibrations. To achieve the last mentioned demand a piezoelectric actuator is integrated into the tool shank and works against the vibration forces.

1 INTRODUCTION

Chipping technologies (e.g. turning, milling or grinding) are still of high importance in the field of industrial production. For instance both combustion engine and electrically driven automobiles need many parts that have to be produced or finished by chipping processes because of accuracy and cost effectiveness. Some of the current developments in this field are listed below:

- Increasing number of parts made of innovative materials (e.g. titanium, composites) for lightweight constructions;
- High temperatures caused by hard machining and dry processing;
- General demand of optimized cutting parameters and less vibration;
- Hybrid machine tools characterized by integration of several techniques (e.g. turning and laser heat treatment or milling and friction stir welding).

Therefore the demand to integrate mechatronics into the tool holders is evident. Preconditions are the robust and simple sensor and/or actuator application at acceptable prices.

2 STATE OF THE ART

This chapter gives a summary of useful basics in the area of test methods and represents an overview of new cutting tools and cutting materials.

Concerning the measurement of cutting forces two different principles can be divided. Most of the laboratory devices use a dynamometer based on the piezoelectric effect. The sensor delivers electric charges that are transported to a charge amplifier through an insulated cable. The amplifier converts the charges into an output voltage (Kistler, 2009). As standard a special platform with four sensors is used to enable a multi-component measurement of forces and torques. In the case of chipping the orthogonal components F_x, F_y, F_z and the drive torque M_z at the main spindle are of special interest.

Turning as a process with a rotating workpiece and tool inserts of defined geometry represents the typical example to measure the orthogonal process force components.

Strain gauge and piezoelectric force measurement devices are presented in (Audy, 2006) with a detailed discussion and classification of the error sources. It is pointed out that a two-component metal machining dynamometer equipped with strain gauges doesn´t have satisfying long term stability without any compensation because of temperature

Haas F., Nuspl E. and Pauritsch M..
Optimized Chipping Processes with a New Mechatronic Tool System - Application of Strain Gauge Sensors and Piezoelectric Actuators.
DOI: 10.5220/0004044006140617
In *Proceedings of the 9th International Conference on Informatics in Control, Automation and Robotics* (ICINCO-2012), pages 614-617
ISBN: 978-989-8565-21-1

effects on the strain gauges.

A small three-component dynamometer with circular holes is described in (Tani, 1983). The linearity of output is excellent without hysteresis. The calibration of all three directions can be carried out with low interaction between measurement directions.

3 LABORATORY DEVICE

3.1 Mechanics and Sensors

The mechatronic tool is constructed similar to a standard tool holder consisting of a shank and the cutting part with the carbide metal inserts. In comparison with standard tool holders the fixation of modules with different insert geometries is enabled.

The basic measurement principle is very simple and can also be utilized in low cost products (Haas, 2011). The tool shank has the function of a beam in bending as the result of cutting and feed force components (see Fig. 1).

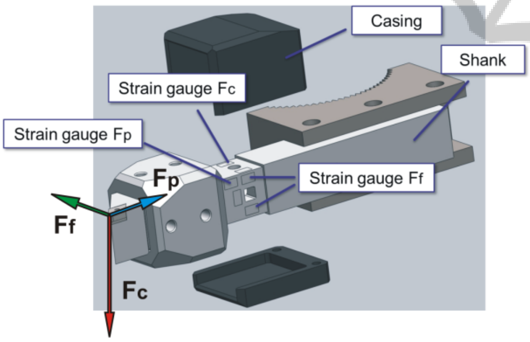

Figure 1: Dynamometer with strain gauges.

The very small deflections cause output signals of each bridge circuit with four strain gauges to compensate for temperature effects. Concerning the third axis the deformation near a rectangular hole is picked up by additional strain gauges, but the signal is small in relation to the others and calibration is much more difficult.

The FEM analysis (Fig. 2) of the mechatronic tool is helpful to estimate the strain values at the virtual model to select the suitable strain gauge types.

Another benefit of simulation is the optimization of stiffness to ensure that distortion und stresses are below the limits.

The force components F_c, F_f and F_p can be calculated according to the equations (1) to (3). The specific force values (kc1.1, kf1.1, kp1.1) are

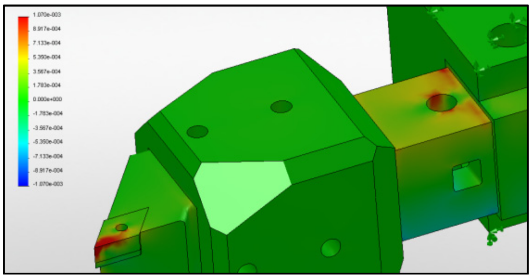

Figure 2: X-component of strain (F_c = 1200 N).

multiplied with the width (b) and thickness (h) of the chips. The exponent (mc-1) considers the decreasing amount of the specific forces with higher values of (h) in the case of cutting force.

$$F_c = k_{c1.1}\ b\ h^{(mc-1)} \quad (1)$$
$$F_f = k_{f1.1}\ b\ h^{(mf-1)} \quad (2)$$
$$F_p = k_{p1.1}\ b\ h^{(mp-1)} \quad (3)$$

To complete the test equipment it is necessary to measure the temperature at the deformation zone simultaneously. In this case a dynamic test shows the direct consequence of tool wear with regard to the process forces and to the thermal load that tool insert and work piece have to withstand. Especially thin and lightweight parts are sensitive to higher temperatures, distortion and failure costs may be the results. Dry processing and hard machining accept higher temperatures to reduce the costs for cooling lubricants and to avoid environmental pollution. These machining strategies require thermal test results to detect the speed limits.

Therefore an infrared temperature sensor with a range of 200°C to 1000°C is integrated into the measuring and evaluation concept. The temperature level is able to be influenced by location and intensity of heat sources, the heat conductance value, the dimensions of heat dissipation parts, time interval of direct contact and at last external cooling.

3.2 Electronics

The interface electronics fulfils functions that exceed commercially available equipment. Four voltage signals can be processed as a multichannel measurement, three bridge circuit values from the dynamometer and the temperature sensor output.

The main item on the printed board (see Fig. 3) is the analogue digital converter with a sampling rate of 70 kHz and a resolution of 24 bit.

In relation to commonly used boards for strain gauge bridges the new design enables the highly dynamic digitalization of the analogue signals.

As electronic protective method a high frequency

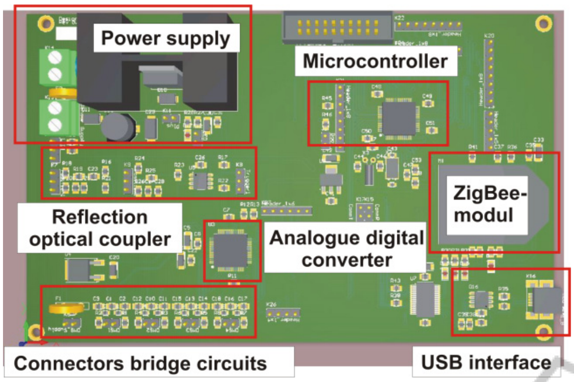

Figure 3: Interface electronics, PCB-layout.

noise filter and an over-voltage protection are integrated per channel. The measuring board consists of a USB connector to communicate with the PC. By default the communication is done by a WLAN module with 2.4 GHz transmission frequency, therefore it is also possible to access the device worldwide per internet. This feature ensures a high reliability of the remote data transfer even under rough conditions on the factory floor. In addition an external analysis or remote maintenance is possible.

In the case of turning operation tests can also be triggered by indication at the main spindle. A microcontroller is responsible for internal measurement control and communication. Configuration and status information are displayed on a small screen.

3.3 Calibration and Errors

During calibration exactly weighted loads are applied to the dynamometer. As consequence each mass causes deformation and defined output voltages at the bridge circuits. One calibration curve per direction must be calculated as a result of output voltages, the applied masses and calibration setup dimensions. Possible device errors are caused by long term and temperature drift, nonlinearity of strain gauge signals. As basic requirements of measurement calibration has been finished and comparisons with other systems and with calculated force results has been done

4 MEASUREMENT RESULTS

The new device offers benefits for a lot of applications, for example research and development as well as large-scale production or education. The independent comparison between measuring results and chipping process simulation illustrates a sufficient compliance.

4.1 Turning Process

First straight turning measurements are presented. To achieve reliable results system calibration should be performed before data collection.

Figure 4 shows force values and the process temperature for hardened steel machining, which becomes more and more important for economic and sustainable production. In this case the dominant factors are heat production, thermal resistance of inserts and efficient cooling.

As a result of cutting depth, cutting speed and feed velocity, the temperature rises up to about 260°C as a constant condition (see Fig. 4 at the right axis).

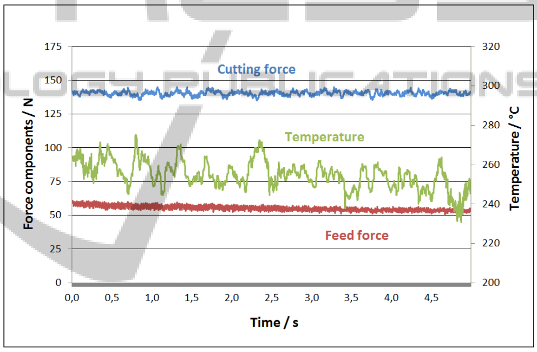

Figure 4: Straight turning of hardened steel (F_c, F_f, T).

The following diagram (Fig. 5) introduces results of stainless steel machining.

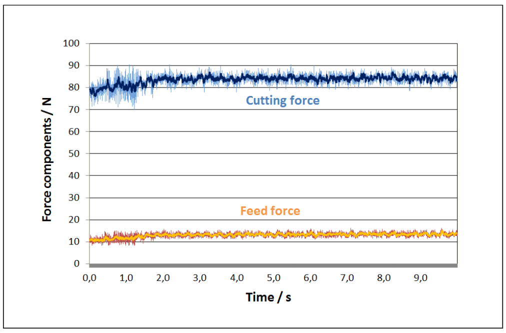

Figure 5: Straight turning of stainless steel.

One of the promising materials of lightweight constructions is titanium, but it is difficult to be machined with chipping processes. Figure 6 shows the increase of the measurement values after the tool starts with machining. The alternating temperature profile is caused by discontinuous chip formation.

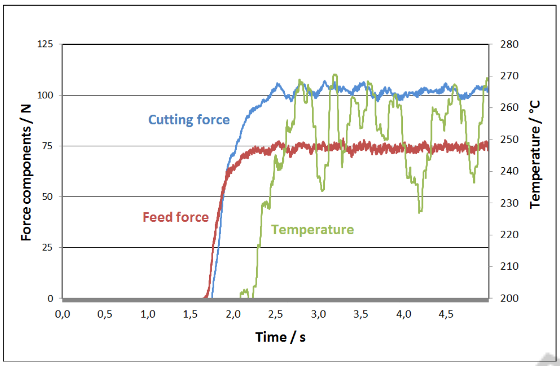

Figure 6: Cutting force, feed force and temperature, straight turning of titanium alloy with carbide inserts.

Infrared camera pictures and videos have been shot to validate the temperature results and to get an impression of the whole thermal field (Fig. 7).

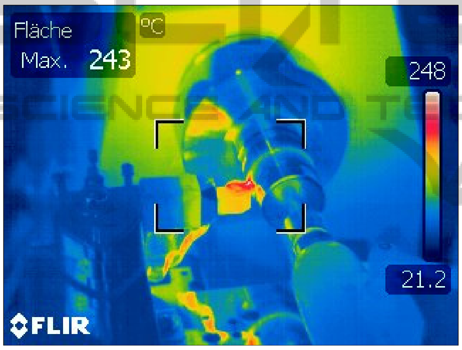

Figure 7: Infrared picture of titanium machining.

It should be pointed out that satisfying correlation between the thermal radiation result (see Fig. 6) and the infrared method could be achieved (maximum temperature of about 250°C).

4.2 Simulation

Optimization of chipping processes based on measurements should be extended to simulation. The target of this project (Blaha, 2010) is the FEM simulation of turning operations for three materials (C45, X2CrNiMo17-13-2 and Ti6Al4V).
As the most important simulation assessment criteria cutting forces have to be analysed and compared with measurements mentioned above.

The required tribologically parameters have to be determined by special tests (Horwatitsch, 2007). The comparison of measurement versus simulation has shown a satisfying compliance in the case of numerical integration of the local cutting forces along the comma-shaped chip (Blaha, 2010). Depending on the material the deviation varies between 2 and 12 percent considering the cutting force results.

5 CONCLUSIONS

The triangle relationship between workpiece, cutting tool and machine tool finally determines the economic production and always requires new solutions for each particular case, which can only be found as a result of chipping tests and process monitoring.

The paper presents a measuring device for laboratory purposes as well as a mechatronic tool for industrial production. The idea of the laboratory device is to pick up all necessary process data for optimization purposes. In the case of the mechatronic product low cost and robust design are of higher importance. This principle is not limited to specific manufacturing techniques, it is generally applicable and represents a significant module to fulfil the targets of intelligent production.

REFERENCES

Audy J., 2006. An appraisal of techniques and equipment for cutting force measurement*, In Journal of Zhejiang University*, p. 1781-1789.
Blaha, J., Horwatitsch, D., (et al.), (2010**)**. Endbericht F&E Headquarter Strategy, *TCM International Tool Consulting & Management GmbH*, p. 7-28.
Haas, F., Nuspl, E., 2011. Präzises, schnelles Messgerät für mobiles Condition Monitoring von Zerspa nungsprozessen, *In AALE 2011*, p. 161-169.
Horwatitsch, D. (et al.), (2007). Ermittlung der Reibung zur Verwendung in einer FE-basierten Prozess-simulation eines Zerspanungsprozesses, *In Proceedings ÖTG Symposium 2007*, p. 45-52.
Kistler (Ed.), 2009. Präzise Messsysteme für die spanabhebende Fertigung, p. 7-9.
Tani, Y., Hatamura, Y., Nagao, T., (1983). Development of Small Three-component Dynamometer for Cutting Force Measurement, p. 657-658.