Journal of Machine Engineering, Vol. 10, No. 2, 2010

process monitoring, tool holder,
piezoresistive thin film sensor

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MONITORING SYSTEM FOR HIGH SPEED WOOD MACHINING PROCESSES

The improvement of product quality as well as the increase of production efficiency is inevitable in modern manufacturing processes. In this regard an increased cutting speed causes dangerous process situations in respect to operator safety and machine damage. In addition to that wood working machines generally do not use process monitoring systems, e. g. tool breakage monitoring.
The aim of this project was the development of a process monitoring system to increase safety in wood working processes. Therefore, the Institute of Machine Tools and Production Technology (IWF) and the Fraunhofer-Institute of Surface Engineering and Thin Films (FhG IST) developed a sensor-integrated tool holder, which is able to detect clamping forces and unbalances during the process. The hollow shank taper 'HSK-63-F' was chosen as tool holder as it is used in the majority of applications in wood working processes. The clamping and balance conditions are measured by an embedded piezo-resistive thin film sensor at the planar contact surface. To ensure a contact-free signal transmission a telemetric system was used. The interaction between this monitoring system and the machine control automatically activates an emergency stop. Hence, a system was developed which significantly increases the process safety during the run-up and the idle speed phase of the spindle.

1. INTRODUCTION

Today's wood machining centers are not only designed to achieve high quality standards. Furthermore, production efficiency is important to reduce manufacturing costs. In this regard an increased feed rate and cutting speed is essential; however, this cannot be realized without appropriate safety observations.

As the main spindle speed is increased, radial dynamic forces (applied to the spindle, workpiece, tool and tool holder) are more and more important to be considered in respect to operator and machine safety. These forces occur due to the unbalances of the mounted tool

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holder system. They do not only lead to a decreased tool life time but also considerably reduce the life time of the spindle’s bearings.

Furthermore, if the excitation frequency caused by the dynamic forces equals the natural frequencies of the used tool, the possibility of tool breakage during the process cannot be excluded [1]. To guarantee operator’s safety solutions must be found to monitor the occurring forces. The aim of such a system should be to develop a process monitoring system which detects the occurring unbalance during the run-up phase of the main spindle. In addition to that, appropriate measures (e.g. emergency stop or spindle speed regulation) should be carried out independently.

2. DEVELOPMENT OF THIN FILM SENSORS

A new and effective way of monitoring forces in tools are thin-film force measuring sensors (also known as DiaForce® sensor layers) [2]. They are able to measure high dynamic force changes and can be integrated into the interface of tool and main spindle. Thus, it is possible to monitor the occurring forces. For this reason these sensors based on piezo-resistive micro-structured layers were used to identify the process parameters. Modern manufacturing processes such as coating- and laser-structuring processes allow a layer thickness of four to six micrometers to be produced. This makes it possible to directly apply the sensor layer into the tool holder without a significant change of its design. The transfer of the sensor’s outgoing signals is realized by a contact-free telemetric system in which the rotor unit is also applied to the tool holder itself.

The integration of the sensor layer into the interface area is independent of the type of tool holder. Due to its high market share of more than 80% [3] in the field of wood working, the tool holder, type HSK F63 was selected [4]. The sensor layers were placed on the polished contact surface of the appropriate inner attachment face. As this area is located in the main force direction it is the best position for detecting clamping and unbalance changes quickly and accurately. The sensor layers recognize critical balance conditions by the change of bending moment and critical states of loads by the change of the normal force (Fig. 1, top).

On the bottom side of Fig. 1, the top view with its inner attachment surface of the tool holder is shown. The sensor’s concept is based on four congruent piezo-resistive sensor segments. Changes of the applied force lead to resistance changes of the sensor-applied layer in each area. When the bending moment occurs it can be observed by monitoring the resistance of both sensor segments, in direction of unbalance and in opposite direction. Thus, the unbalance is measured by the signal of two opposing surfaces being connected according to a Wheatstone half bridge circuit. Furthermore, the clamping force is measured by a series connection of all sensors covering the planar surface. As a result unbalance and clamping forces can be simultaneously detected with this setup using the same sensor elements.

The coating was carried out in a plasma assisted chemical vapor deposition process (PACVD process), in which the sensor layer, consisting of a diamond-like amorphous carbon - hydrogen film, was separated. Regarding friction coefficient and hardness, the

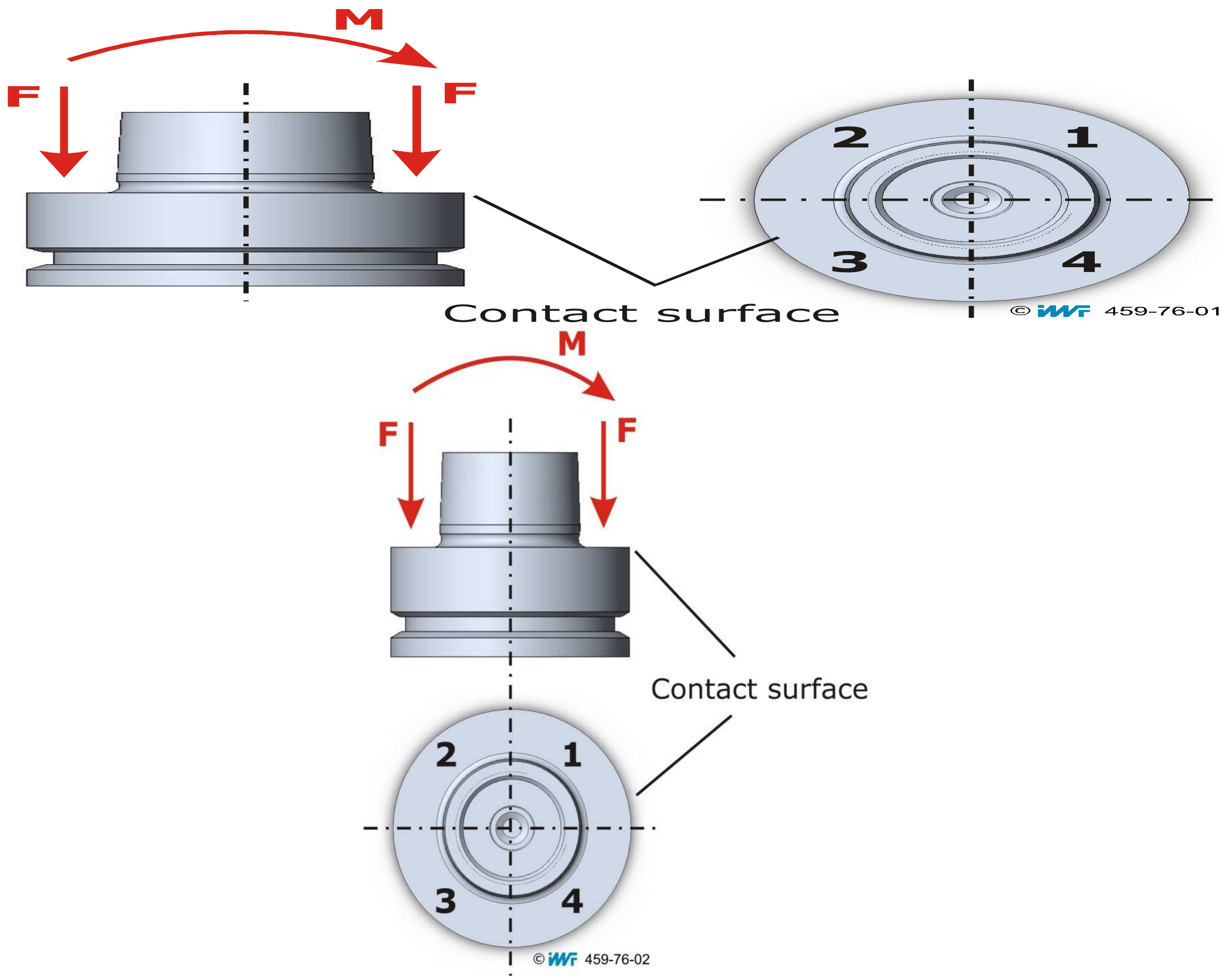

Fig. 1. Top: Characteristics to be measured by the sensor (bending moment *M* and clamping force *F*)
Bottom: Division of the planar contact surface into four areas (sensor segments)

applied sensor layer combines piezo-resistive behavior with excellent tribological properties. The pre-condition for a 'DiaForce® layer' with excellent adhesive strength and minimal defects is a surface with good flatness and low roughness, so that the contact conditions and thus the sensor behavior are reproducible. For this reason, a pretreatment of the inner attachment face by a polishing process to a maximum surface roughness of $R_z = 0.1$ µm is necessary. This will prevent high peaks of the surface profile from causing defects in the sensor layer and leading to short circuits. In direct contact with the thin film sensor gets a photolithographically structured and a metallized polyamide foil. The four electrode structures consist of a galvanically deposited nickel layer with a thickness of five micrometers (Fig. 2, left). At the end of these layers cables for connection are soldered. The application of the connecting layer with the depicted view downwards implicates that recesses (pockets) must be inserted in the planned installation. These prevent damage to the cable in clamping operations, where the inner attachment face is directly applied to the spindle. The location of the electrode structures on the connecting layer was chosen in such a way that the contact wires are located in the areas of the four pockets (Fig. 2, right).

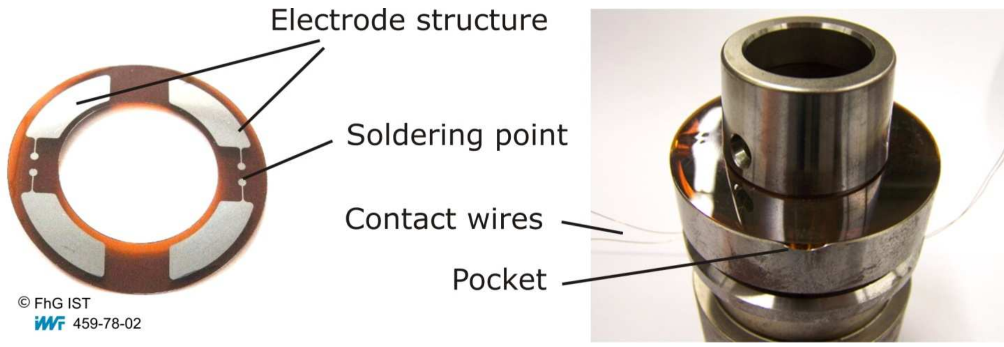

Fig. 2. Left, Contact foil in optimized design; Right: Planar contact surface with applied contact foil

To ensure an undisturbed power supply of the sensor and signal acquisition while the spindle is running, an inductive telemetric signal was used. As shown in Fig. 3, it consists of a transmitter-unit (rotor) which is integrated into the tool holder and a receiver-unit (stator). The stator is linked to an evaluation system and a measuring board. Further, the signal transmisson between the individual sensor segments and the telemetric system was achieved by wires being located in eroded holes between the inner attachment surface (in the area of the pockets) and the telemetric system.

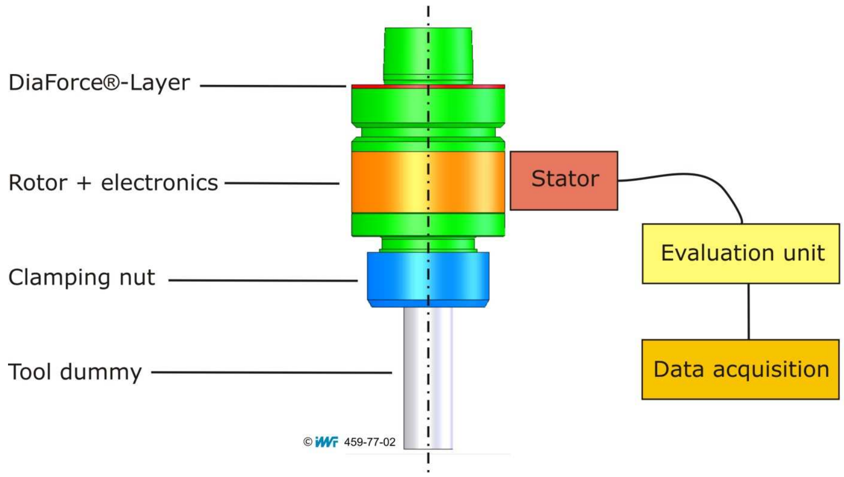

Fig. 3. Scheme of the sensor-integrated tool holder with integrated telemetric module

Fig. 4 shows the structure of the electronic measurement device in which each sensor segment can be understood as a single resistor. These are connected to the Wheatstone half bridge circuit before the signal is transmitted via the telemetric system. In addition to the four resistors, sensorpads were connected in such a way that unbalance and changes in force can be measured.

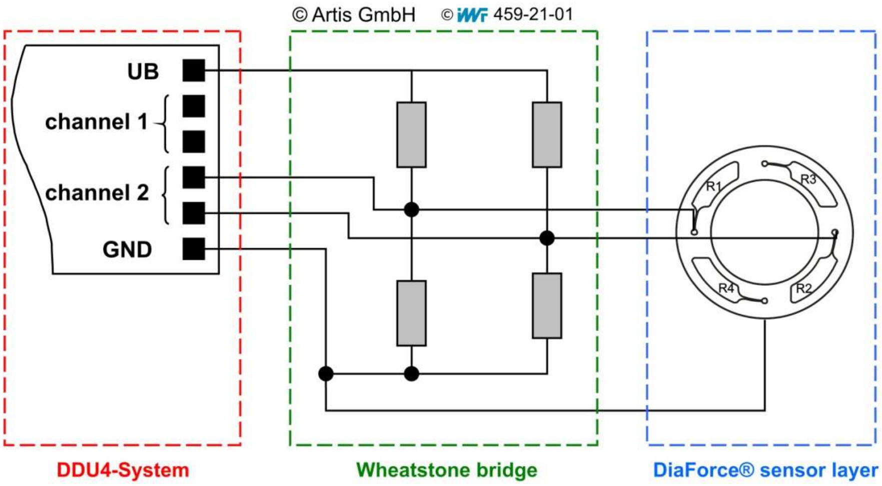

Fig. 4. Scheme and overview of the electronic measurement device (Source: Artis GmbH)

3. EXPERIMENTAL SETUP, RESULTS AND DISCUSSION

Before the first experimental studies were carried out, the single sensor segments were calibrated on a separate test stand for spindles. Since the DiaForce® sensor layers are based on the piezo-resistive principle, the signal sensor surface reacts to a change in force with a change of resistance. As shown in Fig. 5 almost no hysteresis effects occur due to repeated applying of defined loads. The sensor layers show an approximately linear progression in the operational area of more than 7 kN.

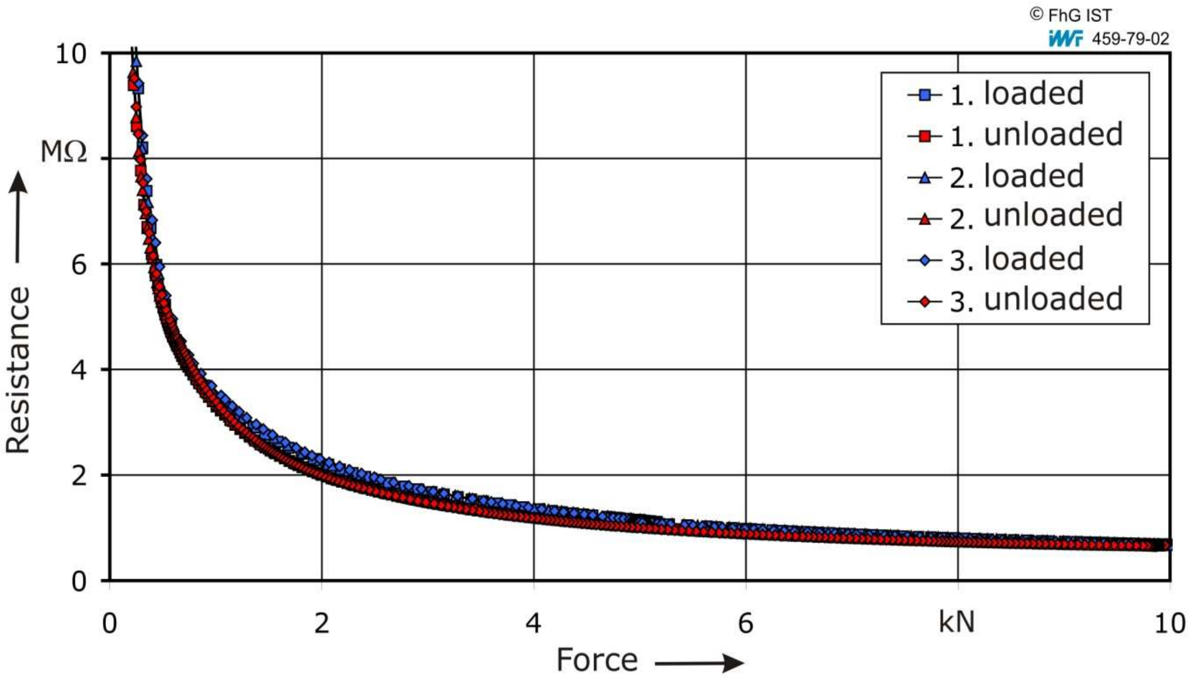

Fig. 5. Characteristic curves of force and resistance

Once the calibration of all sensor segments was done static tests for determining the clamping force and the bending torque were carried out. To analyse the characteristic of the clamping force the tool was repeatedly clamped and unclamped in a pneumatic test stand. As shown in Fig. 6 reproducible results were monitored. Further, the aquisition of occurring bending torque was tested by manual initiation of shear forces. For demonstrating unbalanced tools cylindrical tool dummies in addition to eccentrically located screws were used as shown in Fig. 7. By varying the number of screws and their thread depth the mass of unbalance can be set. According to this method a typical mass-unbalance ratio of common used tungsten carbide cutting inserts can be realized.

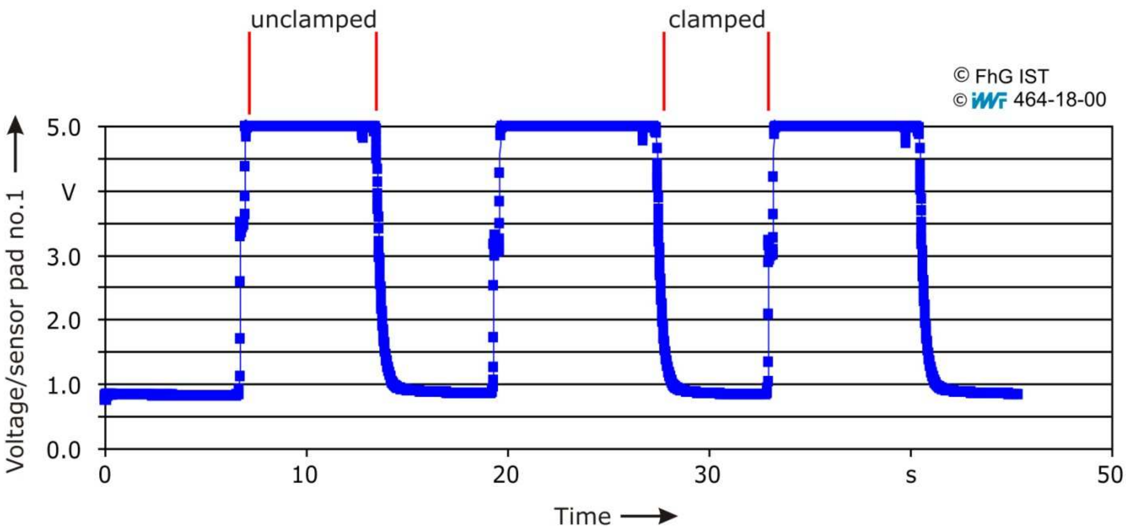

Fig. 6. Static test of the clamping force

The successful test of the tool holder was followed by the examination of its function on a machining center during operation. Therefore, a holder for the stator was designed and integrated into the z-axis of the machining center as shown in Fig. 7.

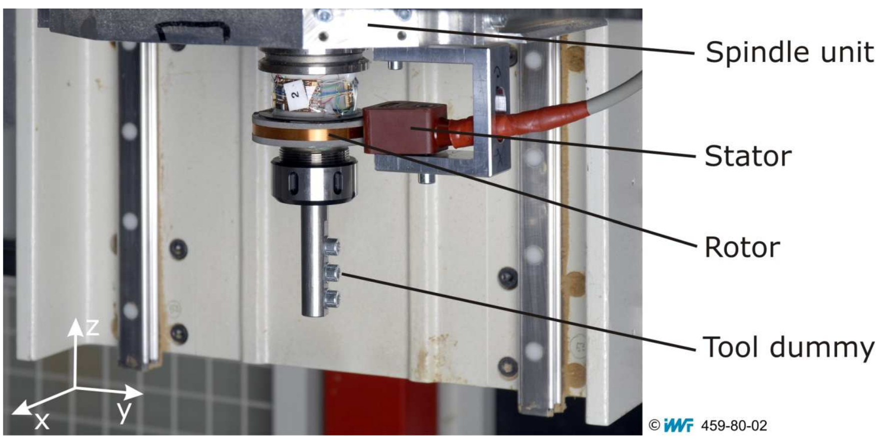

Fig. 7. Integration of the sensor-integrated tool into a machining center

For measurements during dynamic operation the direction of the unbalance has to be accurately defined. In addition to the difference value in the bending moment its direction can be determined as follows. Fig. 8 shows two curves, which were recorded at the spindle test stand. In both tests the tool dummy (shown in Fig. 7) was integrated into the tool holder. Curve 0° shows an increasing voltage signal for the run-up phase of the spindle and a decreasing signal for the decelerating phase. In this test, the unbalance was located orthogonal to the bending moment's axis. The curve shows that the increase of the spindle speed leads to an increase of voltage output. Curve 90° represents the output signal of a similar test, however, in this case the signal was recorded using two sensor segments being located in direction of the axis of the occurring bending moment. Correspondingly, the voltage signal of this test remains constant. Thus, it is possible to determine the direction of the bending moment due to an unbalanced system.

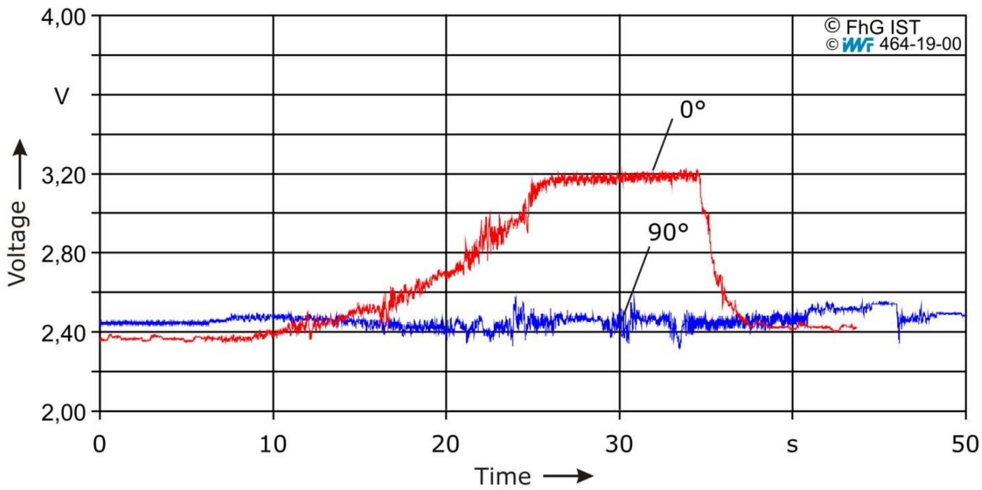

Fig. 8. Sensor signal in both direction to the axis of bending moment, parallel (90°) and orthogonal (0°)

The diagram in Fig. 9 shows single measurement curves of different values of revolution speed. The voltage signal was recorded by two sensor segments arranged oppositely to each other (R1 and R3, compare Fig. 4). The first curve documents that the change of revolution speed of the main spindle with a clamped balanced tool dummy does not effect the voltage output. Further, the tool dummy with defined unbalance is presented according to the second (1,000 rpm) and third (2,000 rpm) curve. The dynamic unbalance is proportional to the output and increases quadratically with the revolution speed. Thus, the change of voltage of the third curve representing a revolution speed of 2,000 rpm is about four times higher than the second curve representing 1,000 rpm. The dynamic test was repeated several times for different unbalance masses so that both could be demonstrated, the function itself and the reproducibility of the sensor's principle.

During the run-up phase of the spindle the signal of each sensor segment was continuously measured and fowarded to an evaluation system which consists of a computer using the data acquisition software LabVIEW® to control appropriate measures. Once a selectable and adaptable limit is exceeded, a digital signal is forwarded to the control of the

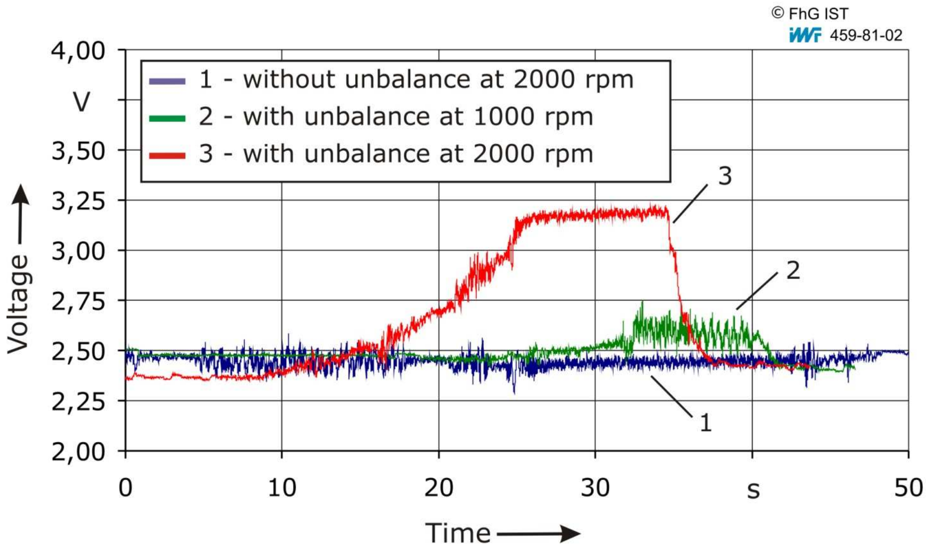

Fig. 9. Measurement results according to varied unbalances

machining center. The signal was used to automatically activate an emergency stop or to shut down the main spindle. Thus, the developed sensor system is able to detect the location and direction of the unbalance as well as variant clamping forces. Based on that, this new process monitoring system increases operator and machine safety.

4. SUMMARY AND OUTLOOK

The development of high-speed machining has led to the consequence that nearly all manufacturers of wood working machinery sell high-speed or high-performance machines. The standard spindle speed has increased in the last few years from 18,000 rpm to 24,000 rpm and a further increase is to be expected [5]. However, high-speed machining also means higher risks for operators from broken parts, e.g. broken tools, and higher risks of machine damage. To protect operators from these risk and to reduce damage related costs manufacturers are forced to take appropriate countermeasures. Nowadays, these are realized by housings or casings which, however, cannot be understood as a damage prevention. Therefore, the modified tool holder with integrated sensor control is developed in addition to already existing safety units. It detects incorrect clamping situations of the tool holder and unbalance occurring out of high manufacturing tolerances or broken tool inserts. In this way, a contribution to the increase of operator and machine safety and a reduction of maintenance is done.

The development of the presented sensor-integrated tool holder shows that it is possible to detect changes in clamping forces and unbalance during the run-up phase of the main spindle [6]. Besides the development and application of the various sensor layers a future aim of the research activities will be the integration of the highly sensitive electronic into the rotating spindle system itself. A recently granted research project based on the shown results will analyze the possibility of directly applying the thin film sensor layers to the spindle. This will reduce cost as not every tool holder has to be equipped with such a system.

ACKNOWLEDGEMENT

Support for this work was provided by the German Society for Wood Research (DGfH) through the grant from the German Federation of Industrial Cooperative Research Associations “Otto von Guericke” (AiF) under Contract No. 14273.

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