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Potential of magnetic Barkhausen noise analysis for in-process monitoring of surface layer properties of steel components in grinding

Potential der magnetischen Barkhausenrauschenanalyse für die In-Prozess-Überwachung von Randzoneneigenschaften beim Schleifen von Stahlbauteilen

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Abstract: Grinding processes are often the last step in the value-added chain of high-performance hardened steel components. However, thermo-mechanical loads which can take place during the process can have a detrimental effect on the surface integrity of ground parts, which are generally tested by post-process measurements. In the present study, two different approaches for an in-process inspection of the workpiece surface integrity were assessed using magnetic Barkhausen noise analysis during cylindrical grinding of hardened workpieces. The results showed that both measuring systems are able to detect changes in the surface state of workpieces in-process or directly after grinding in the grinding machine. After preparations to protect the sensors from influences during the grinding process, changes in the residual stress state and a decrease of hardness could be reliably detected. Due to constant contact conditions between sensor and workpiece a high reproducibility of the measurements was achieved.

Keywords: Grinding burn, Barkhausen noise, process monitoring.

Zusammenfassung: Schleifprozesse sind oft der letzte Schritt in der Wertschöpfungskette von Hochleistungsbauteilen aus gehärtetem Stahl. Thermomechanische Belastungen, die während des Prozesses auftreten können, können sich jedoch nachteilig auf die Randzoneneigenschaften der geschliffenen Teile auswirken, die in der Regel durch Post-Prozess-Messungen kontrolliert werden. In der vorliegenden Studie wurden zwei verschiedene Ansätze für eine In-Prozess-Überwachung der Randzone mittels magnetischer Barkhausenrauschenanalyse beim Rundschleifen von gehärteten Werkstücken untersucht. Die Ergebnisse haben gezeigt, dass beide Messsysteme in der Lage sind, Änderungen des Oberflächenzustandes von Werkstücken während des Prozesses oder unmittelbar nach dem Schleifen in der Schleifmaschine zu detektieren. Nach Vorbereitungen zum Schutz der Sensoren vor Einflüssen während des Schleifprozesses konnten Änderungen des Eigenspannungszustandes und eine Abnahme der Härte zuverlässig detektiert werden. Durch konstante Kontaktbedingungen zwischen Sensor und Werkstück wurde eine hohe Reproduzierbarkeit der Messungen erreicht.

Schlagwörter: Schleifbrand, Barkhausenrauschen, Prozessüberwachung.

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1 Introduction and state of the art

High performance automotive components such as gears, bearings or camshafts have to be ground after hardening in order to achieve the required form tolerances and surface qualities. Various factors such as clogging of the grinding wheel, insufficient cooling or unadapted rough grinding parameters like high material removal rates can be the reason for negative thermo-mechanical influences on the workpiece surface integrity. Depending on the intensity of the influence, various effects can occur which reach from light or heavier tempering zones with tensile residual stresses and reduced hardness to undesired re-hardening

zones (white layer). These negative influences summarized under the term “grinding burn” impair the final functional properties of the ground part [1].

There are numerous methods for post-process grinding burn detection. The most commonly used method is nital etching, which is well-established but also suffers several drawbacks. In particular, it requires qualified and experienced personnel, cannot be fully automatized, is not completely non-destructive since few microns layers can be removed and finally it brings environmental risks due to the used chemicals [1, 2]. Further well known methods for detection of existing damages are surface microhardness and metallographic testing, as well as non-destructive methods e. g. residual stress measurements, eddy current testing or the analysis of magnetoelastic effects [3]. The magnetic Barkhausen noise analysis is also well-established in industrial applications as post-process testing method, since it is particularly sensitive against light damages [1, 4, 5].

On the other hand in-process methods can be used to predict grinding burn and prevent irreparable damages of components. The prediction of grinding burn requires a holistic approach to the grinding process by sophisticated models. Malkin developed an analytical empirical approach in order to determine grinding burn limits on the base of process quantities (grinding power) for hardened steels [6, 7, 8]. Instead of the use of process models, it is also possible to use black box models such as artificial neural networks which, after training, are able to predict the surface and subsurface state based on certain process parameters [3].

Finally, different approaches which are typically used as post-process testing methods such as eddy current testing [4] or Barkhausen noise analysis [9] also have the potential for an in-process detection of thermo-mechanical damages on the workpiece due to the grinding process. However, for different reasons, in particular technical realization, real-time signal analysis and proper detection, these methods are not well-established yet and only few studies are available on this topic. For example Lanzagorta et al. stated that a direct contact between sensor and workpiece is necessary for an in-process Barkhausen noise measurement leading to an impairment of the workpiece surface and the destruction of the sensor due to wear during the sliding contact with the workpiece [4].

In the present study, the capabilities of two different approaches for magnetic Barkhausen noise analysis during grinding were developed and assessed. In the first step, the two measuring systems were prepared for in-process use to eliminate interference signals and to protect them against metal working fluid and wear. To evalu-

ate the capability to distinguish between different surface area states, in the next step measurements on test workpieces were carried out in process-near settings and with one of the systems also in-process during grinding. Due to the lack of experience in in-process detection of grinding burn, the interest was focused not only on concrete challenges such as wear due to contact between the sensor and the rotating workpiece but also on the general applicability of the approach. To give an insight into different applications, two different test workpieces made of AISI 4820 and AISI 52100 were selected. AISI 4820 is typically used for gears while AISI 52100 is used for example for camshafts.

1.1 Barkhausen noise analysis

Ferromagnetic materials consist of homogeneous, unidirectional magnetized domains known as Weiss domains. The so-called Bloch walls separate adjacent domains of different orientations from each other. When magnetized by a magnetic field, domains that are favorably oriented, i. e. those oriented approximately parallel to the external field, initially grow displacing other domains. Thus the separating Bloch walls have to be shifted. If no further Bloch wall shifts are possible, the domains are aligned in direction of the field by a rotation process while the magnetization continues to increase [10]. The stepwise movement of the Bloch walls leads to voltage jumps which can be made audible as a noise signal. This phenomenon nowadays called “Barkhausen noise” (BN) was discovered from Prof. Heinrich Georg Barkhausen in 1919 [11].

In the case of time-periodic magnetization, the ferromagnetic material reacts with a hysteresis loop of the magnetic flux density B as a function of the magnetic field strength of the alternating exciter field H (Fig. 1). The curve rises steeply in the area of the Bloch wall displacements and becomes flatter in the area of the rotation processes until it becomes horizontal in the saturation state. When the external magnetic field decreases, a residual magnetism, the remanence B_R , remains, which can be cancelled by opposite magnetization at the level of the coercivity H_c [12].

The shape of the hysteresis curve is influenced by the chemical composition, the microstructure, residual stress and other properties of the inspected part [1, 13]. Mechanically hard materials behave magnetically hard leading to high coercivity and low remanence values. Conversely, this applies to mechanically and magnetically soft materials. Changes in the level of stress lead to shearing of the hysteresis curve and therefore compressive stresses lead to a

Figure 1: Schematic view of a hysteresis loop.

high coercivity while tensile stresses induce a low coercivity [1]. Moreover, the coercivity value is almost corresponding to the maximum of the BN amplitude. On the other hand, the Barkhausen noise amplitude generally increases with increasing remanence, so that compressive residual stresses lead to a low Barkhausen amplitude and tensile stresses lead to a signal increase [14].

Depending on the analyzing frequency f , different depth ranges can be probed by Barkhausen noise analysis. The penetration depth δ at which the amplitude of the magnetic field is still $1/e$ of the intensity at the surface can be approximated by the Eddy Current skin effect relation given below. Thereby μ_r the relative permeability and σ the electrical conductivity are material-dependent parameters which are also influenced by the microstructure while μ_0 is the constant vacuum permeability [15].

$$\delta = \frac{1}{\sqrt{\pi f \sigma \mu_0 \mu_r}}$$

Different manufacturers developed devices based on the use of the magnetic BN and other micromagnetic methods for the assessment of the surface integrity status of ferromagnetic workpieces. In this work, the 3MA-II technology from Fraunhofer IZFP and the Rollscan technology from Stresstech are used. The different devices are introduced in the following subsections.

1.2 The 3MA-II-technology (micromagnetic multiparametric microstructure- and stress-analysis)

The 3MA-II-technology (Micromagnetic Multiparametric Microstructure- and Stress-Analysis) developed by Fraun-

hofer Institute for Nondestructive Testing in Saarbrücken, Germany (IZFP) combines four micromagnetic inspection methods: Barkhausen noise analysis, harmonic analysis of the tangential magnetic field strength, incremental permeability and multi-frequency Eddy Current analysis. Together these methods provide 41 parameters with different sensitivity to microstructure and stress state as well as different analyzing depths [16]. The combination of those measuring parameters allows for a separation of different influences such as residual stresses and hardness as well as the compensation of disturbances of the signal by unknown or secondary effects [1]. The present work focuses on the use of BN testing module due to its demonstrated high sensitivity against surface-near properties generated by grinding.

The 3MA test system consists of a front end, the probe head and a controlling software. Different types of probes are available for special applications. A sensor consists of an electromagnet for alternating magnetization of the sample volume as well as a hall probe and measuring coils between the pole shoes [1]. The electromagnet consists of a U-shaped magnet yoke and magnetizing coils. The transducer unit with hall sensor for measuring the magnetic field, transmitter coils for eddy current measurement and receiver coils for detecting Barkhausen noise, incremental permeability and eddy current is at fixed position in the presently used sensor. The Barkhausen signal caused by Bloch wall shifts due to magnetization are picked up by the receiver coil as noise signals. After amplifying, filtering and rectifying the signal M , its envelope or profile curve is displayed as a function of the magnetic field strength H . From this profile curve shown in Fig. 2 seven measured variables can be taken. Beside the maximum

Figure 2: Schematic view of the envelope of the Barkhausen noise signal with the different characteristic values which can be determined.

amplitude of the BN (M_{MAX}), the Parameters M_{MEAN} (averaged BN amplitude over one magnetization cycle), M_R (amplitude at remanence point), H_{CM} (magnetic field strength at $M = M_{MAX}$), DH_{25M} , DH_{50M} and DH_{75M} (curve width at 25 %, 50 % and 75 % of M_{MAX}) can be determined [15].

1.3 Rollscan 300

The Rollscan 300 by Stresstech is a digital BN analyzing device offering a wide range for the inspection of parts of various geometric shape. In order to generate an alternating exciter field, the Rollscan feeds the exciter coils integrated in the BN-sensor with an alternating voltage with an amplitude which can be set between 1 V and 16 V and a frequency between 1 Hz and 1000 Hz [17]. The BN signal resulting from the magnetization of the workpiece surface zone is recorded by a receiver coil and filtered in the Rollscan according to a defined analyzing frequency range (e. g. 70–200 kHz). From this signal, the so-called magnetoelastic parameter (mp value) is calculated, which is the root mean square value of the single Barkhausen pulses over one magnetization cycle. The measurement software ViewScan is used to record and save the time course of the mp value. The minimum scanning interval possible is 10 ms.

2 Experimental setup

2.1 Setup for BN measurements with 3MA-II in the grinding machine

The BN-sensor of 3MA-II device was implemented in an outer diameter grinding machine tool Studer S41. Before the implementation is described, the process conditions and thus the experimental environment should be mentioned. The investigations were performed at cylindrical

case-hardened AISI 4820 workpieces ($\varnothing 67.7 \text{ mm} \times 152 \text{ mm}$, surface hardness 730 HV1, carbon content in 50 μm depth 0.82 %, case hardening depth 1.89 mm). These were machined by a cylindrical outer diameter grinding process with variation of relevant process parameters and thus variation of the thermo-mechanical impact. The grinding experiments were carried out using a corundum grinding wheel ($\varnothing 500 \text{ mm} \times 40 \text{ mm}$) in uphill direction. In a plunge grinding process three separate grooves per sample were ground at a total depth of cut a_e of 100 μm . During the grinding process, forces (tangential force F_t , normal force F_n) were measured via a piezoelectric measuring system integrated into the workpiece spindle and tailstock. In addition, the effective power of the grinding spindle was recorded.

The 3MA-II-sensor is especially equipped with flat pole shoes and a fixed resin-cast transducer unit. The sheet metal package of the magnet yoke has been PVD-coated with a TiAlN layer in order to protect it from wear in case of workpiece contact. The housing of the sensor has been sealed against metal working fluid.

In order to eliminate interfering signals of the BN by electromagnetic disturbances, the 3MA-II-device was separated from mains by an isolating transformer (Fig. 3a) (1)). A connection between housing and tailstock (2) ensures potential equalization.

The sensor was fixed in an isolating holder enabling a rough radial positioning to the workpiece via an adjustment screw (Fig. 3b)). In order to prevent the BN-sensor from direct contact with the workpiece an adjustable spacer gets in contact with the workpiece. Hence, the gap between the sensor and the workpiece surface layer can be adapted precisely and kept constant. A spring allows the sensor to follow changing workpiece shape. The contact force is measured by a force sensor. The spacer on the top of the sensor is adjusted with a micrometer screw and enables contactless measurements with a defined air gap.

Figure 3: Principle sketch and photo of (a) the 3MA measurement setup and (b) the sensor guide within the grinding process.

This avoids wear when applying the sensor on the rotating workpiece.

After grinding the residual stress state and the hardness of the workpiece were measured by X-ray diffraction (diffractometer type MZ IV from GE Inspection Technology, Ahrensburg; Cr-K α -radiation, beam diameter 2 mm) and hardness testing (LV-700AT, LECO Instrument GmbH) respectively.

2.2 Setup for BN measurements with Rollscan in the grinding machine

The Rollscan technology was tested on a Kelvaria UR 175-1500 universal outer diameter grinding machine in order to determine if and how the recorded BN signal is affected under grinding conditions such as vibrations due to grinding wheel contact, magnetic interference fields of the drives, metal working fluid influence, etc.. The test workpiece is a multistage shaft made of AISI 52100, which was through-hardened and tempered to a final hardness of 59 HRC. The initial diameter and width of a shaft shoulder were 54 mm and 10 mm. On the second last shoulder (see Fig. 8 top right; shoulder 9), a thermal damage has been induced at the surface over an angle of 30° of its circumference by means of short time flame heating in order to simulate a local damage by grinding burn.

After the grinding test, the depth profiles of tangential and axial residual stresses were determined by X-ray

diffraction at the heat-affected and an unaffected region on the shaft's circumference. The X-ray measurements were conducted with an XStress3000 X-ray diffractometer from Stresstech GmbH. To avoid inducing any new internal stresses, the material was removed using an electrochemical etching device. The measurements of surface hardness were conducted with a portable hardness testing device MICRODUR MIC 10 from ZwickRoell, Ulm.

In order to evaluate the influence of the grinding process on the measured Barkhausen signal but at the same time not to modify the surface layer of the measured shoulder, adjacent shoulders (shoulder number 7 and 8 in Fig. 8) were ground. The Barkhausen noise sensor was mounted in the grinding machine with a device that guides the sensor linearly on a carriage (Fig. 4b)). In order to compensate distance changes of the sensor due to noncircular workpiece contours, a spring presses the sensor against the surface of the workpiece with a constant force. A variation of the contact force is possible by varying the spring preload.

For wear protection, the contact surface of the Barkhausen noise sensor was coated with a ceramic thick layer of aluminum oxide (Al₂O₃; Fig. 4a)). To prevent the penetration of metal working fluid into the sensor housing, a plastic membrane was stretched around the sensor. The supply of compressed air to the measuring position causes an approximately constant metal working fluid film between the sensor and the workpiece and thus nearly steady contact conditions.

Figure 4: Setup for in-process measurements with the Rollscan device: photo and schematical view of the coated sensor (a); device for the sensor's mounting in the grinding machine (b).

3 Results and discussion

3.1 In-process BN measurements with 3MA-II in grinding

In a first step, experiments with reference workpiece conditions were performed in order to assess and optimize the measurement strategy. In a preliminary step, an optimum distance between sensor and workpiece surface of $200\text{ }\mu\text{m}$ was determined. For this study, BN was measured on a ground workpiece rotating with the same rotational speed than in the grinding process. The workpiece used for this tests was ground applying a specific material removal rate of $Q'_w = 10\text{ mm}^3\cdot(\text{mm}\cdot\text{s})^{-1}$, which was the maximum specific material removal rate in the following test series. Figure 5 shows the measurement results for three times repeated positioning of the BN-sensor and $n = 30$ measurement points. Cutting speed v_c , speed ratio q , radial feed speed v_{fr} , metal working fluid flow rate Q_{MWF} and the dressing parameters cutting depth a_{ed} , dressing overlap U_d and speed ratio q_d are given in the box on the right. Each point in the graph corresponds to one magnetization cycle. Low scattering of M_{MAX} with standard deviation within $\pm 0.006\text{ V}$ which means $\pm 4\%$ of the measured value is resulting after multiple positioning actions. This proves the reproducibility of the positioning which is an important prerequisite for the in-process measurement capability. Only a slight increase of the M_{MAX} average values can

be observed which could have been caused by the mechanical play while adjusting the distance between sensor and workpiece surface.

After these preliminary tests, proper in-process experiments were performed. Fig. 6 shows the influence of grinding parameters on the measured BN values. The specific material removal rate Q'_w was adjusted to 1, 6 and $10\text{ mm}^3\cdot(\text{mm}\cdot\text{s})^{-1}$ in order to vary the thermo-mechanical impact on the surface and subsurface area.

The BN was measured in-process (Fig. 6a)), while residual stress depth profiles were generated afterwards (Fig. 6b)). The BN signals and process forces (Fig. 6a)) were recorded from process start while moving the grinding wheel towards the workpiece over the actual grinding process until back position was reached after grinding.

The time resolved evolution of parameters M_{MAX} and M_{MEAN} over the duration of the process with $Q'_w = 10\text{ mm}^3\cdot(\text{mm}\cdot\text{s})^{-1}$ are shown on the left side. With the start of material removal, both measured variables rise steeply within less than one second and reach a plateau. While M_{MAX} remains unchanged at the same level until the end of the grinding wheel contact, the value M_{MEAN} decreases from the beginning of spark out. Without grinding wheel contact, the initial and final values of M_{MEAN} differ only slightly, while M_{MAX} remains at an elevated level. This suggests that the excitation of the BN by the external magnetic field is further influenced by another effect during grinding. Since the maximum amplitude M_{MAX} does not change,

Figure 5: Maximum amplitude of the BN signal measured at a rotating workpiece after grinding.

Figure 6: (a) Maximum amplitude of BN and averaged BN during a grinding process with $Q'_w = 10$ mm³/(mm·s) (left); Average and standard deviations of Maximum BN amplitude, tangential and normal forces during the three grinding processes. (b) Depth profiles of axial residual stresses $\sigma_{\perp}$ and tangential residual stresses $\sigma_{\parallel}$ of the ground surfaces.

this additional excitation seems to have an effect mainly on the width of the envelope (see Fig. 2). This effect is not fully understood and will be investigated in detail in following work.

The bar chart (right) compares the in-process measured BN amplitude M_{MAX} and grinding forces (tangential force F_t , normal force F_n) for the three different specific material removal rates. With increasing thermo-mechanical impact (in this case: increasing Q'_w) the Barkhausen signal increases. Since it is known that the BN amplitude is sensitive to both hardness and residual stresses, residual stress depth profiles and surface hardness were measured (Fig. 6b)).

After grinding with $Q'_w = 1 \text{ mm}^3 \cdot (\text{mm} \cdot \text{s})^{-1}$, residual stresses are in the compressive range over the whole analyzed depth of about $150 \mu\text{m}$. Even after grinding with $Q'_w = 6 \text{ mm}^3 \cdot (\text{mm} \cdot \text{s})^{-1}$ there are still compressive residual stresses, but significantly shifted in the direction of tensile residual stresses in the first $25 \mu\text{m}$ below the surface. In the sample with the highest specific material removal rate of $10 \text{ mm}^3 \cdot (\text{mm} \cdot \text{s})^{-1}$ the residual stresses rise to tensile stresses at a depth of $10 \mu\text{m}$ to $30 \mu\text{m}$ below the surface. The average surface hardness decreases slightly with increasing specific material removal rate. However, considering the standard deviations, the change is not considered as pronounced. The thermo-mechanical influence in the surface and subsurface region increases with the increasing specific removal rates. For both $Q'_w = 6 \text{ mm}^3 \cdot (\text{mm} \cdot \text{s})^{-1}$ and $Q'_w = 10 \text{ mm}^3 \cdot (\text{mm} \cdot \text{s})^{-1}$ the process mainly affected the residual stress state which is therefore in the range of slight damage for the highest value of Q'_w . This type of beginning grinding damages might not be necessarily detectable by nital etching, since with this method only hardness differences are visible due to differences in etching contrast.

Based on these first investigations it could be clearly demonstrated that the BN signals measured in-process can be used to detect changes in residual stresses in the surface and subsurface region qualitatively in real time. An extension of the micromagnetic analysis for in-process quantitative residual stress determination will require further investigations. Hence, an extension of the grinding parameter range will lead to a more pronounced effect on the surface hardness as well as higher tensile residual stresses due to light or heavy tempering. The distinction of these different surface states by means of BN values will be subject of further investigations. For this, further research work will investigate alternative micromagnetic parameters which describe the envelope (Fig. 2) of BN more precisely.

3.2 BN measurements with Rollscan 300 in the grinding machine

The courses of the tangential and axial residual stresses at a heat-affected and an unaffected position of the multistage shaft made of AISI 52100 are shown in Fig. 7. The residual stress states do not differ significantly depending on the thermal influence: directly at the surface compressive stresses are observed which decrease in the region of the thermal damage. From a depth of about $15 \mu\text{m}$ the compressive stresses change into almost constant tensile stresses. The hardness of the unaffected zone is 59 HRC. At the heat-affected surface it decreases to 43 HRC. In summary, the thermal damage is characterized by a significant decrease in hardness and a slight decrease of the compressive residual stresses near the surface. In contrast to the states described in Section 3.1, this is a pure thermal damage. The depth of the influence is larger than it would be expected in the case of thermo-mechanical damages caused by grinding.

The pre-process measurement of the BN on the rotating workpiece (Fig. 8 left) between zero and six seconds shows a mp value about 40 mV from the thermally unaffected microstructure and an increase by about 18 mV in the zone with reduced hardness caused by thermal damage. The thermal damage at the circumference can thus be clearly identified. As a result of the grinding wheel contact from six seconds on, the mp value of the thermally unaffected area rises to about 110 mV and is significantly more volatile than in the pre-process measurement. The mp value measured at the thermally damaged region is again about 18 mV higher. Although the signal course is significantly influenced, different microstructure states can still be identified. At about 66 s the grinding wheel lifts off the shaft. At this moment the signal drops and similar values as before the process are recorded. Measurements taken between zero and six seconds and from 66 seconds on show no significant influence of the moving machine axes on the BN signal.

These results show the potential of BN measurements for the detection of hardness losses on the rotating workpiece as well without grinding wheel contact as in a process-near setting during grinding of a neighbored shaft shoulder. In case of a real thermo-mechanical surface damage the hardness loss would be accompanied by a shift of residual stresses. To separate both influences on the BN from each other a combination of different signals (see Section 1.2) would be necessary. However, this separation is not essential for the monitoring of the surface state. Due to the time resolution up to 10 ms (see Section 1.3) a spatially resolved detection of local damages

Figure 7: Residual stress depth profiles in axial (a) and tangential (b) direction and hardness at the shaft shoulder with thermal damage.

Figure 8: Time course of the mp value with and without simultaneous grinding wheel contact (left); measuring and machining conditions (right).

is possible. The increase of BN signal for measurements with grinding wheel contact is similar to the behavior of M_{MEAN} during in-process measurements with 3MA-II (Section 3.1) and will be subject of further investigations as well as in-process measurements of thermo-mechanical induced damages. A possible explanation for this signal increase is expected in a mechanically-induced activation of Bloch wall movements.

After the measurements carried out till now, neither damages on the sensor nor an effect on the workpiece surface could be observed. For further statements on the long-term performance of the sensor coating and possible effects on the topography of the workpiece surface, a longer time of use must be awaited.

4 Conclusions

The investigations have shown that the BN analysis enables an in-process monitoring of the surface integrity of workpieces during grinding. Both applied measurement techniques allow distinguishing of different surface conditions on the base of in-process measurements (3MA-II) respectively measurements in a process-near setting (Rollscan 300). Wear caused by contact between the sensor and the rotating workpiece could be prevented by suitable coatings or contactless measurements, whereas the long-term resistance of the coating still has to be evaluated.

In future investigations, in addition to an extension of the grinding parameters, both workpiece types should be inspected with both measuring systems in order to assess the detectability of influences of different intensity. Furthermore limits and strategies for a precise assessment of the surface area state should be developed.

The results allow the capability of significant time saving by avoiding inspection times after grinding. They also build the base for a control of the grinding process, in which the parameters are adapted to the current state of the surface and subsurface area.

In future, multi stage grinding processes shall be monitored by this measurement technique in order to achieve process conditions close to industrial conditions. The observed mechanical excitation of the BN is also the subject of future work as well as the suitability of further investigations and methods of the 3MA technique for the detection of the surface conditions.

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Maximilian Rößler studied mechanical engineering specializing in machine tools/production processes at the Technical University of Chemnitz from 2016 to 2019. After his studies he was employed as a scientific researcher at the Fraunhofer Institute for Machine Tools and Forming Technology in the Cutting Technology Department. The range of tasks includes on the one hand the development of new simulation models and the extension of existing ones, and on the other hand the investigation of the applicability of the in-process measured Barkhausen noise.

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Jeremy Epp graduated in Metallurgical science in Nancy, France. Since 2006 he was working as research fellow at Foundation Institute for Materials Science – IWT in Bremen, Germany. He received his Ph. D. degree in 2016 in the faculty of production engineering at the University of Bremen, Germany. Since March 2012 he is head of the department Physical Analysis within the Materials Science division at the Leibniz Institute for Materials Engineering – IWT in Bremen, Germany.

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Jochen Eckebrecht received his Ph. D. degree in 2000 at the University of Bremen, faculty Production Engineering. From 1991 until 2018 he worked as a scientific researcher at the Foundation Institute for Materials Science – IWT in Bremen. Since September 2018 he is head of the department Grinding Technologies and Gear Manufacturing of the Division Manufacturing Technology at the Leibniz Institute for Materials Engineering – IWT. Focus of his scientific work are grinding processes in general, tool development, process monitoring and metal working fluid application.

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Jens Gentzen learned the profession of a mechanical engineer in the former machine tool combine “7 October” of the GDR. In 1990, he completed a distance learning course at the Technical University of Karl-Marx-Stadt (now Chemnitz) in the field of Technology of the metalworking industry and worked as a test engineer for a grinding machine manufacturer until 1995. From 1995 onwards, he built up the department Cutting with geometrically undefined cutting edge at the Fraunhofer Institute for Machine Tools and Forming Technology. Since 2010 he has been head of the Grinding and Honing Processes group.

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Matthias Putz studied mechanical engineering at the Technical University of St. Petersburg. He received his Ph. D. in 1986 in the field of machine tool construction. In 1994, he joined the Fraunhofer Institute for Machine Tools and Forming Technology and has held several management positions since then. In 2007 he was appointed honorary professor at the University of Applied Sciences Dresden. Since April 2014, Professor Putz has been head of the Fraunhofer Institute for Machine Tools and Forming Technology and is responsible

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Bernhard Karpuschewski graduated from the University of Hannover, Germany. He received his Ph. D. degree in 1995 at the Institute for Production Engineering and Machine Tools (IFW), University of Hannover. From 1995 until April 1999 he worked as chief engineer of this Institute. From May 1999 until October 2000 he accepted a position as Associate Professor at the Keio University, Yokohama (Japan). Following he worked as full professor for production engineering at the Technical University of Delft (Netherlands) from 2000 until March 2005. From April 2005 until August 2017 he worked as full professor for production engineering and managing director of the Institute for Production Technology and Quality Management in Magdeburg (Germany). Since September 2017 he is professor at the University of Bremen (Germany) and director of the Division Manufacturing Technology at the Leibniz Institute for Materials Engineering – IWT.