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Fraunhofer Institut Zerstörungsfreie Prüfverfahren

PROCESS-INTEGRATED NONDESTRUCTIVE TESTING OF GROUND AND CASE HARDENED PARTS

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Abstract

To verify the fundamental idea ”Physical properties of heat-treated and machined surfaces contain basic information about the complex microstructure and residual stress state” electromagnetic and acoustic properties are measured using new breeds of testing instruments (prototype). Intelligent sensor systems are the solution to achieve unambiguous results. By utilizing these sensor systems, evaluation of hardness, case depth, and residual stress can be performed nondestructively. Results obtained using manufactured parts demonstrate that quality characteristics of machined and heat-treated parts can be determined in a quantitative way.

Introduction

Heat treatment and finishing processes are necessary to give materials the desired strength, shape, and surface quality. Present quality management systems are based on tests performed in accordance with relevant industrial standards. However, these tests are time consuming and in many cases destructive, and therefore, are unsuitable for process-integrated nondestructive testing (PINT) and for fast post-process testing (FPPT), respectively.

Available systems for nondestructive quality inspections (NdQI) use optical, thermal, mechanical, electromagnetic, or acoustic methods. Parameters such as topography, microstructure, hardness, residual stresses, case depth, texture, and cracks are the most important targets for NdQI. During the past five years, R&D has demonstrated that parameters such as hardness, residual stresses, and case depth can be evaluated simultaneously by using multi-parameter sensor systems.

Results

Nondestructive Hardness and Case Depth

Hardness tests are usually performed according to standards such as Rockwell (DIN 50103), Brinell (DIN 50351), Vickers (DIN 50133), etc., and case depth tests in accordance with DIN 50190 Part 2, DIN 50133 Part 2, EURONORM 116-72, ISO 3754-1976 (E), etc. So far, similar standards and codes are not available for NdE-based testing. Nevertheless, new nondestructive techniques have found their applications in the engineering industry due to various reasons: the methods are economically beneficial, conventional tests are not applicable, different material properties can be measured simultaneously, real-time monitoring systems, and 100% inspection are in need.

Electromagnetic Instruments

Nondestructive evaluations (NdE) of hardness and case depth are based on elastic, electrical, and magnetic material properties. In the case of ferrous materials, electric, magnetic, and magneto-elastic parameters can be measured. These properties depend on microstructure, macro-stresses, micro-stresses, anisotropy, and further intrinsic properties. The challenge is to measure these different parameters with one sensor in an industrial environment, and to develop the best method to analyze all the various information. One possible solution is the 3MA technology.

3MA instruments (**3MA**: **M**icromagnetic-, **M**ulti-parameter-, **M**icrostructure- and Stress **A**nalyzer) are modular systems, which utilize information derived from four different physical quantities:

- Eddy current
- Barkhausen noise
- Time signal of tangential magnetic field strength
- Incremental permeability

The multi-parameter characteristics of these quantities allow intelligent signal processing with main features such as the suppression of disturbances, multi-target-teaching, the control of testing parameters, and simultaneous measurements of up to nineteen parameters (1).

Figure 1: 3MA Test Instrument

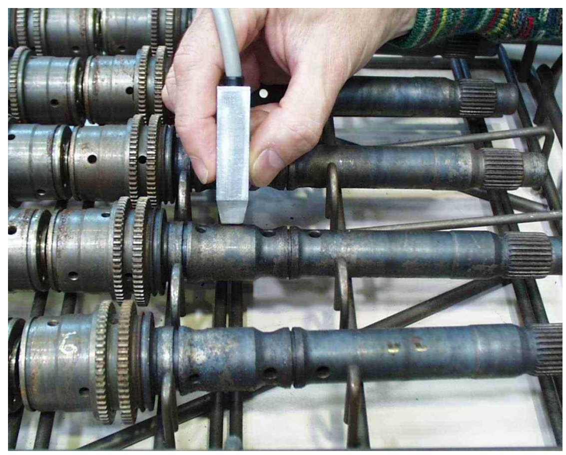

Figure 2: Input Shafts and 3MA Sensor

Multi-parameter least square analysis and neuronal net analysis are applied to achieve the best correlation between 3MA parameters and material properties—the 3MA sensor design uses the same approach. Quantitative nondestructive results require a calibration procedure, which includes the following mandatory steps:

1. Recording of 3MA data on parts with known hardness and case depth
2. Computation of approximation functions by regression analysis
3. Setup and installation of the applicable functions on the 3MA instrument

After this preparatory teach-in, quantitative hardness and case depth values can be evaluated nondestructively at a cycle time of about 1 second per data point. Figure 2 shows the 3MA probe sensor manually positioned on an induction hardened input shaft. Figure 3a presents NdE data for the case depth in comparison to conventional testing results. Figure 3b depicts the screen display of the 3MA system indicating the values of hardness and case depth. Ten 3MA-parameters were used as input variables to evaluate the (NdE) hardness and case depth values. The mean standard error of the nondestructively measured values is comparable to conventional tests.

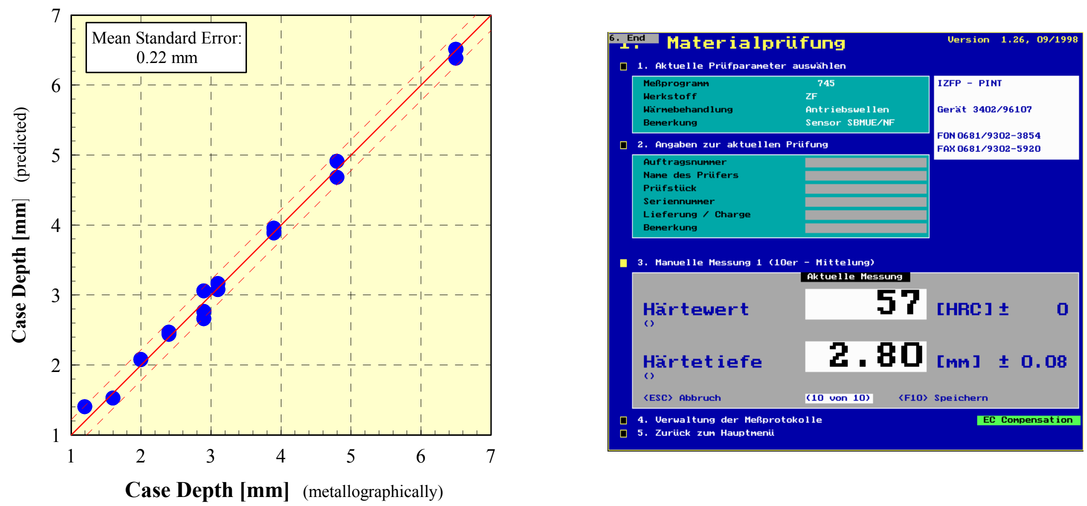

Figure 3: Correlation between 3MA case depth and conventionally determined values for input shafts (a) and screen display of 3MA-system (b)

In another PINT application, the 3MA sensor was integrated into a CO_2 laser-hardening machine, producing guide bars. Hardness and case depth are measured during the hardening process, approximately 5cm behind the laser spot. The 3MA system uses eight parameters for real-time monitoring of both values (3, 4). Up to now, nitride-hardened, laser-hardened, inductive-hardened, and case-hardened parts were examined with the 3MA system. NdE results were obtained on case depths up to 4 mm. The most difficult NdE task is to acquire quantitative results on case hardened parts. Scale, retained austenite, and varying stresses are the dominant disturbance factors for these applications.

Ultrasonic Instruments

Induction hardening improves both, the wear resistance and the fatigue strength of parts under dynamic strain. These characteristics are primarily determined by the case depth and the residual stresses in the hardened transition layer.

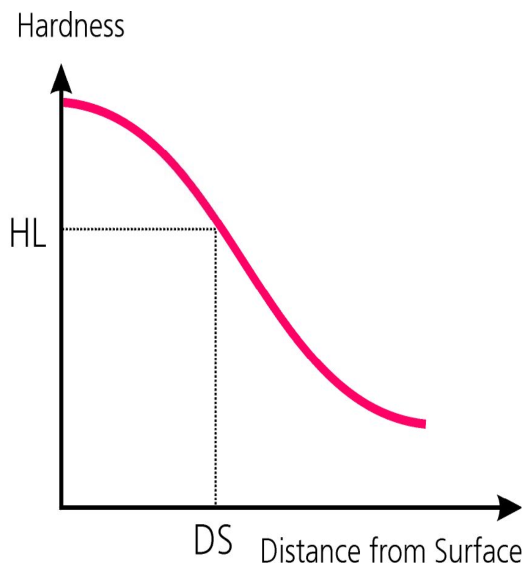

Figure 4: Determination of the Effective Hardening Depth

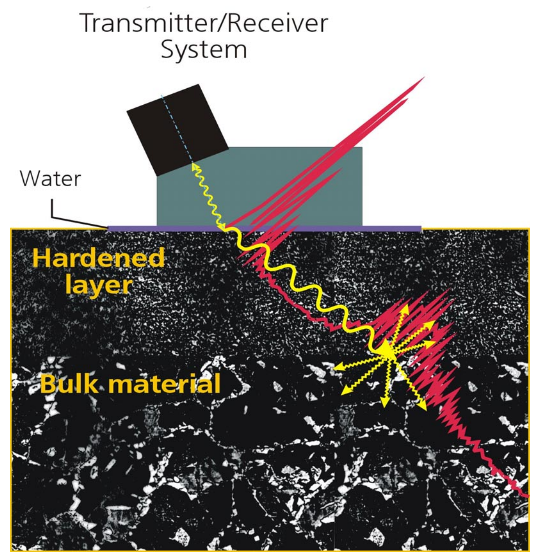

Figure 5: Backscattering Method

DS, the effective depth of hardening (see Figure 4), is an essential quality attribute in case hardening. Until now, quality control of hardening processes is established by random testing only, using destructive techniques, which are time consuming and costly. DS tests are performed either according to known codes or by visual (optical) testing of the cross-section of heat-treated parts.

For FPPT and PINT applications, the ultrasonic backscattering method can be used (see Figure 5). The backscattered ultrasonic amplitude depends, in this case, on the actual gradient of the microstructure. In the transition area, grain boundaries, grain size, and second phases are areas where the acoustic impedance value is changed in a discontinuously, depending on the ultrasonic frequency. If these solid-state properties in adjacent areas increase, different backscattering signals in the hardened and the bulk material occur. These amplitude characteristics can be used to evaluate the case depth by using simple time-of-flight measurements. For inductive hardened parts, the ultrasonic backscattering method uses the fact that the hardened layers (martensite) are almost transparent to ultrasonic waves (in the range of 20 MHz) while the bulk material (e.g. ferrite-perlite) scatters ultrasonic waves very strongly (see Figure 6). The ultrasonic test instrument is shown in Figure 7.

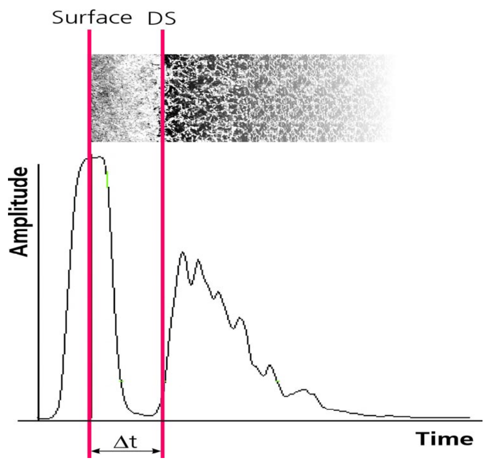

Figure 6: Backscattered UT Signals used to Obtain DS Values

Figure 7: Ultrasonic Backscattering Instrument

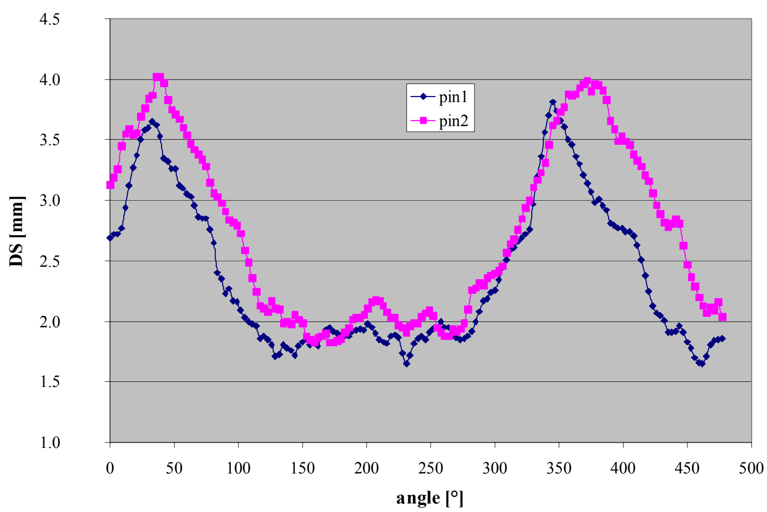

Figure 8: Case Depth Testing on Crankshaft Fillets

Figure 8 shows results obtained from crankshaft fillets. More than 150 data points were recorded in circumferential direction (45° to the axis of the shafts), each of the data points were recorded in approximately one minute. The highest DS values were measured at the top dead center of the crankshafts, while the lowest values were obtained in the area of the bottom dead center.

Results obtained during the past 5 years have shown that the ultrasonic backscattering instrument can be used to:

- Optimize manufacturing parameters
- Reduce idle times
- Perform failure mode and root-cause analysis
- Monitor and analyze DS results for quality management information systems
- Assure a continuous level of high quality
- Effectively reduce testing efforts and costs