

# Method of case hardening depth testing by using multifunctional ultrasonic testing instrument

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**Abstract.** The paper describes usability of ultrasonic case hardening depth control applying standard instrument of ultrasonic inspections. The ultrasonic method of measuring the depth of the hardened layer is proposed. Experimental series within the specified and multifunctional ultrasonic equipment are performed. The obtained results are compared with the results of a referent method of analysis.

## 1. Introduction

Nowadays metalworking industry is growing all over the world. Its primary manufacture operations consist of fabricating or assembling metal parts. This industry produces a very wide range of products, such as: electrical machinery (motors, generators, and transformers), other machinery (engines, turbines, pumps, mining and metalworking equipment), transportation equipment (automobiles, aircraft, railroad equipment, ships and boats) and other fabricated metal products. Each of these areas contains the type of details that are used under certain conditions, such as dynamic loads. Due to the fact that the amount of various parts that work under the influence of dynamic loads is continually growing it is necessary to monitor their quality effectively, both at manufacturing and operation stages. The ability to sustain loads without damaging is provided by specific structure of heavy loaded components. Such components have hardened surface layer and mild core material. The case hardening depth is the criteria of a component quality.

The state-of-the-art principles of diagnostics are based on destructive testing methods which are costly and time consuming, and not always effective. Destructive testing is a statistical method; usually the results of inspection are formed according to the condition of certain selected details. There is no guarantee of each detail quality in a wide line of components. Such method does not provide comprehensive output control. Of course, there are some well-known nondestructive (NDT) methods too. Most of them are based on the physical properties of the material, in metalworking industry it is usually steel or another ferromagnetic material. Unfortunately, these methods of inspection have considerable limitations in use. Electromagnetic method is the most widely used method of nondestructive testing in Russia. However, this method can be applied only for monitoring the subsurface of the hardened layer. The depth of the layer that can be inspected is to be 1 mm or less. Further it is extremely difficult to automate the process of scanning while using the electromagnetic method of control.

The analysis of worldwide experience in this area has revealed that application of ultrasonic methods of control have been applied to solve this problem At Fraunhofer Institute for Nondestructive Testing (IZFP) the method of measuring the depth of the hardened surface layer of metal details was



developed [1]. Furthermore this method formed the basis for development of the instrument which lately found wide application in the metallurgical industry market all over Europe. This instrument has very specific application; basic function of ultrasonic inspection is not provided. This implies that effective quality monitoring requires an operator to use several instruments. One instrument is for measuring case depth hardening and determining quality according to the technical requirements, while the other is for determining whether a component has any defects that may decrease its sustainability. It is useful to combine these two functions in one instrument to provide the effective procedure of quality control of heavy-loaded components. In this respect the main aim of the research was to determine the suitability of the ultrasonic nondestructive testing method for measuring case hardening depth applying multi-operated ultrasonic instrument.

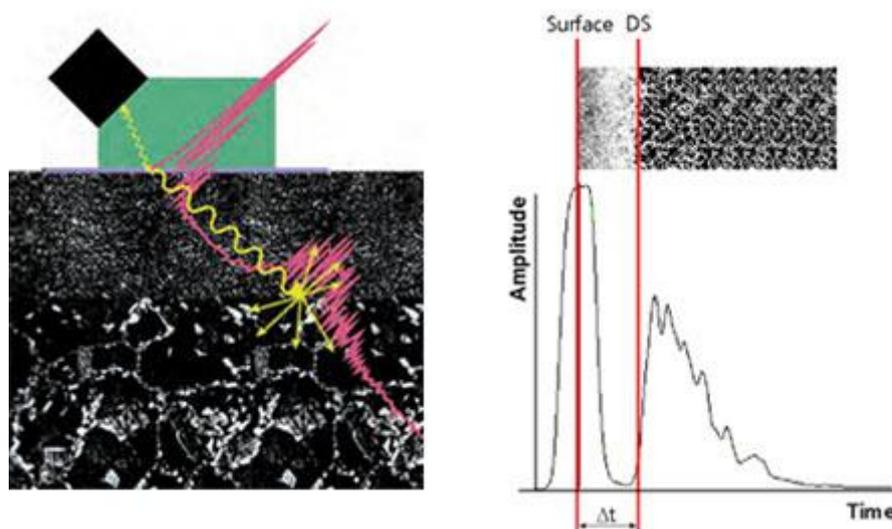
## 2. Ultrasonic Attenuation in Hardened Materials

Usually an ultrasonic inspection system consists of several components, such as electronic unit, transducer and display devices. The receiver is also the transmitter; it can produce high voltage electrical pulses. Transducer with piezoelectric element can convert these pulses into high frequency ultrasonic energy. If there is a flaw such as a crack or a pore some of the energy will be reflected back from the flaw surface. The time between the moment when the signal was generated and when the echo was received, can be measured. According to this time it is quite simple to count the distance that the signal has traveled. Moreover the information about the reflector location, size, orientation and other features can also be obtained.

Ultrasound attenuation is the reduction of the amplitude and the intensity, and consequently of the acoustic wave itself as it propagates. The main reason for this effect is acoustic scattering. Ultrasound scattering occurs due to the sharp change in fluid properties (density, modulus of elasticity) at the boundaries of inhomogeneities which dimensions are comparable with the wavelength.

In general the sound waves are scattered in all directions. Some of them are also scattered back to the ultrasonic testing (UT) probe. On the one hand the effect that means the magnitude of the scattered and backscattered sound energy depends on the change of density and/or the elastic material properties within the volume range. On the other hand it depends on the relation of the geometric size of the volume range and the wavelength of the ultrasonic waves.

When inspection of the hardened surface layer is performed, it is important to pay attention to the structure of materials under inspection. The surface hardened layer is the material with fine grain size permeable to ultrasonic waves (Figure 1). At the same time unhardened material grain sizes are much bigger and this difference causes strong scattering of ultrasonic waves in different directions.



**Figure 1.** Attenuating in steel.

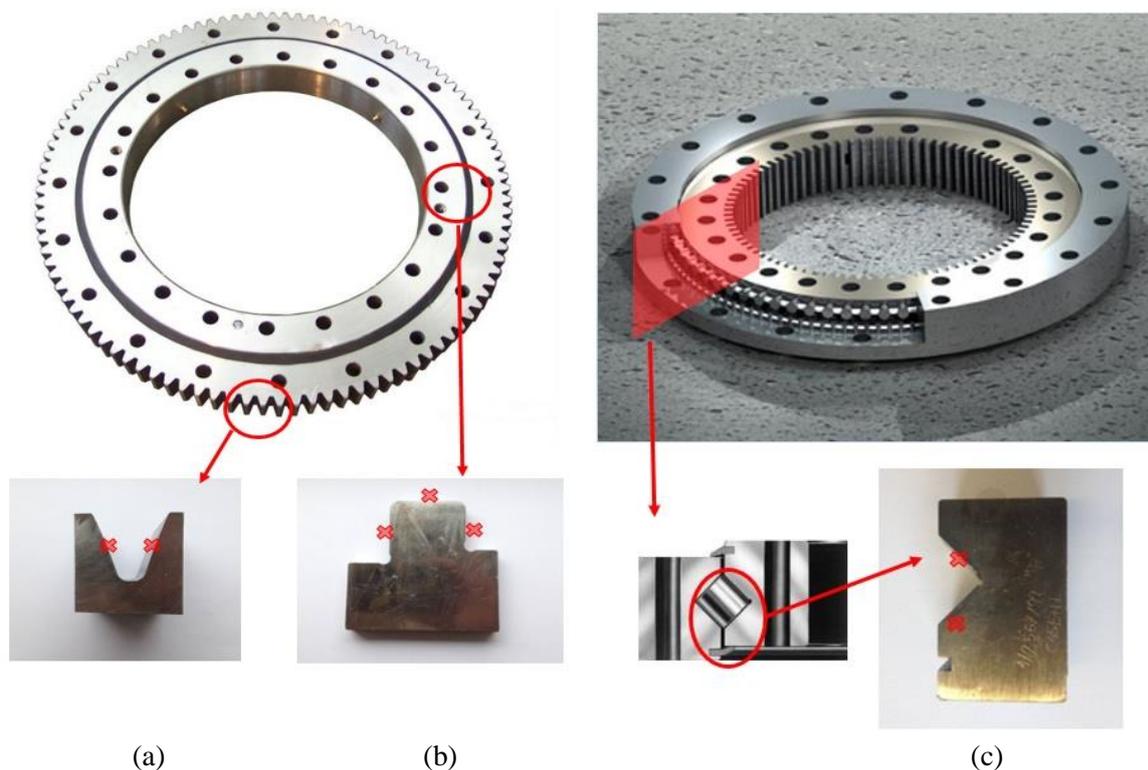
Due to the fact that magnitude of ultrasonic backscattering can be influenced by adjusting the wavelength of ultrasonic waves it is very important to find the right frequency range. Thus in case when size of a grain is larger than the wavelength the sound can be reflected by its boundary.

Ultimately the scattered signal is scattered back to the testing probe. The main item to be measured is the time of wave propagation. Time measurement process can be automated by developing specialized software. As a result of measurement the depth of the hardened layer of material in mm is displayed on the instrument screen.

Following these principles the instrument can be produced to measure the depth of hardened layer which is the main quality characteristic of hardened items.

### 3. Experimental Procedure

The samples were selected for the experiments to verify the use of ultrasonic NDT methods for quality control of dynamically loaded components applying multifunctional instrument. Each of the samples is a part of the slewing bearings. The choice of the component was made due to the fact that bearing is the most commonly used detail in metalworking industry. The experimental samples are of different shape and therefore have different measuring positions (Figure 2). There are two rows of rolling elements: internal and external rings that clamp together axially. Depending on the load point, each part has different points of hardening. This conditioned the choice of measuring positions for the experiment. Series of measurements were performed in each position to provide reliable results.



**Figure 2.** Experimental samples: a – sample №1, b – sample №2, b – sample №3.

Two types of equipment – specific and multifunctional were chosen to provide reliable results of the experiment. Case Depth Tester (P312), QNet was chosen as a specialized instrument. Fraunhofer Institute for Non-Destructive Testing (IZFP) has developed the ultrasonic method for fast and nondestructive case depth testing. This instrument provides fast production control and ensures consistently high quality levels of quality management.

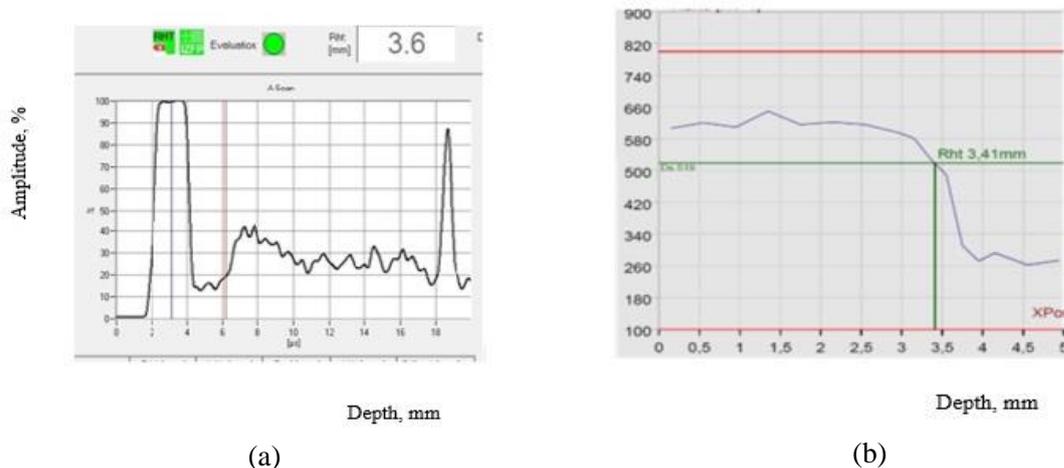
The case depth tester P3121 consists of the following components: computer unit and sensor system (Figure 3).



**Figure 3.** Ultrasonic testing instrument for testing the case depth, P3121, Case Depth Tester.

Case hardening depth values of experimental sample №2 measured by the specific ultrasonic instrument in each position are relevant:

- Rht=4.7 mm, position 1 – right flank;
- Rht=3.6 mm, position 2 – left flank (Figure 4);
- Rht=5.1 mm., position 3 – center.



**Figure 4.** Measurement results for the sample №2 (position 2 – left flank): a – ultrasonic testing; b – metallographic analysis.

Metallographic analysis was chosen as a reference method and the case depth according to this method constitutes 3,41 mm ( test sample №2, left flank). The results are shown in Figure 4 (b).

It is worth mentioning that the case depth determined by ultrasonic backscattering does not necessarily equal to the case depth measured with metallographic-, micro-hardness- or any other established method. However it is also evident that close correlation is often found between the ultrasonic hardness depth and the reference hardness depth. The reason is that the depth of the core

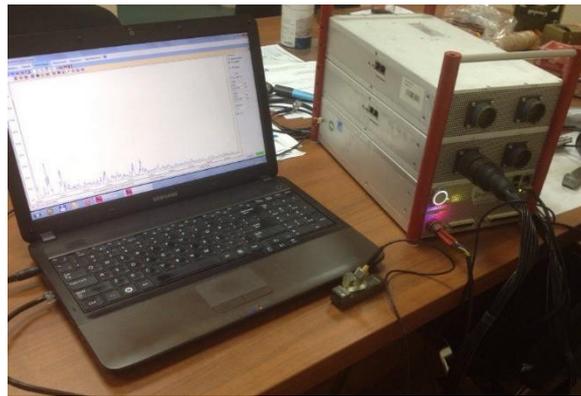
material and the case depth determined by the established methods are influenced by the process parameters of hardening.

The following conditions produce ideal results:

- The test parts are induction-hardened.
- The test parts are forged, not cast.
- The minimum case depth to be measured is 1,5 mm.
- There is no intermediate microstructure between the martensitic and the core material.
- The grain size of the core material is large enough to cause significant backscattering of shear waves with the frequency of 20 MHz.

SAPHIR\_Quantum (AREVA) was chosen as a multifunctional instrument. It is a versatile high end ultrasonic system for phased array as well as for single or parallel multi-channel applications in the industrial UT nondestructive testing. The electronic unit contains the ultrasound transmitter and receiver channels as well as the signal processing. In standard configuration 32 channels are implemented in one electronic unit. Each channel has excellent technical characteristics and is individually adjustable.

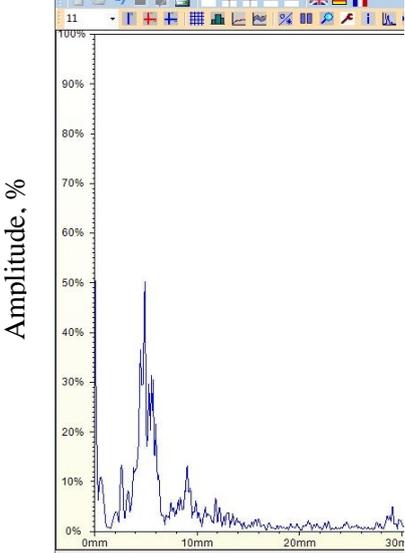
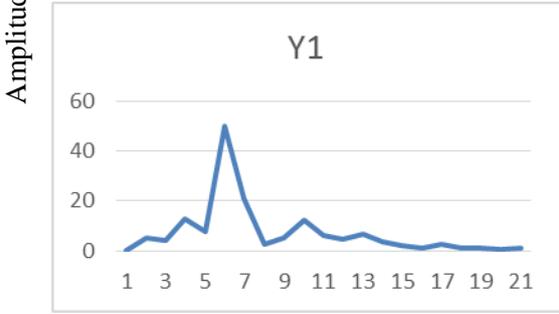
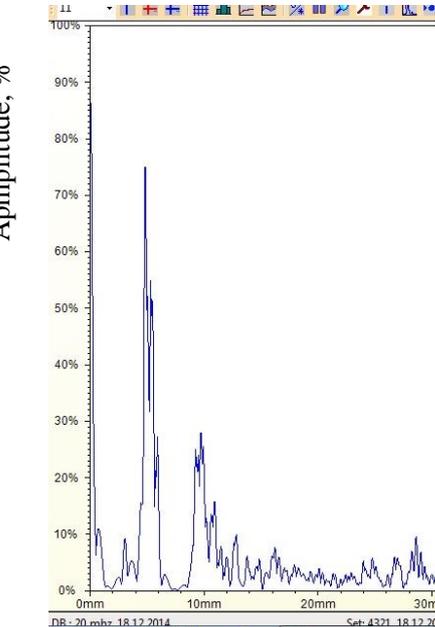
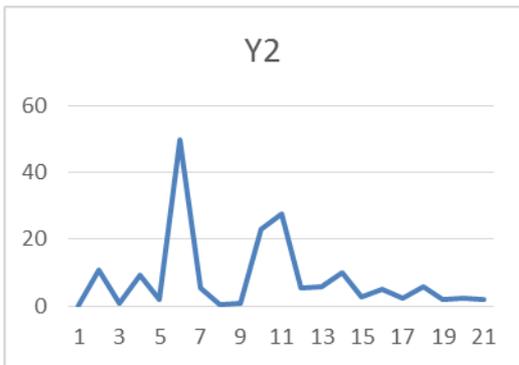
The test stand consisting of the ultrasonic electronics (SAPHIR\_Quantum), transducer (20 MHz) and a laptop constitute the experimental setup (Figure 5).



**Figure 5.** The experimental setup.

To achieve reliable results the experiment was performed on the same samples as in the first case. Typical results obtained by the second series of experiments by using multifunctional ultrasonic system are presented in Table 1 below.

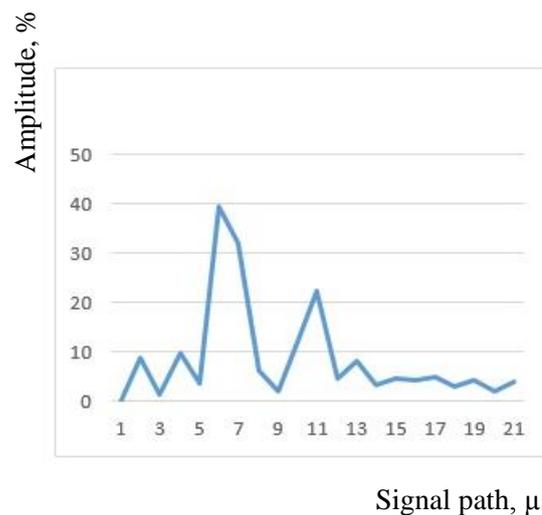
**Table 1.** Experimental results obtained by the test stand (test sample № 2, left flank)

(a) Signal performed by the PC	(b) Digitized signal
 <p style="text-align: center;">Signal path, <math>\mu\text{s}</math></p>	 <p style="text-align: center;">Signal path, <math>\mu\text{s}</math></p>
 <p style="text-align: center;">Signal path, <math>\mu\text{s}</math></p>	 <p style="text-align: center;">Signal path, <math>\mu\text{s}</math></p>

It is notable from Table 1 that the signal received during inspections (Table 1(a)) by standard equipment of ultrasonic testing does not allow to determine the depth of the hardened layer correctly,

in comparison with the specialized instrument used in the first series of experiments (Figure 4). The output signal contains many peaks with close values of the amplitude and high noise levels. However the signal has the same character. It can be assumed that by further signal processing, especially, by signal averaging relevant results could be achieved. Further filtration is to be improved in order to reduce the level of electrical noise.

Averaging is a type of filtering that is aimed at reduction of step-like changes of the signal. In this case there is a range of peaks with the same amplitudes which corresponds to point reflectors within the hardened layer (structure with different grain sizes). Relevant signal does not contain such steps. Due to a range of sudden changes but with small amplitude level difference, step signal contains high-frequency components that are not to be found in the averaged and smoothed signals. However currently there are many ways of averaging and signal processing as well as programs with appropriate algorithms to achieve this goal. Within this research the results obtained by testing samples with SAPHIR\_Quantum system were averaged with the most common algorithm. The results are represented in the form of digitized and averaged signal (Figure 6). The results were digitized by Engauge program (Table 1(b)), the obtained values were summarized and the average value for each of respective measurement points was calculated. According to the obtained results case hardening depth of the left flank of the experiment sample №2 is 3.5 mm (the actual depth of the layer is 3.41 mm).



**Figure 6.** Digitized and averaged signal.

#### 4. Summary

The developed case hardening depth control method discussed in this paper can be used for quality assurance testing in different areas of metalworking industry. The efficiency of the described method is proved by the experimental series with the specified equipment: QNet – P3121, Case Depth Tester. The results of these inspections correspond to the relevant metallographic analysis results. Deviation of the results merely reached 5 %.

SAPHIR\_Quantum system, AREVA was used to verify the suitability of the method of ultrasonic nondestructive case hardening depth testing applying multi-operated ultrasonic instrument. According to the results of these experimental series deviation was only 2.5%. Metallographic analysis showed that case hardening depth was 3.41 mm and ultrasonic testing – 3.5 mm. Series of experiments demonstrated that the method of ultrasonic measurement of case hardening depth can be applied with the multifunctional equipment of ultrasonic testing in the case of implementing additional algorithm of signal processing.

#### Acknowledgments

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