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The Influence of the Hardness of the Tested Material and the Surface Preparation Method on the Results of Ultrasonic Testing

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Abstract: Non-destructive ultrasonic testing can be used to assess the properties and condition of real machine elements during their operation, with limited (one-sided) access to these elements. A methodological question then arises concerning the influence of the material properties of such elements and the condition of their surfaces on the result of ultrasonic testing. This paper attempts to estimate the influence of material hardness and surface roughness on the result of such testing study area testing machine or plant components of unknown exact thickness. Ultrasonic testing was carried out on specially prepared steel samples. These samples had varying surface roughness (Ra from 0.34 to 250.73 µm) of the reflection surface of the longitudinal ultrasonic wave (the so-called reflectors) and hardness (32 and 57 HRC). The ultrasonic measures were the attenuation of the wave, estimated by the decibel drop in the gain of its pulses, and the propagation velocity of the longitudinal ultrasonic wave. Ultrasonic transducers (probes) of varying frequencies (from 2 to 20 MHz), excited by a laboratory and industrial defectoscope were used as the source of such a wave. The results of our research provide a basis for the recommendation of two considered ultrasonic quantities for assessing the material properties of the tested element. This is of particular importance when testing machines or plant components of unknown exact thickness and unknown roughness of inaccessible surfaces, which are the reflectors of the longitudinal ultrasonic wave used for testing. It has been demonstrated that by using the ultrasonic echo technique, it is possible to evaluate the roughness and hardness of the tested elements.

Keywords: non-destructive testing; ultrasonic testing; surface roughness; hardness

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1. Introduction

Non-destructive testing finds wide application both in industrial and laboratory settings. Among the most commonly used non-destructive methods, such as [1–4] X-ray radiography, infrared, or electromagnetic applications, ultrasonic testing holds significant importance. The application of non-destructive methods can be very wide and can also include the testing of modern structures [5]. Ultrasonic testing utilizes the phenomena of refraction and reflection of ultrasonic waves, which are waves with frequencies above 16 kHz. Such testing is practically applied in every industry. The simplest ultrasonic technique involves measuring the thickness of elements accessible from one side, such as pipelines, tanks, boilers, and containers [6,7]. As demonstrated in [8], it is possible to measure the thickness of elements made from various materials, such as aluminum, brass, polyester, and polyethylene, using the ultrasonic method. More complex examinations involve assessing the condition, detecting flaws occurring during production or operation, including cracks, shrinkage cavities, meltings, cross-forgings, or lack of fusion, assessment of joints, and the condition of components made in additive technology [9–12]. These are standardized tests.

Research in the field of ultrasonic testing encompasses various aspects, including the evaluation of properties of welded joints [13], the quality assessment of welded [14] and adhesive bonds [15,16], as well as the evaluation of acoustic properties of materials produced using additive manufacturing technology [17]. These studies frequently encompass defect detection in different materials, not only in conventional ones like steel. In the study [18], the authors investigated the ultrasonic testing of two-phase materials. A more complex microstructure model within the bounds of double scattering response (DSR) was used. The new model was employed to calculate the corresponding grain noise limits, which were then used to define a time-dependent threshold for ultrasonic tests. A Ti-6Al-4V sample with flat-bottom holes was manufactured for ultrasonic measurements to verify the measurement sensitivity for sub-surface defects. Ultrasonic flaw detection methods are relatively well-known, there has been work in which the effect of surface roughness, on the size of detectable defects was determined, but in a very limited range (low frequencies and low roughness) [19].

Both conducted studies and the available literature confirm that several factors can influence the quality and results of ultrasonic testing. Some of these factors are well understood and described in standards, for example, the adaptation of the ultrasonic transducer head to the shape of the tested element, as stated in ISO 5817:2014 [20]. One area that has not been fully explored is the influence of material properties and surface condition on the results of ultrasonic testing.

Researchers have investigated the effect of hardness on ultrasonic wave velocity [21]. The authors demonstrated that the transmission, refraction, diffraction, and scattering characteristics of ultrasonic waves in the material depend on grain boundary features. They examined C1045 steels with varying hardness and established relationships between grain size, ultrasonic velocity, attenuation, and material hardness using two ultrasonic sources. The experimental results showed that a smaller average grain size and higher hardness can be achieved at higher tempering temperatures. Higher material hardness leads to faster acoustic velocities, and the scattering effect is more evident for higher transducer frequencies. The results of the experiment demonstrate that an alternative non-destructive testing method can evaluate the hardening process in industry. Similar studies [22] have used ultrasonic methods to examine hardness and property changes in welded joints. Researchers have also conducted similar investigations on a vastly different material, marble [23], using ultrasonic techniques to analyze the average grain size of certain marbles through ultrasonic velocity measurements. They successfully presented the relationship between ultrasonic velocities and grain size graphically and compared the average grain size of marble samples with microscopic images. Researchers often used ultrasonic wave velocity as a measure of hardness. It has been shown that by using additional material information, such as chemical composition and tempering temperature, high correlation can be achieved between ultrasonic wave velocity and hardness for different types of steel using multiple regression analysis [24]. Essentially, steel hardness can be predicted based on the transverse wave velocity, provided the content of only one chemical element is known. Similarly, in the study [13], the authors observed that the ultrasonic wave velocity correlates with surface hardness in isotropic materials. The results demonstrated that this technique can be considered an effective method for evaluating volumetric hardness. Destructive surface methods and non-invasive volumetric methods provide similar hardness distributions; however, the average hardness and surface hardness values differ.

However, the majority of non-destructive testing carried out takes place not in laboratories, but in industrial settings. To measure the ultrasonic wave velocity with high accuracy, knowledge of the thickness of the tested element or access to both sides of the specimen or actual item is necessary. When examining material properties (e.g., hardness) in industrial conditions, there may not always be information available regarding the thickness of the tested element or access to both sides of it. Therefore, in an industrial testing, a better measure of hardness than wave velocity might be attenuation.

In the present work, the level of ultrasonic wave attenuation in decibels was determined based on the difference in heights between two consecutive reflected pulses (i.e., the first and second ones) obtained on the screen of the ultrasonic flaw detector. For this purpose, measurements of the amplifier characteristics of the ultrasonic apparatus were carried out for appropriate time bases and settings (voltage, pulse width). Based on these characteristics, the level corresponding to a specific height of the reflected or transmitted pulse through the tested sample was determined in decibels. In practice, the first reflected pulse was always set at the same height. The use of the amplification characteristic eliminated errors arising from the nonlinearity of amplification depending on the range and height of the pulse observed on the screen and the pressure force of the ultrasonic transducer head on the tested surface.

Another factor that may impact the results of ultrasonic testing is surface roughness [25]. The authors in their research used a 5 MHz frequency wave and employed an immersion technique. In the study [25], it was shown that the RMS height of the surface microtopography in the normal direction plays a dominant role in the amplitude of the echo signal and the shape of the surface crack wave reflector. Similar studies have been conducted by various research centers, and all the researchers concluded that the surface condition can influence the results of ultrasonic testing, including corrosion monitoring [26]. In the study [27], the authors used frequencies ranging from 2 to 20 MHz but limited the surface roughness to the range of 5 to 50 µm. The authors [26] found that surface roughness significantly degraded the signal-to-noise ratio (S/N) for some typical inspection geometries. Additionally, after appropriate normalization, the transmission and reflection coefficients for the coherent beam were found to be nearly universal functions of the angle of incidence, except near the critical angles.

2. Ultrasonic Testing of Materials

2.1. Studies of Areas with Different Surface Roughness

The results of ultrasonic testing can be influenced by both the acoustic properties of the tested material and the surface condition, which serves as a reflector for the ultrasonic wave. While in laboratory testing, it is possible to have access to both sides of the tested element and measure the thickness and surface roughness, in field conditions, especially when inspecting single-access elements, such possibilities are often limited. Therefore, the aim of this work was to investigate the extent to which the surface condition and hardness of the tested element affect the results of ultrasonic testing.

In the first part of the study, a sample was prepared, containing 13 different areas with varying surface roughness. The sample was intentionally prepared from a single element to avoid variations in acoustic properties for each area. Various surface preparation techniques were used in the study, reflecting those commonly employed in workshop practices. The techniques included electropolishing with grit sizes of 40, 60, and 100; grinding with emery cloth of grit sizes 20, 40, 60, 100, and 150; shot blasting; and milling with depths of 0.1, 0.3, 0.5, and 0.7 mm. The sample with the measurement points marked in the roughness area is depicted in Figure 1. These are typical technologies used in surface preparation for painting, anti-corrosion protection, bonding, or regeneration using methods like metallization or welding.

One of the basic parameters of roughness is Ra, which is the arithmetic mean deviation of the profile from the mean line. In this study, thirteen areas with differential surface preparations were separated, and the values of the roughness parameter Ra are shown in Table 1. A view of two example areas with different roughness is shown in Figure 2.

A graphical representation of the roughness over the entire surface is shown in Figure 3. Due to the large differences between the areas, the surfaces were divided into two parts, the first with a roughness of less than 3 µm (Figure 3a), and the second with a roughness of more than 50 µm (Figure 3b).

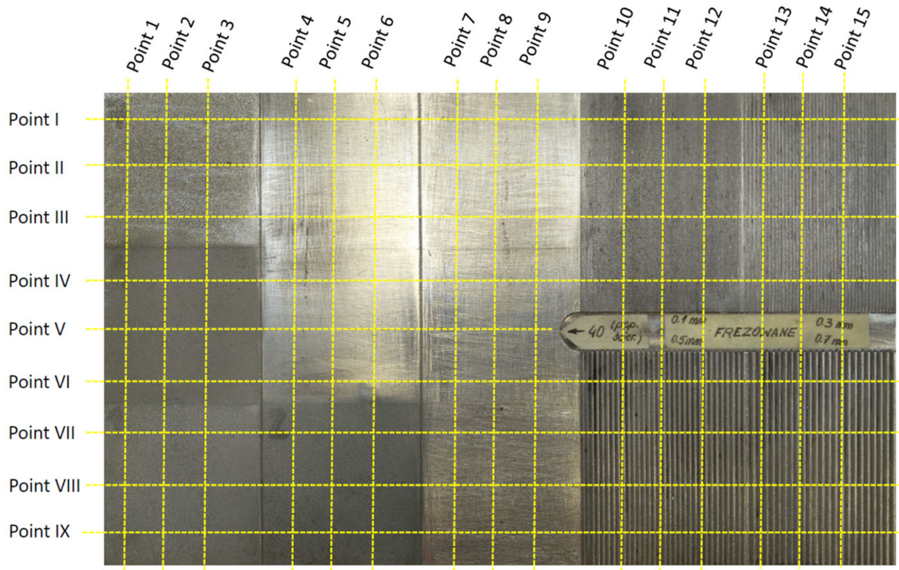
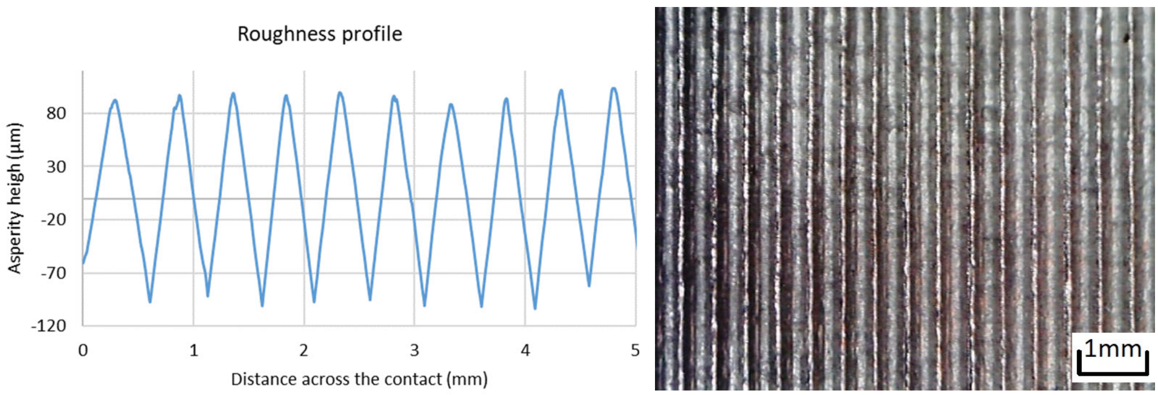


Figure 1. View of the underside of the sample, with thirteen different fields of varying roughness and the coordinates of the measurement points plotted.

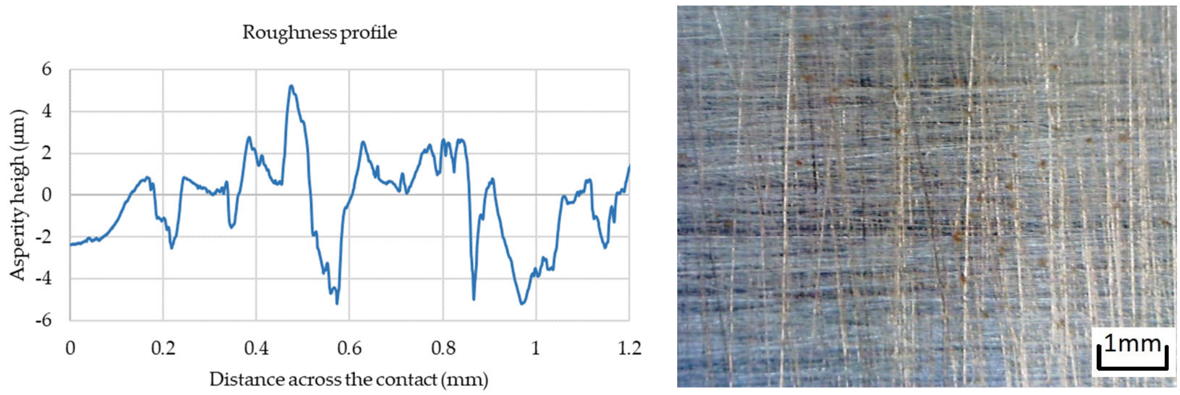
Table 1. Overview of types of surface preparation of wave reflection and the corresponding roughness parameter Ra.

Type of Processing	Ra
Sandpaper 150	0.34
Sandpaper 100	1.06
Sandpaper 60	1.30
Sandpaper 40	1.36
Sandpaper 20	2.57
Sandblasting EK100	0.33
Sandblasting EK60	1.59
Sandblasting EK40	2.27
Blasting	2.59
Milling 0.1	50.62
Milling 0.3	149.15
Milling 0.5	250.73
Milling 0.7	348.69



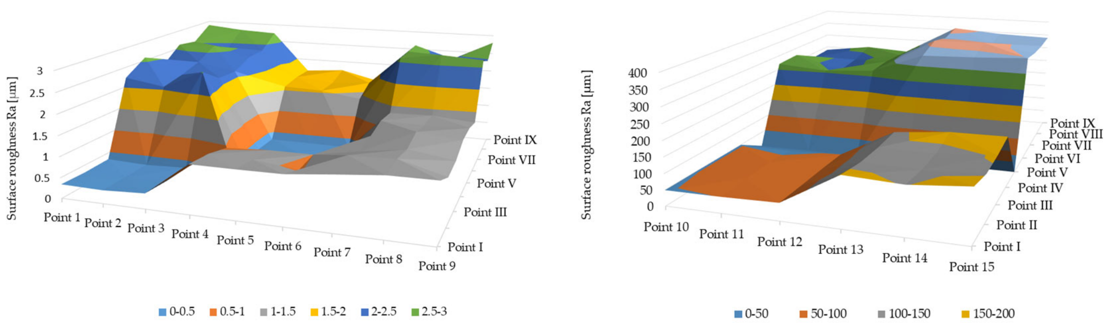
(**a**) (**b**)

Figure 2. *Cont.*



(**c**) (**d**)

Figure 2. View of example areas with different roughness; (**a**) 0.1 mm milling, (**b**) zoomed view of milled area, (**c**) processing with sandpaper 100, and (**d**) zoomed view of area roughened with sandpaper 100.



(**a**) (**b**)

Figure 3. Roughness distribution on the surface of the sample with the coordinates plotted according to Figure 1; (**a**) area with roughness less than 3 µm; (**b**) area with roughness greater than 50 µm.

The measurement setup, illustrating the application of the ultrasonic transducer to the tested sample, is shown in Figure 4.

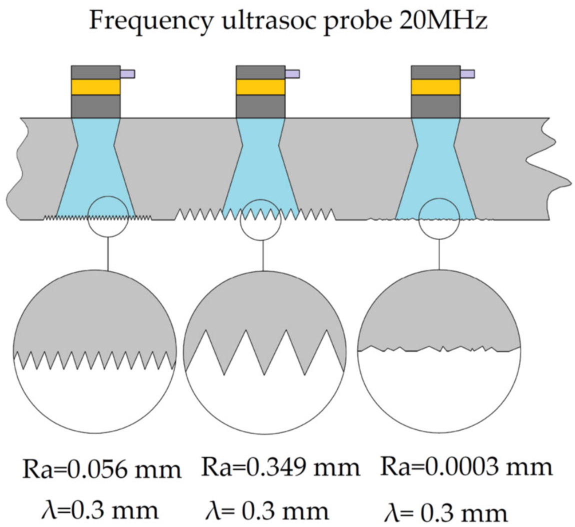
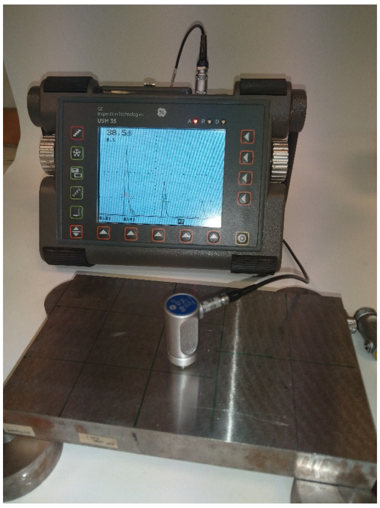
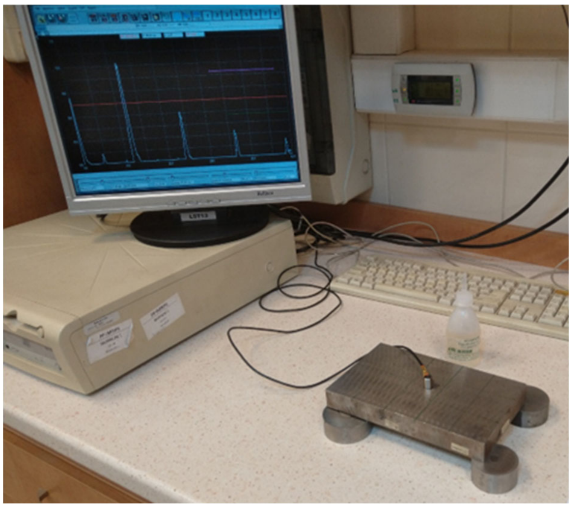


Figure 4. The measurement setup—ultrasonic probe and sample with varying (regular and irregular) roughness of the reflecting surface; R_a—surface roughness, λ—ultrasonic wavelength for 20 MHz wave frequency.

The attenuation of longitudinal ultrasonic waves was measured using two digital ultrasonic defectoscopes: the laboratory UMT15 and the industrial USM35XS. A view of the sample on the test bench, including the ultrasonic probes, is shown in Figure 5.



(a)



(b)

Figure 5. View of measuring system and sample on the test bench; (**a**) industrial defectoscope USM35XS, (**b**) laboratory defectoscope UMT15 in PC.

This work used ultrasonic transducers (probes) with a frequency range of up to from 2 to 20 MHZ, i.e., those that are usually used in industrial conditions. A summary of the heads is included in Table 2.

Table 2. Properties of the ultrasonic transducers (probes) used in the study.

Probe Name	MB2S	KD1-6	KD0.8-3	MB4S	10 MHz	KD4-12	GE20
Number of Ultrasonic Transducer	1	2	3	4	5	6	7
frequency MHz	2	2.4	2.75	4	9	12.5	20
transducer diameter mm	10	12	12	10	6	6	3
effective diameter of the beam mm	9.7	11.64	11.64	9.7	5.82	5.82	2.91
mean wave velocity in tested material m/s	5920	5920	5920	5920	5920	5920	5920
wavelength mm	3.0	2.5	2.2	1.5	0.7	0.5	0.3
near field mm	7.2	13.1	15.2	15.5	12.7	17.8	7.1
decibel drop ratio K	0.87	0.87	0.87	0.87	0.87	0.87	0.87
sin beam divergence angle	0.27	0.18	0.16	0.13	0.10	0.07	0.09
divergence angle° within 25 mm	15.40	10.62	9.26	7.63	5.64	4.06	5.08

The diameter of the ultrasonic wave beam for the selected ultrasonic transducers was determined based on the relationship [17]:

$$B = 2 \cdot s \cdot tg\left(arc\ \sin\left(k \cdot \frac{c}{f \cdot 0.97 \cdot D}\right)\right) \quad (1)$$

where:

B—beam diameter mm,
s—distance from the ultrasonic transducer mm,
k—coefficient of amplitude decrease across the beam width by 6 dB (k = 0.5) and by 10 dB (k = 0.87),
c—wave velocity in the material m/s,
f—probe frequency Hz,
D—transducer diameter mm.

The k factor is the coefficient of amplitude decrease across the width of the beam. In industrial tests, $k = 0.5$ is assumed, which means a 6 dB decrease in amplitude value. In more accurate laboratory tests, $k = 0.87$ can be assumed, which means a decibel drop of 10 dB in the amplitude value.

During the measurements, the pulse pattern was recorded on the screen of the ultrasonic defectoscope with the height of the first pulse from the bottom of the test sample being 80 percent of the screen height. Ten repetitions were performed for each ultrasonic probe and each measurement point. The measurement error was determined before the basic tests were performed, and the gain value for which the defectoscope has the best logarithmic trajectory was determined.

2.2. Testing of Specimens with Different Hardnesses

Another factor that affects the conduct of ultrasonic testing is the acoustic properties of the material under test. The speed of the ultrasonic wave can be affected by the hardness of the material under test. The ultrasonic method of hardness measurement can be used for those parts in which the operator has access from both sides or knows the thickness. In industrial settings, the exact thickness of the component being evaluated is not always known. For this reason, we examined whether there is a better ultrasonic measure of steel hardness estimation. Specimens were made, some of which were heat-treated. Two groups of samples were separated, the first before heat treatment with a hardness of 32 HRC, and the second after heat treatment with a hardness of 57 HRC. For both groups of specimens, both the speed of the longitudinal ultrasonic wave and the decibel drop in height of the first two pulses obtained on the screen of the defectoscope were measured. The work was performed according to the scheme shown in Figure 6.

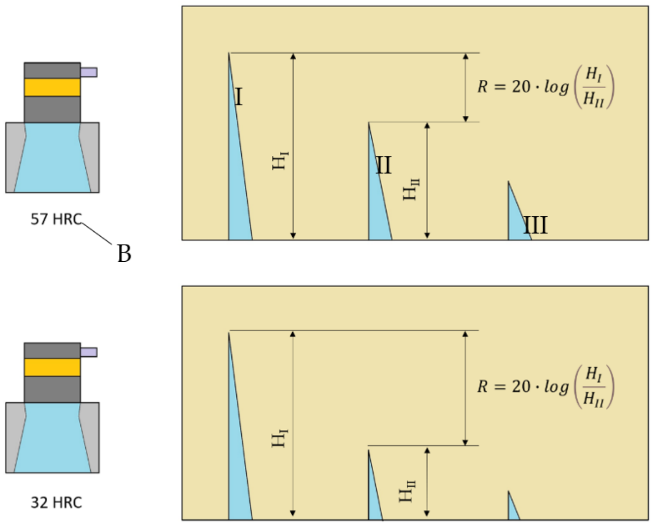


Figure 6. Schematic diagram for measuring and determining of the decibel gain drop based on adjacent impulses of ultrasonic wave reflection when measuring materials of different hardness; I—first echo of the ultrasonic longitudinal wave from the reflector (B); II—second echo of the ultrasonic longitudinal wave from the reflector (B); III—third echo of the ultrasonic longitudinal wave from the reflector (B); B—reflector; H_I—the height of the first pulse on the flaw detector screen (in this case HI = 80%), H_{II}—the height of the second pulse on the ultrasonic flaw detector screen; H_{III}—the height of the third pulse on the ultrasonic flaw detector screen.

3. Results of Our Own Ultrasonic Tests

3.1. Surface Roughness Results

First, an analysis of measurement errors was carried out. A half confidence interval of 0.95 was used as the error. The tests carried out showed that the error is frequency-dependent. The results are shown in Figure 7. The significant increase in the error for the highest frequency was probably due to the fact that the attenuation increased with increasing frequency. An ultrasonic probe with a frequency of 20 MHz was used for testing components' small and thin parts (even less than 1 mm). In this study, the same sample (15 mm thick) was tested with each ultrasonic probe listed in Table 2.

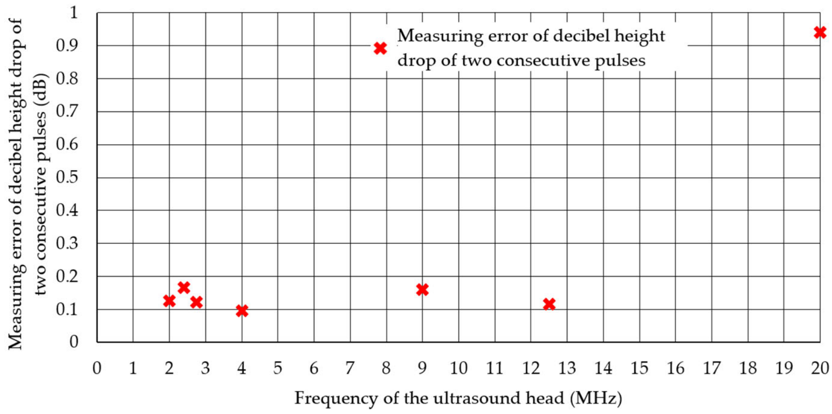


Figure 7. Values of measurement errors depending on the frequency of the ultrasonic probe.

The results of all ultrasonic measurements depending on the frequency of the ultrasonic probe are shown in Figure 8.

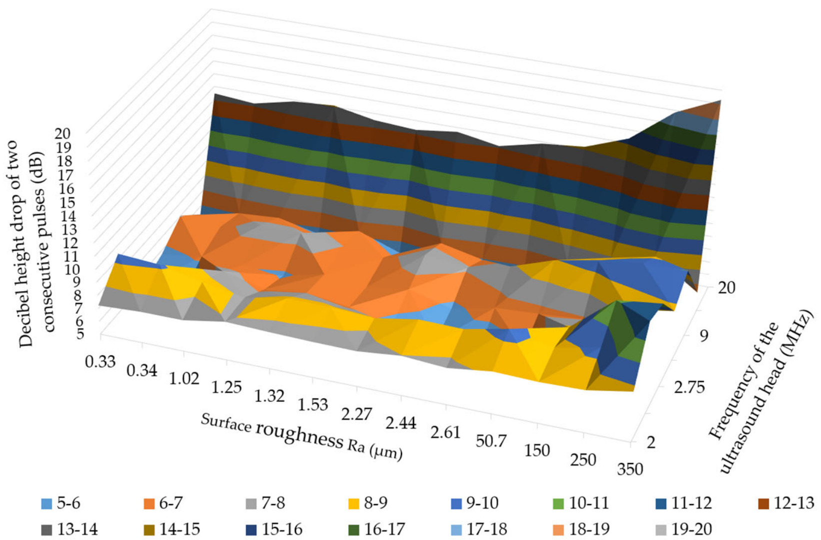


Figure 8. The results of all ultrasonic measurements depending on the frequency of the ultrasonic probe and surface roughness.

All the results in tabular form are shown in Table 3. It can be seen that for roughness parameters in the range from 0 to 5 µm, the changes of decibel amplification values are not significant; however, they are significant for larger values of Ra, whereby, it is clear that as the frequency increases, the attenuation of the ultrasonic wave increases as well, which means that there is scattering of the wave on the surface irregularities. Such scattering can have a significant impact on any ultrasonic measurement and therefore on the results of each ultrasonic testing.

3.2. Hardness Estimation Results

In accordance with the assumptions in the first stage of the research, the velocity of the longitudinal ultrasonic wave was measured, using the probes listed in Table 2, for samples with a hardness of 32 and 57 HRC. The average velocities obtained for all the probes used and for specimens with significantly different hardnesses are shown in Figure 9.

Table 3. Summary of decibel amplification values of reflected ultrasonic wave impulses depending on the height of the reflector surface micro-roughness and the frequency of the ultrasonic probes used.

	Frequency of the Ultrasonic Probe (MHz)						
Ra (μm)	**2**	**2.4**	**2.75**	**4**	**9**	**12.5**	**20**
0.34	7.22	9.37	3.80	5.71	7.02	5.38	13.45
1.06	7.38	9.15	4.22	6.14	6.72	6.06	13.18
1.3	7.38	8.40	7.44	6.10	7.45	6.29	13.88
1.36	7.91	7.86	6.60	5.82	7.43	5.57	14.09
2.57	7.79	8.42	6.97	6.57	7.01	6.41	13.48
0.33	7.70	8.41	6.51	6.19	6.71	5.26	13.28
1.59	7.66	8.21	5.69	6.63	7.55	6.65	13.67
2.27	7.98	8.76	5.13	5.78	7.13	5.94	13.12
2.59	7.75	8.68	4.84	6.48	7.85	5.73	13.86
50.62	8.16	9.35	5.82	6.66	8.95	6.90	14.17
149.15	8.07	8.62	8.20	6.89	9.49	7.94	15.35
250.73	8.15	9.32	10.86	8.28	9.97	8.64	17.84
348.69	8.73	11.87	11.24	8.79	10.01	6.43	19.30

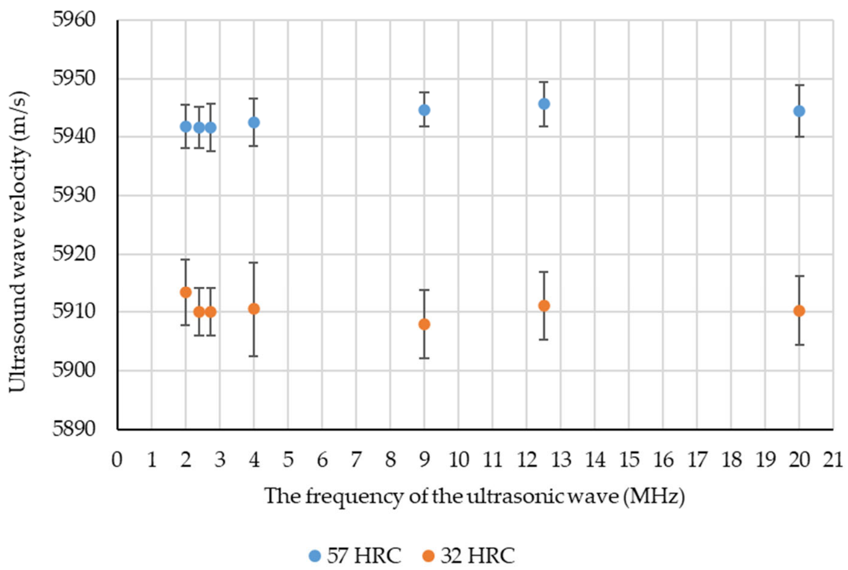


Figure 9. Distribution of the average velocities of the longitudinal ultrasonic wave for the probes used and for specimens with different hardnesses.

There were no significant differences between the velocities of the ultrasonic longitudinal wave for the different probe frequencies in the range tested, whereas there are clearly differences in the velocity of this wave for the different hardnesses of the samples tested. The higher velocity of this wave was verified by the higher hardness of the samples (57 HRC). The lower speed of the wave corresponds to the lower hardness (32 HRC). There is no convergence here, with the trend indicated in [24]. For a given hardness, the velocity differences due to the frequency of the transducers used are small. They are within the range of measurement errors. It can therefore be assumed that the influence of the head frequency on the measured velocity value is negligible.

A significant disadvantage of ultrasonic measurements aimed, for example, at estimating the hardness of elements under industrial or operational conditions is the lack of knowledge of the thickness of the assessed element, which is necessary for the determination of velocity. In the case of built-up components, with one-sided access to them, which is often the case in practice, from an operational point of view, the attenuation of the ultrasonic wave may be a better measure of the hardness of the tested element. Also, the waveforms of the decibel difference in the amplification of the longitudinal ultrasonic wave pulses for the tested hardness of the steel samples (Figure 10), depending on the frequency of the transducers generating it, indicate their similarity for significantly different specimen hardnesses. This can make it difficult to quantify the hardness of the test pieces.

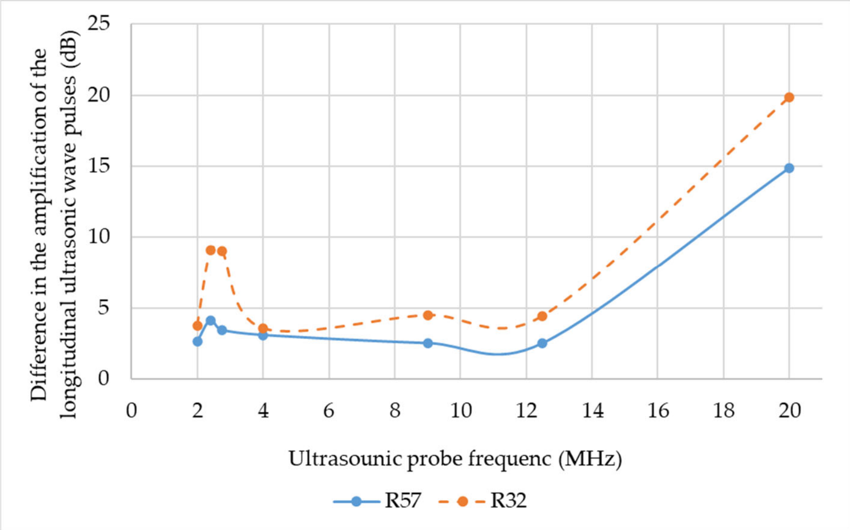


Figure 10. Courses of the decibel gain difference of longitudinal ultrasonic wave pulses depending on the frequency of transducers generating it for tested hardnesses (57 and 32 HRC) of steel samples.

4. Discussion

As is generally known, the attenuation of the ultrasonic wave propagating in the material of the tested samples in the grains and at their boundaries increases with increasing transducer frequency and therefore with decreasing wavelength in the material structure. This explains and indicates the significant (step) increase in measurement error at high frequencies (20 MHz), as well as that most likely at higher frequencies not considered in this paper. The frequencies of the probes used in the range from several to 12.5 MHz caused a measurement error of 10–12%. Thus, the frequency of several megahertz transducers used in industrial measurements should not generate excessive errors caused by the attenuation of the ultrasonic wave in the material structure of the tested elements.

On the other hand, in regard to the contribution to the weakening of the ultrasonic wave of attenuation which is not structural, but rather dependent on the state and roughness of the surface of the so-called reflector, i.e., the reflecting surface of the wave, we found that an increase in its roughness (expressed by the value of Ra) nevertheless causes a weakening of the wave. This requires amplification of its pulse by the decibel amplification system of the ultrasonic defectoscope. The phenomenon of unstructured wave attenuation noticeably increases above Ra = 50 µm. This weakening of the wave is caused by the scattering of the wave on the micro-roughness of the reflector surface. The ratio of the wavelength to the size (height) of the micro-roughness of the substrate can be a quantifiable value determining the intensity of scattering. Our studies (Figure 8, Table 2) show that if this ratio tends towards 1, the attenuation caused by wave scattering on the reflector's micro-roughness increases. Thus, not only the frequency of the ultrasound source (probe), but also the size of the micro-roughness of the surface of the tested elements, from which the ultrasonic wave is reflected, can lead to errors in ultrasonic measurements.

The velocity of ultrasonic waves propagating in the material of the tested element is influenced by the hardness of the material. The mechanism of this influence is explained in various ways in the literature. It is presented that this velocity increases with an increase in the tempering temperature of hardened steel samples, and therefore with a decrease in the hardness of the samples [24]. In our measurements, we found that a sample with a higher intrinsic hardness (57 HRC) had a higher propagation velocity of the longitudinal ultrasonic wave than a sample with a lower hardness (32 HRC). The metallographic structure of the sample material is responsible for its hardness. After hardening (without tempering), it is a martensitic structure with residual austenite. This structure is hard, packed, and stressed, and is responsible for the velocity of ultrasonic wave.

The heating of an element in a machine or technical device in the temperature range equivalent to tempering can cause a change in the hardness of the structure and the stress state, and the reconstruction of this structure towards tempering martensite and sorbite. Then, the velocity of the ultrasonic wave will change depending on the structural and crystallographic reconstruction of the structure of the tested real machine element. Taking into account the possible limited access to the mounted element, it seems more probable that the ultrasonic wave velocity will be more dispersed than its attenuation, because the scattering of the ultrasonic wave from an inaccessible reflecting surface (reflector) has lower values in a large range of its microroughness for a given steel hardness (Figures 5–7).

Measuring the speed of an ultrasonic wave with an unknown exact thickness is virtually impossible. Thickness also affects attenuation, but this effect is much smaller than the effect of thickness on the ultrasonic wave speed. It is also important to note that thickness measurement error will affect attenuation measurements less than velocity measurements. The speed difference for different hardnesses is 0.5%, while the decibel difference in attenuation is almost 90% for a 2.75 MHz ultrasonic probe. For all the ultrasonic probes used, the average difference for decibel drop is 50%.

5. Conclusions

On the basis of the tests carried out, which included ultrasonic measurements on prepared samples and analysis of the results, the following conclusions can be drawn.

The results of ultrasonic tests carried out with the use of a longitudinal ultrasonic wave are influenced by both the structure of the tested element (estimated by its hardness) and the roughness of its surface, which is particularly evident in ultrasonic tests in industrial or operational conditions in an element of an installation, a machine, or mechanism with difficult access to the tested part.

The attenuation of an ultrasonic wave, estimated by the decrease in the gain of successive reflection pulses of this wave, imaged on the screen of an industrial or laboratory defectoscope, is sensitive to the surface roughness at high frequencies of ultrasonic transducers. For the frequency range used in industry and the customary surface roughness, there is an acceptable level of unambiguousness in the results. The propagation velocity of the longitudinal ultrasonic wave can be a measure of the mechanical properties of the materials of the tested elements, but on the condition that there is good access to the element under test and that its thickness is known. This requirement is usually met in the laboratory but is difficult to achieve in real test conditions.

Ultrasonic waves with wavelengths from 0.3 to 3 mm were used. Measurement errors were small, ranging from about 0.1–0.2 dB for ultrasonic probes with frequencies from 2 to 12.5 MHz and 0.95 dB for 20 MHz. Differences in measurement results for different roughnesses (Figure 8) were, for example, for the frequency of 2.75 MHz from 3.8 dB for Ra = 0.32 μm to 11.24 dB for Ra= 384.69 μm (a difference of 7.44 dB). For the highest frequency used (20 MHz) for Ra = 0.34 μm, the decibel drop in pulse height was 13.45 dB while for Ra = 348.69 μm it was 19.30 dB (a difference of 5.88 dB). The differences obtained are definitely larger than the measurement errors (Figure 7). In the hardness tests, differences in ultrasonic measurement values of up to 5 dB were obtained for the 20 MHz frequency.

In the case of limited access during ultrasonic testing to the reflective surfaces of the tested element and one-sided access of the transducer to the element, as well as in the case of insufficient information concerning the dimensions, properties, structure, and mechanical parameters of the machine parts tested under real conditions, using an ultrasonic measure of these properties and structure the decibel drop amplification of successive impulses of a longitudinal ultrasonic wave may be a better methodological solution than using the wave propagation velocity as a measure of the properties of the ultrasonically tested part. This is because the decibel gain of the pulses is permissibly sensitive to the surface roughness and less dependent on the size of the tested part.

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