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*Original Article*

# Detection of quenching cracks in 100Cr6 bearing steel by the eddy current method

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**Abstract:** The article describes the results of research on the identification and localization of quenching cracks in 100Cr6 bearing steel using a proprietary non-destructive testing device based on the eddy current method called Wirotest M2 and an automatic stand AutoWir-S1. A surface probe with a frequency of 861 kHz was used for the tests. The system recorded changes in voltage amplitude and resonant frequency. A significant decrease in both parameters indicated the presence of discontinuities. The edge effect caused an increase in voltage amplitude and a decrease in frequency, but these changes did not affect crack detection. The smallest detected crack had a maximum width of about 20 μm and was invisible by the unaided eye. The obtained surface charts clearly illustrate the course and localization of individual discontinuities.

**Keywords:** eddy current method; quenching; detection of cracks; Wirotest M2

## Introduction

Hardening is a type of heat treatment whose purpose is to strengthen steel (or improve its strength properties) by obtaining a bainitic or martensitic structure. This process involves heating the material to the austenitization temperature, maintaining it at this temperature, and then cooling it. The cooling rate has a determining effect on the final structure and properties of the material. Hardening is necessary to achieve increased hardness, strength, yield strength and abrasive wear resistance [1].

Heat treatment has a significant impact on the microstructure and properties of steel, but also on the value and distribution of residual stresses. Most problems occurring in heat treated components result from the use of incorrect process parameters, the selection of the wrong steel grade, and design or material defects of the processed component. The most common errors during heat treatment include overheating, burning, uneven heating, inappropriate austenitization temperature and improper cooling. All activities causing excessive hardening stresses may result in cracking of the material, which is particularly dangerous because it may lead to the complete destruction of the structure. Therefore, detecting this type of defect at the stage of production or operation is extremely important. For this purpose, non-destructive testing is used, which does not deprive the tested element of its functional properties [2].

Several non-destructive testing methods are used in industry to detect cracks. One of them is the eddy current method (ET - Electromagnetic Testing or Eddy Current Testing), which is included in the group of surface tests. The method uses the phenomenon of magnetic induction, which involves the induction of eddy currents in an electrically conductive material because of the action of an alternating magnetic field. Eddy currents generate their own magnetic field, the intensity of which depends on the electrical conductivity and magnetic permeability of the tested material. Any changes in structure, geometry, presence of discontinuities, etc. affect the values of these parameters. Analysis of changes in the magnetic field generated by eddy currents allows for the assessment of the condition of the tested material [3].

The ET measurement technique involves identifying and analysing changes in the measurement system readings in relation to the level assumed to be correct and, on this basis, assessing the condition of the material. It is a comparative method that requires reference standards or samples.

The eddy current method is used to detect changes in structure, changes in chemical composition, assess hardness, assess the direction and magnitude of stresses, test electrical conductivity, measure the thickness of layers and coatings, as well as detect all types of material discontinuities (defectoscopy). The method is particularly useful for detecting surface and subsurface defects located at a small depth from the tested surface [4-10].

## Materials and Methods

The aim of the research was to qualitatively assess the element after volume hardening for the presence of cracks.

The subject of the research was an element made of bearing steel marked 100Cr6 according to EN (ŁH15 according to Polish Norm) in the form of a disk with dimensions Ø47x10 mm. The element was volume hardened in water at a temperature of 900 °C. The heat treatment was then repeated, increasing the austenitization temperature to 950 °C. The sample was cut in two places to check the presence of cracks on the cross sections marked A and B. The image of the sample after cutting is shown in Figure 1. Observations using a light microscope did not reveal the presence of hardening cracks. Therefore, the element was further processed, in which the austenitization temperature was increased to 1050 °C. Light microscopic observations were repeated. Five cracks appeared on the specimen surface A, similarly to those on the specimen surface B. All cracks propagated from the edge of the sample.


**Fig. 1.** The sample of 100Cr6 steel after quenching

The eddy current method, a technique of measuring voltage amplitude and resonance frequency, was used to detect quench cracks in the sample. The measuring equipment was Wirotest M2, a miniaturized control and measurement device developed and manufactured by the Łukasiewicz Research Network - Warsaw Institute of Technology. A contact head with a nominal operating frequency of 861 kHz was used for the tests [11].

The measurements were performed on the author's automatic AutoWIR-S1 station (Fig. 2) in the flat surface scanning mode [12]. The grid of recorded measurement points during scanning was 0.1 x 0.1 mm. Fig. 3 shows a photo of Wirotest M2 while scanning the surface of the specimen. The holder mounting the measuring device ensured continuous contact of the head with the tested material.

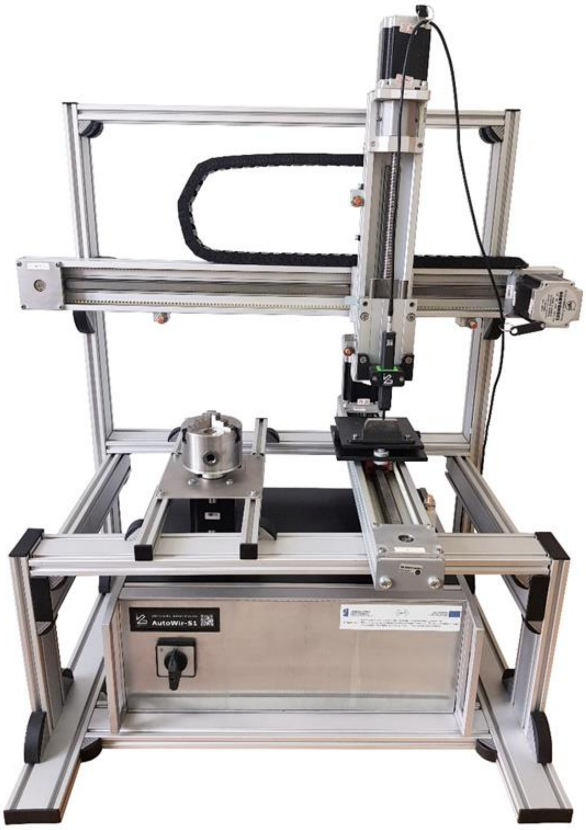


**Fig. 2.** The stationary automatic stand for non-destructive eddy current testing - AutoWIR-S1

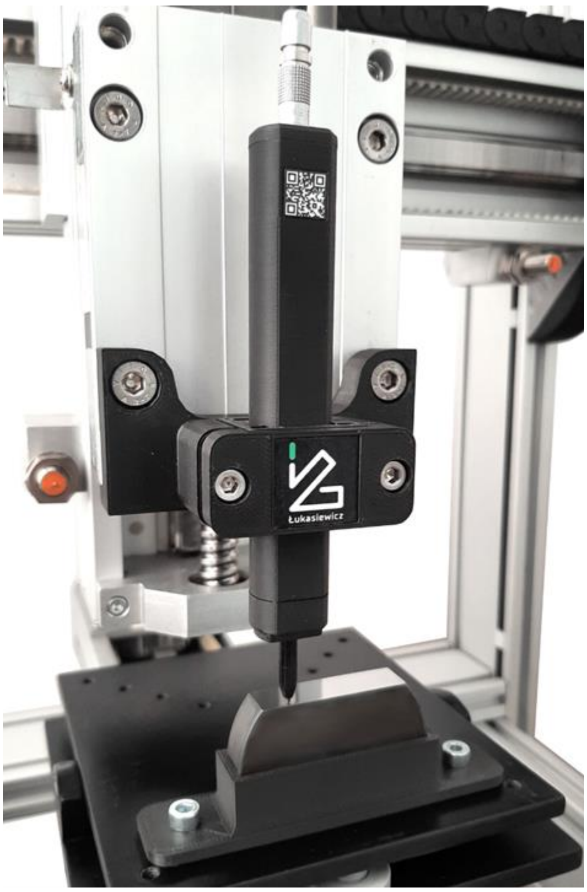


**Fig. 3.** The Wirotest M2 while scanning the cross-section surface with the 861 kHz measuring head

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Welding
TECHNOLOGY REVIEW

## Results and Discussion

The test results refer to specimen A, because the cracks formed were of different sizes - from cracks visible to the naked eye to cracks detectable under magnification. Fig. 4 shows a macroscopic photo of specimen A. Four cracks are visible.

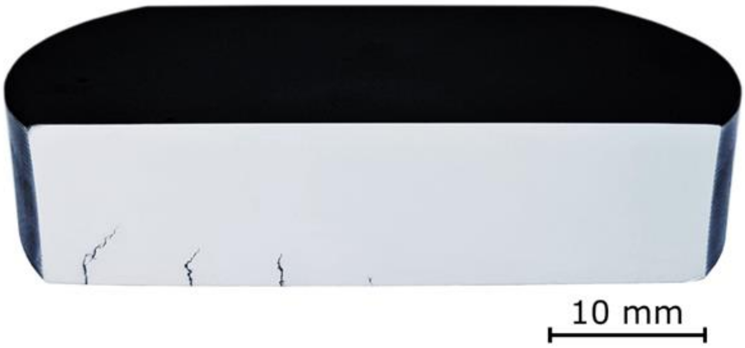
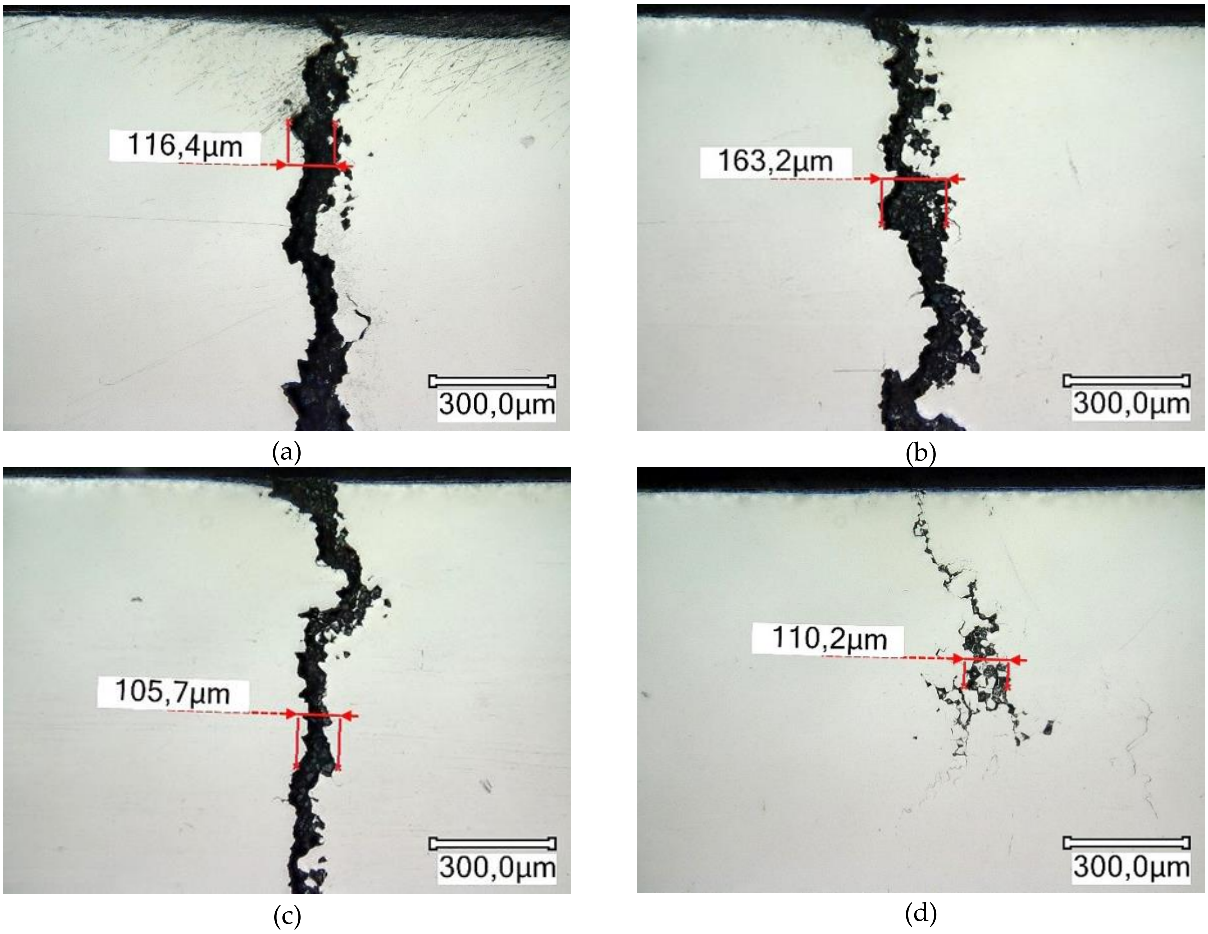
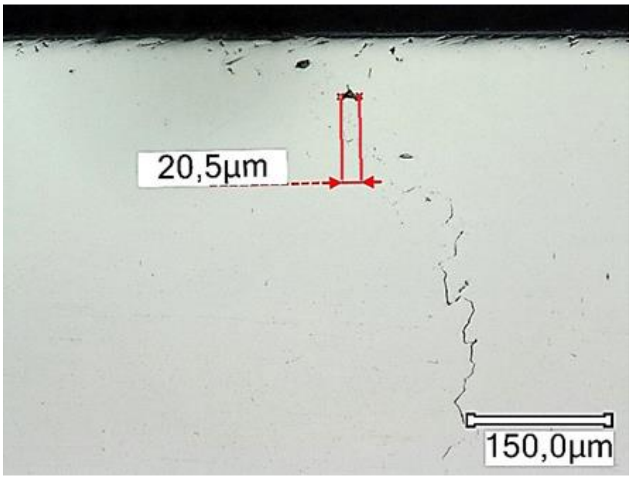



**Fig. 4.** The macroscopic image of the surface of A cross-section with dimensions of 38x10 mm

Fig. 5 shows microscopic images of five cracks on the surface of specimen A. The images were taken using a KeyenceVHX-5000 light microscope at a magnification of 250 to 500x. The width of individual cracks in areas close to the edges was measured using VHX-5000 Communication Software. The hardening cracks were characterized by a width of 20.5 to 163.2 µm.






(e)

**Fig. 5.** The microscopic images of quenching cracks on the surface of A cross-section

Fig. 6 shows a surface graph of voltage amplitude changes for metallographic image A, while Fig. 7 shows a line graph of measurements taken at a distance of 0.6 mm from the edge of the sample. The edge effect is manifested by an increase in the voltage amplitude of the eddy current signal. However, the presence of a crack reduces the value of the voltage amplitude, which is lower the larger the crack is

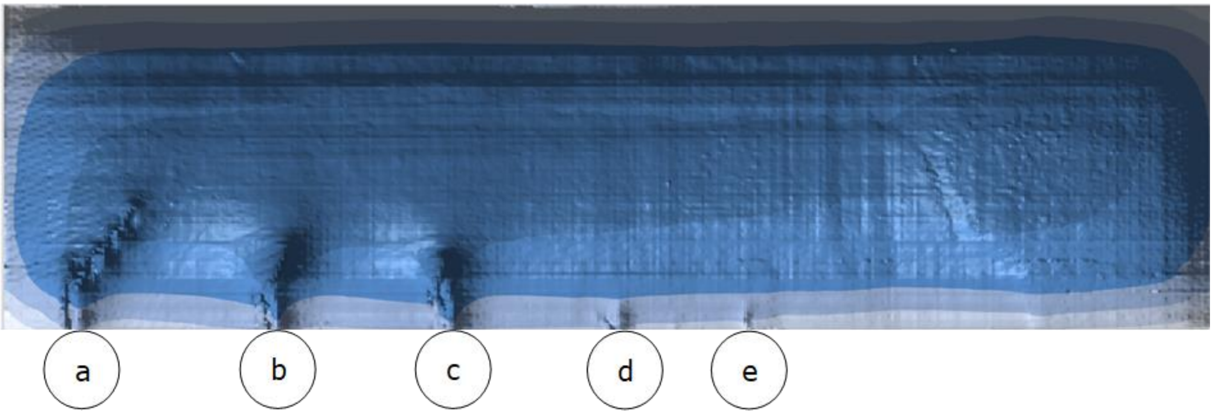



**Fig. 6.** The surface graph of voltage amplitude changes

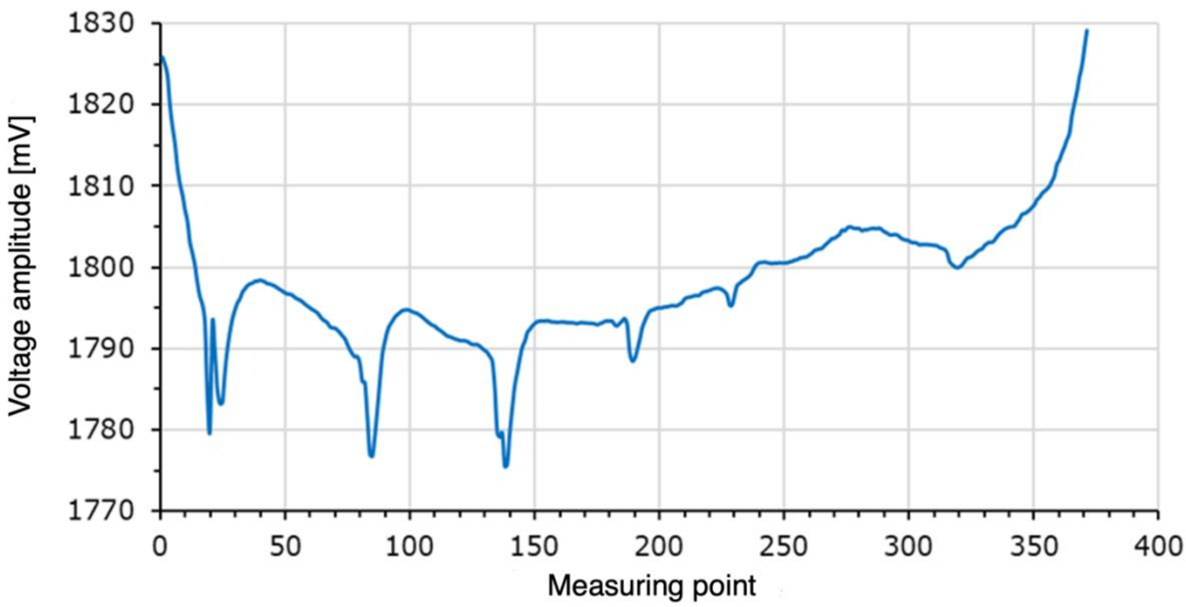



**Fig. 7.** The linear graph of voltage amplitude changes

Fig. 8 shows a surface plot of changes in the resonance frequency for specimen A, while Fig. 9 shows a line chart from measurements taken at the same distance from the edge of the sample as in the case of voltage amplitude measurements. In this case, the edge effect is manifested by a reduction in the frequency of the eddy current signal, as is the presence of a crack. The larger the crack, the greater the decrease in its value.

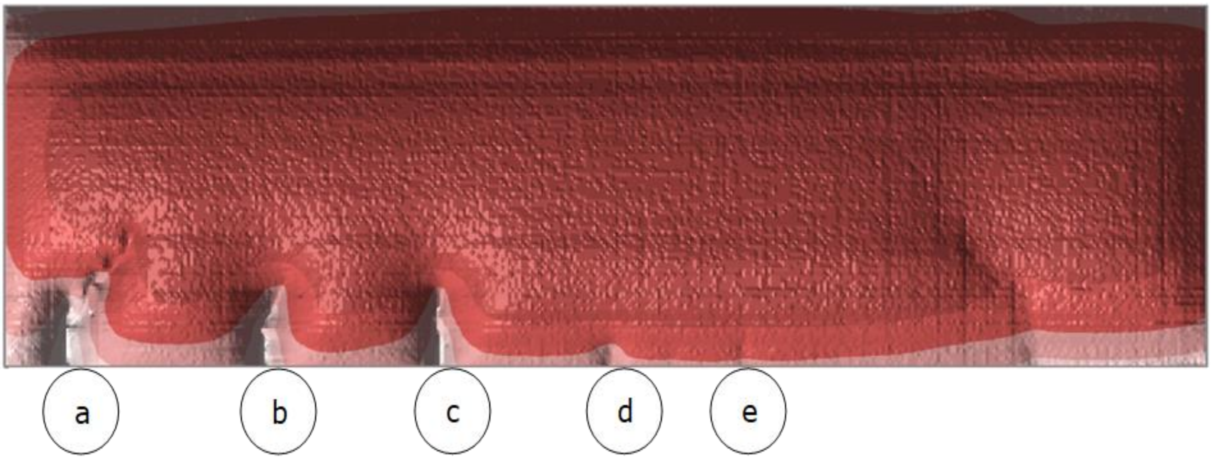



**Fig. 8.** The surface graph of resonant frequency changes

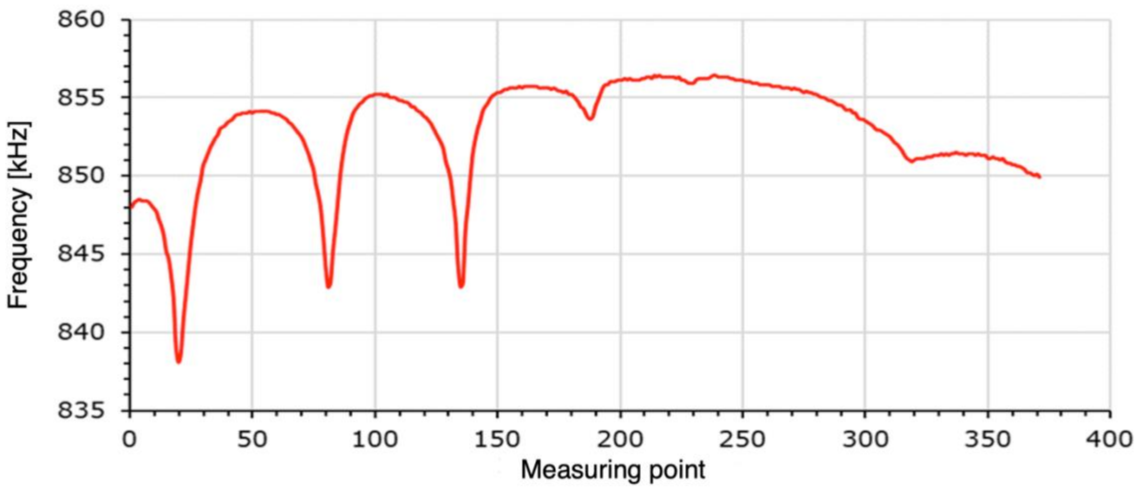



**Fig. 9.** The linear graph of resonant frequency changes

Changes in the voltage amplitude and resonance frequency values visible in the surface graphs (Fig. 6 and 8), between the smallest crack (marked "e") and the right edge, may be caused by a crack in the material located under the surface. In order to verify the source of these changes, it is necessary to carry out further research, including both destructive and non-destructive tests.

## Conclusions

Measurements using the eddy current method and the amplitude-frequency technique allow for a qualitative assessment of the element after volume hardening for the presence of cracks.

Wirotest M2 with an 861 kHz head enables the detection of hardening cracks located at the edge. The smallest crack detected had a maximum width of approximately 20 μm and was invisible to the naked eye. The remaining four cracks were visible on the polished surface. Surface charts clearly illustrate the course and location of individual discontinuities.

The edge effect caused an increase in the voltage amplitude and a decrease in frequency, but these changes did not affect the detection of hardening cracks.

The study only made a qualitative assessment of the element after hardening, but it is expected that the eddy current amplitude-frequency technique also allows for a quantitative assessment. Cracks are three-dimensional defects, their size can be characterized by length width, and depth. Further tests should be carried out to check the correlation between the size of the quench crack and the eddy current signal.

The obtained results are of practical importance because they confirm the effectiveness of the measurement system used in detecting cracks after volume hardening. This system can be used for inter-operational quality control of parts at the stage of their production. Early detection of discontinuities can prevent serious damage, which is especially important for responsible structures. The eddy current method does not deprive the tested element of its functional properties, it allows testing of all manufactured parts, which makes it useful in industry.

**Authors' contributions:** concept, J. S.; methodology, K. A.; software, L. P.; investigation, K. A., L. P.; writing—original draft preparation, K. A.; writing—review and editing, J. S.; visualization, K. A.; figures, K. A.; supervision, J. S.

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**Conflicts of Interest:** The authors declare no conflict of interest.

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