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EXPERIMENTAL STAND FOR INVESTIGATION OF INDUCTION HARDENING OF STEEL ELEMENTS

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The experimental stand for investigation of induction surface hardening of gear wheels was described in the paper. In order to control parameters of the process a specialized equipment for identification of all important process parameters including registration of temperature changes in time and measurements of current intensity was installed. Exemplary results are presented. It is planned that the stand will be used as a demonstrator for a presentation of advantages of modern induction hardening technologies.

Key words: steel, gear wheel, induction heating, surface hardening, microstructure.

INTRODUCTION

Induction hardening (IH) consists of three consecutive stages: induction heating, austenitisation and cooling [1]. It causes expected changes in the crystalline microstructure resulting in higher hardness. In case of the induction surface hardening (ISH) the second stage - austenitisation could be neglected or its time is very short. As a result we have local changes in the crystalline microstructure of surface layers only.

Microstructure of internal zones of the treated body does not change at all. In order to investigate the ISH process a specialized laboratory stand was designed and built. It was done within the framework of the research project realized by the consortium of three Polish Universities [2].

The laboratory stand makes possible to investigate various kinds of ISH processes including Continual Induction Surface Hardening (CISH) and Spin Induction Surface Hardening (SISH) [3]. Investigations were concentrated on steel elements with different shapes including gear wheels and cylinders. The stand was equipped with two separate transistor generators making possible to provide contour induction hardening of gear wheels. Universal character of the stand makes possible to use it as the demonstrator presented advantages of IH technologies.

EXPERIMENTAL STAND

A general view of the experimental stand is presented in Figure 1. The process was provided in the chamber 1. Two separate generators selected accordingly to process requirements were located in power cabinet 2 (Figure 2). Automatic steering system placed in the control cabinet 3 makes possible to establish requested parameters of the process and their registration. Closed cooling system (column 4) making possible to use as a quenchant both water, mixture of water and air as well as or any polymer solutions.

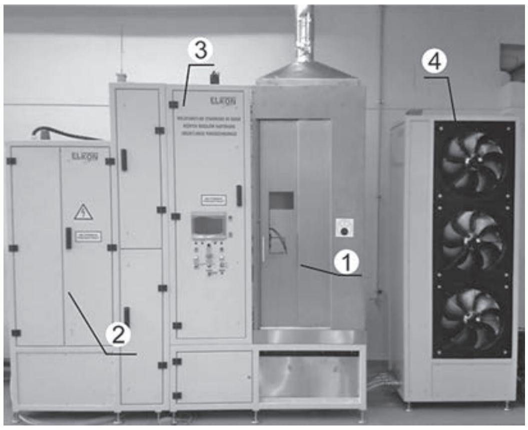

Figure 1 Experimental stand 1 – hardening chamber, 2 – power cabinet, 3 – control cabinet, 4 – cooling column

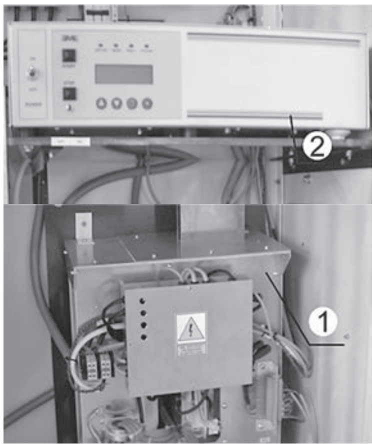

Figure 2 Transistor generators in the power cabinet. 1 – medium frequency (MF), 2 – high frequency (HF)

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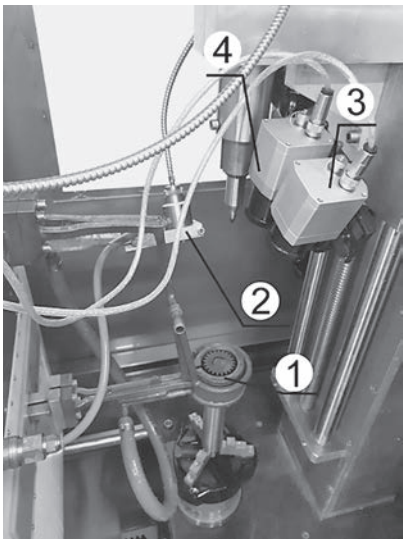

Figure 3 Temperature measurement arrangement. 1 – gear wheel, 2 – bio-color pyrometer, 3, 4 – infrared cameras

MEASUREMENT SYSTEMS

Correct identification of time evolution and spatial distribution of temperature in a hardened element seems to be crucial aspect influencing on control systems of the process. Such kind of measurement was complicated because of big heating rates (1 000 K/s or even more) characteristic especially in case of high frequency induction heating. The equipment for temperature measurement applied in the stand was shown in Figure 3.

The measurement of temperature during the process was provided simultaneously by three different methods.

The first of them means use of the pyrometer 2 making possible to provide continual measurement and temperature registration in a point at the working surface of the gear wheel and identification of maximal temperature reached there. The second method means use of the measurement system with two infrared cameras making possible to identify temperature distribution at working surface of gear wheel during the first step of the induction heating typically to a temperature which exceeds the Curie point (camera 3) and then in the second step to the hardening temperature (camera 4). The third method makes possible to identify time when the color of selected drops (points) painted on the working surface changes or disappears when the point reaches the assumed temperature [4]. All methods were compared and finally the combination of pyrometer and two cameras system was used for temperature measurement.

The laboratory stand was applied mostly, but not only, for investigation of two kinds of the SSIH processes: the Single Frequency Induction Hardening (SFIH) and Consecutive Dual Frequency Induction Hardening (CDFIH).

The steering system could register basic parameters of the hardening process including time, current, power and frequency of MF (HF) heating, time of austenitisation, velocity of rotation, kind of quenchant, its flow-

Figure 4 Control panel

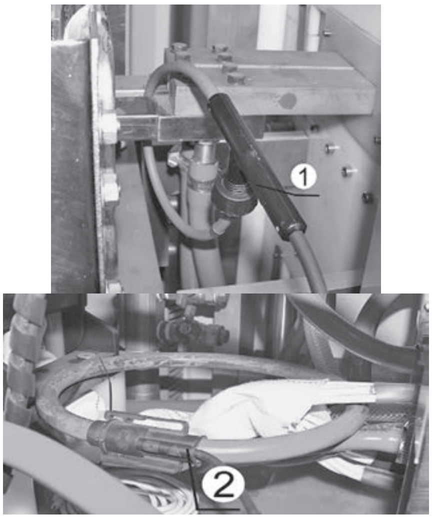

Figure 5 Location of MF Rogowski coils 1 , 2. 1 – placed at the primary winding of MF matching transformer, 2 – placed directly at MF inductor

rate and pressure, time and temperature of tempering in order to repeat the cycle of process in the same conditions. A front cover of the control cabinet is presented in Figure 4.

In order to measure correctly current and power the stand is equipped with three Rogowski coils installed in the primary winding of the MF matching transformer (1 in Figure 5) and directly at the MF inductor (2 in Figure 5) and directly at the HF inductor (Figure 6).

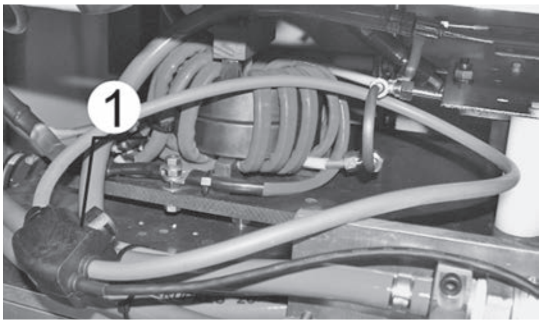

Figure 6 Location of HF Rogowski coil 1, 2 – HF matching transformer

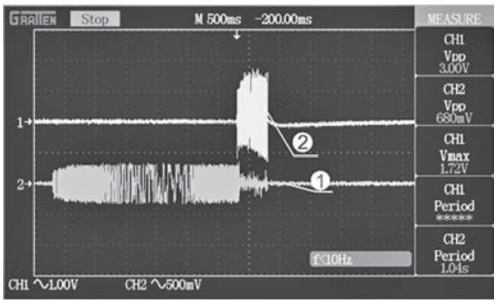

Figure 7 Oscillograms of MF current (1) and HF current (2)

Figure 8 The meter for the concentration of the quenchant

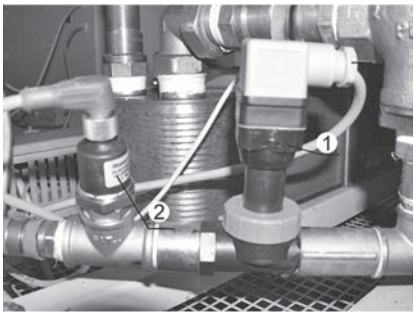

Figure 9 Location of converters for measurements of flow-rate 1 and pressure 2

Current intensity are measured by means of Rogowski coils are presented and registered by oscilloscope (exemplary oscillograms for the CDFIH process are presented in Figure 7).

The stand was equipped in the specialized computer system for registration of all measurement data. Gear wheel immediately after the hardening process was tempered in the resistance chamber furnace. The first approximate measurement of hardness was realized at the experimental stand [5]. As a quenchant the polymer solution Aqua Quench 140 was mostly applied. The stand was equipped with converters and meters making possible to identify cooling parameters: concentration of a quenchant (Figure 8) and its flow-rate and pressure (Figure 9).

ILLUSTRATIVE EXAMPLE

As an illustrative example the CDFIH process of gear wheel made of steel 300 M was described. The hardening system is presented in Figure 10.

The gear wheel 3 was heated first by the MF inductor 1, then by the HF inductor 2 with flux concentrator and finally cooled by the sprayer 4. In order to obtain similar hardness distribution for all teeth the cylinder 5

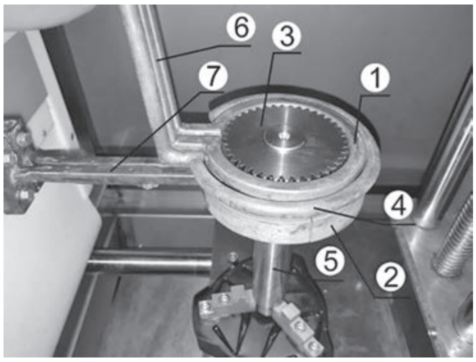

Figure 10 CDFIH system. 1 – MF inductor, 2 – HF inductor 3 – gear wheel, 4 – sprayer, 5 – cylinder, 6 – MF bus-bars, 7 – HF bus-bars

rotates with a velocity of about 3 – 5 r/s. In order to minimize electrical losses in the bus-bars 6 and 7 their lengths and distance between conductors were as small as possible. The process was provided for following parameters and dimensions of the CDFIH system:

<u>Material</u>: steel 300M

<u>Gear wheel</u>: teeth number – 40, width of the tooth ring – 0,007 m, external diameter 0,087 m, internal diameter – 0,079 m,

<u>MF inductor</u>: height – 0,008 m, external diameter – 0,109 m, internal diameter – 0,9 m, length of bus-bars – 0,363 m,

<u>HF inductor</u>: height – 0,0205 m, external diameter – 0,121 m, internal diameter – 0,89 m, length of bus-bars – 0,127 m, flux concentrator made of Fluxtrol 50,

<u>Sprayer</u>: distance between MF inductor and sprayer – 0,01 m, external diameter – 0,135 m, internal diameter – 0,1235 m,

<u>MF heating</u>: power – 60 kW, time – 4,5 s, frequency – 35,6 kHz, intermediate temperature – 720 ^{0}C,

<u>HF heating</u>: power – 20 kW, time – 1,3 s, frequency – 276 kHz, hardening temperature – 990 ^{0}C,

<u>Other parameters:</u> time between MF/HF heating – 0,1 s, time between heating and cooling – 0,1 s, rotation velocity – 3 r/s,

<u>Cooling:</u> Quenchant: Aqua Quench 140, concentration – 12 %, flow-rate – $2{,}5 \cdot 10^{-4}$ m^3/s, pressure – 0,11 MPa.

<u>Tempering</u>: temperature – 160 ^{0}C, time – 7 200 s.

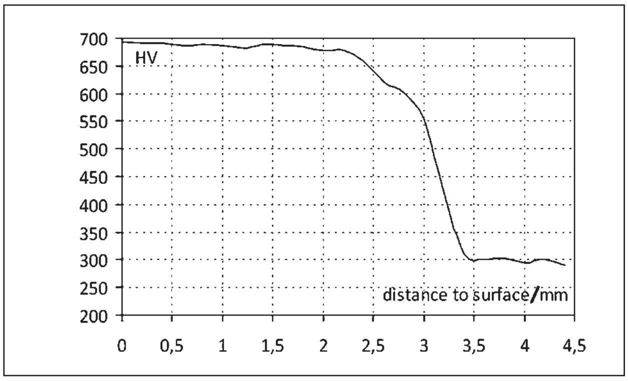

Figure 11 Dependence of hardness on distance from the surface at symmetry line perpendicular to the top of the tooth

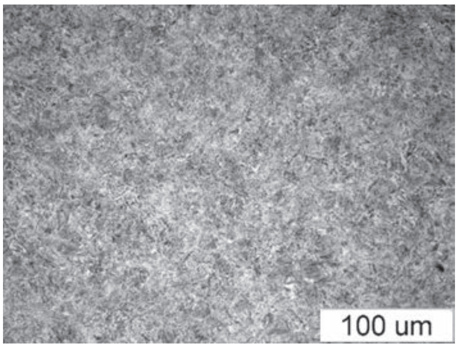

Figure 12 Martensitic microstructure in the hardened surface layer (x 500)

The hardening depth was equal to 3 mm (Figure 11). In order to obtain an uniform contour hardness distribution it is necessary to optimize parameters of the CDFIH process. Microstructure of hardened zone of the gear wheel was shown in Figure 12.

Microstructure of internal zone has not changed at all (tempered martensite).

SUMMARY

The laboratory stand for different kinds of ISH processes was presented in the paper. The stand was equipped with specialized measurement systems making possible to determine and register the most important parameters of the process like: dependence of temperature on time and modified critical temperatures for investigated steel. As the example the CDFIH process for gear wheels made of steel 300M was presented. Expected hardness and microstructure distributions were observed, however in order to obtain uniform contour hardness distribution it is necessary to optimize parameters of the CDFIH process by means of advanced mathematical modelling validated by experiments. The stand will be used as a demonstrator of modern IHS technologies.

Acknowledgment

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Note: Krajewska T. is responsible for English language, Katowice, Poland