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# AUTOMATED EDDY CURRENT INSPECTION SYSTEMS WITH SURFACE PROBE OF DOUBLE-DIFFERENTIAL TYPE

**V.N. Uchanin[1], G.G. Lutcenko[2], A.V. Opanasenko[2]**

[1]Karpenko Physico-Mechanical Institute of the NASU
5 Naukova Str., 79060, Lviv, Ukraine
[2]Ukrainian Scientific Institute for Non-Destructive Testing
8 Naberezhno-Lugova Str., 04070 Kiev, Ukraine

**ABSTRACT**

The prospects and state-of-the-art related to the development of automated non-destructive testing systems are considered. The formation of the tendency concerned with creation of the adaptive automated systems for complex testing based on the application of various physical principles to obtain a synergistic effect is indicated. The factors affecting the variability of eddy current probe signals during the manual and automated eddy current testing were analyzed. The advantages of selective probes of double-differential type for automated systems development are indicated. Features of the design and characteristics of multi-channel automated systems based on the eddy current method application developed in Ukraine are presented, in particular: a robotic eddy current testing system for detection and identifying of in-service defects in the tubes of secondary reforming furnaces; the eddy current unit of the multi-channel system of complex testing of railway axles during their production; automated system of complex testing of wheel pairs in the conditions of repair plants; eddy current block of the system for complex inspection of railway rails during their production.

**KEYWORDS:** automated system, complex non-destructive testing, eddy current defect detection, eddy current probe of double-differential type

## INTRODUCTION

Rebuilding of industry in scope of the Fourth Industrial Revolution results in formation of the new approaches in non-destructive testing (NDT) using NDE 4.0 abbreviation (Non-destructive Evaluation 4.0), where the issues of automation of testing operations (including with robots application) take a leading place [1, 2]. Let's consider automation as a complex of technical and program means providing NDT performance without direct human participation. It is impossible to provide large scopes of NDT in many spheres of industry without partial or complete automation. Automated NDT is not only used during manufacture where it is easy to provide testing of products of simple shape in form of rotation bodies (pipes, rods, wires, balls etc.) that can be considered a common phenomenon long ago. This testing during operation of products creates the unique possibilities for NDT without human participation in the dangerous and harmful for health environments [3, 4]. At the first stages of NDT development the methods of manual NDT were mainly implemented. At that all procedures from equipment preparation and scanning of surface of tested object (TO) to making a decision on quality or defectiveness of products were made by operator. Such an approach resulted in significant limitation of reliability and validity of testing due to dependence of the obtained results on operator qualification. In order to get rid of effect of this factor there were implemented the rigid requirements as for training and certification of personnel by NDT methods and commercial sectors, accreditation of laboratories and verification of NDT procedures. Ukraine in particular to realize these requirements has the acting standard DSTU EN "Non-destructive testing — Qualification and certification of NDT personnel". It in full corresponds to international reference documents. Therefore, the most important positive effect from implementation of automated NDT is the increase of its reliability. At the same time scientific literature contains warnings as for possible risks and production losses that can accompany automatic NDT due to its inappropriate application and widespread (and not always grounded) trust in its reliability [5, 6].

Increase of NDT efficiency can be considered other by value effect of automation, which is in particular important under conditions of continuous manufacture. It is necessary to note that NDT automation does not detract a value of operator or engineer who makes a decision on product quality or structure operational integrity. Implementation of automated NDT systems require from them knowledge of higher level necessary for determination of rejection criteria, introduction of changes in algorithm of product testing depending on reference documents (standards) corresponding to the requirements of specific client etc.

The aim of this work is the analysis of peculiarities of automation of eddy current (EC) testing and presentation of domestic automated system (AS) of eddy current testing with surface selective double-differential eddy current probes (ECP).

**STATE OF THE ISSUE**

A separate methodology for development of automated NDT systems (ASNDT) has not been developed yet. At this stage the logical step is application of methodological principles and approaches developed for information-measuring systems (IMS) which are sufficiently developed [7–9] as well as consideration of existing works on general theory of automation [10–12]. At that it is necessary to take into account the peculiarities of functioning of specific NDT method. It is also necessary to note that the purpose of testing systems (including NDT) in contrast to IMS is determination of correspondence of technical condition of TO to standard requirements and registration of deviations in the parameters characterizing TO technical condition from determined norms. For ASNDT, the purpose of which is technical diagnostics of TO in operation (in foreign scientific literature this direction is abbreviated as SHM — structural health monitoring), it is also necessary to determine the reasons of non-conformity of TO technical condition (in particular, presence of defects, degradation of materials, wear out of operating surfaces etc.) with evaluation of reliability and prediction of its further service life.

It is necessary to note that very often existing ASNDT not only generate a protocol by the results of performed NDT, but also have in their content the means for formation of the signals based on obtained results for regulation of executing mechanisms, to which in particular the mechanisms of presorting and marking of defective zones can be referred. Such ASNDTs have already the features of automated systems for regulation of technological processes [13].

It should be noted that there is no accurate terminology for the issues of NDT automation. In the literature such terms as “mechanized”, “automated”, “semi-automated” and “automatic” [14] can be found. NDT means, in which operations of scanning are completely or partially (by one of the coordinates) performed automatically, can be referred to mechanized ones. Operator at that usually checks workability and calibrates unit on a standard specimen (SS), makes a decision on defect presence and forms testing protocol. Automated NDT systems mostly foresee automation of operations of TO delivery on testing position and scanning of TO surface, check of workability on SS and formation of protocol about defects presence and their coordinates. However, a decision on product quality is made by operator of the highest level of qualification based on analysis of testing protocol and, if necessary, results of additional test operations. To automatic ones it is possible to refer the NDT systems, in which all operations including taking decisions on product quality and correspondence to normative documents and reject of poor products are made without operator participation. Does such classification reflect the modern level of technological development? Probably not, since there are, in particular, AS based on application of robots which carry various NDT equipment. Lifting and underwater types of robots or pilotless vehicles [4] are used for NDT of difficult-to-reach zones of structures. Besides, there were developed technical solutions as for creation of adaptive AS, in particular, based on application of technical vision devices [15] (see Kuts Yu.V., Shapovalov E.V., Uchanin V.M. et al. Method of adaptive eddy current testing. Patent of Ukraine 140906, 2020, Bul. No. 5 and Uchanin V.M., Vertiy O.O., Yatsenko O.Yu. et al. Adaptive method of scanning eddy current testing. Patent of Ukraine 149803, 2021, Bul. No. 49), AS of complex NDT using different physical methods (for example, ultrasonic and EC) and AS using tomography principles [16–18]. Therefore, there is a need in development of up-to-date classification of ASNDT based on expansion of a list of classification features.

In total is can be told that there is a formation of a tendency of development of multi-functional adaptive AS for solution of several tasks, including based on realization of complex NDT built on application of different physical principles for production of synergy effect related with limitations of each separate NDT method and different probability of defect detection depending on type and place of location [19, 20].

In recent years the spheres of application of EC NDT methods using the reaction of TO material on probing action of alternating electromagnetic field have significantly expanded [21–23]. It is related with a series of advantages of this method in comparison with other NDT methods. It is a well-grounded statement that the EC method has high sensitivity to different type defects and sensitivity to a series of electrophysical and geometry parameters of TO (multi-parameter). However, for automation the most important is a factor of contactless of EC method, i.e. possibility to provide sufficient sensitivity to defects at certain distance between ECP and TO surface or even through dielectric coating. At that the basic importance is the possibility of reduction of interferences from a gap change, i.e. distance between ECP and TO surface during scanning. Double-differential ECPs providing high sensitivity in testing with large gap [24] correspond to such requirements.

A Table 1 shows an attempt to compare automatic and manual eddy current NDT analysing the factors affecting variability of ECP signals, and, respectively, testing reliability.

**Table 1.** Factors affecting variability of ECP signals during manual and automated EC testing

| Automated testing | Manual testing |
|---|---|
| 1. Violation of ECP positioning<br>2. Violation of scanning rate | 1. ECP positioning (gap, inclination, orientation) by operator.<br>2. Parameters of scanning of TO surface (step, rate etc.).<br>3. Adjustment of device (selection of operating frequency, amplification, level of signalization of defects etc.).<br>4. Correspondence of SS for adjustment to TO characteristics.<br>5. Selection of method of interpretation of ECP signals (for example, using a complex plane)<br>6. Selection of parameters of high frequency filter for suppression of effect of interferences related with changes of electrophysical and geometry parameters of TO, effect of edge etc.<br>7. Selection of parameters of filters of low frequencies for suppression of effect of electronic interferences respectively to scanning frequency.<br>8. State of operator health and environment. |

The right part of the table provides sufficiently large list of operations which should be realized by operator during manual testing for its reliability. Obviously, that inaccuracy of performance of each operation can result in violation of optimum scanning of TO surface, wrong adjustment of equipment and, as a result, defect skipping. In AS most of the procedures of the right part of the table are selected at the stage of preliminary investigations and being realized in correspondence with the set algorithms of operation of AS constituents. To provide testing selectivity it is important to choose such informative signs of ECP signals which allow reliably finding the defects under conditions of interferences action. AS functioning virtually has no dependence on operator qualification, state of health and working conditions. The left part of the table determines importance of the requirements to quality operation of scanners and AS positioning devices. Presented table proves the perspectives of automation of EC testing as for increase of testing reliability under conditions of creation of reliable scanners and positioning devices.

## ROBOTIC SYSTEM OF EDDY CURRENT NDT FOR DETECTION AND IDENTIFICATION OF SERVICE DEFECTS OF PIPES OF FURNACE OF SECONDARY REFORMING

A relevant problem of chemical industry is a detection of service cracks on inner and outer surfaces of pipes of furnaces of secondary reforming. Pipes of 102 mm diameter with 15 mm wall thickness are manufactured using the method of centrifugal casting from stainless steel 40Kh25N20. Testing should be carried out from outside without excess to pipe inner surface with high sensitivity to defects lying at 7–8 mm depth (around 50 % of pipe thickness). The task is complicated by large structural inhomogeneity of pipe material, which significantly decreases efficiency of ultrasonic method. Therefore, leaving no alternative solution of the problem is application of EC method using low operating frequencies. Besides, means of EC testing should identify found defects by their division for several classes, namely inner and outer relative to pipe surface on which they are initiated as well as longitudinal and transverse relatively to pipe axis. Besides, it is necessary to evaluate defect depth (in percent from pipe thickness) independent on the fact on which surface they were found. All these tasks should be solved under conditions of high level of interferences appearing due to structural inhomogeneity of material and roughness of pipe surface.

When designing ECP the attention was paid on sufficient sensitivity to defects on inner pipe surface, level of signal of which shall exceed the level of structural noise. In ECP design there were used sufficiently large coils located on ferrite cores of 10 mm diameter that provided a possibility due to integration properties to reduce the level of structural noise with conservation of necessary sensitivity to the defects. The best sensitivity to inner defects was provided by ECP of MDF 3301 type with diameter of operating area 33 mm. It allows EC testing in a range of operating frequencies 50 Hz – 150 kHz. ECPs were investigated using EDDYMAX type EC board on operating frequency 1.5 KHz, which provided the sensitivity to the defects on inner pipe surface during testing from pipe outer surface. There was used a fragment of pipe on inner surface of which three semi-elliptical longitudinal defects of 0.2 mm thickness were milled. The latter simulate a crack of 35 mm thick and 7.5 mm depth (D1); 9.0 mm (D2) and 10.0 mm (D3) that corresponds to lying depth 50; 40 and 33.3 % from pipe wall thickness (15 mm) in testing from outer pipe surface [27].

Figure 1, *a*, *b* provides signals from three defects on inner pipe surface (D1, D2, D3) in a complex plane (after demodulation) as well as vertical and horizontal components of ECP signal in mode of time-base sweep.

Figure 1, *c*, *d* for evaluation of the possibility of detection of inner defects provides the corresponding signals from structural noise which were obtained by means of scanning of defect-free zone of the pipe as well as the signals from change of a gap which were obtained by withdrawal of ECP from pipe surface at a distance more than 3 mm. The signals from structural noise can be observed in a complex plane (on Figure 1, *c* shown by dashed circle) or in a mode of time-base sweep of signal components (Figure 1, *b*). It can be seen that the signals from inner defect of crack type (D1) with lying depth 7.5 mm (50 % of pipe wall thickness) are more than for 6 dB higher than the signals from structural noises.

Figure 2 shows the ECP signals from surface cracks of different orientation on operating frequency 1.5 kHz at sensitivity by 18 dB lower than during registration of signals on inner pipe surface (Figure 1). Figure 2 *a*, *b* provides the ECP signals in a complex plane and in a mode of time-base sweep from longitudinal relatively to pipe axis surface crack of 5.0 mm depth. Figure 2, *c*, *d* gives corresponding signals from transverse crack. Data on Figure 2 indicate the peculiarity of the signals of double-differential ECP when the signals from longitudinal and transverse cracks have opposite direction of hodographs and, respectively, different sign of vertical component. This peculiarity can be used for identification of detected cracks respectively to their direction.

Comparison of the signals from inner (Figure 1, *a*, *b*) and surface (Figure 2) defects and signals from gap change (Figure 1, *c*, *d*) indicates the possibility of differentiation of the signals from the defects and the signals from gap change and identification of detected defects as for surface of their location by direction of hodograph (phase angle) of the signal. In particular, a hodograph of the signal from defects on inner pipe surface differs from the signal caused by a gap by ~90° angle that gives the possibility to mark it out effectively by rotation of complex plane.

The results of the investigations were used by SPC "Promprylad" for development of a system of robotic EC testing of pipes of secondary reforming of CRAB type [25]. The CRAB system provides 4-channel double-frequency testing of pipes under service conditions. It consists of 4 ECPs connected to 4 identical EC channels, mechanical scanner-robot with control block, that provide independent scanning of pipe surface by all ECPs, and commercial computer. Specially developed scanner-robot (Figure 3) provides simultaneous movement of four ECPs each of which scans separate sector of the pipe on meander type trajectory. After testing of one section of the pipe from all sides the scanner together with ECP automatically moves to the next area. Original pneumatic mechanisms are used for scanner construction. This allows reducing the level of electric noise due to absence of electric drives in ECP zones.

Rate of movement along the pipe is 1 m/min. A scanner can be installed on the pipe not only from the edge,

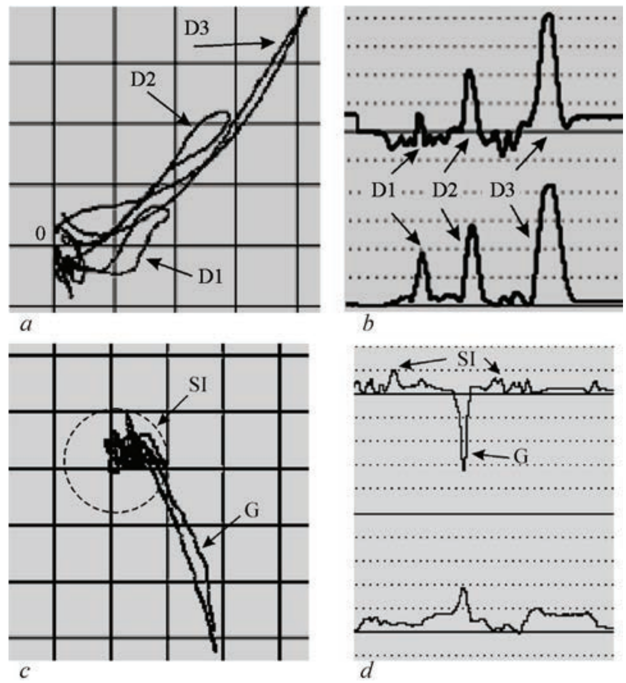


**Figure 1.** Signals of ECP of MDF 3301 type from inner defects of pipes lying at 7.5 depth (D1); 6.0 (D2) and 5.0 mm (D3) as well as signals of structural noises (SI) and gap change (G) in complex plane (*a*, *c*) and components of ECP signal in a mode of time-base sweep (*b*, *d*)

but also from its cylindrical surface that provides the possibility to test built-in pipes during their repair.

A block for scanner regulation forms six control signals, takes four signals from executing mechanisms of scanning device as well as takes and processes signals from angular movement sensor. Each eddy current channel processes signals from one ECP on two operating frequencies 1.4 and 5.0 kHz necessary for detection

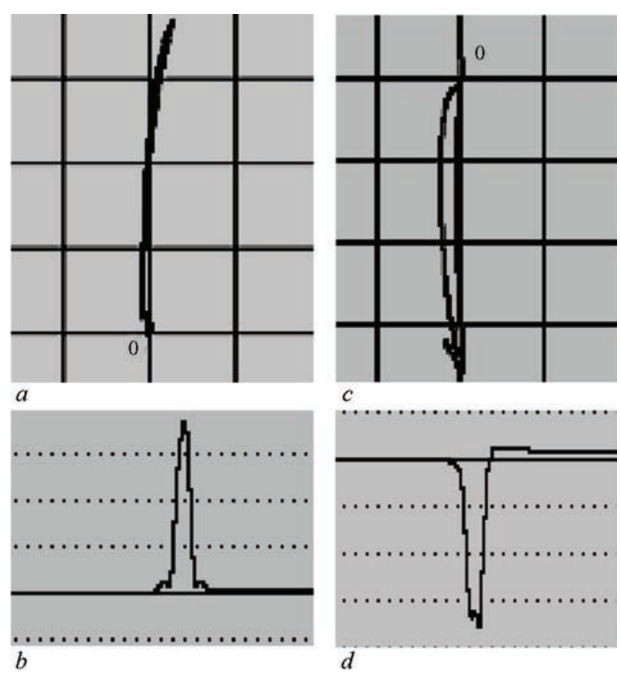


**Figure 2.** Signals of ECP of MDF 3301 type from longitudinal (*a*, *b*) and transverse (*c*, *d*) defects in complex plane (*a*, *c*) and in mode of time-base sweep (*b*, *d*)

**Figure 3.** EC scanner of CRAB system installed on pipe of secondary reforming furnace

and identification of defects on different pipe surfaces. Registration of signals on different operating frequencies from each ECP separately allows identification of defects by surface of their location. During testing it is possible to observe and register the signals from all four ECPs on operating frequencies 1.4 and 5 kHz simultaneously (Figure 4). Inner defects form a signal only on frequency 1.4 kHz and outer ones on frequency 1.4 kHz as well as on 5 kHz frequency. The system has a possibility to register hodograph of ECP signal from defect in a complex plane or its components in a time-base sweep mode. To realize an automatic defect signalling (ADS) on each of channels it is possible to mark out up to four zones of defect registration in a complex plane. The possibility is stipulated to build a sweep of selected sector of the pipe for separate channel as well as sweep of whole pipe for inner or outer defects. CRAB system provides for storage of all collected data for their further analysis and documenting and possibility of evaluation of depth of detected defect in percent relative to pipe wall thickness independent on its location.

The investigations showed that the CRAB system detects defects of more than 20 % depth on outer surface and more that 50 % from pipe wall thickness on inner one. The CRAB system identifies detected defects by

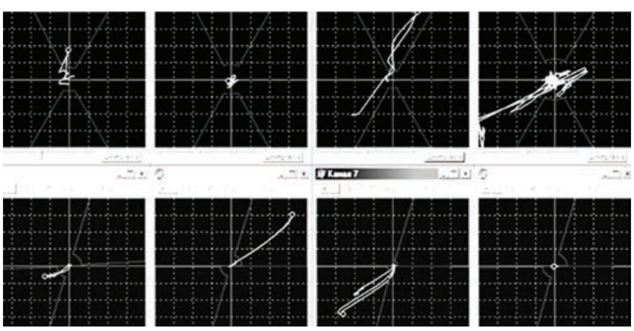

**Figure 4.** Signals from four ECP on operating frequencies 1.4 (top) and 5 kHz (bottom)

their location (on inner and outer surfaces of pipe) and orientation (longitudinal or transverse) as well as evaluates their depth in percent relative to pipe wall thickness.

## EDDY CURRENT BLOCK OF MULTI-CHANNEL AUTOMATED SYSTEM FOR COMPLEX TESTING RAILWAY AXES

Manual testing of railway axles with formation of test results protocol for each axle has low productivity that limits their testing on zones of possible defect nucleation. Significant increase of productivity and reliability of axles testing can be achieved by application of complex NDT that is caused by different sensitivity of selected NDT methods to separate groups of defects. Defects of railway axles can be divided on two main groups, namely 1) inner which are sufficiently well identified by ultrasonic method; 2) surface, sensitivity to which during ultrasonic testing is not enough high. In some AS during NDT of axles the ultrasonic method is combined with magnetic-particle testing which provides high sensitivity to surface defects, but at the same time it has a series of significant disadvantages. Therefore, EC method is more perspective for complex automated NDT of axles. Ukrainian SRI for Non-destructive testing (Kyiv) created an automated system of complex NDT of railway axles SANK-3, in which EC method was added to ultrasonic testing [26]. Railway axles of RU1Sh and RU1 type from axle steel subjected to NDT have sufficiently complex shape (Figure 5).

Total length of RU1Sh makes 2216 mm and RU1 axle is 2294 mm. Diameters of neck, near-hub part, hub and middle part of the axle make 130; 165; 194 and 172 mm, respectively. Length of areas of axle along the neck, near-hub part and hub of axle is 190 (for RU1 — 176), 76 and 250 mm, respectively.

Due to its complex shape, sufficiently large area of testing, and necessity to provide high productivity the axle surface is divided into separate zones being tested in parallel in multi-channel mode. In whole there were marked 16 testing zones (Figure 5). At that zones 1, 3, 5, 6 and 8 are tested with two ECPs and zone seven with four ECPs. Zones 2 and 4 of fillets should be tested in a separate mode since the tested surface in this case have small curvature radius. Therefore, ECP with a smaller radius of the working area is used for these zones. For testing of different zones of railway axles, ECPs of two types were used:

- MFD 0701 with working area diameter 7 mm for testing of cylinder surfaces, fillets of middle part and axle edges (all zones, except for second and fourth);

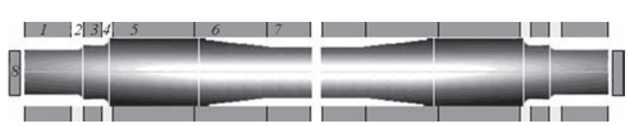


**Figure 5.** Scheme of division of railway axles on separate test zones

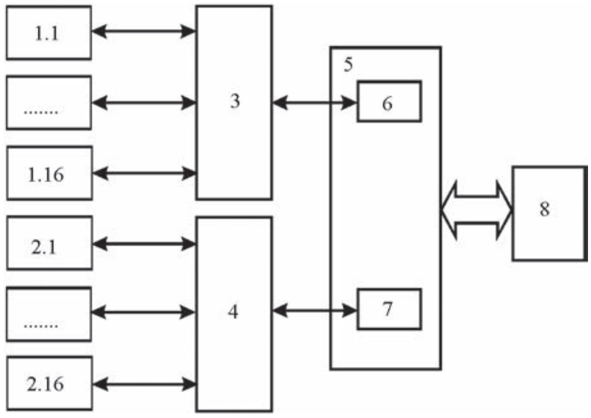


**Figure 6.** Scheme of EC block of SANK-3 type system for complex NDT of axles: 1.1-1.16 and 2.1-2.16 — ECP; 3 and 4 — multiplexers; 5 — electronic module OKO-13, 6 and 7 — eddy current blocks; 8 — central computer

● MDF 0602 with 6 mm diameter for testing of small radius fillets (zones 2 and 5 on Figure 5).

A structural scheme of eddy current block of automated system SANK-3 (Figure 6) contains 32 ECPs divided on two groups 1.1-1.16 and 2.1-2.16. Each group of 16 ECPs is served by two multiplexers 3 and 4 which in turn interrogate ECP. Each of multiplexers can switch up to 32 ECPs which are fixed in the mandrels with possibility to scan surfaces of axles with 0.2 mm gap. The mandrels with ECP in start position are shown on Figure 7.

Electronic module 5 of previous collection and processing of the information OKO-13 consists of two eddy current blocks (ECB) 6 and 7 (Figure 6), each of which serves one multiplexer. Module OKO-13 is improved central block of multi-channel flaw detector OKO-01 with no display and control elements. It can have up to four ECB. Electronic module 5 and ECPs 6 and 7 connected to it are located in one body. Module 5 is equipped with field-bus module WizNet for connection with PC 8, which is carried out using standard protocol TCP/IP 4.0. ECB sends a signal from generator of sine oscillations and code to multiplexer that corresponds to current ECP and channel. The multiplexer activates channel corresponding to obtained code and signals from selected ECP come to ECB where their primary processing and accumulation take place. After testing completion these data are transferred to the central computer 8 which processes them and stores information on defective areas in a data base. The inserts with artificial defects mounted on SS in form of special control axle are provided for verification of workability and calibration.

The results of experiments and operation of SANK-3 system showed that EC testing using double-differential ECP of MDF type provides sufficiently high sensitivity to defects. This provided the possibility to replace magnetic-particle NDT and increase productivity of AS testing of railway axles.

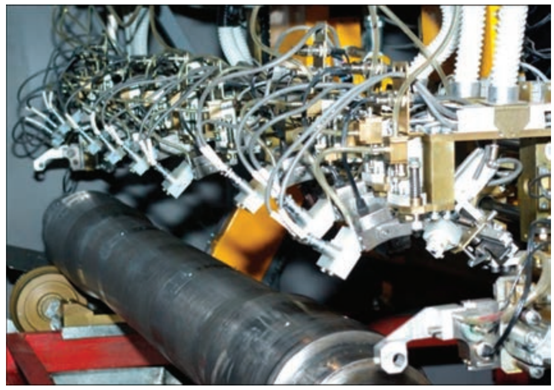

**Figure 7.** Automated SANK-3 system with ECP on start position

## AUTOMATED SYSTEM OF COMPLEX NON-DESTRUCTIVE TESTING OF WHEEL PAIRS

Automated system SNK KP-8 (Figure 8) of complex (ultrasonic, electromagnetic-acoustic and EC) testing of wheel pairs of RU1 and RU1Sh-957 type was developed at Ukrainian SRI for Non-destructive testing (Kyiv) after long-term operation [27].

Eddy current tract AS SNK KP-8 provides multi-channel testing of different zones of wheel pairs that guarantees high testing productivity. One of the variants of AS for different zones of wheel pair applies the following amount of EC channels, namely 16 channels for testing of side surfaces of wheel rim; 6 channels for testing of wheel rolling surface; 9 channels for testing of wheel flange; 24 channels for testing of near–rim zone of disk; 8 channels for middle part of axle; 8 channels for testing of axle neck and 10 channels for testing of inner racers. Double-differential ECPs are used for testing of rim (MDF 1201), fillets (MDF 0601), flange (MDF 0901) and rolling surface (MDF 1201) of wheel, middle part (MDF 1201) and necks (MDF 0601) of axle as well as inner racers (MDF 0901). Figure 9 demonstrates scanners of AS SNK KP-8 for testing of different zones of wheel pair.

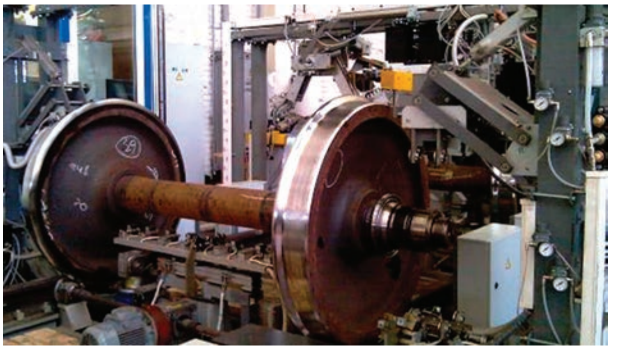

**Figure 8.** Automated system of complex testing SNK KP-8 with tested wheel pair

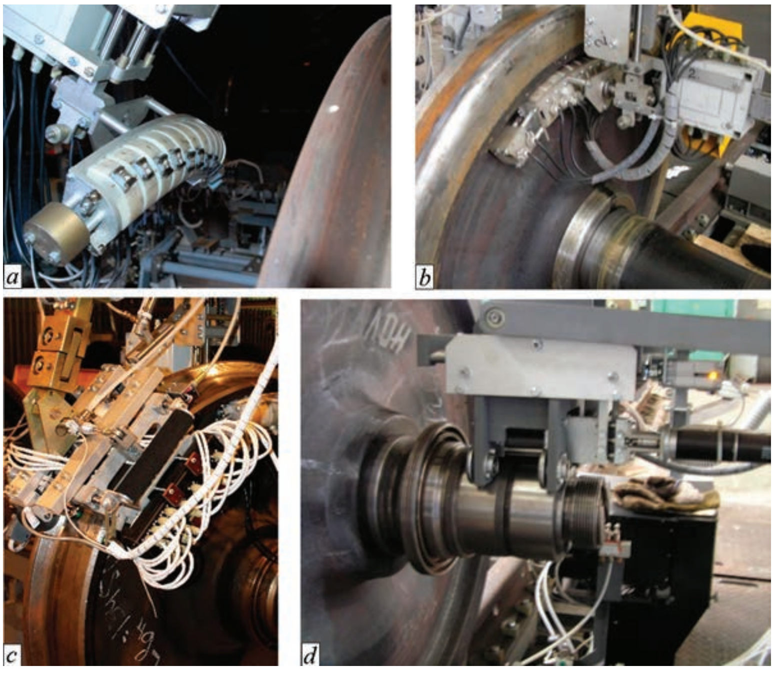

**Figure 9.** AS SNK KP-8 scanners for testing of fillets of wheel rim in start (*a*) and operating positions (*b*), for testing of rim (*c*) and racers zone (*d*)

The system provides complex testing of not less than ten wheel pairs per hour under condition of their uninterrupted supply on testing position. During commercial experiments and operation of automated system SNK KP-8 the eddy current method detected the defects in middle parts of axles, inner racers as well as rims, flanges, rolling surfaces and in near-rim zones of wheels.

## EDDY CURRENT BLOCK OF AUTOMATED SYSTEM OF COMPLEX TESTING OF RAILWAY RAILS

Complex NDT of rails at the stage of their manufacture is provided by series of standards as an important factor of reliable and trouble-free operation of railway transportation. Ultrasonic and EC methods of NDT are often combined for reliable detection of rails defects. In this case synergy effect of such an approach is reached by their orientation on different groups of defects [19, 20]. For development of selective EC system under condition of effect of strong interferences there are used different variants of the method including application of rotation ECPs [28]. Such an approach can significantly limit productivity of EC testing and disturb the synchrony of operation cycles that can result in decrease of productivity of rail manufacture in whole. Multi-channel AS using selective ECP are prospective for increase of NDT productivity. They can carry out testing under conditions of effect of large interferences including connected with inhomogeneity of magnetic properties of steels and instability of gap between ECP and TO surface [29].

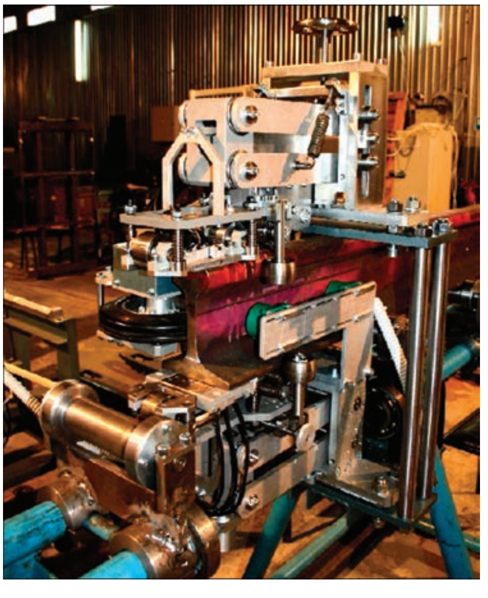

**Figure 10.** General view of AS of complex NDT of rails after their rolling

Automated system for complex (ultrasonic, electromagnetic-acoustic and EC) testing of railway rails after their rolling was developed by SPC "Promprylad" (Figure 10) [30].

Let's consider in details EC block of this AS which provides testing of rails with productivity to 2 m/s due to application of 56 channels [30]. Main requirements to ECP of such AS stipulated high sensitivity to longitudinal and transverse cracks, possibility of testing under conditions of distance between operating surface of ECP and rail surface not less than 1 mm to prevent ECP damage and high level of noise suppression related with changes of this distance (gap) during scanning. Preliminary tests showed that double-differential ECPs of MDF 1201 type with working sur-

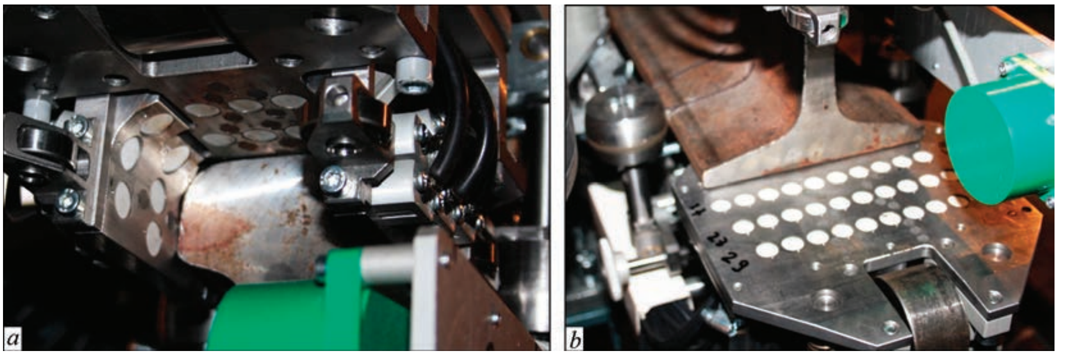

**Figure 11.** Sets of ECP for testing of head (*a*) and base (*b*) of rail

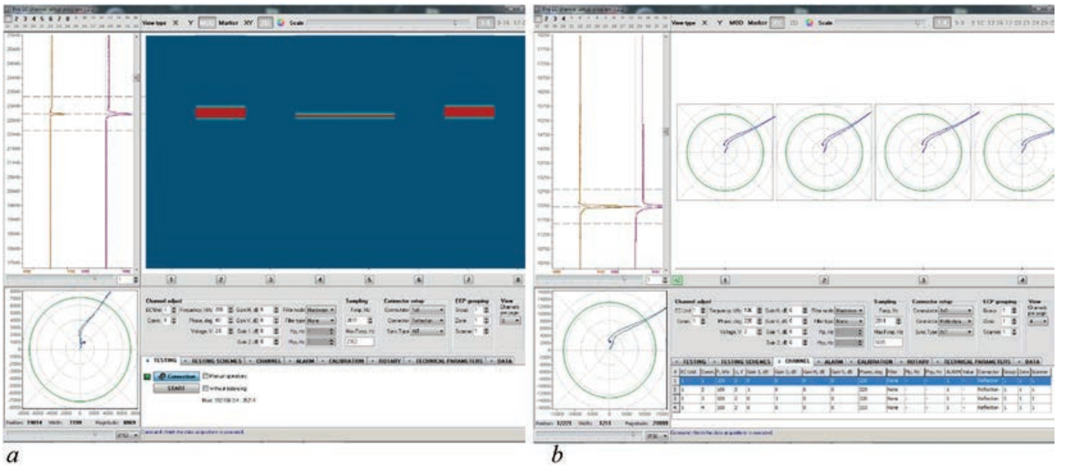

**Figure 12.** Display of EC block of AS with signals from defects in rail head in mode of 2D presentation (*a*) and in mode of complex plane (*b*)

face diameter 12.5 mm fulfil these requirements. They provided maximum sensitivity to defects in ferromagnetic steel on operating frequency 100 kHz. In total there were used 25 ECPs for testing of rail head including with side surfaces (Figure 11, *a*) and 31 ECPs for testing of rail base (Figure 11, *b*). EC block of AS provides detection of longitudinal and transverse cracks of depth more than 1.0 or 1.5 mm and length more than 20 or 10 mm, respectively.

Appearance of display of EC module of AS with visualization of the testing results in modes of 2D visualization (*a*) and complex plane (*b*) is given on Figure 12.

## CONCLUSIONS

The state of the problem of ASNDT development is considered. It was noted a tendency to development of adaptive AS for complex NDT built on application of different physical principles for provision of synergy effect. There were analysed the reasons affecting variability of ECP signals during manual and automated EC testing. The advantages of selective double-differential ECPs for development of EC testing systems was noted.

There were presented the peculiarities of design and characteristics of developed in Ukraine (SPC "Promprylad" and Ukrainian SRI for Non-destructive testing) multi-channel AS using EC method, in particular:

- robotic four-channel EC testing system for detection and identification of operation defects of pipes of second reforming furnaces on two operating frequencies 1.4 and 5.0 kHz with rate of movement of ECP block along the pipe 1 m/min;
- eddy current block of multi-channel (32 channels) AS of complex testing of railway axles in their manufacture;
- automated system for complex NDT testing of wheel pair under conditions of repair enterprises (different variants have at least 98 EC channels), which provides the possibility of NDT of not less than ten wheel pairs per hour;
- eddy current AS block for testing of railway rails in their manufacture with productivity to 2 m/s due to application of 56 channels, sensitivity of which allows detection of longitudinal and transverse cracks of depth more than 1.0 or 1.5 mm and length more than 20 or 10 mm, respectively.

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**ORCID**

V.N. Uchanin: 0000-0001-9664-2101

**CONFLICT OF INTEREST**

The Authors declare no conflict of interest

**CORRESPONDING AUTHOR**

V.N. Uchanin

Karpenko Physico-Mechanical Institute of the NASU

5 Naukova Str., 79060, Lviv, Ukraine.

E-mail: vuchanin@gmail.com

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