Development of Multichannel Computer-aided Testing Systems based on Eddy Current Method Application

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1. Introduction

Manual inspection is time consuming and doesn’t ensure needed demands concerning with productivity. Especially it is critical when two or more NDT methods must be applied for reliable detection of different types of flaws. This problem can be solved by the development of computer-aided multichannel systems where main inspection NDT procedures including the mechanical scanning are operated by software control.

2. EC probes for flaw detection in automated systems

The main demand to EC probes possible to be applied for computer-aided EC system creation is high sensitivity to flaws when there is large enough clearance between probe and inspected surface. High lift-off noise suppression also is needed. Developed double differential (multidifferentcial) type EC probes satisfy such requirements [1-3]. For different application set of such probes with different operational frequency range (from 50 Hz to 6-8 Mhz), spatial resolution and operational diameter from 4 to 33 mm was developed. Some of them are presented in fig. 1.

Figure 1. Double differential MDF type EC probes with different operational frequency range and spatial resolution

Possibility to detect flaws with large distance from inspected surface was investigated with special steel 45 reference standard with 0.1 mm thick electroerosive slots. Produced slots have different depth from 0.1 to 2.0 mm and were extended to full length of the sample (30 mm). Signals of two types EC probes were investigated: MDF 12 (SS170K13DA0) and MDF 06 (SS650R06DA0) with 12.5 mm and 6.0 mm of operational surface diameters respectively. Signals were registered in complex plane (fig. 2 and 3 left) and in time-base mode (fig. 2 and 3 right).

Signals of MDF 12 type EC probe obtained for 0.5; 1.0 and 2.0 mm deep flaws on operational frequency 30 kHz for direct contact with inspected surface and with 5.0 mm clearance are presented in fig. 2. Amplification of EC device was adjusted 36 dB more sensitive for signal obtained with 5.0 mm clearance (fig. 2 below) than when signal without clearance (fig. 2 top) was recorded.
Figure 2 shows the possibility of MDF 12 type EC probe to detect 0.5 mm deep flaws through 5.0 mm gap with very high signal to noise ratio. We can observe some difference in phase angle (see signal in complex plane) and amplitude. The latter can be applied for flaw depth estimation after calibration procedures will be executed.

Signals of MDF 06 type EC probe obtained for 0.2; 0.5 and 1.0 mm deep flaws on operational frequency 100 kHz for direct contact with inspected surface and with 2.5 mm clearance are presented in fig. 3. Amplification of EC device was adjusted 36 dB more sensitive for signal obtained with 2.5 mm clearance (fig. 3 below) than when signal without clearance (fig. 3 top) was recorded.

Figure 3 shows the possibility of MDF 06 type EC probe to detect 0.2 mm deep flaws through 2.5 mm gap with very high signal to noise ratio. We can observe the some difference in phase angle (see signal in complex plane) and amplitude such as for MDF 12 type EC probe (fig. 2). It is essential to note that MDF 06 type EC probe have small enough size (only 6 mm) and is very convenient for fillet zone inspection. In addition this probe have better spatial resolution due to the smaller coils application.

3. Automated Eddy Current System for Stainless Steel Tube Inspection
Computer–aided EC system “CRAB” is developed for detection and sizing of cracks situated on inner and outer surface of secondary reforming furnace tubes in chemical industry. It is possible to mention that this task cannot be solved by ultrasonic method due to the large material structural heterogeneity and large ultrasonic wave attenuation and scattering. The inspected 15 mm thick tubes were produced from 40X25H20 stainless steel by centrifugal casting process. The important requirement to EC system is the identification of cracks by displacement on inner and outer tube wall with depth sizing. Inspected tubes have 102.0 mm in diameter.

To solve the problem a low frequency MDF 33 (SS10K33DA0) type EC probes with 33.0 mm operational diameters was developed. EC probes were investigated at operational frequency 1.5 kHz and provided the best sensitivity to internal defects on the inner surface. As reference standard a real piece of tube was applied with 3 artificial 35 mm long longitudinal flaws 0.2 mm thick with different depth 7.5 mm (D1); 9.0 mm (D2) and 10.0 mm (D3), which corresponds to the residual thickness 50; 40 and 33.3 % of the tube wall thickness (15 mm).

Signals from three defects situated on inner tube surface (D1, D2 and D3) in the complex plane (fig. 4a) and vertical and horizontal components of the signal in the time base mode (fig. 4b) are presented in fig. 4. Structural noise obtained by scanning tube surface in flaw-free area and the lift-off signal (fig. 4c,d) also were recorded. Signals from structural noise can be seen in the complex plane (on fig. 4c marked by circle) or in time-base mode for vertical and horizontal components (fig. 4d). So we can found that the signal from the subsurface crack-like flaw (D1) with depth of 7.5 mm (50% of the thickness of the tube wall) is more than 12 dB higher than the signal of structural noise.

![Figure 4. EC signals from subsurface flaws on inner tube surface laying on the depth 5 mm, 6 mm and 7.5 mm (a,b); structural noise (c) and lift-off change noise (d) in complex plane (left) and in time-base mode (right)](image)
Presented results were used to create an automated EC system CRAB for secondary reformer tube inspection [3]. Developed system provides 4-channel two-frequency EC inspection of tubes during their operation life and consists of four EC probes connected with four identical EC channels. Scanning mechanism (fig. 5) with a control unit provides simultaneous scanning movement along tube surface by all EC probes. Each EC channel processes the signals from one EC probe at two operational frequencies 1.4 and 5.0 kHz needed for detected flaw identification. The system software makes it possible to save all the collected data for further analysis and documentation and provides the flaw depth assessment in a percentage of the tube wall thickness regardless of its location. Each EC probe tests the separated sector of tube surface by meander type trajectory.

4. Automated EC systems for combined inspection of rolling stock components

Reliability of railway transport is dependent on the quality of wheel sets including the axles. Only automated axles and wheel set inspection give the possibility to increase the inspection reliability and effectiveness and to improve wheel sets and axles quality.

4.1 Automated system for combined axle inspection

EC section of automated system SANK-3 provides computerized 32-channel inspection with 32 EC probes simultaneously. The EC probe sensitivity was investigated by application of reference standards with artificial like crack slots. Longitudinal slots are 15.0 mm long, 0.5 mm deep and 20 µm thick. Transversal slots are longer (50 mm) with the same slot depth and width. Two types of double differential (multidifferential) EC probes (fig. 1) were applied: first - SS400K07DA0 (MDF 07) type EC probe with 7.0 mm operational surface diameter for inspection of cylindrical surfaces, midsection fillets and axle ends; second - SS650K07DA0 (MDF 06) type EC probe with smaller operational surfaces (6.0 mm in diameter) for small radius fillets zone inspection (fig. 6). Presented EC probes have reasonable sensitivity for such artificial flaw in 100-400 kHz operational frequency range [4]. Figure 7 shows mounted EC probes in initial position.
Figure 7. EC probes for axle inspection in initial position

Figure 8 presents EC probe signals obtained by reference standard inspection in different modes (operational frequency ~ 300 kHz). On time-base mode we can see 2 technological signals obtained from reference standard edge mounted on the special testing axle. Flaw signal response in fig. 8 is situated in the center. Presented results demonstrate reliable flaw detection with high signal to noise ratio.

Figure 8. Signal responses of PN-07MDF 01 (MDF 0701) type EC probe obtained for transversal slot: complex plane (left); time-base sweep (right).

Figure 9. Scheme of EC part SS400K07DA0 (MDF 07) of combined automated inspection system “SANK-3: 1.1-1.16 and 2.1-2.16 – EC probes; 3 and 4 – multiplexers; 5 - electronic module; 6 and 7 – EC units; 8 – central computer.

Electronic module 5 includes two EC blocks 6 and 7 (fig. 9), each of which is connected to one multiplexer 3 or 4 respectively. Module 5 represents central unit of universal multi-channel OKO-014 type flaw detector, in which display and control units are absent. Module (5) is equipped with the network module WizNet for communication with central computer (8) by standard protocol TCP/IP 4.0 application. From EC blocks harmonic signal and the code that corresponds to the current EC probe and channel is transmitted to multiplexers (3), (4). Needed channel is activated and the signal from selected EC probe enter to EC block, in which primary processing and accumulation is carried out. After inspection is finished all data obtained are transmitted to a central computer (8) for processing and saving.
In presented automated system **SANK-3** (fig. 10) EC method was applied instead of MP method. Due such technology of combined ultrasonic and EC axle inspection the considerable increasing of inspection productivity was achieved. Due this feature the inspection productivity was synchronized with productivity of the axle production equipment. The influences of subjective factors connected with quality of tested surface preparing also were eliminated.

### 4.2 Automated system **SNK KP-8 for combined wheel set inspection**

Automated system **SNK KP-8** is intended for computer-aided ultrasonic (UT), electromagnetic-acoustical (EMA) and EC non-destructive inspection of wheel sets incoming after long-term operation to the overhaul plants [4]. EC inspection is carried out by differential type EC probes for rim filets inspection and by multidifferential type EC probes for rim, apex and roll surfaces of wheel. Multidifferential type EC probes are also applied for inspection of axle neck, middle part of axles and inner bearing rings. The bearing rings are inspected by differential type EC probes.

To increase the inspection productivity the next quantity of EC probes and channels were applied:

- 16 multidifferential type probes for lateral surfaces of wheel rim inspection;
- 6 multidifferential type probes for roll surface inspection;
- 9 multidifferential type probes for wheel apex inspection;
- 8 multidifferential type probes for middle part of axle inspection;
- 8 differential type probes for axle neck inspection;
- 10 differential type probes for inner bearing rings inspection.

Figure 12 shows the EC probe scanning units for different zones of wheel set inspection.

Automated system **SNK CP-8** provides combined ultrasonic and EC inspection at least 10 wheel sets per hour. Presented systems were put into operation on some repair plant in Ukraine and Russia.

## 5. Automated system for combined tube inspection

Automated UNISKAN–LUCH type system with ultrasonic T-18 type module and eddy current T-18 VT type module is designed to detect flaws in tubes with outside diameter from 140 to 377 mm in accordance with the requirements of EN 10246-2, EN 10246-3 and API Spec 5 CT regulation documents. Tube must be inspected in production line immediately after hot rolling during their reciprocating and rotating motion on a special roller conveyor.

Ultrasonic part of the automated system inspects the tube body for flaws (such as bundles of metal) and measures the wall thickness using immersion baths (fig. 13 in the foreground).

EC part of the automated system consists of two scanning mechanisms with surface type EC probes (fig. 13 in the background) and units of the through type EC probe (figure 14). Automated EC system has 19 channels: one for through type probe and 18 for surface type probes. Operational frequency can be chosen in the range from 1 kHz to 12 MHz. Sensitivity threshold corresponds to
an artificial slot with 2 mm length and 0.1 mm depth. EC method provides detection of flaws oriented along and across the axis of the tube.

Each scanning mechanism for rotational EC inspection is equipped with 9 surface MDF 1201 type EC probes. Each EC probe is installed in a protective case and has an independent suspension, which provides invariable clearance between the probe and inspected surface. Since the tubes can come to the inspection position with oxide remnants the details of scanning mechanism are supplied with wear-resistant replaceable hard-alloy plates for protection.

![Figure 14. Inspected tube in through type EC probe.](image)

6. Conclusions
Application of EC method for creation of combined automated systems provides multichannel inspection with high productivity. EC method based on new selective EC probes replaces inefficient magnetic particle method used before. In this system EC method ensures the surface defect detection and optimally supplements ultrasonic method oriented for detection of subsurface defects. Due to EC method application the productivity of developed systems was estimated 8-10 times greater than the productivity of the systems based on the magnetic particle method application.

References