Eddy Currents Versus Magnetic Particles

Ghennadi LUTENCO 1, Valentyn UCHANIN 1,2, Vladymyr MISHCHENKO 1, Anton OPANASENKO 1

1 Ukrainian scientific research institute for non-destructive testing, Kiev, Ukraine; ndt@carrier.kiev.ua
2 Karpenko Phisico-Mechanical Institute of National Academy of Sciences, Lviv, Ukraine; uchanin@ipm.lviv.ua

Abstract
Magnetic particle inspection method is very popular with surface flaw detection and is used as an auxiliary method together with ultrasonic inspection for complex automatic inspection system creation. Meanwhile this method have many limitations connected with low productivity due to time-taking operations such as surface cleaning, low reliability due to the human factor and surface condition influence, high costs for material expendables and impossibility to estimate the flaw depth. All these factors motivate the new inspection technology creation possible to enter into competition with magnetic particle method. Eddy current method can be used for surface flaw detection as an ultrasonic method partner especially with a glance of recent progress in selective eddy current probe creation. The conducted comparative investigations with new multidifferential type eddy current probe application validate the high efficiency of eddy current method. The obtained results were used for development of new automatic inspection systems for railway axles and wheelpair inspection in which ultrasonic and eddy current methods are combined. The plant experience of developed automatic systems application confirms the eddy current method efficiency in production conditions.

Keywords: magnetic particle inspection, eddy current method, automatic inspection system

1. Introduction
At least two nondestructive methods are usually needed for flaw detection in railway rolling stock components: one for subsurface flaw detection and second for surface breaking flaws detection. For first task, the ultrasonic (US) method satisfies all sensitivity and resolution requirements without any competition. For second task the magnetic particle methods are usually applied.

Magnetic particle (MP) method is very popular for detection of surface flaws in different type components fabricated of ferromagnetic materials. The main reasons of such popularity of MP method are the comparative simplicity and remarkable possibility to evaluate the components with irregular form. Due to the long-time experience this method is presented in many normative documents. In certain documents MP inspection is recommended as just one method to be combined with ultrasonic inspection for complex automatic inspection system creation.

Meanwhile MP method have many limitations connected with low productivity due to time-taking operations such as surface cleaning, component magnetization and demagnetization, suspension treatment and removal and so on. On the other hand MP method has low reliability in real manufacture conditions due to the human factors and surface condition influence. Other disadvantages of MP method are high costs for material expendables and inability to estimate flaw depth. Problems in MP method application decrease also when the inspected component is coated and thickness of paint coating is more than 0.3 mm [1].

All MP method disadvantages motivate the new inspection technology creation possible to enter into competition with magnetic particle method especially for inspection of the components with comparatively simple form (figures of revolution or components with flat surface) in automatic mode. Is this case, low productivity of MP inspection system creates the conflict due 8-10 times restriction of the manufacturing line productivity.

The attempts to replace the MP method by another up-to-day nondestructive method meet the opposition of manufacture managers with reference to normative documents in which only MP method is recommended. Thus, we can observe the absurd situation when the normative documents create the barrier to new technologies progress.
The last tendency of NDT development shows - the eddy current (EC) method is more perspective for surface flaw detection, especially for simple form components inspection [1]. The main advantages of EC method are:
- the comparatively high productivity;
- the possibility to carry out the inspection with few millimeters clearance between EC probe and tested surface;
- the comparative simplicity of inspection procedures automatization;
- the possibility to estimate the detected flaws depth.
To overcome presented obstacles in EC method application the next tasks must be solved:
- the new selective EC probes development;
- the development of special algorithms for signal processing to suppress the noise connected with material magnetic property inhomogeneity and surface roughness;
- to carry out the comparative investigations of developed EC inspection technologies and conventional MP technologies;
- the implementation of EC method to existed normative documents and recommendations for ferromagnetic material component inspection;
- the development and implementation of computer aided systems of combined nondestructive (ultrasonic and eddy current) inspection of railway rolling stock components.

2. The development of the effective EC probes for ferromagnetic components automatic inspection

Special selective EC probes were developed for inspection of ferromagnetic components in automation systems for combined railway carriage components inspection, in which EC method was used as US method partner instead of traditional MP method. The best results were obtained by the multidifferential EC probes application [2]. This type EC probes were developed few decades ago and some difficult NDT problems were solved with this type probes application last time [3-5].
The most essential requirement for used in automated system EC probes is the sufficient sensitivity with large clearance between inspected and EC probe operational surfaces. So, one of the important specificity of multidifferential EC probes is high sensitivity when inspection is carried out over the few millimetres of dielectric or air. On figure 1 the signal responses obtained by MDF 1202 type EC probe when ferrous sample (steel 45) with 0.5 mm depth surface crack was inspected over the 7 mm thick dielectric sheet. The signal responses were obtained on operational frequency 100 kHz with EddyMax flaw detector (Test Macshinen Tecknik, Germany) application.

![Figure 1. EC probe signal responses for 0.5 mm depth crack over the 7 mm dielectric sheet: complex plane mode (left); time-base sweep mode (right).](image)

Presented results show that EC method with multidifferential probes application ensure high sensitivity to cracks with good signal to noise ratio (more than 12 dB) when inspection is carried out through the 7 mm thick dielectric coating or air clearance. For multidifferential
probes we have good spatial resolution in combination with good inspection productivity due wide sensitivity strip because this type of EC probes has 4 sensitivity points. For different axle’s and wheel pair’s zone inspection EC probes with different operational face size were developed.

3. Comparative investigations of EC and MP methods

For justification the possibility to include the EC method to technological normative documents 2 stages of comparative investigations were conducted. On the first stage the MPD type reference standards intended for MP sensitivity verification was applied. The artificial flaw size is in compliance with MP inspection sensitivity level (class A) in accordance with active regulative document GOST 21105-87. The flaw presence was confirmed by standard MP inspection procedure with MD-01PK device application. Eddy current inspection was carried out by application of the universal VD 3-81 type EC device and multidifferential MDF 0602 type EC probe on the operational frequency 340 kHz. Obtained EC flaw signal response (fig. 2) demonstrates excellent signal to noise ratio (more than 12 dB) and the compliance of EC sensitivity with highest (class A) MP sensitivity level.

![EC probe signal responses obtained during inspection reference standard with artificial flaw applicable for class A sensitivity level verification.](image1)

On the second stage the special РУ 1-Ш (in Russian abbreviation) type wheel pair with 8 artificial 5.0 mm diameter ring flaws with dimensions in accordance with class B (GOST 21105-87) MP sensitivity level. All artificial flaws were confirmed by MP inspection by standard procedure. The magnetic powder footprints obtained for ring flaws are presented on fig. 3 (encircled by second red ring). This figure presents also the real surface conditions.

![The magnetic powder footprints obtained for ring artificial flaws.](image2)

All flaws in presented reference standard were detected by EC method with high reliability (signal to noise ratio more than 12 dB) and without the wrong rejection (fig. 4).
4. Eddy current method as reliable partner of ultrasonic method in automation systems for combined inspection of rolling stock components

4.1. The development of the computer-aided system “SANK-3” for combined axle inspection

The computer-aided system «SANK-3» for automatic combined (ultrasonic plus eddy current) testing of rail axles in their manufacture is the first example when eddy current method is successfully applied instead of MP inspection [6]. As it was demonstrated above the characteristics of developed EC probes make it possible to obtain the sensitivity respective to MP inspection. In the developed computer-aided system for inspection of the rail axles 32 EC probes were applied (fig. 5). The developed EC section of computer-aided system “SANK-3” provides computerized 32-channel inspection with 32 EC probes simultaneously.

PN-09MDF 01 (MDF 0901) type EC probe with 7.0 mm operational surface diameter was intended for inspection of cylindrical surfaces, midsection fillets and axles ends. Another PN-06MDF 02 (MDF 0602) type EC probe with smaller operational surfaces (6.0 mm in diameter)
was intended for small radius fillets inspection. The sensitivity investigation was carried out application of reference standards with artificial like crack slots. Longitudinal slots were produced with next parameters: length - 15.0 mm, depth – 0.5 mm and width – 20 $\mu$m. Transversal slots were longer (50 mm) with the same slot depth and width. Such slot is in competence with technical requirements for axle’s inspection sensitivity level. Presented reference standard is registered by № MT 039.2001 (in Russian abbreviation) in the branch measuring tool list-register accepted for the rolling stock MP inspection. Presented EC probes have reasonable sensitivity for such artificial flaw in 100-400 kHz operational frequency range [6].

Figure 6 present the PN-09MDF 01 (MDF 0701) type EC probe signal responses obtained by reference standard inspection in different modes (operational frequency – 300 kHz). On time-base sweep signal response we can 4 technological signals (marked by T on fig. 6) obtained from the reference standard edge, because all of the reference standards consist of two fitting peaces mounted on the special testing axle. Flaw signal response on figure 6 is situated in the center (F on fig. 6). On the complex plane defectogram (fig. 6, left) technological signals are not visible because are truncated by cursor alignment choice. Presented results demonstrate the reliable flaw detection applicable with class B sensitivity level of MP inspection with very high signal to noise ratio.

In presented computer-aided system “SANK-3” EC was applied instead of MP method. Due such technology of combined ultrasonic and eddy current 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 (for example connected with quality of tested surface preparing) also were eliminated. The inspection reliability also was increased due influences of subjective factors suppression the (for example connected with quality of tested surface preparing) [6].

4.2. The development of the computer-aided system “SNK KP-8” for combined wheelpair inspection

Computer-aided system “SNK KP-8” is intended for automated ultrasonic (UT), electromagnetic-acoustical (EMA) and eddy current (EC) non-destructive inspection of wheelpairs incoming after long-term operation to the overhaul plants. EC inspection is carried out by differential type EC probes for rim filets inspection and by multidifferential type EC probes for rim, fillet and roll surfaces of inspected wheel. EC probes also are applied for inspection of middle part of axles. 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;
- 24 differential type probes for near wheel rim area;
- 9 multidifferential type probes for wheel fillet inspection;
- 8 multidifferential type probes for middle part of axle inspection;
- 14 differential type probes for axle neck inspection;
- 10 differential type probes for inner bearing rings inspection.

The range of operating frequencies and operational face sizes of developed EC probes are presented in the next table.

<table>
<thead>
<tr>
<th>EC probe type</th>
<th>Operational face size, mm</th>
<th>Operational frequencies, kHz</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>PN-17×24TD 01</td>
<td>17×24</td>
<td>80 – 120</td>
<td>Near rim zone inspection.</td>
</tr>
<tr>
<td>PN-12MDF 01</td>
<td>Ø 12</td>
<td>100 - 250</td>
<td>Rim and roll surface inspection. Middle part of axle inspection.</td>
</tr>
<tr>
<td>PN-09MDF 01</td>
<td>Ø 9</td>
<td>250 - 400</td>
<td>Wheel fillet, cylindrical part of axle neck and inner surface of bearing rings inspection.</td>
</tr>
<tr>
<td>PN-06MDF 01</td>
<td>Ø 6</td>
<td>200 - 600</td>
<td>Fillet zone and ring collar inspection</td>
</tr>
</tbody>
</table>

Presented computer-aided system “SNK KP-8” was putted into operation on the railway depots (Debaltsєvo and Odessa, Ukraine) and wheelpair repair plant “Ukrspetsvagon” (Paniutino, Ukraine).
The system productivity is estimated as no less than 10 wheelpairs in hour.
Scanners intended for different wheelpair zones inspection are presented in figures 8-10.
Flaws detected in manufacture conditions on the different wheelpair parts are presented on figure 11.
5. Conclusions

Eddy current method with the application of new selective EC probes and special signal processing algorithms can be effectively used instead of the inefficient MP method. The additional advantage of EC method is the possibility to automate the inspection procedures and to estimate the sizes of the detected cracks. Due to this feature, EC method optimally complements the ultrasonic method during the automated system creation. EC method makes it possible of the inspection results recording and memorizing for further analyzing.

Two computer-aided multi-channel systems for combined (ultrasonic and eddy current) rolling stock components inspection are presented. First system is intended for new axle inspection on the manufacture plants. Second system is intended for inspection of wheelpairs after long-term operation on the overhaul plants. Due to EC method application the productivity of developed systems is estimated 8-10 times as better than the productivity of the systems based on the MP method application.

References