New portable eddy current flaw detector and application examples

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Abstract

New eddy current flaw detector EDDYCON C with broad operational frequency bandwidth (from 10 Hz to 16 MHz) and large set of different type eddy current probes to solve different inspection problems is proposed. EDDYCON C flaw detector is especially convenient for application in the field open air conditions due to the small size, wide temperature range (from -20°C to +45°C) and possibility to be controlled only by one operator hand. Presented device is supplied with two frequency mode and different type signal processing and filtering algorithms. The device is supplied with operator-friendly interface and high resolution color display. EDDYCON C flaw detector can be provided with rotary scanner and scanning encoder. EC flaw detector can be supplied with special-purpose EC probe for conductivity measurements.

In this paper some inspection technologies realized by EDDYCON C application are presented for detection of different type of defects in threaded joints of gas and oil tubing; in aluminum alloy arc welding of aerospace constructions; in fastened multilayer aircraft constructions; on side surfaces of bore holes and in steel castings with roughly finished surfaces.

Keywords: Eddy current, flaw detector, operational frequency, aircraft, welding, casting

1. Introduction

Modern eddy current (EC) flaw detectors developed by different producers have universal properties. The majority of up-to-date flaw detectors supports:

- Possibility to be operated with different types of EC probes;
- Wide operation frequency range;
- Wide range of signal amplification possible to be different for Y and X components;
- Different type of filters (HP, LP or BP filters, Avrg, Diff);
- Representation of EC probes signal responses in complex plane (Y/X) and in time-base modes for signal response components (Y/t and X/t modes);
- Complex plane rotation in the range 0 - 360º;
- Possibility to store results obtained in PC image formats.
- Operation with two (or more) frequencies simultaneously for noise suppression.

All presented features and demands were realized in new portable flaw detector EDDYCON C (fig. 1) developed in Promprylad LLC. In this device all operational characteristics of previously developed portable flaw detectors were improved [1-4].

2. EDDYCON C type flaw detector characteristics

EDDYCON C type flaw detector was developed to be usable hand-held device with possibility to be operated by single hand. In this case other hand can be used for inspected surface scanning. Small size (230 mm × 135 mm × 98 mm) and light (only 0.9 kg) flaw detector is very comfortable for field open air and aircraft inspections. The device menu is intuitively understandable by experienced operator. Flaw detector can be operated in wide temperature range from -20°C to +45°C. Presented device is supplied with two frequency mode and different type signal processing and filtering algorithms. The device is supplied
with operator-friendly interface and high resolution color display. Flaw detector can be provided with rotary scanner and scanning encoder. EC flaw detector can be supplied with special EC probe for conductivity measurements.

Other EDDYCON C type flaw detector specifications are presented in the next table.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
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<tbody>
<tr>
<td>Frequency range</td>
<td>10.0 Hz – 16.0 MHz</td>
</tr>
<tr>
<td>Phase</td>
<td>0-360° with 0.1° increments</td>
</tr>
<tr>
<td>Pre-gain</td>
<td>-6.0 to 40.0 dB with 0.1; 1 and 10 dB steps</td>
</tr>
<tr>
<td>Gain</td>
<td>0 to 30 dB with 0.1; 1 and 10 dB steps</td>
</tr>
<tr>
<td>Sampling frequency</td>
<td>1 to 8 kHz</td>
</tr>
<tr>
<td>Filters</td>
<td>Conventional High Pass, Low Pass and Band Pass. Additional Differential or Average Modes.</td>
</tr>
<tr>
<td>Test modes</td>
<td>Single, Two frequency and Mix</td>
</tr>
<tr>
<td>Flaw alarm</td>
<td>Circle, Threshold, Sector, Cutoff</td>
</tr>
<tr>
<td>Setting number</td>
<td>100</td>
</tr>
<tr>
<td>Interface</td>
<td>USB 2.0</td>
</tr>
<tr>
<td>Casing</td>
<td>230 mm \times 135 mm \times 98 mm</td>
</tr>
<tr>
<td>Temperature range</td>
<td>-20°C to +45°C</td>
</tr>
<tr>
<td>Internal power</td>
<td>Li-Ion Battery with 8 hours life and 3 hours full charge time</td>
</tr>
<tr>
<td>External power</td>
<td>AC – 100-240 V, 50-60 Hz, 50 Watts</td>
</tr>
</tbody>
</table>

![Figure 1. EDDYCON C type flaw detector and rotary scanner](image)

3. **EC inspection of threaded joints in gas and oil industry**

It is known that the lifetime of the drill pipe and other tubing used in the oil and gas industry is determined by the reliability of threaded joints (fig. 2). So, reliable NDT in the threaded joints will reduce the number of accidents due to the well-timed removal of defected components.

Some regulatory document all drill pipes provides for the detection of defects (mainly fatigue cracks) in the threaded joints the application of magnetic and ultrasonic NDT methods. But
these NDT methods have several disadvantages which reduce the reliability of flaw detection and are not convenient for field inspection. In this regard EC method can be considered as perspective for thread inspection. In this section the developed technology for flaw detection in the thread based on EDDYCON C type EC flaw detector is presented. To solve this task special-purpose EC probe and scanning tool for threaded pipe joints with different diameters were developed. Due to the sensitivity demand the detection of 0.25 mm depth cracks situated in thread grooves with lift-off suppression [5].

Scanning device should provide a relatively normal position of EC probe relatively to inspected surface during scanning along helical thread line with a minimal clearance between the bottom of the thread and EC probe operational surface. Absolute type EC probe with exciting and pick-up coils mounted on a common ferrite core was applied. For positioning of the EC probe sensitive element with small separation on the bottom of the thread groove the probe operational part is produced in the form of thread profile. Scanning tool for pipe thread inspection contains roller with mechanism to set its height, fixture with clip for ECP installation, adjusting mechanism to change the distance between the probe and the bottom of the thread groove and guide rollers (fig. 3).

To select the optimal modes of EC inspection and the sensitivity estimation special KO2353.08 type pipe reference standard with threaded part was developed. Along the bottom of the thread two electroerosive 0.25 and 0.5 mm depth and 8 mm length artificial flaws were carried out. In fig. 4 the signal responses in the complex plane on the screen of the 3-81 EDDYCON C for artificial flaw with depth 0.25 mm (fig. 4a) and 0.5 mm (fig. 4b) and lift-
off (fig. 4c) obtained on operating frequency 350 kHz are presented. Lift-off signal was oriented in horizontal direction for better selectivity.

Presented results (fig. 4a and 4b) show the high sensitivity of the developed EC inspection technologies for flaws in drill pipe thread. In our case, the detection of defects with depth of 0.25 mm and 0.5 mm were obtained with 12 dB and 20 dB signal-to-noise ratios respectively. At the same time, flaw signals in the complex plane are oriented to the vertical direction (fig. 4a and 4b) and lift-off signals have horizontal direction (fig. 4c).

4. EC inspection of arc welding

For inspection arc welding low frequency MDF 0801 type double differential EC probes possible to detect surface and subsurface crack and pores were applied. Due the heterogeneity of material structure and electrophysical parameters in welded zone additional specific noise is produced during EC probe scanning. This structural noise can significantly limit the inspection sensitivity and depth of inspection and noise influence should be suppressed or separated from signals produced by flaw. Figure 5 shows the signals in complex plane (right) and in time base mode (left) from the subsurface flaw with 3 mm depth of bedding (identified by F), which can be compared with the structural noise (circled and identified by the dotted line N). Separation of the signals produced by flaw and structural changes were enhanced by complex plane rotation and different signal amplification along the vertical and horizontal axis. In this case the gain along vertical axis was 6 dB more gain along horizontal axis. It can be seen that the vertical component of a signal from a defect of about 6 dB greater than structural noise, which is particularly essential on the vertical signal component in time base mode (fig. 5b above). Such signal-to-noise ratio is considered sufficient for reliable detection of the defect. These signals show the possibility of separating the useful signals from the subsurface flaw lying on the depth 3.0 mm from the structural noise [6].
Presented EC inspection technology is the part of complex arc welding inspection with high sensitivity of EC method for detection the defect in the 3 mm thickness near surface layer is combined with the advantage of ultrasonic method for detection of flaw with higher depth of bedding.

5. Inspection of components with roughly finished surfaces

With double differential EC probe application it is possible to detect surface breaking flaws in casting with rough surface [2,6]. Special reference standard with artificial flaws and Rz 320 surface roughness was developed. MDF 1201 type EC probe signal responses obtained on the operational frequency 17 kHz are presented in fig. 6. Presented signals were obtained from 0,6 mm depth and 10 mm length crack with differential signal processing with 10 signal samplings. Presented results show the effectiveness of proposed EC probe and differential signal processing for surface noise and slow signal trends suppression.

Presented results show that EDDYCON C flaw detector in connection with double differential EC probe and simple differential signal processing algorithm can effectively be applied for cast rolling stock component inspection [6].

6. Examples of EDDYCON C flaw detector application in aircraft

6.1 Example of EC inspection of fastened multilayer aircraft units
One of the most complicated problems is the detection of subsurface cracks developing from rivet holes. This problem arises during inspection of multilayer plating in the Boeing 737 doorway zone [1,8]. The difficulty of this problem consists in the need to identify cracks in the area of rivets in the third and forth layers of 5-layered unit without disassembling. To
solve this problem an anaxial SPF- 2346 type EC probe operated in the frequency range of 0.2-4.0 kHz was developed. In its design two separated coils placed in the ferrite cup core were applied to reduce the influence of primary electromagnetic fields on the output signal.

![Figure 7. Location of artificial cracks in the third (left) and forth (right) layers of NDT 3049 type reference standard.](image)

Developed technology was tested on a special 5-layered NDT 3049 type reference standard produced by US company «NDT engineering corporation» with total thickness of 13.7 mm at the operating frequency of 500 Hz. Two like crack flaws if third and forth layer originated from the rivet holes produced by electroerosive method were used. First flaw have length of 11.4 mm and it is placed in the 3rd layer at a depth of 3.6 mm (Fig. 7, left). The second flaw with 16.5 mm length is placed in the 4th layer at a depth of 6.1 mm (fig. 7, right). Flaws were oriented perpendicular to the rivet line. Flaw signals were investigated on operational frequency 500 Hz. Figure 8 shows the signal from flaw at the depth of 3.6 mm in the 3rd layer \((F1)\) as well as signal from the crack at the depth 6.1 mm in the 4th layer \((F2)\) on fig. 8. To evaluate the possibility of selective signal interpreting signals the signals from the flaw-free rivets and the lift-off effect also are presented \((R\) and \(L\) in fig. 8). Signal from the flaw-free rivet was oriented in horizontal direction by complex plane rotation. Lift-off signal is oriented downward from the balance point \((0\) in Fig. 8). These results demonstrate the ability to detect cracks in the rivet area with a depth of 6 mm with separation from the influence caused by the rivets and lift-off.

![Fig. 8. Interpretation of inspection EC in complex plane](image)

### 6.2 Detection of cracks on side surfaces of bore holes

EDDYCON C flaw detector can be supplied with rotary scanner (fig. 1) for a hole sidewall inspection. The rotation speed can be selected by software in the range from 600 to 3000 rev/min. Due to the developed rotary scanner the actual problem of detection fatigue crack in aircraft fastener holes in dynamic mode was solved. In figure 9 we can see the hole part of relevant NDT 1084-10DIA reference standard with corner artificial like crack slots and signal responses obtained for minimal size slot \((B = 0.5 \text{ mm}, C = 0.5 \text{ mm})\) in 3.2 mm diameter hole.
7. Conclusions

EDDYCON C type flaw detector was developed as convenient portable flaw detector with universal properties possible to solve most difficult problem of EC inspection. Some results of surface and subsurface crack detection in threaded joints, aluminum alloy arc welding of aerospace constructions, fastened multilayer aircraft constructions, side surfaces of bore holes and steel castings with roughly finished surfaces are presented.

References