XXIV Seminarium
NIENISZCZĄCE BADANIA MATERIAŁÓW
Zakopane, 14-16 marca 2018

DETECTION OF THE SUBSURFACE CRACKS PROPAGATED FROM RIVET HOLES IN THE MULTILAYER AIRCRAFT STRUCTURES

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1. INTRODUCTION

Detection of subsurface defects in multi-layered units fabricated from aluminum alloys in the riveted areas without disassembling and removing of rivets is one of the most crucial and complicated NDT problems of aircraft industry. Such inspection is needed to provide a reliable long-term aircraft exploitation, especially when operation time exceeds the primarily prescribed life limit. In some cases, cracks are considered dangerous, when they do not propagated beyond the rivet head (fig. 1). In general, the number of riveted sheetings can be greater, than two (as it is shown in fig. 1) and defects can be located in inner layers.

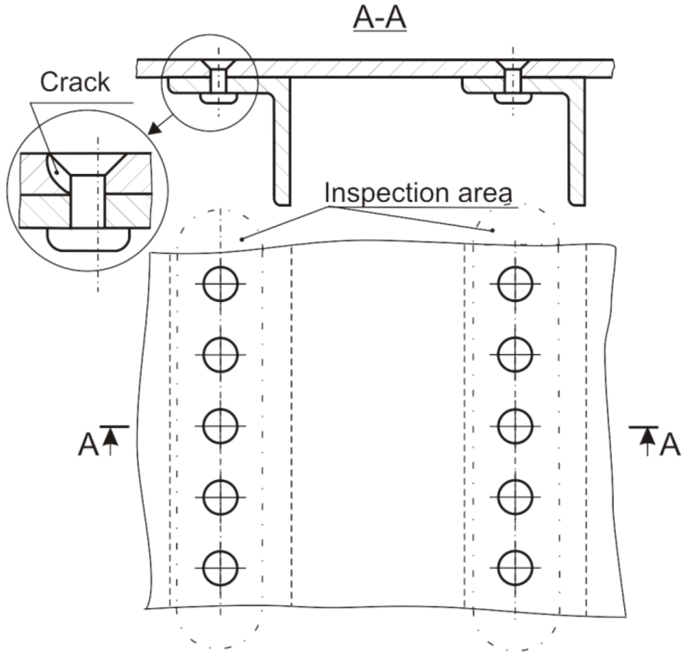


Fig. 1. Typical aircraft riveted unit with originated crack.

According to the type of the rivet area scanning mode, all eddy current (EC) inspection techniques can be conventionally classified into three main groups [1,2]:

1) Static mode – carried out by placing the EC probe on the rivet (in most cases coaxially with the rivet axle);

2) Sliding mode – performed by the movement of EC probe along the rivet line or near it;

3) Rotary mode – the EC probe is installed on the rivet head and rotated around manually or by means of a driver.

2. STATIC MODE

To realize static mode the ring type EC probes usually are used (fig. 2). To reduce the unbalanced signal (the output EC probe signal for probe installed on defect free specimen) the generator and measuring coils are divided into two identical sections: principal and compensating. Thereby, the ring type EC probe consists of two serially connected sections *1* of the generator coil and two serially differentially connected sections *2* of the measuring coil. The compensating section is positioned directly above the primary (see fig. 2). Presented ring type EC probes can be classified as the probe of absolute compensated type.

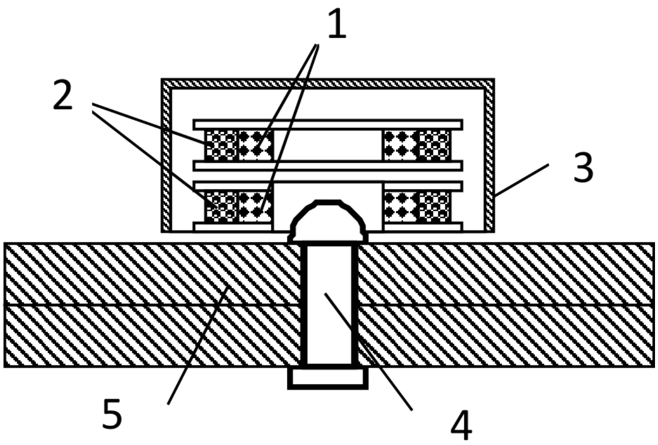


Fig. 2. The typical design of the ring type EC probe: 1 – the sections of the generator coil; 2 – the sections of the measuring coil; 3 – the probe case; 4 – the rivet; 5 – inspected unit.

The special ARK2/8 ring type EC probe was developed for inspection of the riveted joints in the "Boeing-747" bulkhead area [3]. In this area the EC probe detects cracks with length more than 5mm in the second layer (the layers thicknesses – 1.8 and 0.8 mm). For the ring type EC probe adjustment the calibration block fabricated as two riveted plates with appropriate thickness (fig. 3) was recommended by Boeing Company. The calibration block has the flaw-free rivet (DF) and rivet with like crack artificial 5 mm long defect (D) that satisfies the needed detection sensitivity. An artificial defect was produced by the electro-discharge method and has the width (opening) less than 0.1 mm. The developed ARK2/8 ring type EC probes differs from standard ring probes with the significantly less height (9,5 mm for ARK2/8 against 25 mm for the ring type EC probe produced by Rohmann). This peculiarity gives the possibility of inspection in some hard-to-reach "Boeing-747" bulkhead areas. The operational frequency range is from 600 Hz to 10 kHz. For the positioning on the rivet head the EC probe has the 8.3 mm diameter internal hole.

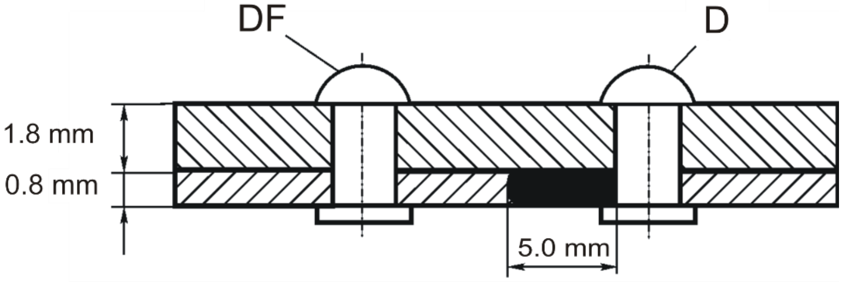


Fig. 3. Calibration block for the adjustment of EC flaw detector with ring type EC probe.

Fig. 4 illustrated the real signals of ARK 2/8 type probe obtained in the complex plane of the EDDYMAX flaw detector (Test Maschinen Technik, Germany) with the application of the presented calibration block. Before the inspection, the EC probe was installed on the defect free (DF) rivet of the calibration block (DF on fig. 3) and the orientation of complex plane was regulated to obtain the horizontal direction of lift-off signal (see. fig. 4). When the EC probe was situated on the rivet with defect the signal was changed from balance point in vertical direction as it is shown on fig. 4.

So, the proposed inspection technique provides the high sensitivity to defects longer than 5 mm with simple lift–off separation. The lift-off signals and signals for defect have different direction (phase) in the complex plane.

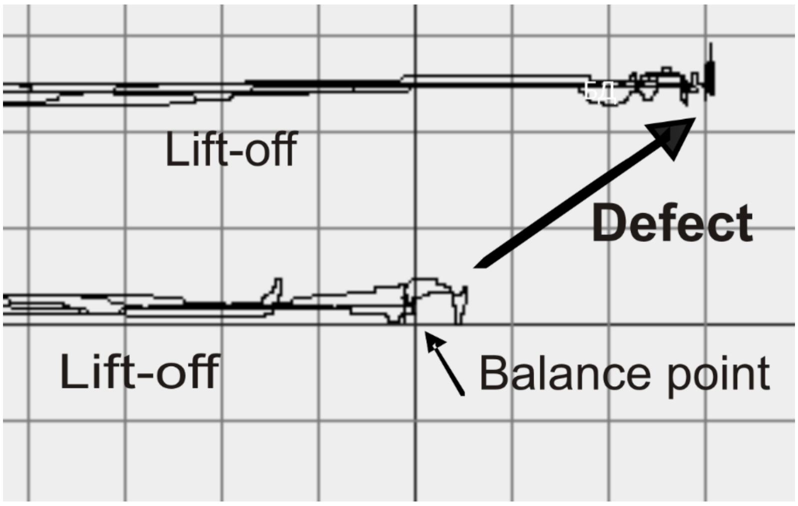


Fig. 4. Changes of ring type EC probe signals in complex plane for defect and lift-off obtained with calibration block application.

The main **advantages** of static inspection techniques are the **simplicity** and relatively **high** inspection **productivity**.

The **disadvantages** are associated with the influences of great number of interfering factors, such as: variations in the hole or rivet diameter, the changes of the rivet material electrical conductivity, the changes of layers thickness or the clearance between the layers of the multi-layered units, the changes of the protective coating thickness etc. Therefore in practice sufficiently long (about 5 mm and more) cracks are detected by this technology application.

Fig. 5 exhibits the inspection procedure by installation of the ring type EC probe on the rivet head in “Boing-737” bulkhead area in the “INTERNATIONAL AIRLINES OF THE UKRAINE”.

Fig. 5. The inspection with the ring type EC probe application.

3. SLIDING MODE

During the realization of sliding technique the EC probes is moved along the rivet line, (along the line connected the rivet axis centers). For this purpose on the EC probe operating surface special groove is produced, the width and depth of which responds the diameter and height of the rivet head. One of the most popular sliding type EC probe consists of one central generator coil *1* and 4 measuring coils *2*. Measuring coils are placed symmetrically and connected in tandem (fig. 6) [1,2]. As shown in fig. 6 the EC probe is placed on the inspected multi-layer unit 3 with the rivets line 4. During the inspection the EC probe is moved along the XX axis that connects the rivets centers. When the crack 5 is appeared, the contours of EC are reallocated (dashed lines in fig. 6). The signal changes are observed in the complex plane of the universal type EC flaw detectors (fig. 7). After the EC probe balancing the hodograph direction is guided by the complex plane turning for the defect free rivet to be oriented mainly in the horizontal direction.

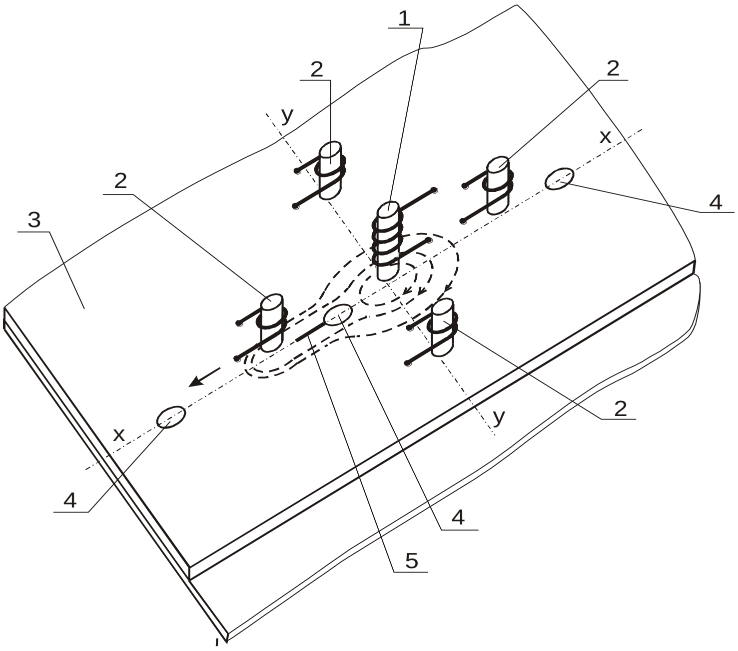


Fig. 6. The sliding type EC probe design and the scheme of the rivet row scanning.

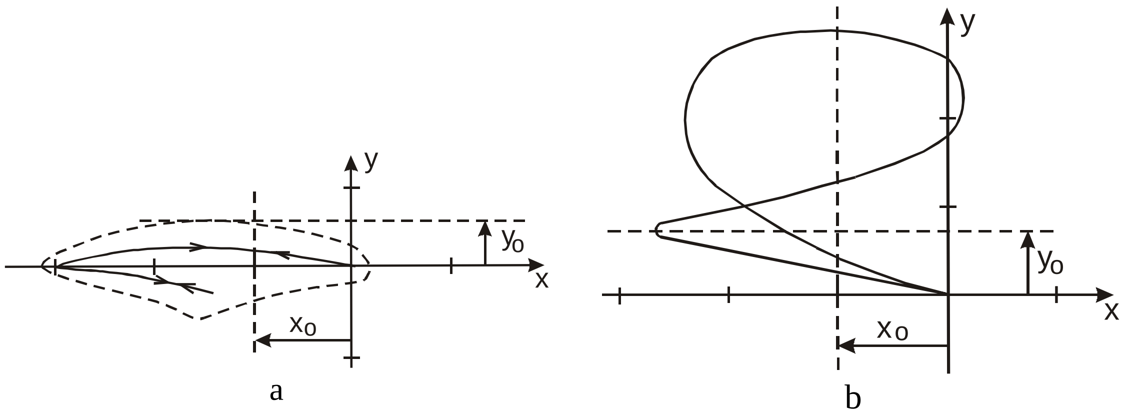


Fig. 7. Typical signal responses in complex plane produced by sliding type EC probe for defect free rivet scanning (a) and rivet with the transverse crack scanning (b).

An area for EC probe passing along defect free rivets (even for EC probe accidental displacement from the central scanning axis) is marked in fig. 7 by the dashed line. The derivation of the signal from the defect free rivet in the vertical direction do not exceed the value y_o.. Fig. 7*b* depicts the typical loop shape form signal from the rivet with the transverse crack. So an operator can easily recognize signal from defect and defect free rivets. It is possible also to mark the complex plane sector to regulate the automatic defect detector alarm: the upper right sector is marked by the dashed lines, that corresponds $y \le y_o$ and $x \le -x_o$.

One of the most difficult problems – the detection internal crack propagated from holes in 5-layer unit ("Boing-747"). It is needed to detect crack in 3-d and 4-th layers without disassembling. For this purpose new SPF-2346F type EC probe (fig. 8) for inspection on low operational frequencies from 0.5 to 4.0 kHz was developed. In this probe two separated coils are installed on two half cup cores to suppress and influence of the primary electromagnetic field on the measuring coil and to minimize the level of the unbalance signal.

The inspection procedure was tested with special NDT 3049 type specimen produced by US company "NDT Engineering Corporation on the operational frequency 500 Hz. In this specimen 2 electro discharged defects were produced: one defect with length 11.4 mm in 3-d layer with the depth of lying 3.6 mm (fig. 9a) and second - with length 16.5 mm was situated in fourth layer with depth of lying 6.1 мм (fig. 9b).

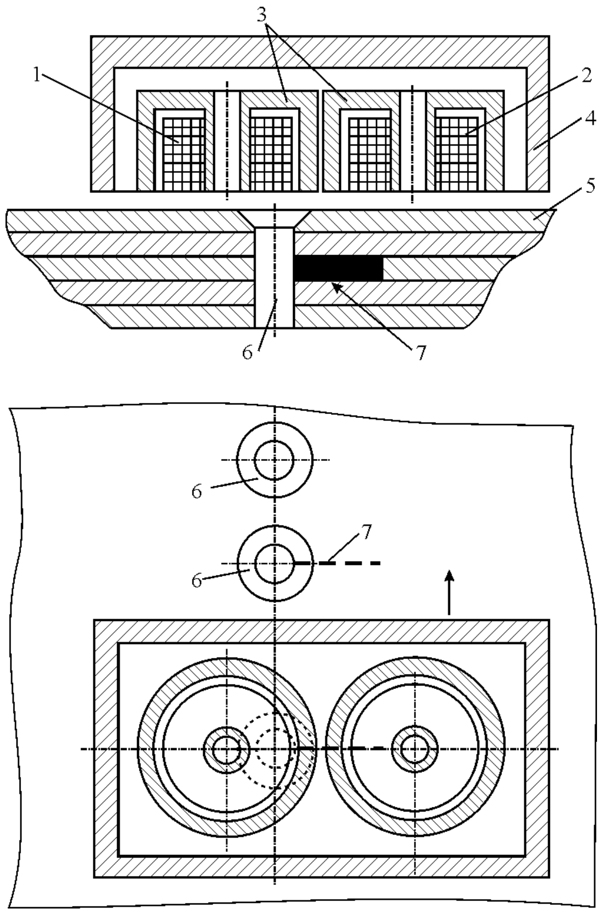


Fig. 8. Inspection scheme for SPF-2346F type EC probe:
1 – generator coil; 2 – the measuring coil; 3 – half cup core; 4 – probe case; 5 – inspected multilayer unit; 6 – rivet; 7 – crack.

Fig. 10 shows the real signal obtained with the NDT 3049 type specimen application and the possibility to separate the signals obtained from crack in third and fourth layers from the typical noise concerned with defect free rivet influence and lift-off.

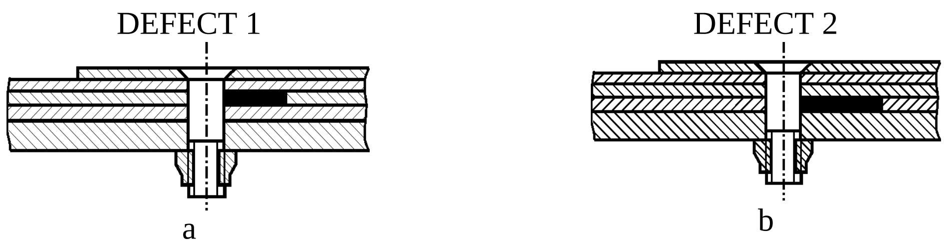


Fig. 9. The location of the cracks in third (a) and fourth (b) layers of NDT 3049 type specimen.

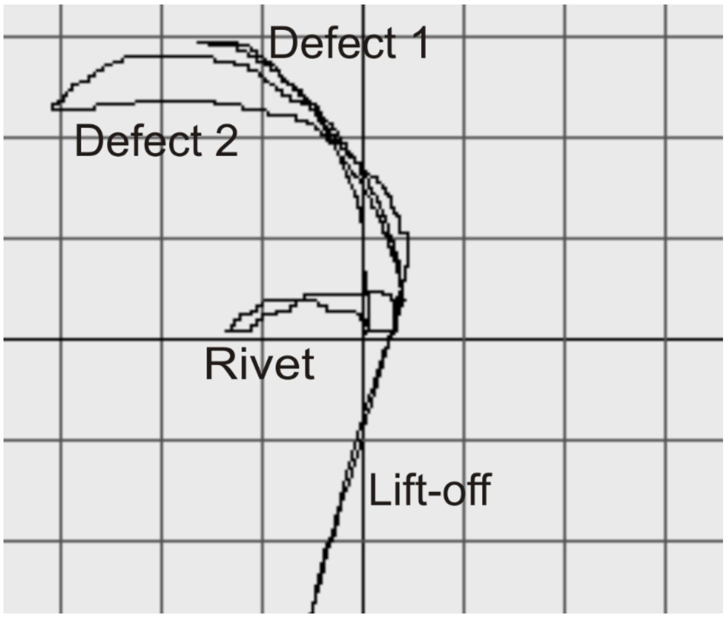


Fig. 10. The signals for defects in third and fourth layers of NDT 3049 type specimen and signals for scanning the defect free rivet and EC probe lift-off.

The main **advantage** of the sliding testing technique is its high productivity that exceeds such for the static mode with the ring probe application. But there are some **limitations**, such as: requirement of the regularity of the rivets location etc. Therefore this method is effective, when the direction of the possible crack is known in advance and requirements to the sensitivity are not very high.

4. ROTARY MODE

The best sensitivity during the rivets zone inspection is appropriated with the techniques, based on the rotation of the EC probe around the rivet. The technique uses the EC probe construction peculiarity, at which the high level of unbalance compensation is ensured during its placement coaxial with the rivet. This unbalanced signal due to the circular symmetry is remained during the EC probe rotation around the rivet.

In out earlier work it was shown that in rotary mode with double differential type EC probe application it is possible to detect cracks with the length more than 1mm [2]. The location of EC probe relative to the countersunk type rivet and the scanning diagram for the cracks detection is represented in fig. 11. During the inspection the EC probe is installed coaxially to the rivet using the special dielectric tool. After the balance operation the EC probe is rotated and the changes of the tested signal are observed. For the inspection it is enough to provide the rotation in two sides under an angle from 45 to 90 degrees. When the direction of the crack is known, the rotation angle can be limited by 45 degrees. The good centering of the rivet and the EC probe is very essential to minimize the rotation noise concerned with conductivity anisotropy of material.

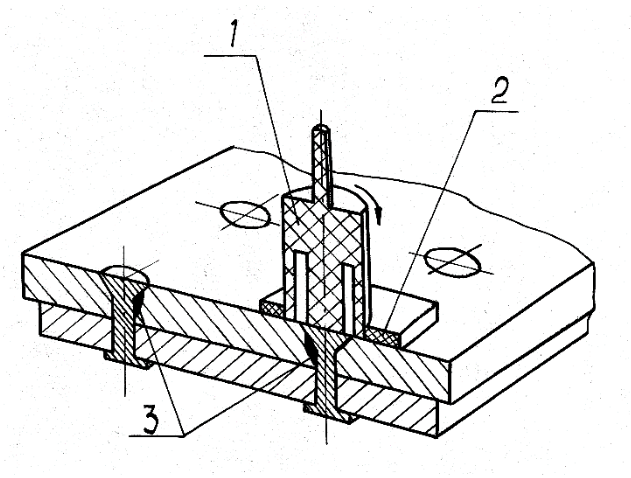
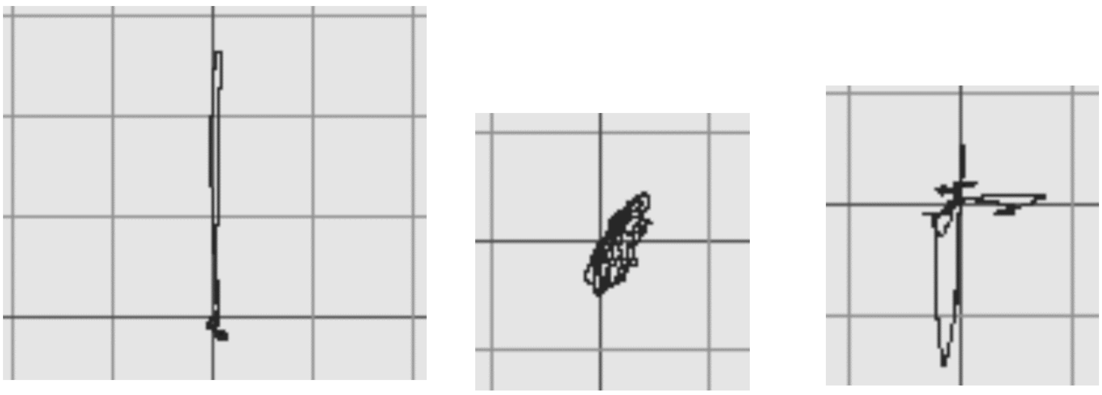


Fig. 11. The inspection procedure for defection of crack under the countersunk type rivet head:1 – EC probe;2 – dielectric tool, 3 – cracks.

For detection the defects under the round and cylindrical rivet heads the specialized MDF2201/10R type EC probe with the diameter of 22 mm was developed. In this case the dialectical overlay tool is not necessary, because the EC probe is centered by the rivet head [3]. The developed EC probe was examined at the operating frequency of 2 kHz with the signal registration in the complex plane of EDDYMAX EC board (Test Maschinen Technik). The aluminum specimen have 6 mm diameter hole, from which the artificial like crack defects were cut with the opening of 0.1 mm and with the length from 1 to 6.0 mm. The sample with the defect was covered with the defect free plate of 2 mm thickness with the 6 mm diameter central hole and connected by means of the rivet.



a b c

Fig. 12. The signals of MDF2201/10R type EC probe from 1 mm long crack through rivet head and 2 mm thick sheet (a) and noise concerned with EC probe rotation (b) and lift-off (c).

The EC probe signals were tested in complex plane during the probe rotation above the 2-layer specimen with the minimal 1 mm length crack (fig. 12a). For the comparison and sensitivity level set up the noise signals were investigated also. Possible noise was concerned with EC probe rotation around defect free rivet in specimen (fig. 12b) and its lift-off from the specimen surface (the gap signal) to the height approximately of 3…4 mm (fig. 12c). The sensitivities during the registration signal from the crack with 1mm length (fig. 12a) and the signals from the noise (fig. 12b and fig. 12b) are the same. It was shown also that the crack length considerably influences on the signal amplitude. Particularly, the signal from the crack with 2 mm length is three times bigger, than from the crack with the 1 mm length. Thus, the signal from the small 1 mm long crack is more than on 6 dB exceeds the signal level from different types of noise [2].

The main **advantages** of rotary inspection techniques are very high sensitivity. The main **disadvantage** of this technology is associated with **very low** inspection **productivity**.

REFERENCIES

[1] V. Uchanin, Eddy current methods for detection of the defects in rivet areas of multilayer aircraft structures., Technical diagnostics and nondestructive testing. Vol. 3, 2006. P. 3-12 (in Ukrainian).

[2] O. Ostash, V. Fedirko, V. Uchanin et al., Fracture mechanics and strength of materials, Reference book, Vol. 5. Strength and durability of airplane materials and structural elements., Lviv, Spolom. 2007. 1068 p (in Ukrainian).

[3] V. Uchanin, S. Siomochkin and A. Loginov, The detection of fatigue cracks in hole areas during the in-service inspection of Boeing aircraft., Technical diagnostics and nondestructive testing. Vol. 2, 2012. P. 13-17 (in Ukrainian).

[4] J.-L. Arnaud, M. Floret, Procede et dispositif pour l'examen non destructif de junctions rivetees ou analogues au mouyen d'une sonde a courants de Foucault / J.-L. Arnaud, M. Floret (Франція).Pat. № 2541772 (France), G 01 N 27/90, appl. № 8303043 (24.02.1984), publ. 31.08.84.

[5] V. Uchanin, Surface double differential type eddy current probes., Lviv, Spolom. 2013. 266 p. (in Ukrainian).