Engineering Failure Analysis 35 (2013) 597–608

Contents lists available at SciVerse ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Methodology of short fatigue crack detection by the eddy current method in a multi-layered metal aircraft structure

Marie Bohacova *

VZLU, a.s. (Aerospace Research and Test Establishment), Czech Republic

ARTICLE INFO

Article history:
Available online 21 June 2013

Keywords:
Eddy current
Low frequency
Inspection
Multi-layered
Aircraft

ABSTRACT

The field of non-destructive inspection (NDI) is an integral part of aircraft maintenance and service. It is optimal to apply the eddy current (EC) method on the complex multi-layered metal aircraft structure to detect cracks and other damage. A range of standard eddy current probes giving satisfactory results with respect to crack detection are available. However, these EC probes are not always suitable for the detection of short fatigue cracks hidden under a rivet head. This article presents a new methodology for eddy current inspection of a critical area on the wing. The development of the new methodology was inspired by a catastrophic glider accident in 2010. Because of this accident, all glider service was prohibited. The critical area is located in the structure of the wing spar, which consists of six layers. The position of the critical area is hidden under the countersunk rivet head in the third layer of the spar flange and under two layers of metal sheets. Thus, the actual location of the area is in the fourth layer, created by the countersunk rivet head. In addition, another rivet of a smaller diameter is inserted into the rivet in the flange. This article presents the work related to the development of a special EC probe that is able to measure in an operating frequency range between 200 Hz and 100 kHz with a single-value interpretation of the individual EC signals.

1. An introduction to the history of the glider

A glider called the L13 Blaník, which was designed by Karel Dlouhý of VZLU in 1956, crashed in 2010. The L13 Blaník is a two-seater-class glider suitable for basic flight, aerobatic instruction and cross-country training. A fatal accident occurred in which the main spar of the right wing of the glider failed near the root due to a positive load. The right wing detached from the aircraft, and the pilots lost control of the glider. The preliminary investigation has revealed that the fracture may have been due to fatigue [1]. Because of this catastrophic accident, VZLU requested the development of a methodology for the NDI of the critical area on the wing.

2. A general description of the critical area of the wing

The critical area is located at the bottom of the wing in the section of the steel wing-fuselage attachment fitting (refer to Fig. 1). The critical area is under the rivet head in the aluminium alloy spar flange in the thinnest cross-section of the steel

Abbreviations: EC, eddy current; EDM, electric discharge machining; NDI, non-destructive inspection; S/N, signal to noise; VZLU, Aerospace Research and Test Establishment.

* Address: Beranovych 130, 199 00 Prague, Czech Republic. Tel.: +420 225 115 171.
E-mail address: bohacova@vzlu.cz

1350-6307/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.engfailanal.2013.06.009

wing-fuselage attachment fitting and is composed of an aluminium alloy edge and the middle rivets (refer to Figs. 2 and 3). The whole area is hidden under two layers of aluminium alloy sheets of thicknesses 0.63 mm and 1.2 mm. The initiation of a fatigue crack occurs under the countersunk rivet head in the spar flange of thickness 5 mm. These characteristics apply to both the edge rivet and the middle rivet. For the edge rivet, a visible rivet of diameter 3 mm on the surface of the skin is inserted into a rivet of diameter 6 mm in the spar flange. This arrangement makes inspection difficult, but it is a good clue for obtaining the position of the rivet in the spar flange. A detailed schematic of the area is shown in Fig. 2. In the case of the middle rivet, there are no additional rivets, but the metal sheet separation is located above one side of the rivet head (see Fig. 3). This metal sheet separation causes complications for the inspection. In addition, it is difficult to find the true position of the rivet in the spar flange, in contrast to the case of the edge rivet. A detailed schematic of the area is shown in Fig. 3 (the dimensions are the same as in Fig. 2).

The several aspects of the composition of critical areas that make NDI difficult are:

– The visible rivet of a smaller diameter inserted into the edge rivet in the spar flange.
– The metal sheet separation.
– The proximity of the rivets.
– The total thickness of the inspected area.
– The requirement to detect cracks under the countersunk rivet head in the spar flange.

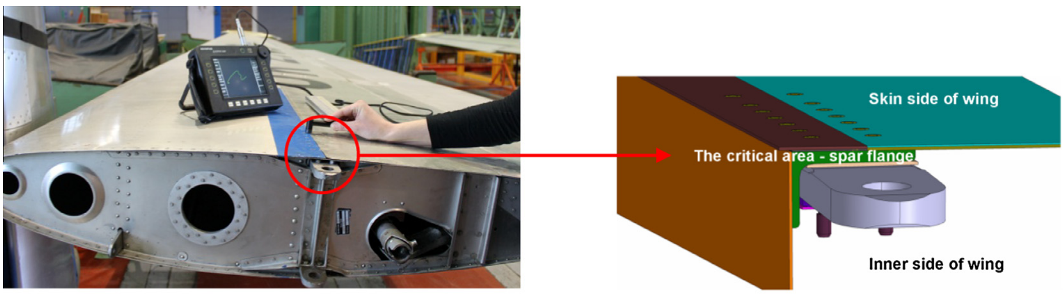
3. The eddy current probe and the inspection methodology

A range of standard low frequency eddy current probes as sliding, ring probes with the satisfactory results of crack detection is available at the present market. Indeed, several these EC probes were used for the inspection. Unfortunately, they were not suitable for very short fatigue crack detection hidden under a rivet head in such complex structure. An INDETEC ndt/ADPF 200 Hz–100 kHz probe (“ADPF probe”) (refer to Fig. 4) has been developed for the inspection of the critical area. It is an asymmetric wideband differential low noise focusing probe, which allows for the detection of cracks within a frequency range between 200 Hz and 100 kHz. The probe makes use of the conventional eddy current technology. The basic principle is based on a mix of individual voltage vectors in a complex impedance plane. The resultant eddy current signal displayed in the impedance plane is a vector sum of the EC signals of the:

– Rivets of diameters 3 mm and 6 mm.
– Individual layers of metal sheets.
– Middle rivet(s).
– Metal sheet separation.
– Presence/absence of cracks or other damage.

Calibration standards are necessary for the verification of appropriate probe function and instrument settings [2]. Two types of multi-layered standards were manufactured. The standards correspond to the real structure’s composition, including its heat and surface treatments. Table 1 lists the individual layers, which are compounds of the calibration standards. In the case of eddy current testing, the calibration standards should contain EDM notches of various sizes [3]. The first calibration standard (VZLU/L13-004) contains EDM notches of different radii at the edge and the middle rivets under the countersunk head rivet in the spar flange (refer to Table 2). The second calibration standard (VZLU/L13-005) contains straight EDM notches of different sizes over the complete flange width (refer to Table 2). These EDM notches also represent artificial cracks. The position of the EDM notches is illustrated in Fig. 5.

The steel fitting situated in the critical area is simulated as a metal band with constant thickness, whereas the steel fitting in the real structure has variable thickness. This modification does not affect the magnetic flux of the eddy currents or the critical area inspection because of the eddy current’s standard depth of penetration for aluminium alloy [4].



From Aircraft Industries. Published with permission.

Fig. 1. The critical area of a wing.