Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 168 (2016) 1698 – 1701

Procedia Engineering

www.elsevier.com/locate/procedia

30th Eurosensors Conference, EUROSENSORS 2016

Embedded OMTDR Sensor for Small Soft Fault Location on Aging Aircraft Wiring Systems

W. BEN HASSEN[a,*], M. GALLEGO ROMAN[a], B. CHARNIER[a], N. RAVOT[a], A. DUPRET[a], A. ZANCHETTA[b], F. MOREL[b]

[a] *CEA, LIST, Laboratoire Fiabilité et Intégration Capteurs, 91191 Gif-sur-Yvette, France*
[b] *Nicomatic - 173, rue des Fougères - Zone industrielle les Bracots 74890, Bons-En-Chablais, France.*

Abstract

Based on OMTDR technology, the first embedded Smart Connector (SmartCo) which could locate very small soft defects resulting from partial degradation of cables is introduced in this paper. To do so, the SmartCo injects the generated OMTDR signal at an extremity of the cable and then listens to the echoes created at each discontinuity of the cable characteristic impedance. Since soft defects result in faint reflected energy, they are hard to distinguish from the noise. Hence, the SmartCo uses an innovative approach based on advanced post-processing methods data fusion to eliminate false alarms and to determine the small soft fault position.

Peer-review under responsibility of the organizing committee of the 30th Eurosensors Conference

Keywords: Cable diagnosis, reflectometry, soft defect, SmartCo, OMTDR, post-processing, fusion.

---

1. Introduction

In aircrafts, soft defects represent 45% of wire faults such as chafing, corrosion, insulation according to NASA. These defects may not lead to catastrophic incident since they do not interrupt energy or information propagation, but can generate hot spots and hard faults (open circuit and short circuit). Hence, the detection and location of small soft defects permit to plan predictive maintenance and avoid system dysfunction (about 150 000 dollars per hour for Aircraft On Ground [1]). In this context, reflectometry remains the most interesting method for cable diagnosis [2]. It injects a signal at an extremity of the cable and listens at the same port to the echoes created at each discontinuity of the cable characterstic impedance. An embedded wire Health Monitoring System (HMS) is crucial to ensure continuous cable diagnosis. Thus, the miniaturization of Orthogonal Multi-tone Time Domain Reflectometry (OMTDR) systems is necessary to enable their implementations into connectors [3]. Introducing intelligence into the commercial connector, named SmartCo, permits to maximize the diagnosis coverage and increase accuracy. Indeed, the OMTDR technology is chosen for SmartCo thanks to sensor fusion enabling using the same test signal [4].

---

[*] Corresponding author. Tel.: +33-169-080-771; Fax.:+33-169-088-395
E-mail address: wafa.benhassen@cea.fr

Peer-review under responsibility of the organizing committee of the 30th Eurosensors Conference
doi:10.1016/j.proeng.2016.11.493

In [5], authors have discussed the feasibility of locating small fray using reflectometry. It has been concluded that its signature on the obtained reflectogram seems to be invisible since the corresponding reflections at both the front and back ends may cancel each other out when the time width of the test signal is greater than the size of the fray defect. As solution, a further development is needed to make reflectometry method sensitive enough to detect and locate small frays. In this context, interesting post-processing methods have been proposed in the literature [6–9]. In [6], authors propose to apply a time-frequency cross-correlation function using the Wigner-Ville transform (WVt). Although it improves soft defect detection, it introduces false alarms caused by cross-terms presence. The latter constraint has been resolved in [9]. However, the proposed solution is high complex and greedy in calculation time, especially for test signals with more than 1000 samples (more than 7 minutes for a computer with 15.9 GB of memory). For complexity decrease, a Self-Adaptive Correlation Method (SACM) where the gain is automatically adjusted depending on the soft defect signature is proposed in [7]. Recently, a Signature Magnification by Selective Windowing (SMSW) method is proposed to select the critical zone based on a predetermined window. The performance of the SMSW depends strongly on the defined window width. Although those methods seem promising to locate soft defects, they are false alarms prone since they are able to confuse the signature of soft default with other inhomogeneities in the cable. As a solution, an innovative approach based on advanced post-processing methods data fusion is introduced.

2. An innovative approach for soft defect detection

The proposed approach, described in figure 1, includes several steps. After reflectograms construction, a difference between healthy and faulty cable reflectograms is performed to eliminate inhomgeneities related to cable manufacturing, installation, etc. Here, several peaks are present on the reflectogram leading to diagnosis ambiguity. Hence, a post-treatment method is called in step 3 such as SACM, SMSW, etc. After that, a windowing is performed on the post-processed reflectogram to eliminate the peaks related to the impedance mismatch present at the cable extremities.

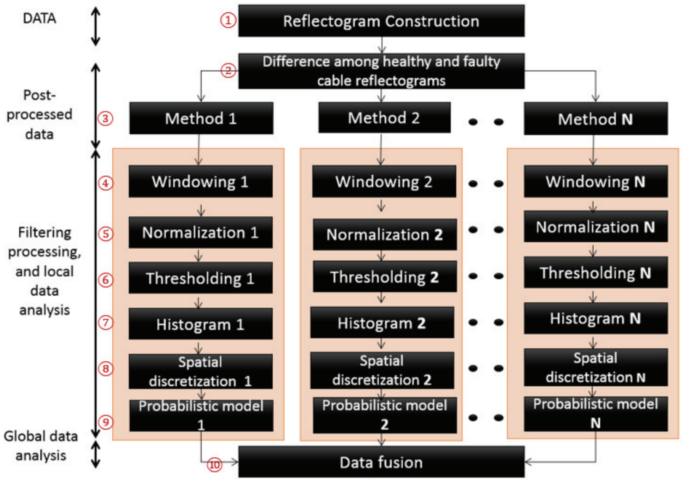

Fig. 1. Description of the innovative approach for soft fault location.

Since the post-treatment methods are heterogeneous, their results are adapted to make them consistent for further data fusion. To do so, a normalization step is performed with respect to optimum values of remaining samples. In step 6, a dynamic threshold, noted $s(n)$ is updated as $s(n) = s_0 + np, \forall n \in [0, N]$, where s_0 is its initial value and is chosen to be higher than the noise. p is the step between two successive values of the threshold $s(n)$ and N is the number of values of the threshold $s(n)$. The step 7 converts each reflectogram obtained at step 5 into a signal where the amplitude of each sample represents the percentage of satisfied thresholds. In fact, we notice that each post-processing method may introduce a slight delay. As solution, a spatial discretization is called. The cable length is divided into sections based on predetermined spatial intervals. The amplitude of the samples of the same interval are then summed.

In step 9, the signal is converted into a measure of probability of the defect presence in each section according to method m, noted $P(D_i/m)$. To do so, each section t_i of cable obeys to a random binary experience where $E(t_i)$: "state of the section t_i". Two events are possible: (1) D_i: the section t_i is faulty and (2) $S_i = \bar{D}_i$: the section t_i is healthy. The probabilities close to 1 indicate the defect presence and the defect absence, otherwise. The probability $P(D_i/m) = 0.5$ means that the two states (faulty and healthy) of the section are equally likely. In order to convert the signal S to a measure of probability of default presence on section t_i , a mapping function f_m is considered:

$$\begin{aligned} f_m : [0, S_{max}] &\rightarrow \quad [0,1]. \\ S(t_i) \quad &\rightarrow P(D_i/m)\,. \end{aligned} \tag{1}$$

The mapping function f_m must be strictly increasing [10]. In this case, it is expressed in equation (2) as follows:

$$P(D_i/m) = f_m(S(t_i)) = P_{min} + [(P_{max} - P_{min}) \,/\, (S_{max})] \times S(t_i). \tag{2}$$

The function expressed in (2) transforms the interval $[0, S_{max}]$ into $[P_{min}, P_{max}]$ where the parameters P_{min} and P_{max} respect the following constraints $0 \leq P_{min} \leq P_{max}$. P_{min} is the minimum probability of the default presence and P_{max} is the maximum one. P_{min} close to 0 indicates a high confidence level that a very low amplitude peak does not correspond to a defect and P_{max} close to 1 indicates a high confidence level that a very high amplitude peak corresponds to a defect presence. Thus, the values of P_{min} and P_{max} parameters may be different from one post-processing method to another. Finally, measured probabilities of default presence according to post-processing methods are gathered. Considering the assumption that the selected post-processing methods are sequentially performed and are completely independent, the fusion of data of two post-processing methods m_1 and m_2 are calculated using the following formula:

$$P(D|m_1, m_2) = (P_1 P_2) \,/\, [P_1 P_2 + (1 - P_1)(1 - P_2)]\,, \tag{3}$$

where $P_1 = P(D|m_1)$ and $P_2 = P(D|m_2)$. The function (3) is called for all independent post-processing methods.

3. Experimental Results

Figure 2 shows the experimental setup consisting of an electronic board, which implements both the OMTDR signal injection/acquisition. It communicates with a computer unit responsible for advanced post-processing performing. A shielded twisted pair TWINLINK 50 FA with length 30 m is considered where a -8 mm long, 3 mm wide- shield damage is present at 10.9 m from the injection point. Figure 3 shows the measured reflectogram, where the soft fault response is actually flooded in the noise. The implementation of the innovative algorithm described in figure 1 makes possible the detection and an accurate (1%) location of the soft fault at 10.98 m (cf. figure 4).

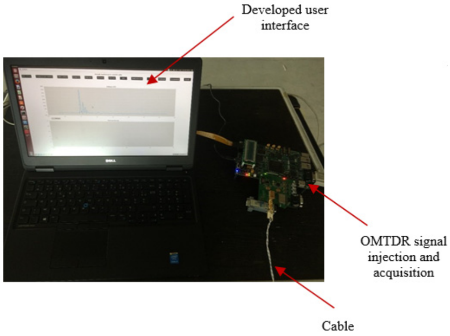

Fig. 2. Experimental Setup Description

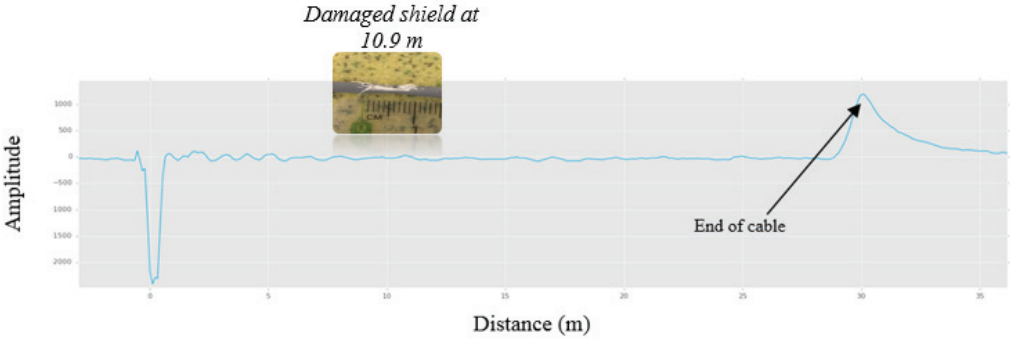

Fig. 3. OMTDR Reflectogram of the faulty cable: The detection of soft fault from the direct reflectogram is difficult.

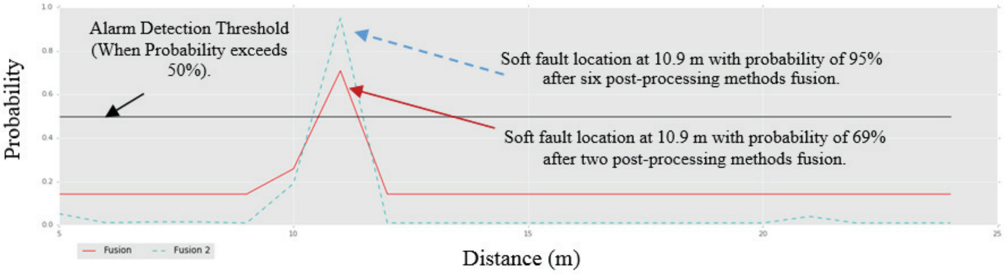

Fig. 4. Soft fault detection and location at 10.9 m.

4. Conclusion

This paper has presented the first embedded HMS able to diagnose very small soft defects using OMTDR. To do so, a patented post-processing approach has been introduced to eliminate false alarms. Experimental results show the efficiency of the developed demonstrator to detect and locate small sheath damage with high accuracy (1%). As future works, OMTDR-based sensor fusion will be implemented to maximize the diagnosis coverage.

References

[1] F. Auzanneau, Wire troubleshooting and diagnosis: Review and perspectives, Progress In Electromagnetics Research B 49 (2013) 253–279.

[2] W. Ben Hassen, F. Auzanneau, L. Incarbone, F. Pérès, A. P. Tchangani, Distributed sensor fusion for wire fault location using sensor clustering strategy, International Journal of Distributed Sensor Networks 2015 (2015) 54.

[3] L. Incarbone, S. Evain, W. B. Hassen, F. Auzanneau, A. Dupret, Y. Bonhomme, F. Morel, R. Gabet, L. Solange, A. Zanchetta, OMTDR based integrated cable health monitoring system SmartCo: An embedded reflectometry system to ensure harness auto-test, in: Industrial Electronics and Applications (ICIEA), 2015 IEEE 10th Conference on, 2015, pp. 1761–1765. doi:10.1109/ICIEA.2015.7334396.

[4] W. B. Hassen, F. Auzanneau, F. Pérès, A. P. Tchangani, Diagnosis sensor fusion for wire fault location in can bus systems, in: SENSORS, 2013 IEEE, 2013, pp. 1–4. doi:10.1109/ICSENS.2013.6688264.

[5] L. Griffiths, R. Parakh, C. Furse, B. Baker, The invisible fray: A critical analysis of the use of reflectometry for fray location, IEEE Sensors Journal 6 (2006) 697–706.

[6] M. Franchet, N. Ravot, O. Picon, The use of the pseudo wigner ville transform for detecting soft defects in electric cables, in: Advanced Intelligent Mechatronics (AIM), 2011 IEEE/ASME International Conference on, 2011, pp. 309–314. doi:10.1109/AIM.2011.6026992.

[7] S. Sallem, N. Ravot, Self-adaptive correlation method for soft defect detection in cable by reflectometry, in: SENSORS, 2014 IEEE, 2014, pp. 2114–2117. doi:10.1109/ICSENS.2014.6985455.

[8] S. Sallem, N. Ravot, Soft defects localization by signature magnification with selective windowing, in: IEEE SENSORS, 2015, pp. 1–4.

[9] M. FRANCHET, Procédé de réflectometrie pour la détection de défauts non francs dans un câble électrique et système mettant en oeuvre le procédé, 2014. URL: `http://www.google.com/patents/EP2769230A1?cl=fr`, eP Patent App. EP20,120,775,483.

[10] T. Rakotovao, J. Mottin, D. Puschini, C. Laugier, Multi-sensor fusion of occupancy grids based on integer arithmetic, in: 2016 IEEE International Conference on Robotics and Automation (ICRA), 2016, pp. 1854–1859. doi:10.1109/ICRA.2016.7487330.