Flexible EC Array Probe for the Inspection of Complex Parts Developed Within the European VERDICT Project

Jean-Marc DECITRE, Denis PREMEL, CEA Saclay, Gif-sur-Yvette, France
Gérard MANGENET, SNECMA, Evry, France
Etienne JULIAC, Turboméca, Bordes, France
Wolf Dieter FEIST, MTU Aero Engines, München, Germany

Abstract. Within the framework of the European project named VERDICT (Virtual Evaluation and Robust Detection for engIne Component non destructive Testing), an Eddy Current multi-element probe has been designed using CIVA modelling tools. In this paper, we present the development and tests of a dedicated EC flexible array probe dedicated to the detection of very small surface breaking flaws (few hundreds of micrometers length) within engine parts. The capabilities of detection are discussed with respect to SNR compared to a more conventional EC probe on planar or curved geometry. It is possible to detect flaws with a very good SNR (20 dB minimum).

Introduction

This paper concerns new developments of an eddy current (EC) flexible array probe within the framework of the European project named VERDICT (Virtual Evaluation and Robust Detection for engIne Component non destructive Testing). The major aim of this project is to provide to the designers a tool that is able to simulate efficiently non destructive testing configurations in order to improve the detection capabilities of EC probes for NDT of complex engine parts. This program aims to develop an innovative approach which consists in including simulations results of an appropriated non destructive testing method during the design of a probe.

In this paper, we present the development of an EC flexible array probe designed for the detection of very small surface breaking flaws (dimensions less than 400µm length, *100* µm width and *200* µm depth) dedicated to test curved geometries within engine parts.

Given the complex shapes of the aeronautical components, we propose to design an eddy current flexible sensor: coils are etched on a kapton film. This technology allows to maintain the probe in close contact with the surface of the work piece during the inspection and to ensure a low sensitivity to lift-off variations which could drastically reduce the EC detection capabilities [1,2].

The paper is organized in three parts. In a first part, a test of a mono-element scheme, obtained by using simulation tools integrated in the CIVA platform, is presented and a comparison between simulated and experimental data is shown. In a second part, the multi-element probe is introduced. Then, in the last part, experimental images resulting from scanning complex shapes by the new flexible probe are given.

1. Tests of the Mono Element Schema

1.1. Design of the Mono-Element Sensor with CIVA

A mono-element sensor has been firstly studied by using the CIVA software in order to design the best geometry dedicated to our application [3].

During the design of the structure, the main objectives lie in the improvement of the sensibility and the resolution of the sensor. The study has led to a configuration which contains an emitting coil and a receiving coil [4]. Simulated and experimental data provided with the sensor are displayed on Figure 1. Let's consider a typical notch (*0.4* mm length, *0.1* mm width and *0.2* mm depth). This figure presents images of the magnitude of the EC signal and a slice view according to the dashed line. Each channel corresponds respectively to the real and the imaginary components of the EC signal.

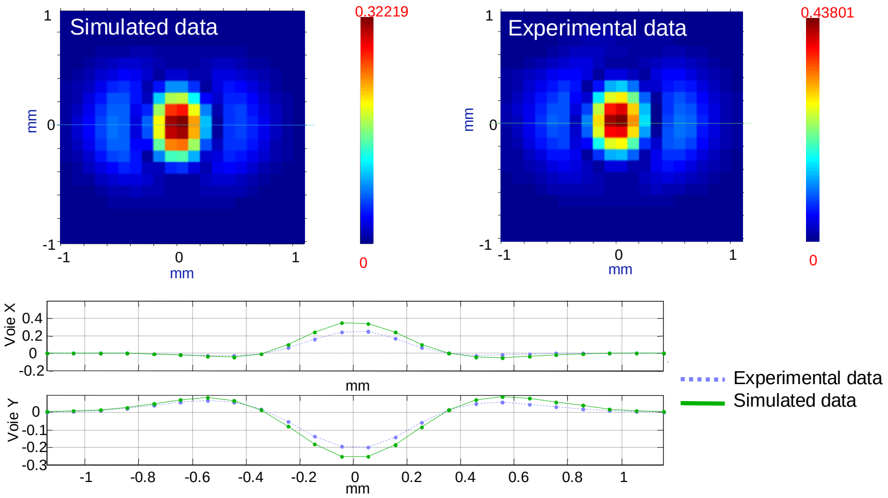

Figure 1 : Experimental and simulated data resulting from a typical notch (0.4x0.2x0.1mm).

Simulated and experimental data are in very good agreement and the SNR is very good.

1.2. Comparison with a Conventional EC Sensor (Copper Wire Winded an a Core)

Figure 2 shows images of the magnitude of the EC experimental signals provided by two kinds of sensors. Let's consider a *0.4* mm length notch affecting a planar test block. On the left side, the image presents results provided by the new flexible sensor, whereas the image of the right side displays the cartography obtained by an emitting/receiving classical winding coil (the outer diameter is about *1* mm). We have noticed a difference of *8* dB in the SNR between the two sensors. We can conclude that the new flexible EC probe gives quite good results even if the number of turns is significantly reduced (the ratio is approximately equal to *10* dB).

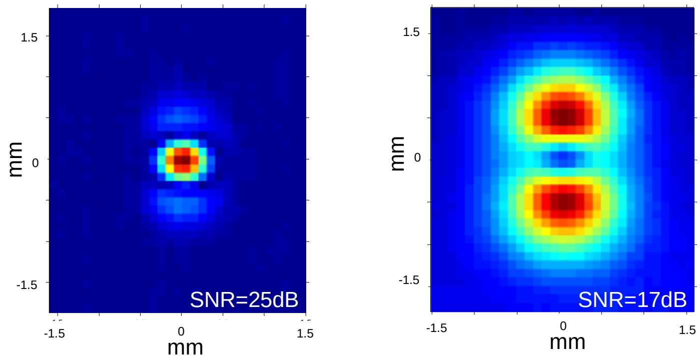

Figure 2 : Images provided by the two sensors (left : new flexible sensor, right : winding coil)

It is clear that the spatial resolution is better with the new sensor and two defects very close to each other may be well detected.

Figure 3 gives the same images considering a notch of *0.2* mm long. The same value of the difference of the SNR has been approximately observed in this testing configuration.

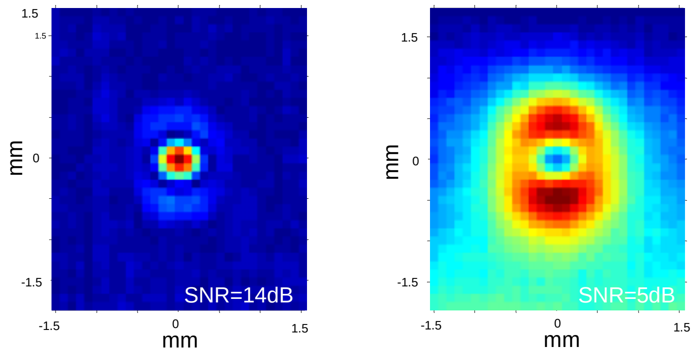

Figure 3 : EC images for a 0.2x0.2x0.1mm notch (left : new flexible sensor, right : classical winding coil)

The design of the flexible EC mono-element layout gives satisfactory results with respect to the objectives (SNR and resolution). The manufacturing process of the multi-elements probe consists in duplicating the mono-element layout.

2. Design of the Multi-Elements Probe

2.1 Description

The new multi-elements probe is made of the following components:

- Coils are etched on a flexible kapton film,
- The kapton film is adapted on a silicone roll in order to comply to curved surfaces. This structure provide a good flexibility for testing complex shapes (Figure 4),
- Electronic components (amplifiers, multiplexers, sequencer,…) are placed near to the etched coils in order to keep the noise low.

With this arrangement, it is possible to inspect a large variety of pieces. However, the radius of the silicone roll must be adapted the curvature radius of the surface to be tested.

Figure 4 : Design of the probe in order to inspect complex shapes.

2.2 Coils on Kapton

The flexible sensor consists in an 8 channels flexible kapton film on which 16 small coils (8 emitting and 8 receiving) are etched. Due to the surface taken by each element and to the small spatial resolution wanted for the multi-element probe, the elements are disposed in staggered rows as shown in Figure 5).

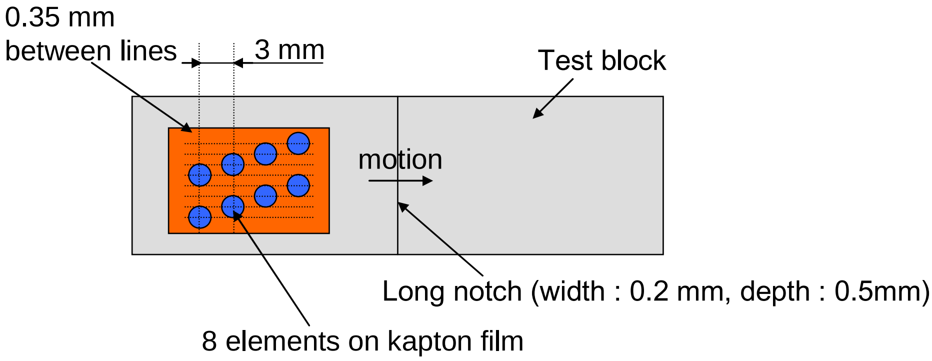

Figure 5 : Elements are shifted on the kapton film.

The distance between the elements has been chosen equal to *350* µm, which allows obtaining a good detection for all the notches which are inside an area of a *2.5* mm large.

2.3 Acquisition System

We use an eddy-current PL340 Rohmann device in order to demodulate the signals provided by the 8 receiving coils. The device has only 4 separated channels. So multiplexers are used for this probe (see Figure 6). A sequencer drives the multiplexers, and sends trigger pulses to a data acquisition device when the complex demodulated data coming from the Rohmann device are ready.

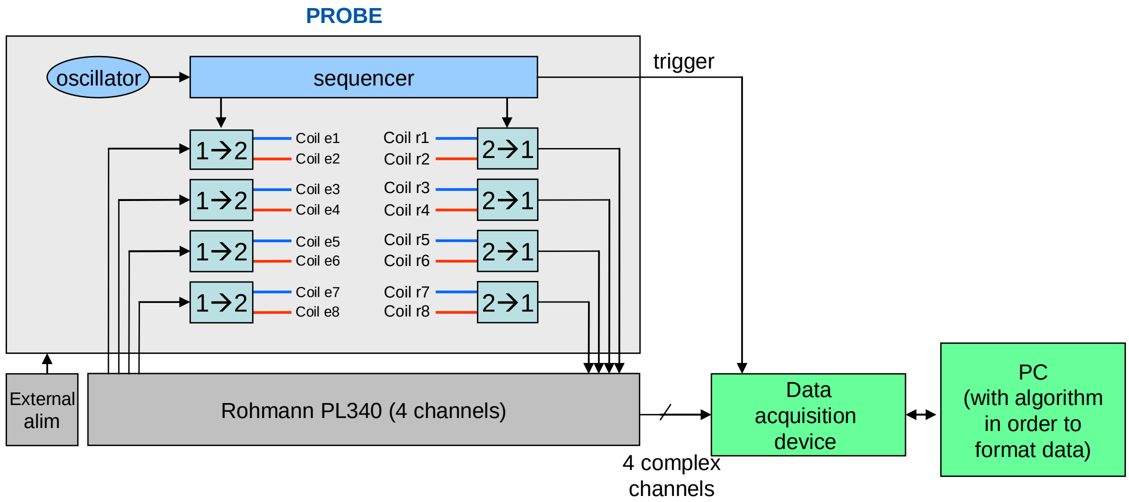

Figure 6 : System acquisition.

Data coming from the 4 channels of the device are successively saved. A post-processing algorithm arranges data in order to display them.

2.4 Post-Processing

In order to test the good performance of the probe we have scanned an aluminium flat work piece with a long notch as displayed in Figure 5. Figure 7a presents the image provided by the probe.

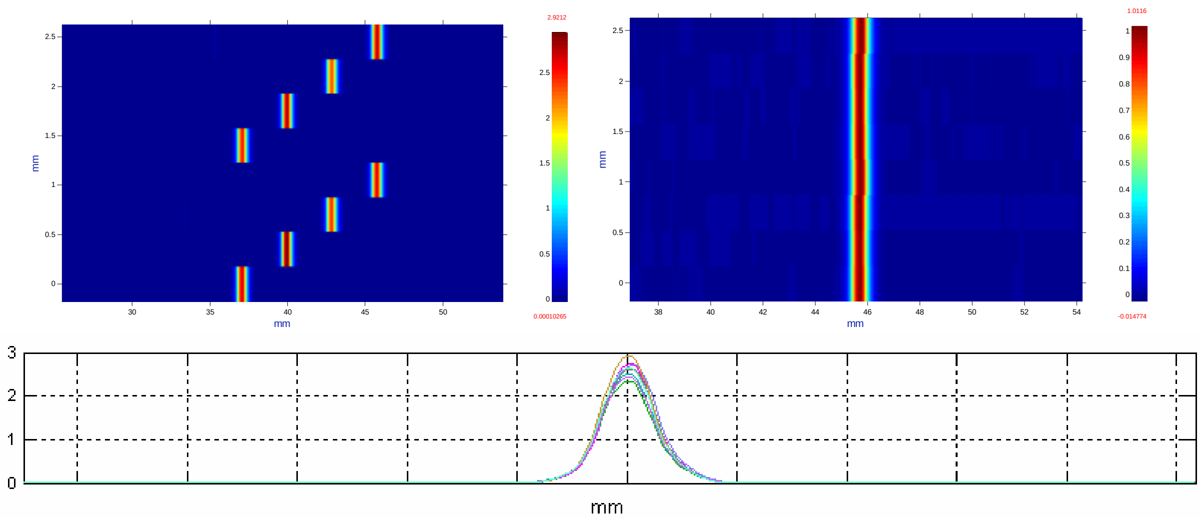

Figure 7 : (a) Image without processing (on the top and on the left), (b) image after balancing and centring (top and left) and (c) 8-elements signal amplitude (bottom).

Due to the shift of the elements on the kapton film, we operate a post-processing on experimental data. The 8 signals are spatially translated with a step of *3* mm in order to obtain the same response (Figure 7b).
The amplitude of the 8 channels, as the probe passes by a long notch, is given in Figure 7c. As it is expected, each element gives the same response (all signals have the same shape and the difference in the magnitude is lower than 10%). Moreover, a correction coefficient may be applied on each EC signal provided by each element.

3. Results of the Multi-Elements Probe

3.1 Detection of Small Notches Close to the Edges

Notches have been made near to the edge of a titanium planar test block (see Figure 8). All defects are *0.4* mm long and the distances of each notch to the edge are *0.5*, *1*, *1.5* and *2* mm. The probe was moved parallel to the edge. More experimental data are displayed in Figure 8. The post-processing previously discussed in section 2.4 was used to link the received data. Moreover, the signal has been filtered by using a high pass filter (*1.8* Hz) in order to reduce edge effects. All notches are well detected with a SNR of about *25* dB.

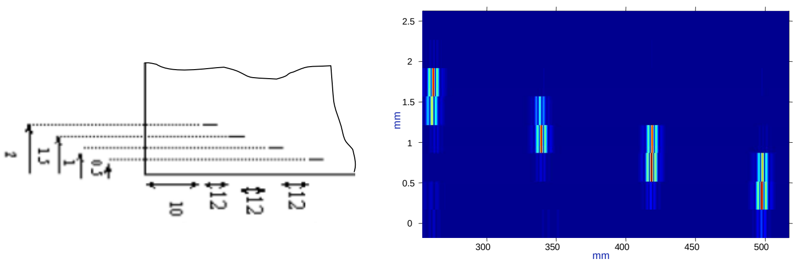

Figure 8 : The notches are close to the edge of the planar test block.

3.2 Curvature Effects

We wish to test the capabilities of the new flexible probe when scanning curved surfaces. Let's consider notches simulating half penny shaped fatigue cracks in the *2.5* mm concave radius between a flange and a large diameter cylindrical contour. A test block of Titanium6Al4V reflects this situation. Figure 9 shows the geometry of the curved work piece and Figure 10 presents the results obtained by the multi-elements probe. All notches are well detected with a good SNR at least equal to *20* dB even if the probe is unfavourably oriented with respect to the length of the notch: for the notches 3 and 4, the axis defined by the centre of the emitting/receiving coils is perpendicular to the length of the notch.

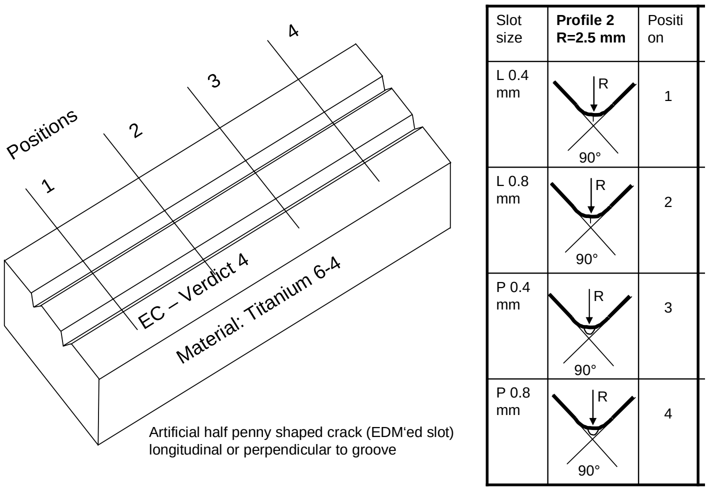

Figure 9 : Small radius mock-up with half penny shaped EDM notches.

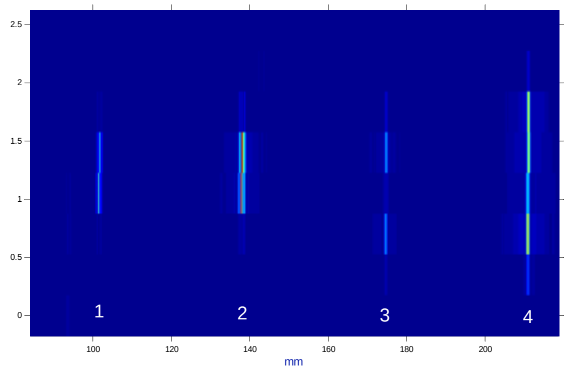

Figure 10 : Detection of the surface breaking flaws in the small radius mock-up with the multi-elements probe.

3.3 3D geometry

Let’s consider another testing configuration involving a 3D geometry. Figure 11 presents the flexible EC probe testing a more complex shape; the dimensions of the notches are also defined in the same figure (area 2). The curvature radius in area 2 is equal to 10 mm.

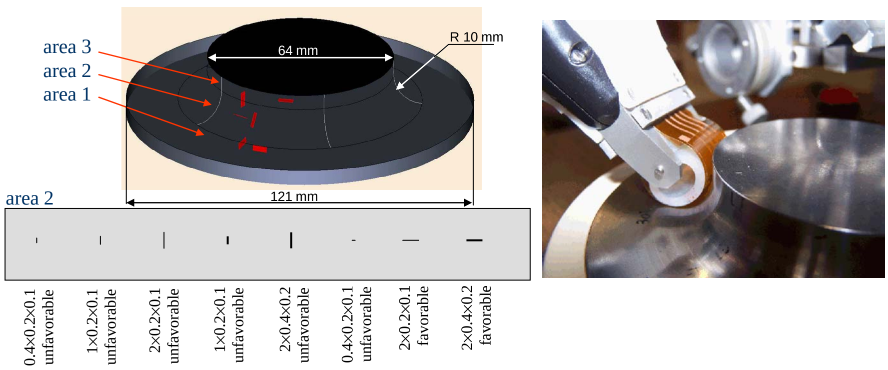

Figure 11 : 3D - complex shape for multi-elements flexible probe evaluation.

Experimental data are displayed in Figure 12. In spite of additional difficulties due to the 3D complex shape, all defects are still well detected.

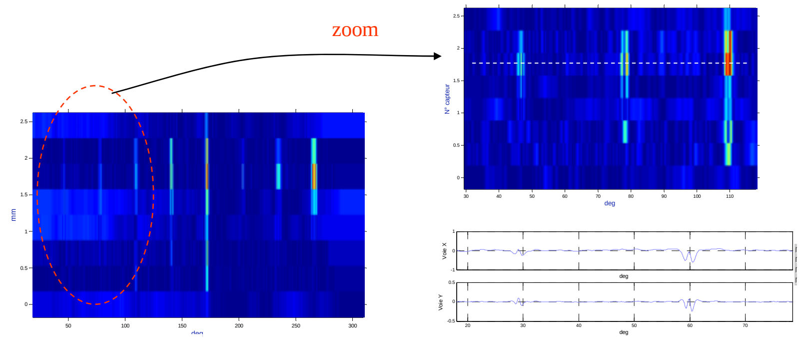

Figure 12 : Experimental data provided by the EC probe scanning a 3D-complex shape.

3.4 Testing in Industrial Conditions

The capabilities of the EC flexible probe have been evaluated on a SNECMA test block (see Figure 13) built from a real part (CFM 56-3 fan disc). One notch is placed parallel to the axis, in the middle of the dovetail. The length of the notch is *0.8* mm. The image on the right side of Figure 13 presents the variations of the magnitude of the EC signal.

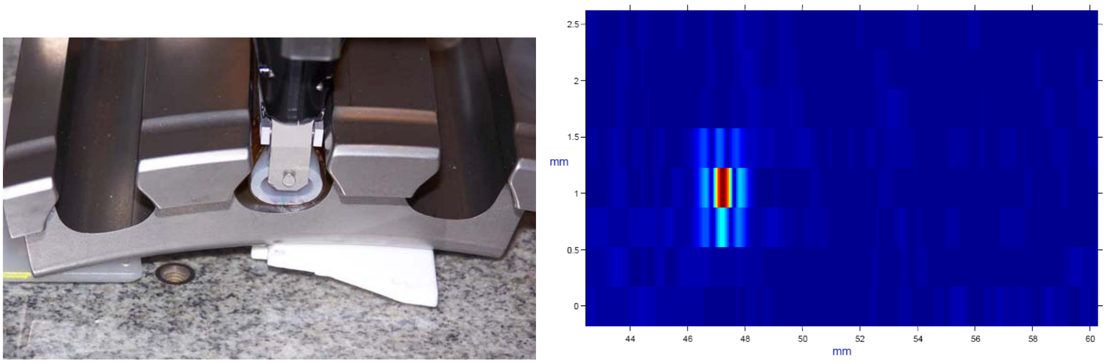

Figure 13 : The probe has been evaluated on a dovetail mock-up of the CFM56-3 fan disc. The EDM notch is well detected.

Conclusion

The new flexible EC probe provides very good results for the detection of very small notches breaking a planar or a curved surface. In most of cases, the SNR is at least equal to *20* dB. Due to the flexibility property, the EC probe is able to fit curved surfaces. Moreover, edge effects can be significantly reduced by high pass filtering. The etching process of coils on kapton films opens a large domain of applications.

The simulation tools recently integrated into the CIVA platform have largely contributed to the improvement of the design and thus to the performances of this flexible EC probe.

Acknowledgements

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References

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