FLEXIBLE AND ARRAY EDDY CURRENT PROBES FOR THE INSPECTION OF COMPLEX PARTS

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Introduction

Eddy Current (EC) is a powerful mean of detection of defects located in conductive parts. This technique has already proved great performances and brought original solutions to different industrial issues in nuclear or in aeronautics domains for instance. EC Probes used in Non Destructive Testing (NDT) are mainly based on winding coils. This technology has proved good efficiency and gives good results in a lot of applications. Nonetheless, it reveals some limits in some cases. First, this technology is not adapted when flexibly and high spatial resolution are required. Therefore the inspection of complex parts turns out to be difficult or unfeasible. Second, the sensitivity of winding coils decreases along with frequency. Thus, detection of deep buried defects, which requires low frequency use, is hardly achievable.

To bring solutions and improve non destructive techniques, other technologies have been investigated at CEA LIST. Original Eddy Current probes have been developed for specific needs. In this paper, the technology of flexible array probes based on micro-coils is described, several probes are presented and experimental results are given. In a second part, EC probes based on magnetic sensors are presented and their advantages with regards to classical winding coils are demonstrated.

1. Flexible micro-coils probes

64 micro-coils flexible probe

A typical issue that occurs in many domains as nuclear energy or aeronautical industry is the detection of very small surface defects located in planar or non-planar parts. Solutions concerning flexibility, accessibility and fast accurate scanning had to be found to give an adapted answer to every singular case. Taking advantages of the possibilities offered by the NDT platform CIVA [1], several new designs have been studied. This research led to an original separated functions scheme [2], consisting in two 1mm diameter coils, etched on both sides of a thin kapton film. This pattern has been characterized and its performances in the detection of a 400µm surface notch have been compared to the ones of a classical winding coil with an equivalent size. The experimental results are shown on figure 1. The new scheme gives a better CSCAN, from a Signal to Noise Ratio (SNR) point of view as well as from a spatial resolution point of view. Given this first good result, a flexible large array probe has been developed. Figure 2 is a photo of it. This probe is composed with 64 micro-coils set in a matrix: 4 lines, 8 columns. Thanks to a staggered row arrangement, the spatial resolution is reduced to only 350 µm and a 11 mm width strip is inspected in one scan. The thin kapton film is connected to a Printed Board Circuit (PCB) where amplifiers allow improving the SNR.

Flexibility is given by a silicone roll set between the kapton film and the frame of the probe. Furthermore, its shape can be adapted in order to fit to a given complex part, as dovetails for example.

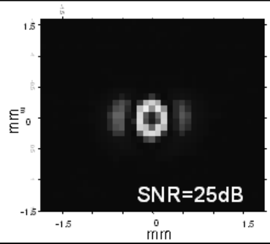
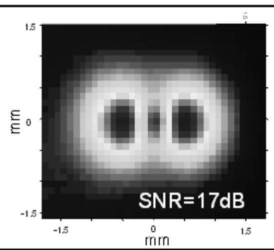
	New pattern 	Coil Φ 1mm 
Defect 0.4x0.2x0.1mm		

Figure 1: Experimental comparison between the new pattern and a classical winding coil

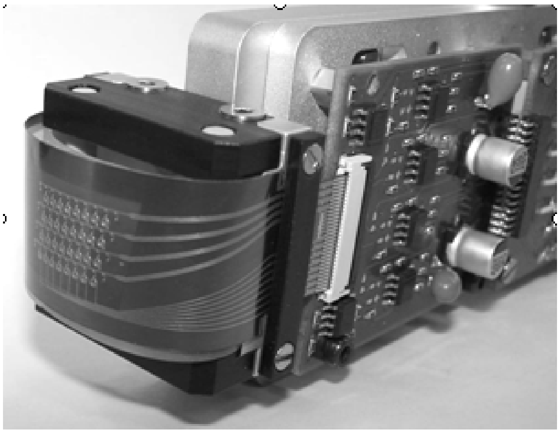


Figure 2: Photo of the 64 micro-coils flexible probe

The 64 micro-coils probe is driven by the MultiX-EddyCurrent device designed by M2M Company. This device is able to drive 32 independent and multi-frequencies emitting channels and has 64 independent digital demodulators.
The objective of the experimental test described hereafter is to size a defect located on the surface of an Inconel elbow, as shown on figure 3. The probe is mechanically moved and a photo of the experimental testing is given on the left side of figure 3. Thanks to the large inspection area of the probe, only one scan is required to give the screen shots represented on the right side of figure 3. The top part is the row C-SCAN and the bottom part is the reconstructed C-SCAN. Indeed, as the pattern of the probe has been registered into the MultiX-EC, C-SCAN is reconstructed in real time. This cartography corresponds to the 32 responses of the elements (emitter and receiver) of the probe and the pitch between two lines is equal to the one between two elements, that is to say, 350µm. The defect is well detected and it is also possible to estimate its size, by simply measuring the spot on the C-SCAN.

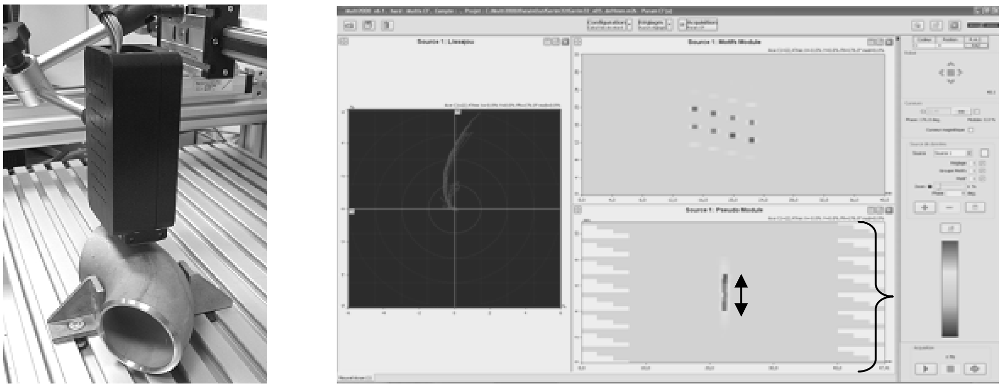


Figure 3: Experimental configuration and result of the detection of a 4mm long defect located on the surface of an Inconel elbow

Probe for pipe inspection

The detection of cracks located into pipes is a critical issue, especially in nuclear domain where steam generator pipes are numerous. With the support of the Institut de Radioprotection et de Sûreté Nucléaire, we have developed a probe specially designed for the control of pipes with thickness close to 1 mm and diameter around 22mm. Therefore, the NDT probe, which inspects the pipe from its internal side, has to be customized with regards to the evolving internal geometry of the pipe and must be flexible. The technology based on micro-coils etched on kapton film has proved good results and has been used for the design of a new probe, dedicated to this application. A photo of this probe is given on figure 4. Its principle is almost the same as the 64 micro-coils probe presented in the previous part. Thanks to a flexible material located under the kapton film, the probe is able to inspect the pipe even in the area where its diameter changes.

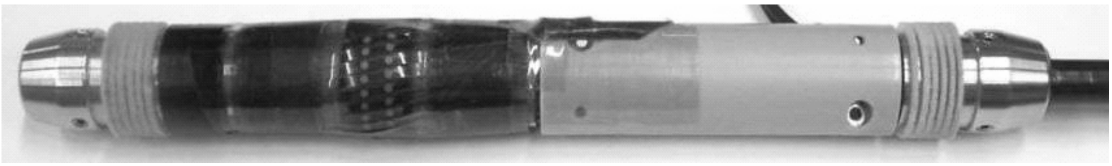


Figure 4: Photo of the flexible probe for pipe inspection

To evaluate the performances of the probe, an experimental test has been performed. It consists in the detection of a 6mm long defect, perpendicular to the pipe and located on the external side. Its deepness is 40% of the thickness of the pipe. The experimental CSCAN is compared to the simulated one, computed thanks to CIVA software. As shown on figure 5, there is a good agreement between the two results.

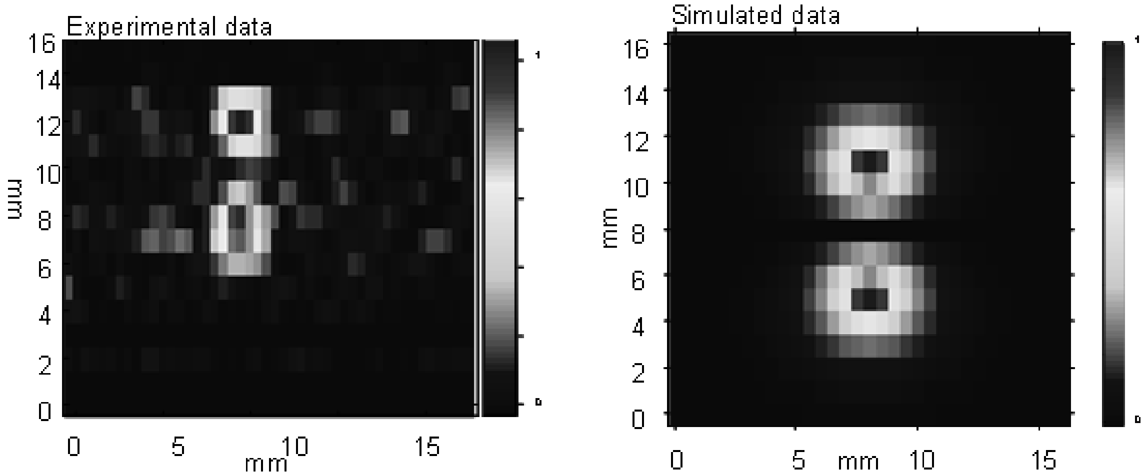


Figure 5: Comparison between experimental and simulated data, 40% external defect 6mm long, located into a pipe

To go further, experimental testing has been performed in the area where the diameter varies. Two identical defects have been machined into the pipe, one in the area where the diameter is constant and one in the part where it increases. Both are 6mm long, perpendicular to the pipe and 40% external. As shown on figure 6, the CSCAN reveals that both defects are as well detected.

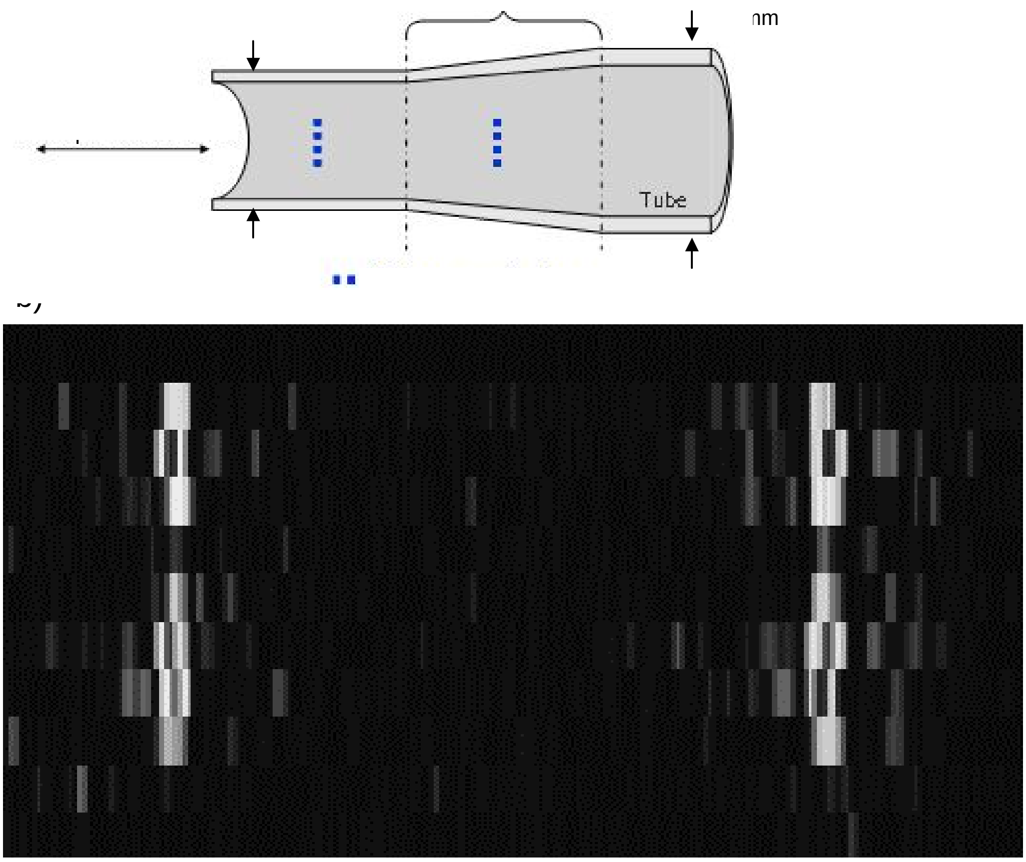


Figure 6: Experimental CSCAN when the diameter of the pipe goes from 22.2mm to 22.6mm

The technology of micro-coils etched on kapton film allows the development of flexible and high spatial resolution probes dedicated to the detection of small surface defects in non-planar parts.

2. Magnetic sensor probes

Magnetic sensors are very attractive for NDT applications [3]. First, their small size is interesting from a spatial resolution point of view and allows the development of very large arrays, useful for accurate and fast inspection. Furthermore, their broadband sensitivity makes them attractive for both small surface notches and deep defects detections. This technology has been studied at CEA LIST with different partners in a collaborative project and several probes have recently been developed for different applications [4].

22 Giant Magneto-Resistances probe

This probe is dedicated to the detection of small surface notches at high frequency. It consists in an array, composed with 22 GMRs sensors. The GMRs are put in a row and the spatial resolution is 100µm. A special packaging using a beveled glass led to a lift-off minimization and guarantees a good SNR. A current foil is used to generate the Eddy Current at high frequency into the inspected part.
Experimental tests have been performed to evaluate its performances. Three small notches (200x100x200μm^3, 100x100x200μm^3 and 100x100x100μm^3) have been made into an Inconel mock-up. The experimental C-SCAN obtained at 2MHz is shown on figure 7 and reveals that the three defects are detected with a good SNR.

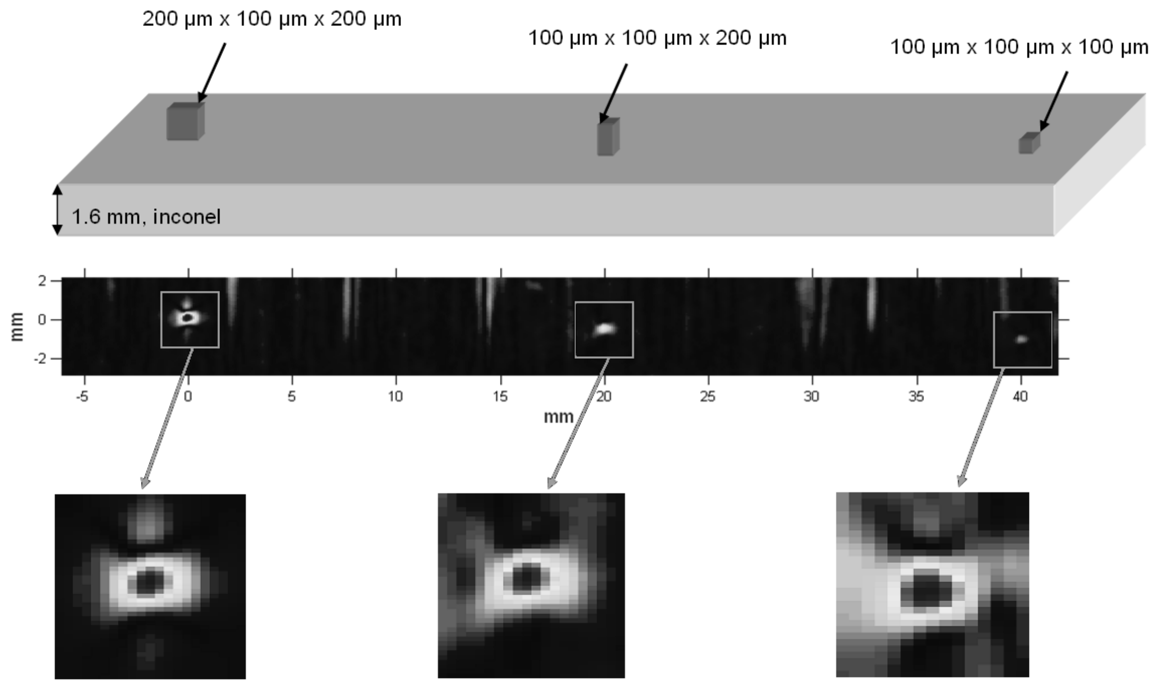


Figure 7: Experimental configuration and result of the detection of a 3 small notches into an Inconel mock-up

96 Anisotropic Magneto-Resistance probe

In the framework of a multi-partners project, another magnetic sensors probe dedicated to the detection of small surface defects have been developed. This probe is based on

Anisotropic Magneto-Resistance (AMR) sensors. To estimate the sensitivity of this sensor and validate the design of the probe optimized with CIVA, a first one-AMR prototype probe has been achieved. A ph
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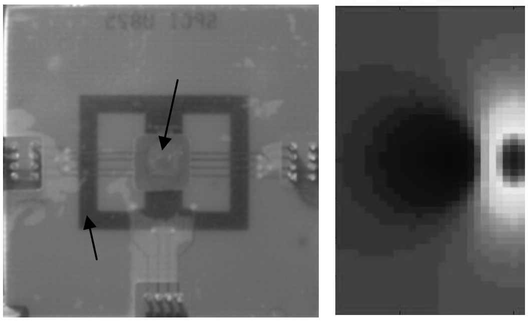

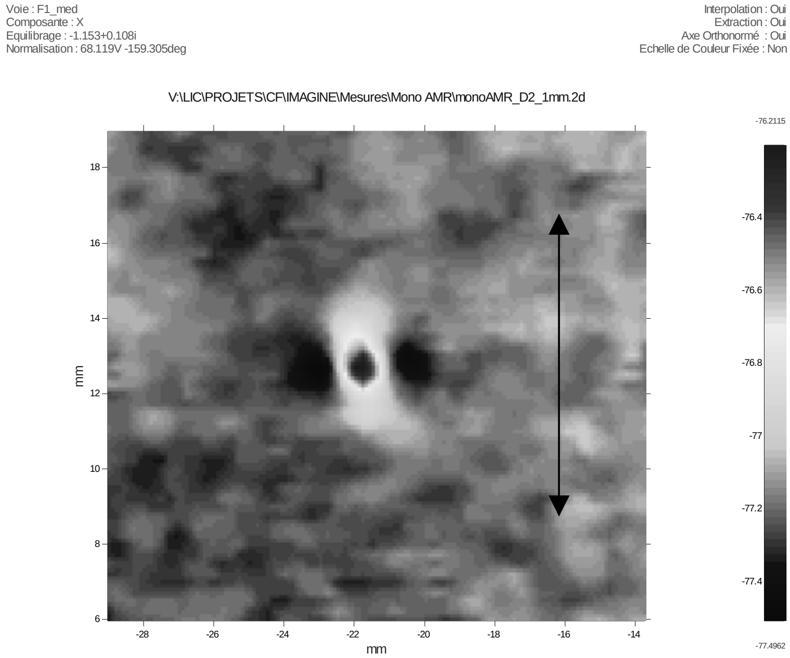

Figure 8. AMR prototype probe and co
data – 1mm surface de

The 96-AMRs probe has been developed, using the same design. The 96 AMR are set in a row and wire bonding is used to connect each one to the PCB, as shown on figure 9. The pitch between sensors is 100µm and the width of the scan strip is almost 10mm. A second PCB containing amplifiers is used to improve the SNR. Thanks to a special packaging, the array has been set as close as possible to the inspected surface to reduce the lift-off. Experimental tests are in progress at CEA.

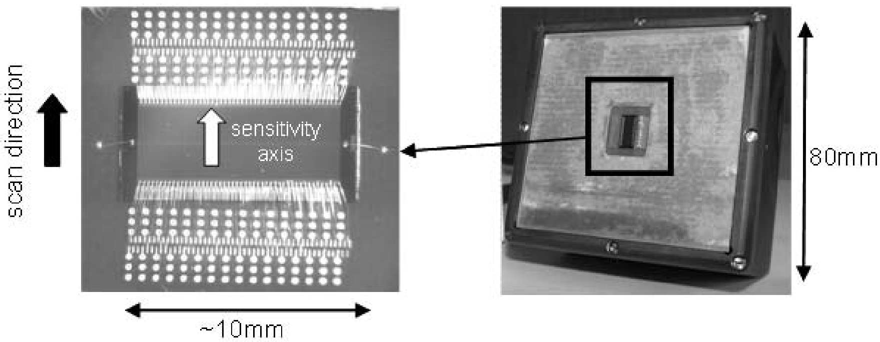

Figure 9: Photos of the 96 AMR array: zoom of the sensitive area and probe for NDT

Flexible magnetic sensor probes

A typical issue in NDT is the detection of deep defects into components. This kind of inspection requires the generation of Eddy Current at low frequency so as to inspect deeply into the part. Therefore, the sensor used has to be sensitive at such frequencies. Contrary to winding coils, magnetic sensors are broadband and remain sensitive at low frequency. Taking advantage of this property, a flexible probe based on a GMR sensor has been developed at CEA [5]. Eddy Currents are generated thanks to a winding coil and both emitter and receiver are embedded into silicone to give flexibility to the probe. The inspection of non-planar parts is therefore possible, as seen on figure 10.

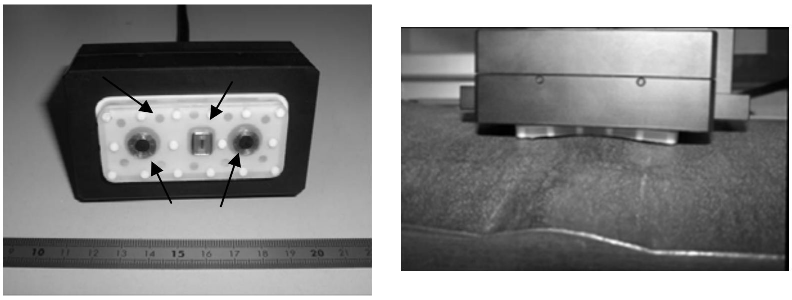

Figure 10: Photos of the flexible GMR probe

Experimental testing has been performed. Its objective is to study the detection efficiency of the probe regarding the deepness of a 10mm long defect located into a multi-layers Inconel mock-up. Figures 11 are C-SCAN of the experimental results for three different ligaments. For each measurement the frequency has been computed using the skin-depth relationship and then experimentally optimized. The three defects are detected with a pretty good SNR.

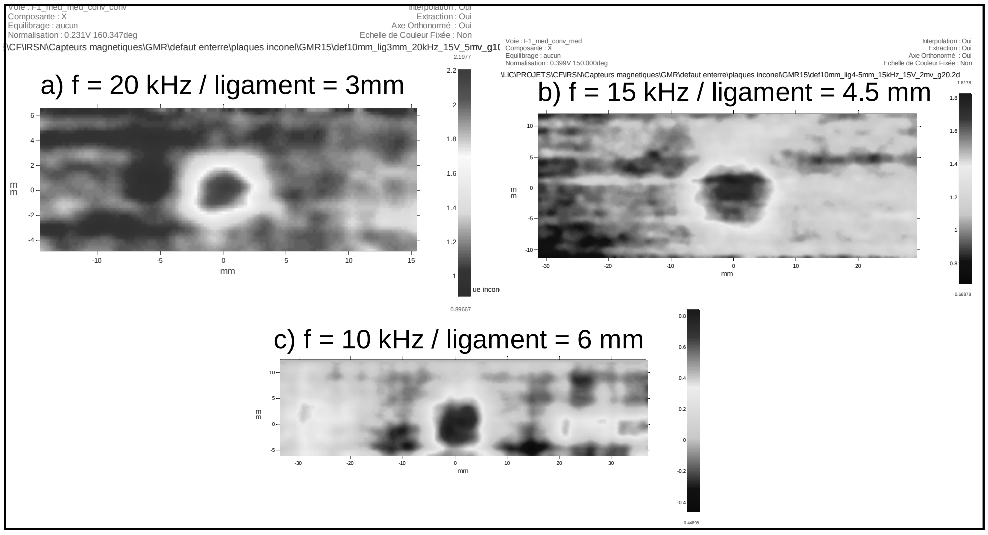

Figure 11: CSCANs of the detection of 3 deep defects into a multi-layers Inconel mock-up, with 3 different ligaments: 3mm, 4.5mm and 6mm

Conclusions

Probes based on different technologies have been developed at CEA LIST to give solutions to industrial constraints in terms of sensitivity, accessibility and accuracy. For the detection of small surface defects located in non-planar parts, the flexible 64 micro-coils array probe shows good sensitivity and reliability. Concerning the inspection of pipes, a specific flexible probe using micro-coils has been developed. It inspects the pipe from the internal side and even in the areas where the diameter varies it is able to detect defects with a good efficiency.

Magnetic sensors turn out to be very attractive in NDT. Concerning the problem of fast detection of small surface defects, their small size and high sensitivity has allowed the development of two large array probes. The first one, composed with 22 GMR sensors is able to detect notches as small as 100µm. The second one is a high spatial array of 96 AMR sensors. Tests are in progress. With regards to the detection of deep defects, a flexible probe based on a GMR sensor embedded into silicone has been achieved. First tests have demonstrated that a 10mm defect, 6mm deeply located into an Inconel mock-up is detected. Others tests are in progress to look for deeper defects.

References

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