Inspection of Hidden Defects in Metal-Metal Joints of Aircraft Structures Using Eddy Current Technique with GMR Sensor Array

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Abstract. To realise increased inspection depths in eddy current (EC) technique, giant magnetoresistive (GMR) magnetometer can be used as receiver element for an EC sensor.

This paper reports on the efficient GMR sensor array for ET inspection of hidden defects in metal-metal joints of aircraft structures. This new developed sensor array is a result of the collaboration of Airbus Deutschland (Bremen) and Fraunhofer Institute for Non-destructive Testing (Fraunhofer IZFP, Saarbrücken).

1 Introduction

Usage of new materials and assembling technologies in modern aircraft design allows reaching high long-time quality and efficiency but also requires the application of qualified inspection techniques during the whole aircraft lifetime. The inspection of new materials with stronger requirements becomes possible using new technologies of non-destructive testing (NDT). In addition, the application of improved NDT techniques can reduce the maintenance costs for currently used as well as for future aircraft designs.

The most frequently used inspection techniques for metallic components of aircrafts are ultrasonic testing (UT) and eddy current testing (ET). For metallic structures ET is the preferred technique for the detection of surface-breaking flaws as well as for hidden flaws in regions with specific geometry (e.g. joints, respectively riveted lap joints) as well as in areas which are difficult to access with UT. Especially the complex inspection situations generate the demand for improved ET techniques with increased inspection depth.

The higher inspection depths are only possible at low EC frequencies because of the electromagnetic skin effect. Use of the sensitive magnetic field sensors such as SQUID's or magnetoresistive sensors can increase the efficiency of the EC measurement since this type of sensors compared with coils indicates frequency-independent sensitivity beginning with 0 Hz. Magnetic field sensors based on the GMR-effect are available on the market [1] and offer a good compromise between magnetic field sensitivity on one hand and simple handling on the other hand. Since the first application in 1998 [2], GMR sensors are used in Fraunhofer IZFP for eddy current technique as well as for magnetic flux leakage technique [3], [4], [5].

Especially for developing of efficient sensor arrays, the combination of the key features of the GMR sensors is important:

- high, frequency-independent sensitivity to the magnetic field,

- small geometrical dimensions (in comparison with inductive sensors of the same sensitivity),
- simplicity in use, low power consumption (in comparison with other sensor technologies).

2 GMR Array Design

2.1 Arrangement of the Array Elements

Fig. 1 shows the basic construction of the single GMR-based EC probe developed in the IZFP (EC GMR probe, fig. 1 a) as well as a comparable conventional EC probe with high inspection depth (fig. 1 b). The EC GMR probe provides higher sensitivity than the inductive probe with same geometrical dimensions but at lower inspection frequencies.

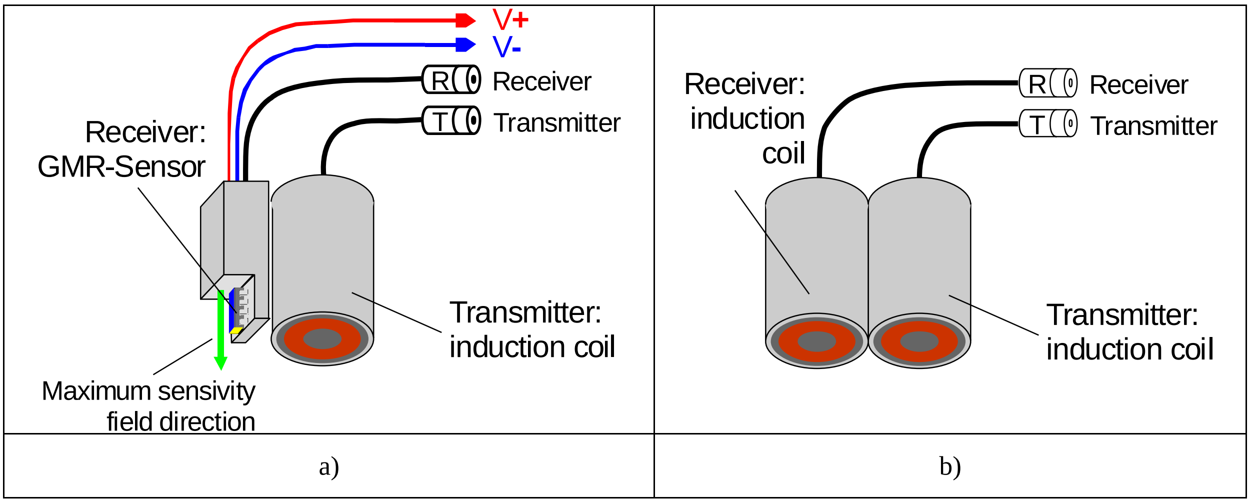


Figure 1: Basic arrangements of EC GMR probe (a) and a comparable inductive EC probe - so called half-transmission probe (b).

Based on the experience with this probe design [2], [3], a GMR sensor array with one transmitter coil (excitation coil) and 16 GMR elements as receiver has been realised. Fig. 2 shows the selected arrangement of the array elements. The following array parameters are documented:

- Total inspection width of the array is 64 mm: 16 GMR elements, element spacing (pitch) 4 mm.
- The dimensions of the transmitter coil have been determined empirically. The width of the coil (here: 77 mm) should be as large as possible - to provide the homogeneous distribution of the excitation field at the locations of GMR elements. For the determination of the coil length (here: 20 mm) should be considered that reducing of the coil length causes decreasing of the penetration depth of the excitation field.

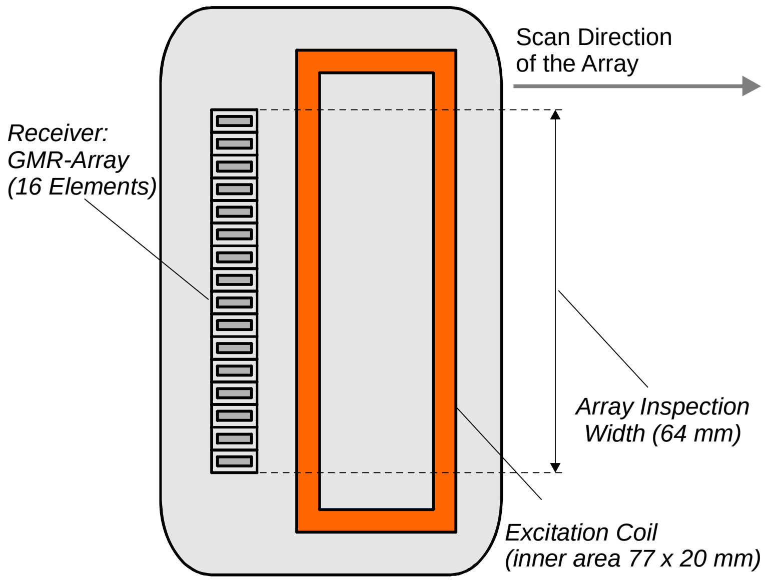


Figure 2: Arrangement and main dimensions of the EC GMR Array

2.2 Complete GMR Array System

Fig. 3 shows the block diagram of the complete prototype inspection system with EC GMR sensor array. Some of the most complex functions of the EC signal processing are realised by the standard components (PC with multifunction ADC card) in combination with the PC software. For this hardware concept, the electronics of the GMR array can be essentially simplified.

The hardware and the software of the GMR array are realised for operation with sinusoidal EC excitation at a single frequency between 100 and 3000 Hz.

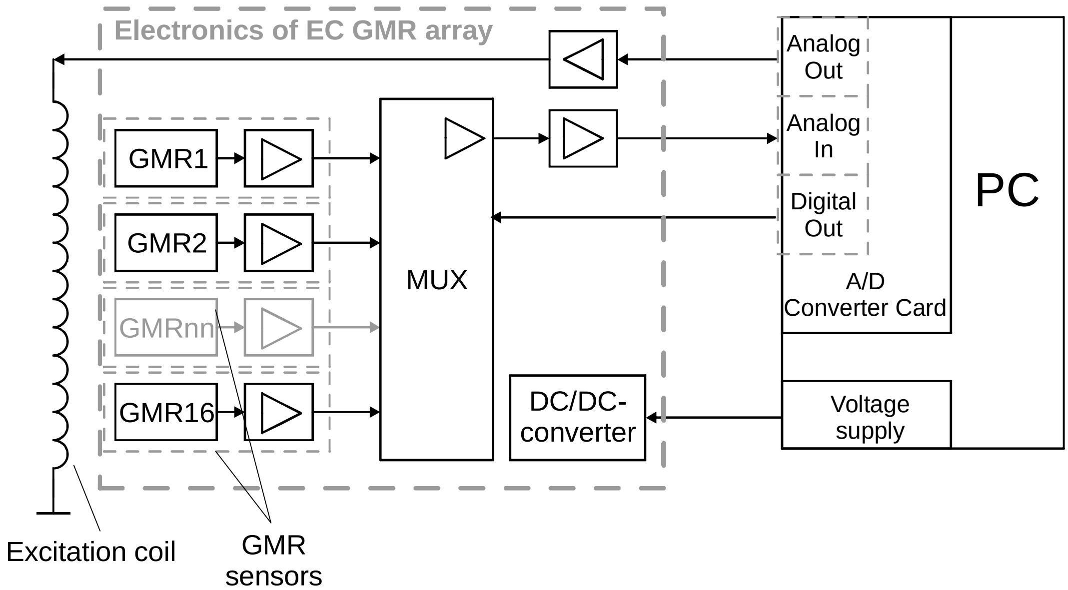
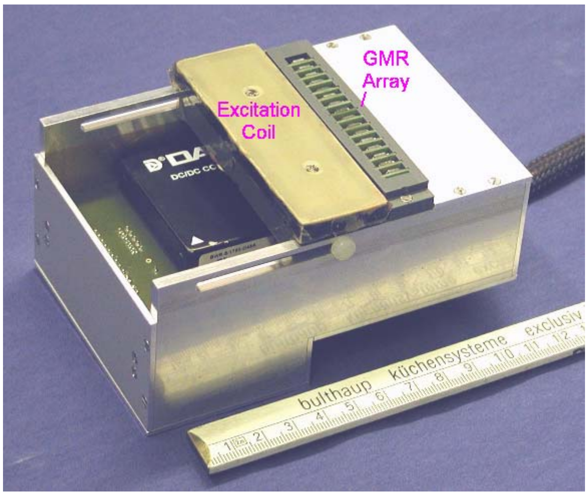
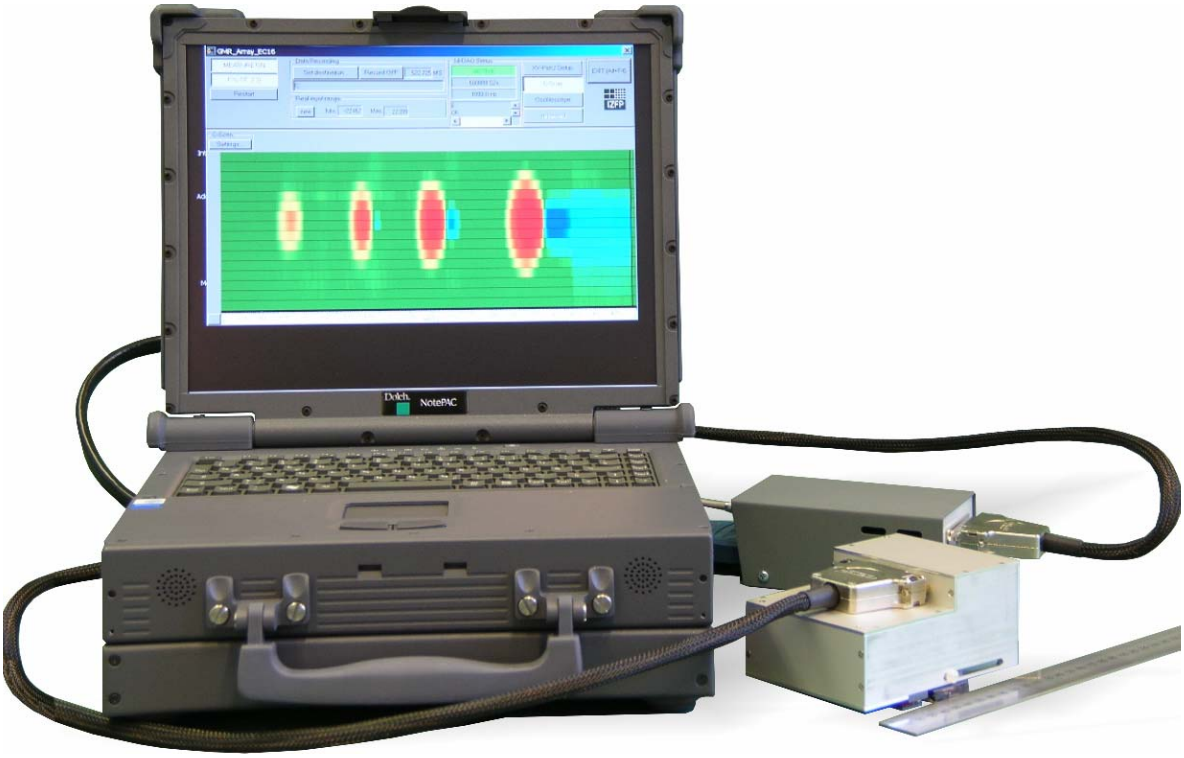


Figure 3: Block diagram of the inspection system with EC GMR array

Fig. 4 shows the EC GMR sensor array including the array electronics (fig. 4 a) and the complete inspection system including the GMR sensor array and the PC with software (fig. 4 b).



a)



b)

Figure 4: Photographs of the GMR Sensor Array (a) and the complete ET system (b)

2.3 Representation of the measurement results

After setting up of the inspection parameters (EC frequency, amplification factors, phase shift, threshold level, etc.), measurement results can be visualised online as two-dimensional colour-coded picture (C-scan image). Horizontal axis of the C-scan image corresponds to the time progress during the measurement. Vertical axis of the C-scan image corresponds to the location coordinate across to the array scan direction on the scanned surface. Different colours in the C-scan image represent the magnitude of the imaginary part of the GMR sensor voltages after demodulation and signal processing.
On the PC display in figure 4 b, the user interface of the GMR array with a C-scan image is shown.
In addition to the colour-coded online visualisation, all processed measurement data can be saved to hard disk to allow an offline post-processing as well as documentation of the results.

3. Experimental Results

3.1 Detection of Hidden Cracks in a Riveted Structure

Detection of hidden fatigue cracks in riveted aircraft structures as shown in figure 5 is a known challenge. Since the specific geometry (rivet holes etc.) produces strong EC indications which should be separated from possible defect indications, an enhanced inspection effort is usually required. The developed GMR sensor array allows a drastic reduction of the inspection time and consequently of the costs, because the result can be obtained just after a single scan with the array along the rivet row.

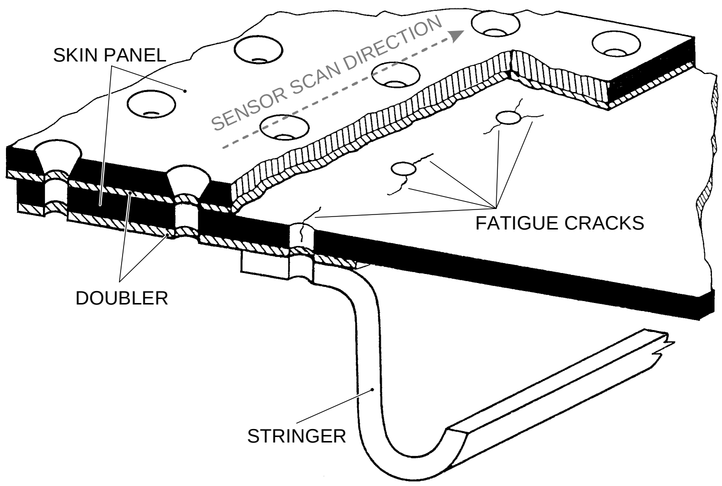


Figure 5: Longitudinal lap joint with fatigue cracks in an aircraft skin panel (typical example)

To detect these defects (located at the depth of approx. 3 mm under the specimen surface), the EC frequency 1500 Hz has been applied.

Figure 6 shows the result of the GMR sensor array measurement, obtained on the lap joint of aluminium panels with artificial defects. As the C-scan image (fig. 6 on the bottom) shows, the defect signals can be clearly visualised as well as evaluated according to defect length.

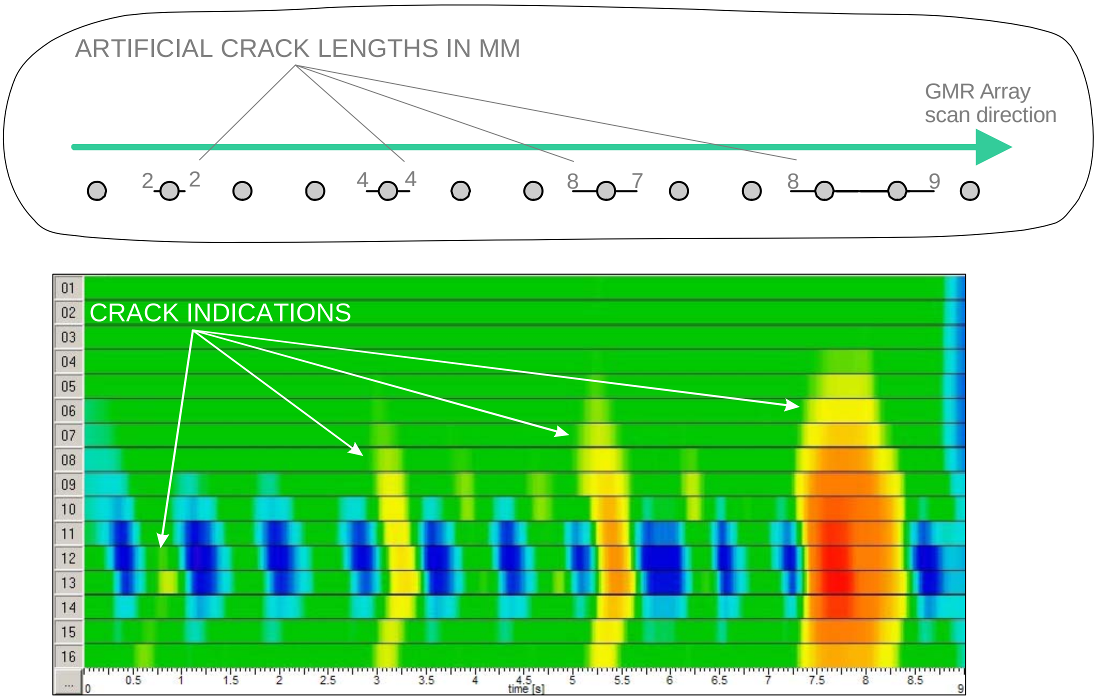


Figure 6: Layout of the lap joint of aluminium panels with artificial hidden defects (on the top) and the corresponding result of the measurement with the GMR sensor array (colour-coded C-scan image, on the bottom)

3.2 Investigation of the Maximal Inspection Depth in Aluminium

The maximal inspection depth of the developed GMR sensor array has been investigated on the specimen with the geometry as described in figure 7:

The bottom aluminium plate of thickness 1.4 mm contains 3 "defects" - slots with length 60 mm and various widths (10, 5, and 1 mm, see fig. 7 on the top). The cover depth for the defects can be varied by adding defect-free aluminium plates over the bottom plate (see fig. 7 on the bottom).

To reach the maximal penetration depth, the lowest possible EC frequency of the realised GMR sensor array - 100 Hz - has been applied.

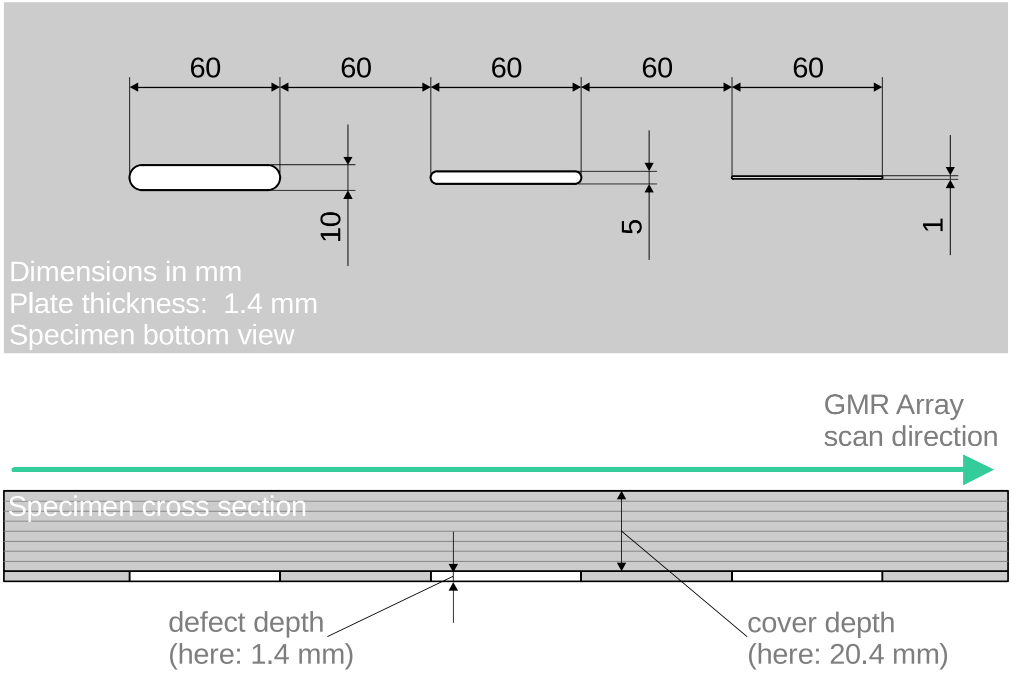


Figure 7: Investigation of the maximal inspection depth in aluminium: Geometry of the specimen with fixed depth of the hidden defect and the variable cover depth

Figure 8 shows the result of the GMR sensor array measurement, obtained on the specimen according to the fig. 7 at the cover depth of 20.4 mm. As the C-scan image in figure 8 shows, the defect signals can be reliably visualised.

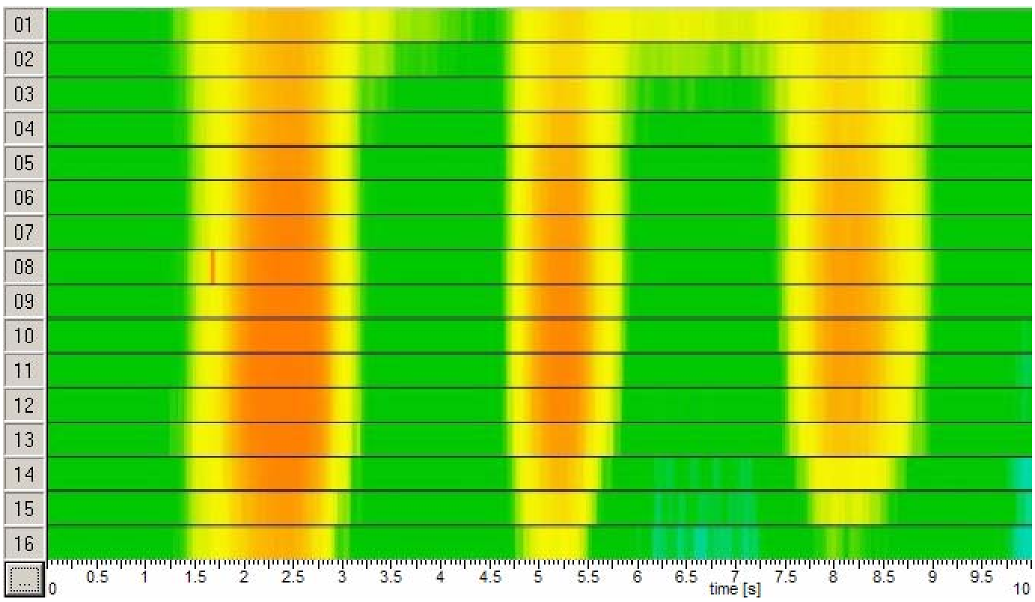


Figure 8: Investigation of the maximal inspection depth in aluminium:
Result of the measurement with the GMR sensor array (colour-coded C-scan image), obtained on the specimen according to the fig. 7.
EC frequency 100 Hz; Cover depth: 20.4 mm

4. Conclusions

An EC sensor array using 16 GMR sensors has been developed and optimised for operational frequencies between 100 Hz and 1500 Hz. Reduction of the inspection effort on the one hand as well as enhanced inspection depths on the other hand become possible with the realised array design. As the present results shown, the inspection depth of more than 20 mm in aluminium can be reached with the described GMR sensor array.

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