A Benchmark Problem for Eddy Current Nondestructive Evaluation

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***Abstract*—Currently, there are three TEAM Workshop benchmark problems involving eddy current nondestructive evaluation configurations, No.8, 15 and 27. Regarding the first two, they have seized to constitute challenging problems, since they can be routinely solved with existing commercial software. In this work, we present precision impedance measurements in a configuration involving a system of plates with through holes and a crack and propose them for benchmarking numerical codes. The benchmark represents a simplified version of eddy current inspection of fastener holes in aircraft structures, provides a lot of experimental data and, overall constitutes a more challenging problem.**

***Index Terms*—Benchmark testing, eddy currents, impedance measurement, nondestructive testing.**

I. Introduction

The basic setup in eddy current nondestructive evaluation (NDE) comprises a probe coil driven by a harmonic current, a conductive testpiece and a rather small defect/discontinuity usually in the form of a narrow crack. The aim of the inspection is to reveal the presence and the characteristics of the defect through the variation of the coil impedance as this is scanned over the testpiece. Simulation of this basic setup as well as of other more complicated setups is of paramount importance in the optimization of the inspection parameters as well as in the interpretation of the acquired impedance signals. From the computational point of view, both differential and integral methods can be used. Regarding FEM, modeling of eddy current nondestructive evaluation is quite challenging since: (i) it is a multi-scale problem, i.e. the defect area constitutes a small part of the solution domain and the field perturbations and defect signals are weak compared to the signal produced by the coil and the conductor, and (ii) thin areas arising from narrow cracks or small lift-offs are usually present and affect the mesh quality. Integral equation methods are also commonly used, but the need for dedicated Green's functions with analytical expressions that correspond to the specific conductor geometries limit their scope.

All solution methods and available codes require validation which is usually performed by comparing theoretical results to precision measurements taken from very well prepared experiments. Over the past years, several experimental data-sets have been presented in the literature including the TEAM Workshop No.8, 15 and 27 problems. The purpose of this work is to propose a new benchmark problem in the field of eddy current nondestructive evaluation and to provide various sets of precision impedance measurements.

II. Existing Benchmarks For Eddy Current NDE

Since the 90's there have been a number of eddy current NDE benchmarks used for code validations or measurement data that are of such high quality that could be regarded as of benchmark quality. As already mentioned, there are three benchmarks in the TEAM Workshop series. In problem No.8, there was no sophisticated measuring device, plate conductivity was only assumed, lift-off was large, solenoid coils were used instead of the usual pancake ones and finally the output signal had to be rotated and scaled in order to compare it with the theoretical results. No.15 is a much better benchmark problem but it involves a simple testpiece and provides data only for a line scan for two coils at two specific excitation frequencies. The research group that produced No.15 has produced additional problems of this genre, including cracks in thin plates and cracks in double plate systems [1] as well as elliptical and epicyclic crack configurations [2], that are of higher accuracy compared to problem No.15. Unfortunately, these high quality data are not widely known to the public and most researchers are only familiar with problem No.15. Finally, problem No.27 is more challenging and involves a pulsed excitation and a calibrated magnetic field sensor, but the configuration does not involve any kind of probe movement.

Other benchmark problems involve a set of 6 geometries prepared from the ENDE Benchmark Working Group that simulate eddy current testing of steam generator tubes of nuclear power plants [3]. A similar proposal that is industrially oriented was also made by the COFREND [4] Working Group. On an annual basis, the World Federation of NDE centers presents benchmark eddy current problems [5]. Other high quality data that can be considered of benchmark level have appeared in individual publications [6]-[8].

III. Benchmark Problem Description

Two aluminum plates are used in the experiments to simulate a layered structure. Both of them have dimensions

300mm×300mm, a thickness of 2mm and a through-hole in their middle area. In addition, one of them has a narrow, through crack emanating in a radial direction with respect to the hole. If we designate the plate without the crack as A and the one with the crack as B, we have performed measurements in the following 4 configurations that are named depending on the plate(s) used and their position when stuck together:

A : plate-A alone (no crack)
B : plate-B alone (through the thickness crack)
AB : plate-A placed above plate-B (subsurface crack)
BA : plate-B placed above plate-A (surface crack)

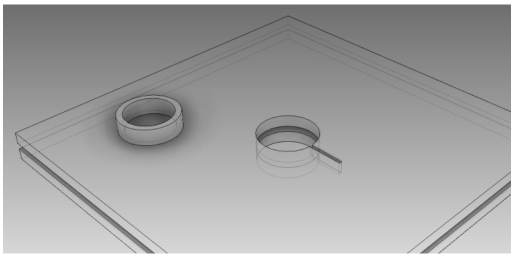

Fig. 1. Experimental setup for one of the configurations (BA).

In all cases, the coil impedance is recorded with an impedance analyzer, for two frequencies, 1 and 5 kHz. The coil and plate parameters are shown in Table I, where both coil lift-off and plate conductivities were first measured and then fitted (for greater accuracy) with the established method described in [2].

TABLE I
TEST SETUP PARAMETERS

COIL	M1650	PLATE(S)	A and B
Inner radius	7.0 mm	Thickness	2 mm
Outer radius	12.0 mm	Conductivity	17.34 MS/m
Height	4.0 mm	Rel.Permeability	1
Wire-turns	1650	Gap between	70 μm
Lift-off	1.082 mm	Hole radius	10.0 mm
L_0 (meas.)	53.655 mH	Crack length/width	9.8 mm/0.234mm

One of the experimental setups is shown in Fig.1. The coil was moved above the hole-crack area with an XY stage (controlled by a PC, position accuracy 0.05mm), which correlated the position of the coil with the measured data. A C-scan was performed, i.e. measurements were taken for a square raster of positions of the coil above the hole-crack area.

IV. Experimental Results

Fig.2 shows the pattern produced in the B configuration from the amplitude of the coil impedance. The asymmetry in the circular pattern of the hole signal reveals the presence of the radial crack. The data along the *x*-axis are the signal produced for a coil moving above the hole and along the crack. Fig.3 depicts this crack signal, at both 1 and 5 kHz, in the normalized complex impedance plane.

V. Conclusion

Results are presented for a new benchmark problem in eddy current NDE. Contrary to previous benchmarks, the current problem offers precision impedance measurements (a full C-scan of the area under interest using an XY stage). Certain geometrical aspects, like the very thin gap between the plates and the combination of two structural variations (hole(s) and crack) make the benchmark more challenging.

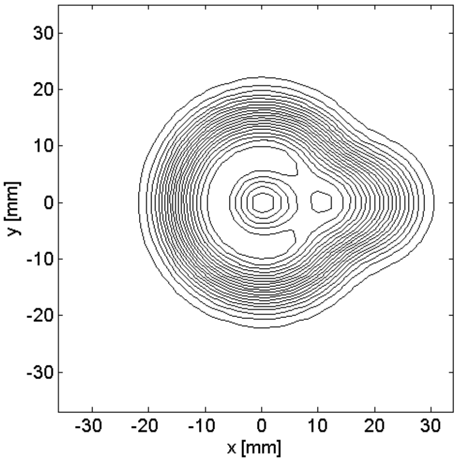

Fig. 2. Contour of impedance change amplitude for a C-scan of the coil and the B configuration, at 5 kHz.

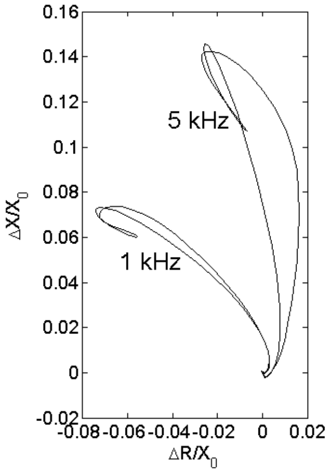

Fig. 3. Normalized impedance change of a coil above a plate due to hole and a crack for two frequencies. The impedance value with the coil standing away from the hole and crack has been subtracted from the total coil impedance.

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