# Demonstration stand for non-destructive conductive material defect inspection by eddy current

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*Abstract –* **To aid in the education of master's level electronic engineering students in our department, we have developed a simple stand that utilizes eddy currents for the non-destructive testing of conductive materials. This method is commonly used for detecting various cracks in the material. The purpose of the stand is to demonstrate the basic idea of such testing during laboratory exercises. The article details the design and implementation of the measuring stand, which includes a measuring device, reference test samples, and accessories. The measuring device is based on the myRIO DAQ device by NI and features a sensing probe that contains an excitation coil, a GMR magnetoresistor AA002-02, and a laser motion sensor. The control software for myRIO was developed in LabVIEW and utilizes both the processor and FPGA in myRIO.**

## I. INTRODUCTION

The eddy current method is a universal non-destructive measurement method for detecting surface, subsurface, and internal material defects [1]. The idea is not new, professional instrumentation can be found in the market and many improvements and variants of the principle itself have been proposed and developed over the years, e.g. [2], or in combination with other test methods, e.g., [3]. The material suitable for testing must be electrically conductive, but it does not have to be ferromagnetic. The fundamental concept behind this type of testing involves subjecting the material under examination to a fluctuating electric current, commonly referred to as an eddy current. This current is induced by the alternating magnetic field generated by the excitation coil. The principle of the eddy current excitation is shown in Fig. 1.

The excitation coil is powered by alternating current in a frequency range typically from 100Hz to 10MHz [1]. The current produces a magnetic field which induces an eddy current in the near conductive material. Copper wire is used to create the air coil, which can take on various shapes and typically consists of 10 to 500 turns.
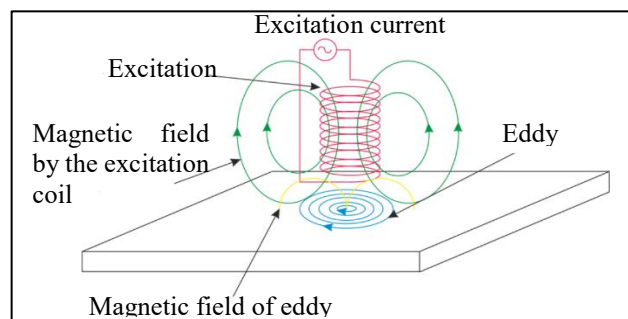


Fig. 1. The principle of induction of eddy current

The eddy currents are in the form of closed current loops in the planes perpendicular to the primary magnetic field induced by the excitation current. The induced eddy current is also called the reaction current. The primary magnetic field is affected by the reaction current, which in turn impacts the primary current. The effect depends on the electrical conductivity of the tested material, permeability, and dimensions of the test sample as well as on other factors such as coil properties, etc. but those can be supposed constant in a simplified model of testing. Changes in the magnetic field indicate a change in the properties of the tested material. Changed properties are mostly caused by a structural defect in the material. Detection is commonly possible for defect dimensions from about 0.1mm located at different material depths.

There are 3 possible ways to detect changes in the magnetic fields:
- monitoring current in the excitation coil,
- using additional sensing coils,
- sensing magnetic field by a magnetic field sensor such as a giant magnetoresistive (GMR) sensor[4].

Due to its sensitivity, affordability, and ease of integration, the NVE AA002-02 GMR sensor [5] was selected for use in the development of the demonstration stand.

## II. DESIGN OF THE DEMONSTRATION STAND

The main aim of the demonstration stand design was to develop a very basic, easy-to-use prototype, which can be utilized in laboratory exercises of master students of electronics to demonstrate the principle of testing defects in conductive materials. The block diagram of the developed instrument is shown in Fig. 2.
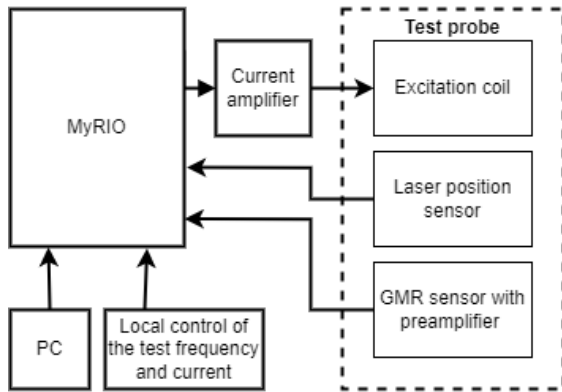


*Fig. 2. Block diagram of the instrument.*

### A. Hardware

The instrumentation is open for students to look inside and perform additional changes and improvements. To simplify the educational process, the myRIO DAQ device by NI [6, 7] is used as the core of the instruments. MyRIO is intended as an embedded system for education and includes analog inputs, analog outputs, digital I/O lines, a Xilinx FPGA, a dual‑core ARM Cortex‑A9 processor, WiFi support, and other hardware components such as LEDs, push buttons, and an onboard accelerometer. It can be programmed in LabVIEW or C.

Additional external components, including a current amplifier and probe with an excitation coil, a laser position sensor, and a GMR sensor, are integrated with the myRIO. The myRIO is linked to the control PC via the internet. The main tasks of myRIO hardware and software are:

- To generate an exact sinewave to excite the excitation coil in the test probe. To achieve the exact timing of sinewave, FPGA calculates and generates samples of sinewave, which are converted by DAC in myRIO to an analog signal, filtered, converted to current, and amplified by a current amplifier. The amplitude and frequency of excitation sinewave current are set by the local controls in the instrument or remotely as well.

- To sense, digitize, and analyze the signal from the GMR sensor in the probe, which is sensing magnetic field given by a combination of vectors of excitation field and field produced by eddy current in the tested material. The analysis consists of an evaluation of the magnitude and phase of sensed sinewave in comparison with reference sinewave generated by

FPGA. The results are transferred together with information about the placement and movement of the test probe to the PC across WiFi.

- To follow the movement and position of the test probe, which is sensed by the laser position sensor.

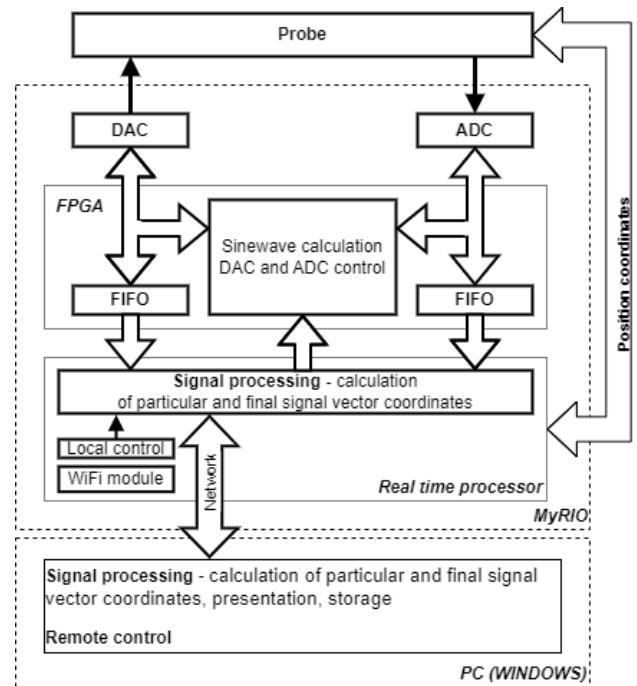The more detailed structure of the instrument is in Fig. 3.



*Fig. 3. Instrument hardware and software architecture.*

The basic test probe (Fig. 4) consists of an excitation coil, GMR sensor, and preamplifier.



*Fig. 4. The basic probe without positioning sensor.*

The coil was realized as an air coil with a diameter of 60mm, and 60 winds of Cu wire with a diameter of 0.4mm. In the center of the coil, the GMR sensor is placed, and all are mechanically fixed and protected as it is shown in Fig. 4. To demonstrate the effects of excitation coil design, an alternative planar coil with an integrated GMR sensor was realized (Fig. 5).

The signal from the GMR sensor is filtered by a high pass filter and amplified using instrumentation amplifier LT1167. The advanced version of probes (Fig. 6) is equipped with a laser position sensor.
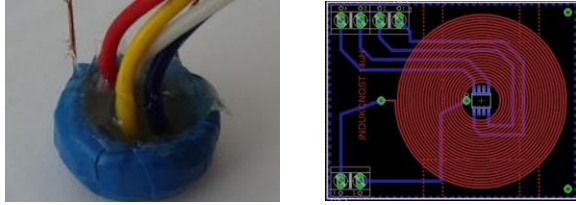
*Fig. 5. Air coil with integrated GMR (in the left) and design of planar coil with GMR (in the right).*
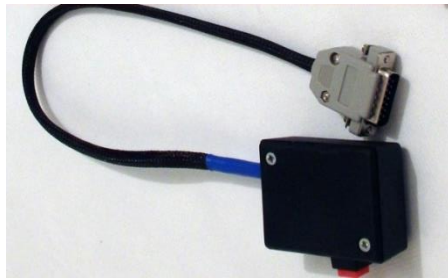


*Fig. 6. The advanced probe equipped with a laser position sensor*

The position of the probe over the material under test is sensed by the laser sensor ADNS-9800 connected to the Teensy 2.0 board (Fig. 7).
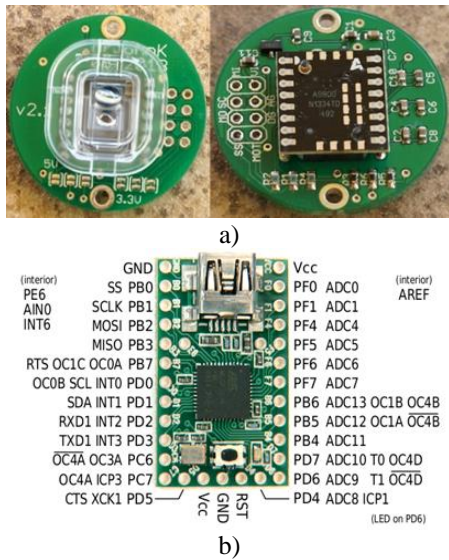


a)



b)

*Fig. 7. a) Laser sensor ADNS-9800 and b) Teensy board.*

The Teensy board software controls the laser sensor and calculates the actual probe position coordinates from data acquired from the laser sensor. The coordinates are transmitted to myRIO to complete information about performed measurements. Before measurement, the positioning system is calibrated. The reference position of the probe is acquired and stored in myRIO memory to easy detection of a probe position when moving.

The excitation coil is powered by a current amplifier converting the voltage signal generated by FPGA and DAC in myRIO (Fig. 8).
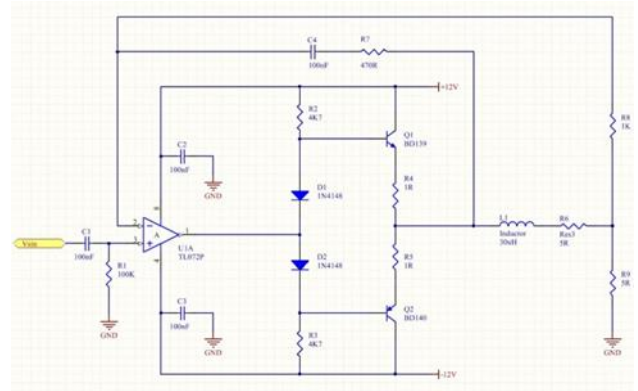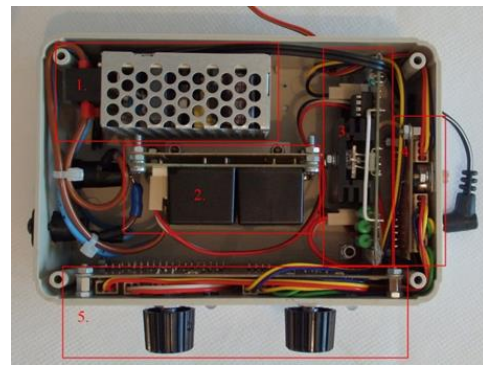


*Fig. 8. The schematic diagram of the current amplifier for the excitation coil*



a)



b)

*Fig. 9. The core unit of the instrument – a) inside view and b) overall appearance.*

The core unit of the developed instrument is shown in Fig. 9. myRIO is placed on the top of the box. The box contains power source (1, 2), current amplifier (3), local control board (5) to set of frequency and amplitude of excitation sinewave, and connector for connection of myRIO and probe.

### B. Software

The software was developed in LabVIEW and partially in C. LabVIEW was used for the development of the application for PC with Windows, for the processor in

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myRIO as a real-time application (LabVIEW Real Time), and for FPGA in myRIO (LabVIEW FPGA). Language C was used for the Teensy 2.0 board.

The structure of the developed software is in Fig. 3. The communication between myRIO and PC uses network variables. FPGA structure ensures precise timing of excitation sinewave by DAC in myRIO. The calculated excitation sinewave samples as well as the signal acquired by myRIO ADC from the GMR sensor are transferred to real-time signal processing software in myRIO. The vector (magnitude and phase) of the acquired signal is estimated and subtracted from the excitation vector (sinewave). The coordinates of resulted vector characterizing the transfer of signal from the excitation coil to the GMR sensor through tested material are calculated and transferred to PC optionally together with probe position coordinates.

Software in PC visualizes these data in plots – course history of magnitude and phase of the difference vector in time with and without position coordinates. Also, the history of changes in the vector is shown in the plot. The actual values of magnitude and phase of excitation and acquired signal together with the difference vector are indicated in numerical indicators.  The software also allows setting the frequency, magnitude, and offset of the excitation signal. The front panel of the PC software is in Fig. 10.
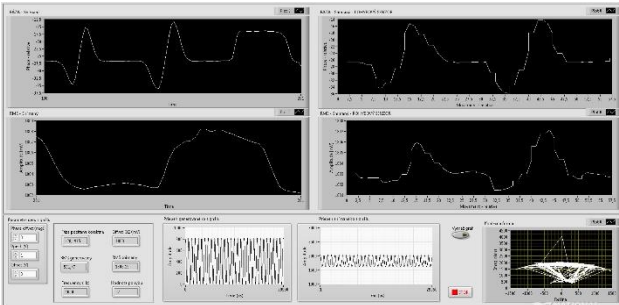


*Fig. 10. Front panel of PC software*

## III.    EXPERIMENTAL RESULTS

To experimentally demonstrate the principle of conductive material defect inspection a few aluminum test plates with artificial cracks of various sizes were realized. An example is in Fig. 11. The aluminum plate has a few milled slots with a width of 2mm and depth of 2, 4, 6, and 8mm. Using the developed instrument and experimental aluminum plates, students can perform measurements at various conditions – various cracks, frequencies, amplitudes, and offsets of excitation sinewave and different probes. Two examples of results are in Fig. 12 and 13.
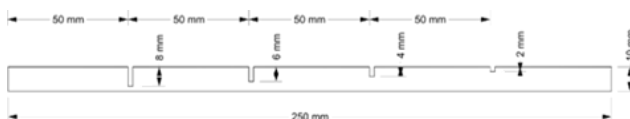


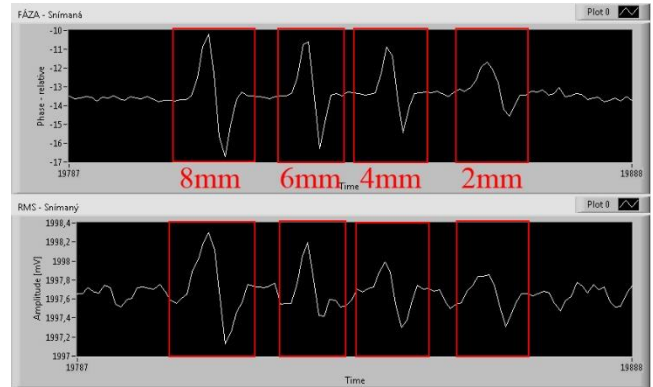*Fig. 11. The side view of the testing aluminum plate with milled slots.*



*Fig. 12. Magnitude and phase achieved at the testing plate in, frequency and amplitude of excitation signal were 2000Hz and 1V.*



*Fig. 13. Detail of magnitude and phase achieved at the testing plate, frequency, and amplitude of excitation signal was 1000Hz and 1V, the slot with the depth 6mm, the probe was moving from right to left and then in opposite.*

## IV.    IMPLEMENTATION IN EDUCATION

The realized system has been implemented in experimental exercises in the course "Advanced measurement system" taught in the master study program "Automotive electronics". A short electronic guide covering the basic theory of non-destructive testing principles, a description of the measuring stand, and a list of experimental tasks have been created and are accessible to students in advance. Before conducting experimental measurements, students must complete the following tasks:

- To understand the basic theory of non-destructive testing of conductive materials based on eddy current and sensing magnetic field generated by the current. The theory is a part of the the short electronic guide.
- To familiarize with the design and structure of hardware of the measuring systems using the guide.

- To familiarize with the control software of the stand at the user level.

The on-site experimental exercise begins with a short test implemented in Moodle to evaluate the entrance knowledge of students. The result of the test is then included in the final evaluation of students achieved on the stand.

The on-site tasks of students are:

- To meet with the experimental stand, hardware, and software using the guide.
- To measure near the center of the aluminum plate without breaks. This may be supposed as a reference.
- To perform measurements on the aluminum plates with different depths and widths (see an example of such plate in Fig. 11). The measurements are performed on both sides of the plates. The students have to evaluate how the measured signals depend on break sizes and probe position.
- To perform measurements on the edge of the plate with and without connecting the plate to another plate.

The results of measurements can be saved in graphical form on a PC. The knowledge and results achieved by students are evaluated later after performing other experimental measurements on other stands, e.g., measurement of temperature using different sensors, etc.

At the end of a measurement round consisting also from other tasks and test stands, the students choose by lot a stand and prepare the PowerPoint presentation. Subsequently they defend it in front of other students and teacher. The final evaluation of each student consists of the defense evaluation taking also into account the evaluation from the entrance Moodle test.

## V. CONCLUSION

In this paper, a straightforward test stand is introduced for non-destructive conductive material defect inspection. The development of this stand was a collaborative effort between Pavol Kababik, a master's level student in electronic engineering, and the author. The test stand is constructed using the educational embedded module myRIO from NI, and it is an open system that can be reprogrammed using LabVIEW by other students who wish to incorporate their own signal processing and presentation techniques. The integration of FPGA, real-time software, and PC software in this system allows students to gain hands-on experience with these components from both hardware and software perspectives. Additionally, students have the option to design alternative or additional hardware components, such as various test probes and amplifiers.

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