LARGE AREA INSTANT CRACK DETECTION AND IDENTIFICATION USING MAGNETIC CARPET PROBE

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Introduction

Over the years, engine reliability has improved steadily as technology advances. The failure rate of high-energy rotating components has been cut to its lowest rate ever. Engines account for a low percentage of all commercial aviation accidents. However, the FAA forecasts that commercial aircraft operations will continue to increase by 3 to 5 percent per year over the next decade. Working in partnership, government and industry have agreed to use enhanced inspections for certain high-energy rotating engine components.

The current NDT technologies, such as conventional Eddy current pencil probes provide very low inspection speed and are bothered by significant noises. Fluorescent Penetration method presents low sensitivity and works also at relatively low speed. Magnetic particle method does not work for non-ferromagnetic materials.

A number new NDT methods and R&D projects are currently going on towards an optimal solution of this problem. Magnetic Carpet Probe (MCP) is one among these efforts.

MCP is a two-dimensional coil array built on a piece of very thin, ≤ 0.015” (0.38 mm), flexible printed circuit board called Flex Circuit. Placing an MCP on top of a metallic surface under inspection one can finish the inspection, without moving anything, and see the crack identification image on the instrument screen in a few second. Actually a two-dimensional scan is going on electromagnetically within the MCP.

Objectives & Requirement in development of MCP

Before starting this project FAA W. J. Hughes Technical Center set the following objectives and requirements for developing the MCP technique:

1. Capable of detection of fine surface cracks, ≤ 0.020”, on titanium engine disc;
2. Ten times faster then any of the traditional inspection methods;
3. Flexible to conform to curved surfaces;
4. Robust and reliable;
5. Simple to use and low cost.

Unique Features of MCP

Unlike any other eddy current array techniques MCP is a real two-dimensional probe array. The unique features of the MCP technique include:

1. No mechanical movement of a probe during inspection. It is an absolute static inspection of the entire area covered by the probe. The consequence includes:

    a. There is no any mechanical noise. This ensures high sensitivity to flaw detection.

    b. It is an electronic and electromagnetic scan. This ensures high speed, or instant, inspection of large area;

   c. It is a pure electronic device. No mechanical parts or components are needed for supporting any mechanical motions. This ensures simplicity, robustness, light weight and reliability of the device, as well as, ease in use and low cost.

2. An MCP is built on a thin and flexible 2-Dimensional sensor array. This provides the capabilities of an MCP in conforming to curved surface; being attached to inaccessible or difficult accessible areas for heath monitoring; and possibility for future remote control of NDI and heath monitoring through networking and/or wireless techniques.

3. The flaw call/reject action is controlled by built-in software. This provides minimum human factor involved in flaw detection.

Significant progress has been made and a number of prototypes of MCP have been developed by Innovative Materials Testing Technologies, Inc., supported by FAA AANC at Sandia Labs under a project sponsored by W.J. Hughes Technical Center.

It is the purpose of this paper to introduce relevant information regarding MCP, present current status and progress in developing this new technique.

Working Principles of MCP

Recent advances of Flexible Printed Circuit Board (Flex Circuits) technique allow building very thin, < 0.002" (50 μm), copper traces and spacing in very thin material layer, close to 0.001" per layer. This enables building a large number of electromagnetic coils, or coil array, in a thin layer structure with reasonable coil size, impedance value and inspection resolution. Meanwhile, recent advances in digital electronic devices have enabled complex and high speed electronic and electromagnetic scan over a coil array with a large of elements, or coils, using a very limited number of miniature chips. Achievement of these two techniques has established the foundation of the MCP technique.

Working principle of MCP includes the follows:

1. Densely populated 2-D coil elements, coil array, covering the while area of inspection;

2. Connection of each coil element of the coil array to an eddy current instrument through multiplexers;

3. Electronic control of high speed electromagnetic scan over the entire area of inspection using programmable chips;

4. Automatic image, crack/corrosion identification, and display.

Two photos showing a flex circuit prototype of an MCP, Prototype MCP-1-V.2, are given in Figure 1. It consists of three parts, see the left photo: coil array, wiring unit, and control unit. It is a six layer circuit with a total thickness about 0.012" (300 μm). The flex circuit is bendable, see the right photo, and can be conformed to a curved surface.

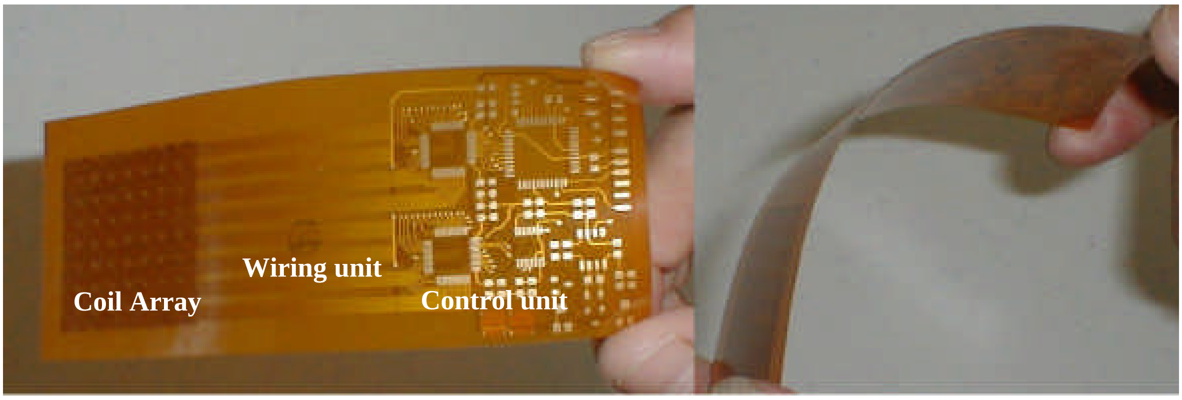

Figure 1: Photos of the flex circuit for an MCP Prototype, MCP-1 V.2

A block-diagram of Prototype MCP-1 V.2, is shown in Figure 2. A 6-layer 8 × 8 two - dimensional coil array of the MCP is placed on the object under inspection. After receipt of a scan command from the Super-Sensitive Eddy-Current (SSEC) system, the probe control unit controls the electromagnetic scan over the entire scanned area through a programmable logic chip and a number of multiplexers. The SSEC system provides the excitation currents to coils and collects eddy current signals obtained from the coils. A built-in SSEC software package processes the data, form an image from the data from the entire scan area, identify cracks/corrosion, then display the image, crack/corrosion identification information in specially designed windows on the computer screen.

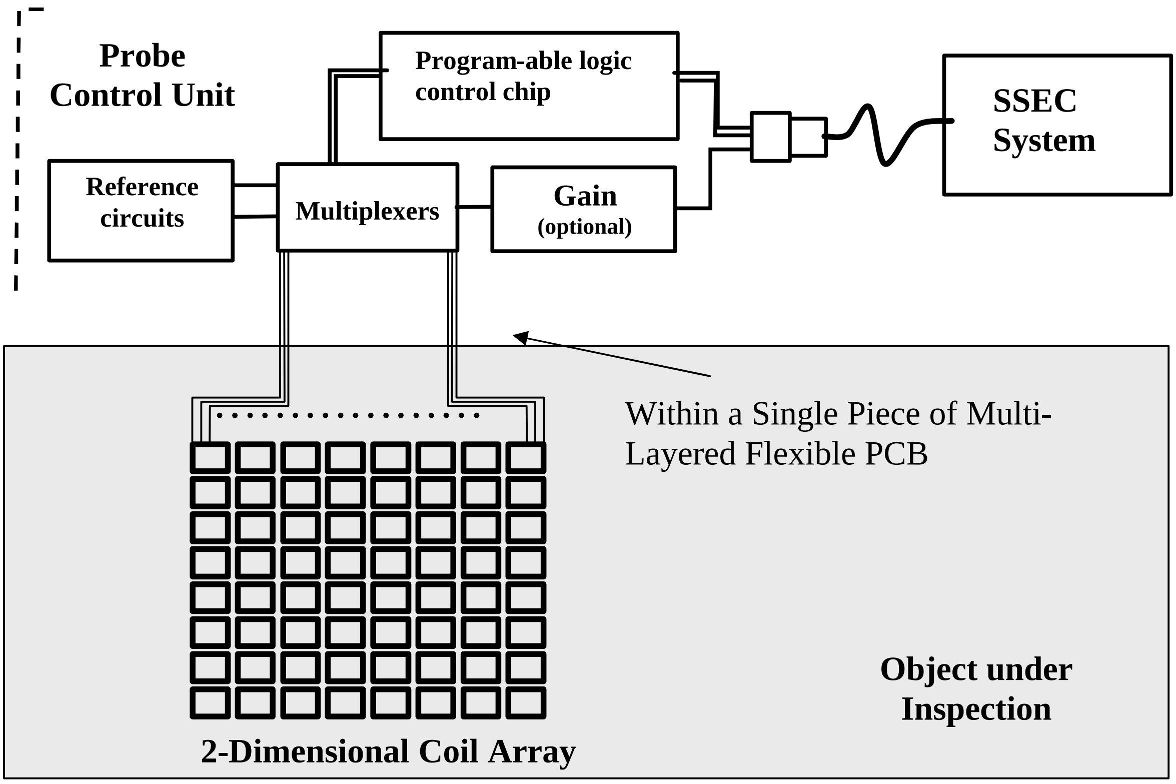

Figure 2: Block-diagram of a typical MCP, Prototype MCP-1 V.2

Typical displays in crack detection are given in Figure 3. The left plot shows the row image obtained from a scan. In the center plot it is a processed image showing the identified crack location as a function of number of column and number of row. The right plot in a text display telling the maximum value of the detected crack signal and the crack location. In the case when there is no crack detected, the plot will show “No Crack Found”.

In practical applications the displays can be customized easily according to customer requirements.

The impedance and X and Y strip signals seen on the SSEC screen during a process of crack detection is shown in Figure 3. The SSEC is set at “DIFF”, Differential Mode. Two specially designed buttons are use for collecting data from a no-crack reference specimen, Data Collection No.1, and from the specimen under inspection, Data Collection No.2. The A-Scan Button is where to click to start a scan over the area covered by the MCP.

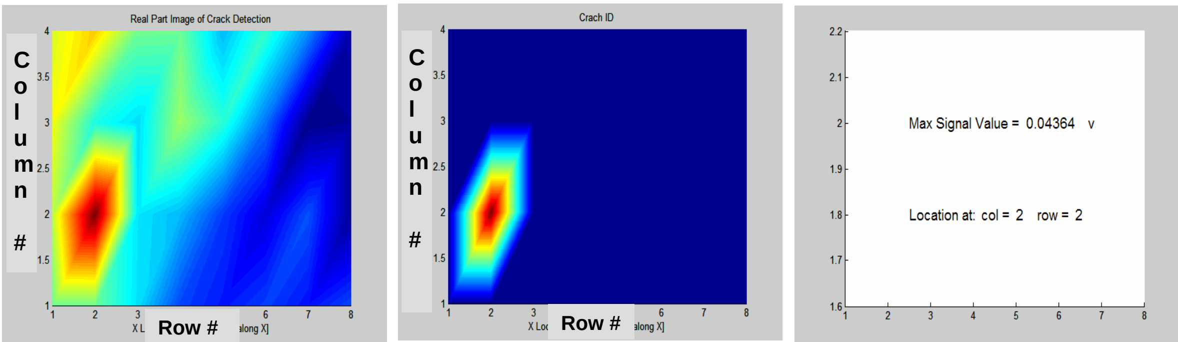

Figure 2: Typical displays in crack detection using MCP-1-V.2

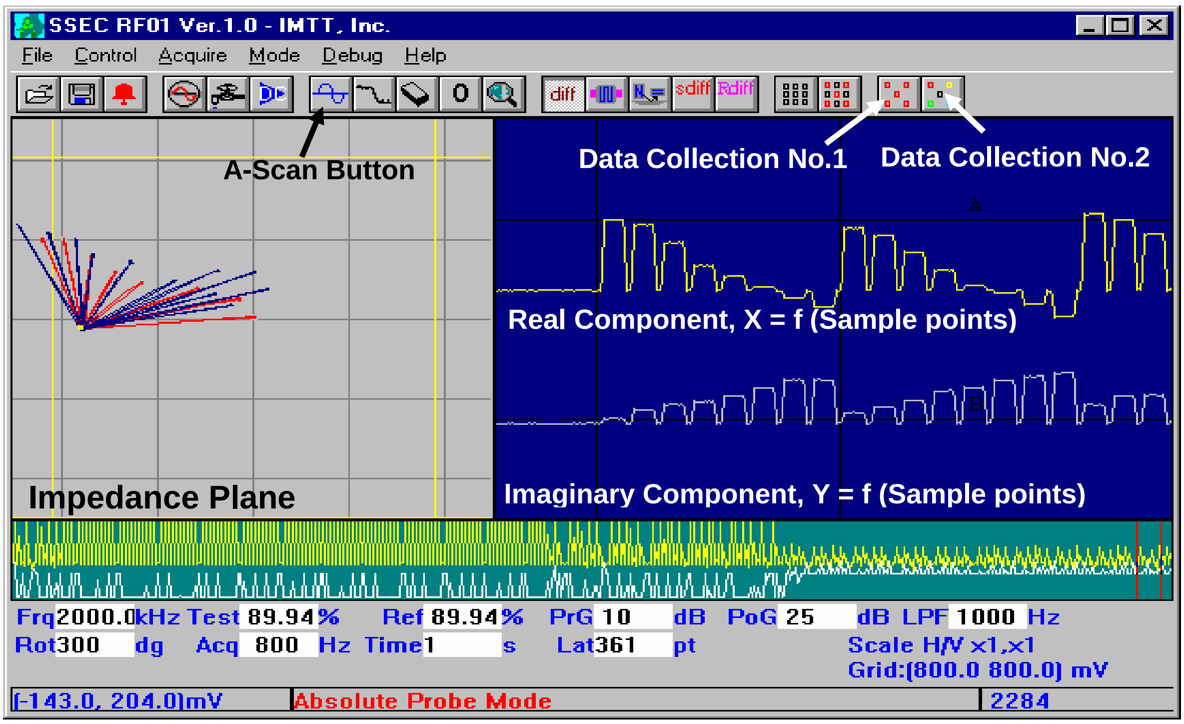

Figure 3: SSEC screen seen during crack detection using Prototype MCP-1 V.2

The crack detection process can be summarized as follows:

1. Firmly place MCP on a no-crack area;

2. Click A-Scan Button to start a scan and wait for about 2 seconds;

3. Click Data Collection No. 1. No-crack data are collected and processed practically in no time;

Note: we need to do 1, 2, and 3 only once per an inspection.

4. Firmly place MCP on the area of inspection;

5. Click Data Collection No. 2. Crack data are collected and processed practically in no time;

6. All three images appear on the screen in a couple of seconds.

Programmable Logic Control Unit
FPGA or CPLD are typical program-able chips. They can be programmed to generate logic control signals we need. These signals include:

1. Multiplexer timing signals for scanning sequence of coils in coil array ;

2. Signals for working in differential mode;

3. Signals for working in nulling mode and selection of null position that appears on the screen;

4. Signals for working in zoom-in mode and selection of the column and row numbers for the zoom-in location. For example, in the test results shown in Figure 2 the MCP was of 8 × 8, but only 4 columns and all 8 rows were used there.

Detecting EDM Notches on a Titanium Standard
The standard is specially designed and made by NDT Engineering, Corp, see Figure 4. Three EDM notches are made on the standard: A – 0.100” (L) x .022” (D); B – 0.060” (L) x 0.022” (D); and C - 100” (L) x 0.016” (D). Prototype MCP-1 V.2 was used to detect the notches. The displays signals obtained from the two smaller notches are shown in Figure 5.

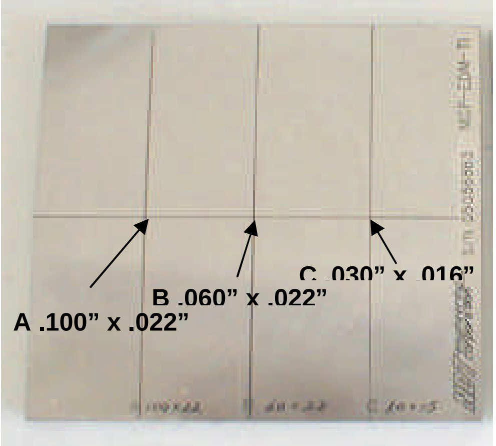

Figure 4: Titanium crack standard

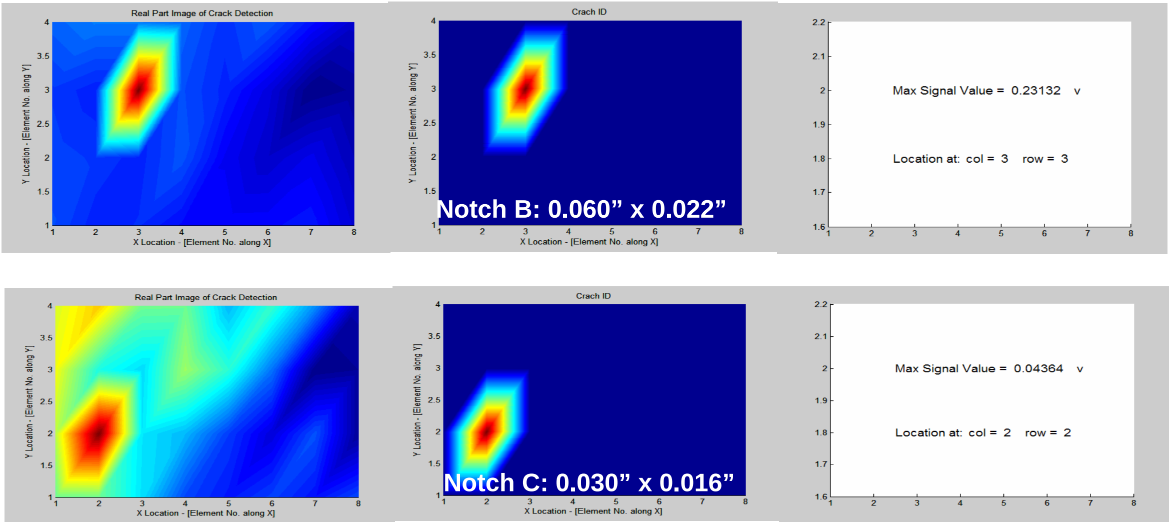

Figure 5: Displays of the signals the two smaller notches

Detecting Fatigue Cracks Made on Titanium Standards
Four 6.0” × 1.0” × 0.25” titanium standards were provided by FAA AANC at Sandia National Laboratories as shown in Figure 6 A. Fatigue cracks were generated on these standards, one crack on each standard, Figure 6 B. The displays obtained when testing these standards are shown in Figure 7.

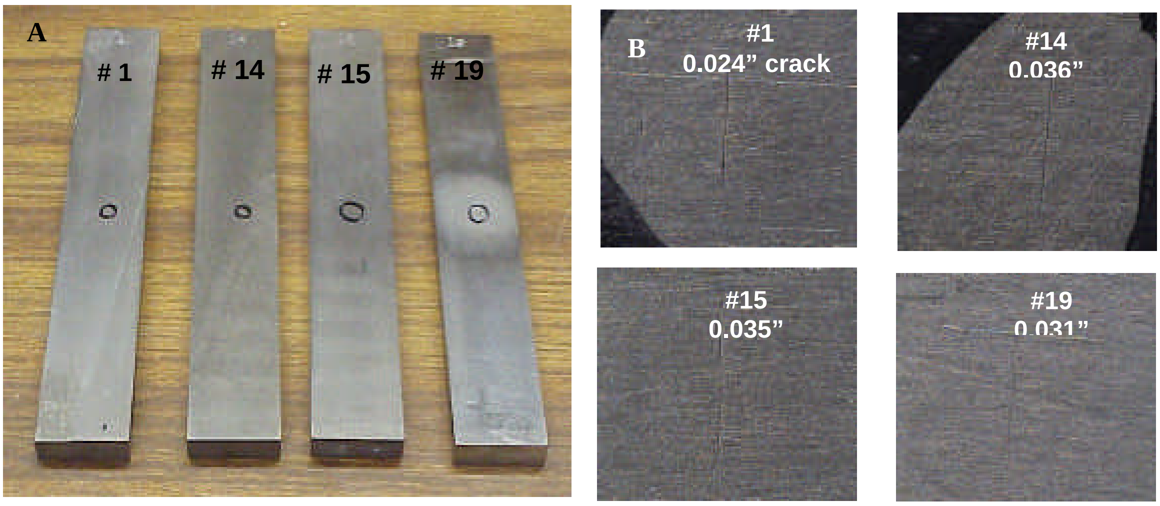

Figure 6: Four Ti fatigue crack standards provided by FAA AANC at Sandia Labs

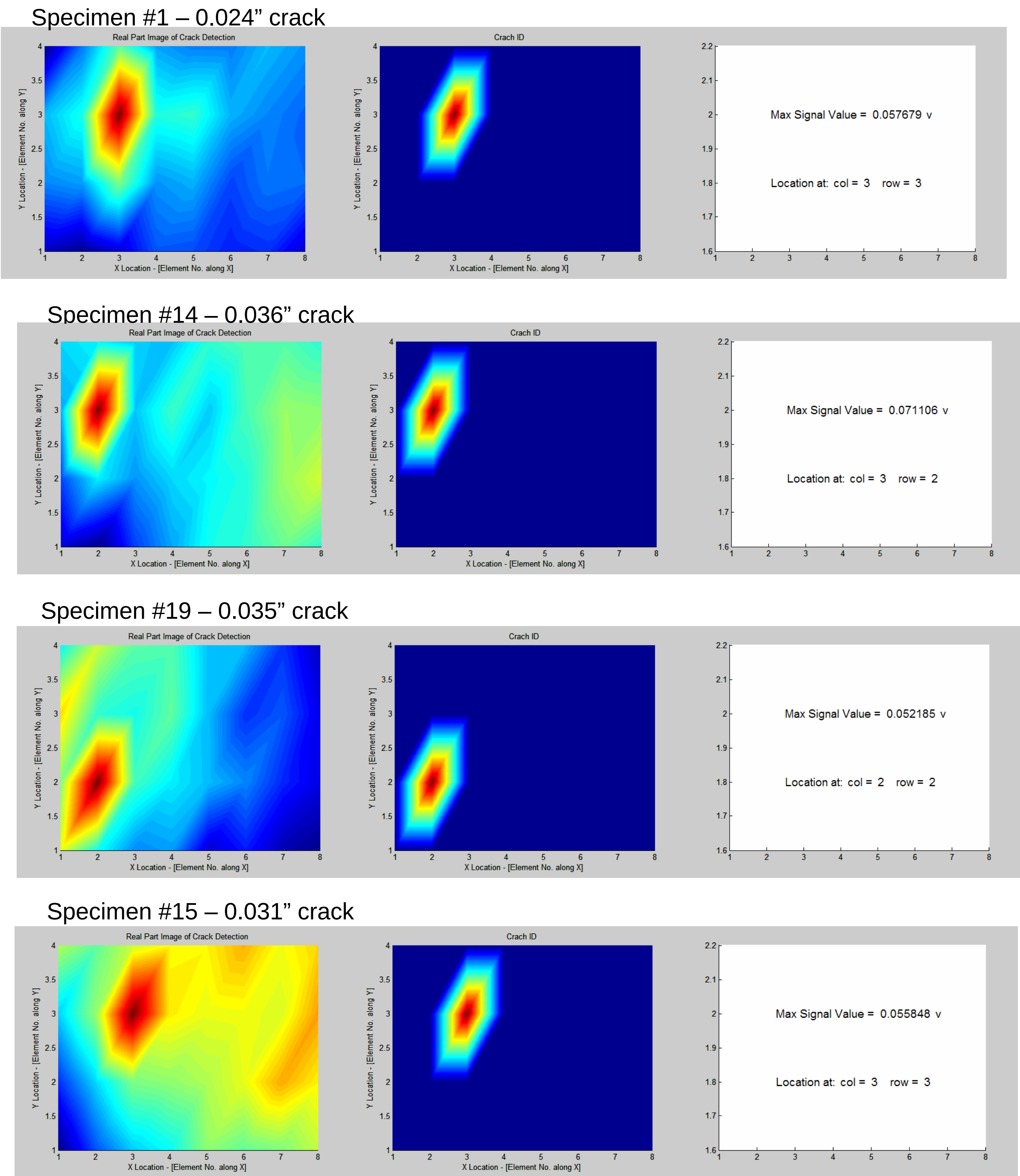

Figure 7: Displays obtained when detecting cracks in the four fatigue crack standards

Planned Inspection of Engine Bore ID using MCP-1-V.5

The bore ID of an engine is selected as the first application of MCP technique. A photo of the selected engine disc is shown in Figure 8. A number of EDM notches are fabricated on different parts of the disc including Bore ID, Bore Face and Web.

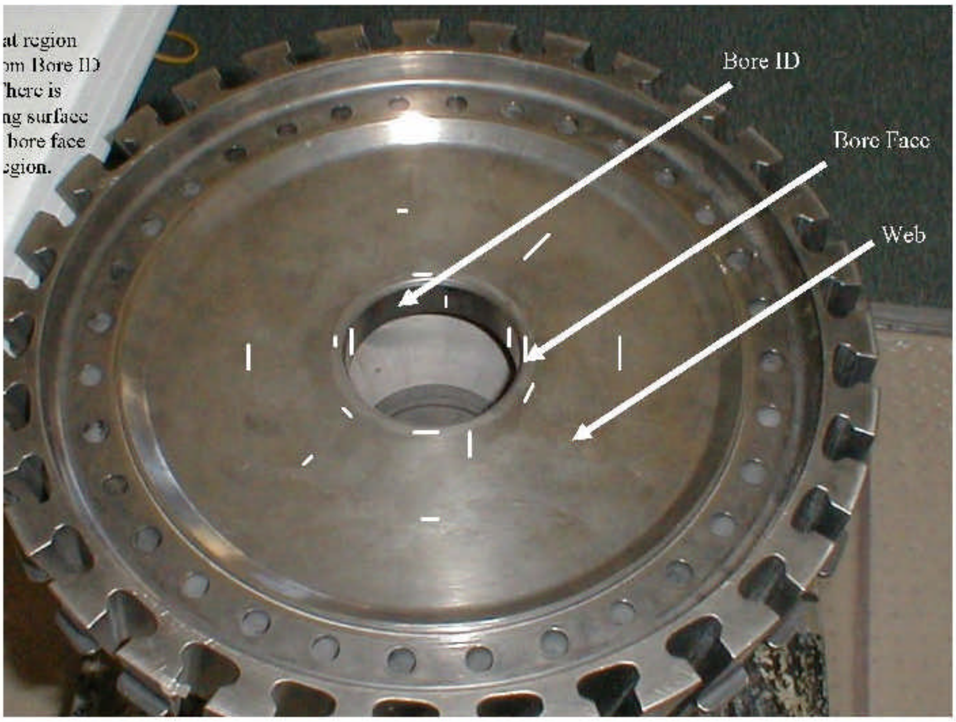

Figure 8: Engine disc selected as a standard to verify the performance of MCP technique

An MCP prototype, MCP-1 V.5, is specially designed for inspection of the bore ID. A photo of the flex circuit for the MCP is given in Figure 9. It is a 10-layer 0.015" thick circuit with 4 × 24 (= 96) coil elements built in it. It covers an area slightly greatly than half of the bore ID circumference. The control unit is built on three rigid Printed Circuit Boards (PCB) connected to the flex circuit by soldering of each wire from the flex circuit to the rigid PCBs. A modified version of the built-in software is used to control the electromagnetic scan and signal display.

To ensure good contact of MCP-1 V.5 with the bore ID surface a special fixture is built to hang the MCP on top of the engine and press the flex circuit tightly against the bore ID wall, see Figure 10.

Currently the EDM notches are in the process of fabrication. The bore ID inspection will be started as soon as the engine with fabricated EDM notches is delivered to IMTT.

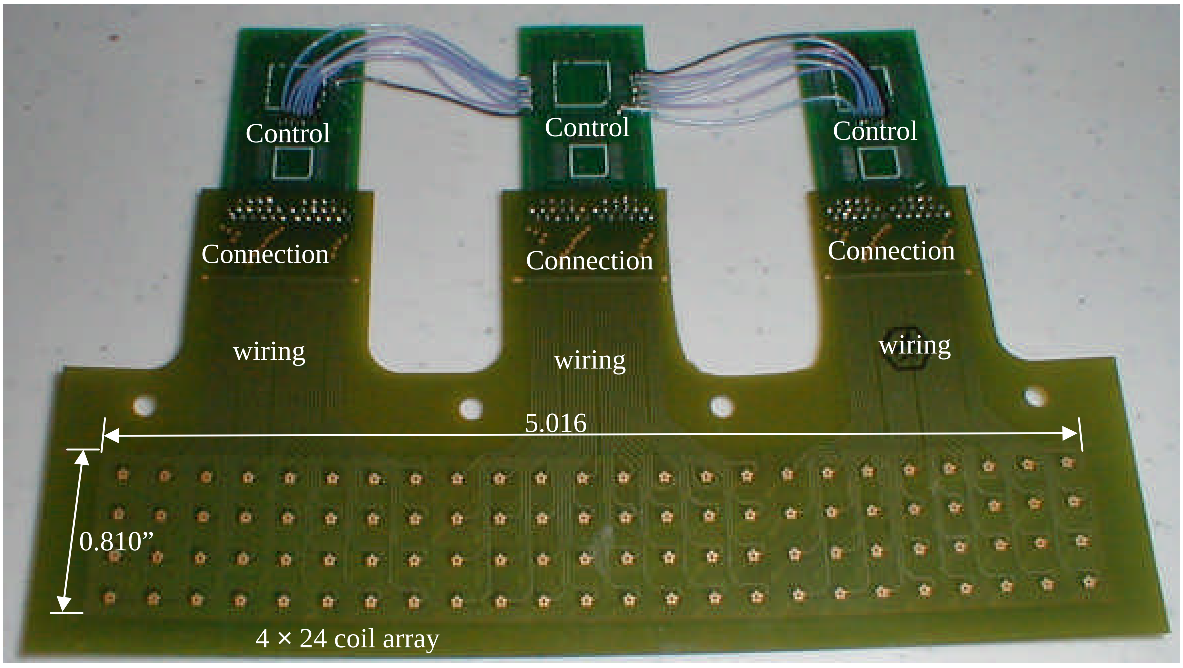

Figure 9: A photo of the flex circuit for Prototype MCP-1 V.5

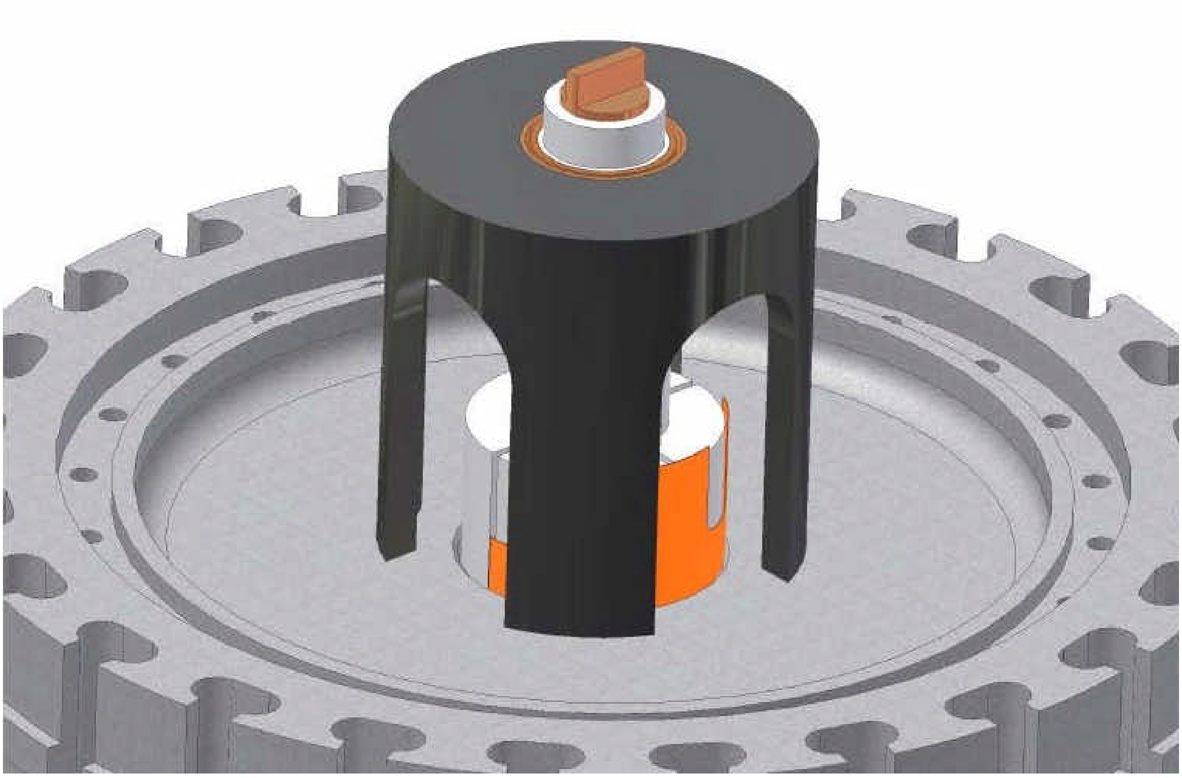

Figure 10: Designed Fixture Placing and Holding MCP at Engine Bore ID Location

Conclusions

1. A new NDI method for large-area and instant inspection of engine disc, MCP Technique, has been developed. A number of prototypes have been developed.
2. Test results have shown it is promising. The unique features include:
    - No mechanic noise, high sensitivity;
    - High speed large area inspection;
    - Simplicity, robustness, and low cost;
    - Conformable to curve surfaces;
    - Attachable to non-accessible areas for possible health monitoring;
    - Software controlled call/reject actions, minimum human factor.
3. Future work – apply the technique in read engine disc inspection applications

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