MAGNETIC CARPET PROBE FOR LARGE AREA INSTANT CRACK/CORROSION DETECTION AND HEALTH MONITORING

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ABSTRACT. Large area crack/corrosion detection and health monitoring have a big concern for NDE society for different applications, especially aircraft and helicopter industry. Recently a new NDE tool, Magnet Carpet Probe (MCP), has recently been developed by Innovative Materials Testing Technologies, Inc. supported by FAA to meet the above demands.
MCP is a two-dimensional coil array built on a piece of very thin flexible printed circuit board, FPCB. Placing an MCP on top of a metallic surface under inspection one can finish the inspection, without moving anything, and see the crack/corrosion identification image on the instrument screen in a few second. Actually a two-dimensional scan is going on electromagnetically within the MCP. A few prototypes of MCPs have been built. Recent test results show that it can detect 0.030 x 0.016” EDM notches on a Titanium standard; 0.024” ~ 0.036: real cracks on titanium standards, as well as penetrate through a 0.040” aluminum layer for corrosion detection.

Keywords: crack/corrosion detection, two-dimensional coil array, electromagnetic scan, static inspection, EDM notch, flexible printed circuit board.
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INTRODUCTION

Large area crack/corrosion detection and health monitoring have a big concern for NDE society for different applications, especially aircraft and helicopter industry. Recently a new NDE tool, Magnet Carpet Probe (MCP), has recently been developed to meet the above demands.

MCP is a two-dimensional coil array built on a piece of very thin flexible printed circuit board, FPCB. Placing an MCP on top of a metallic surface under inspection one can finish the inspection, with out moving anything, and see the crack/corrosion identification image on the instrument screen in a few second. Actually a two-dimensional scan is going on electromagnetically within the MCP.

A few prototype MCPs have been developed by Innovative Materials Testing Technologies, Inc., supported by FAA W.H. Hughes Technical Center. See Figure 1.

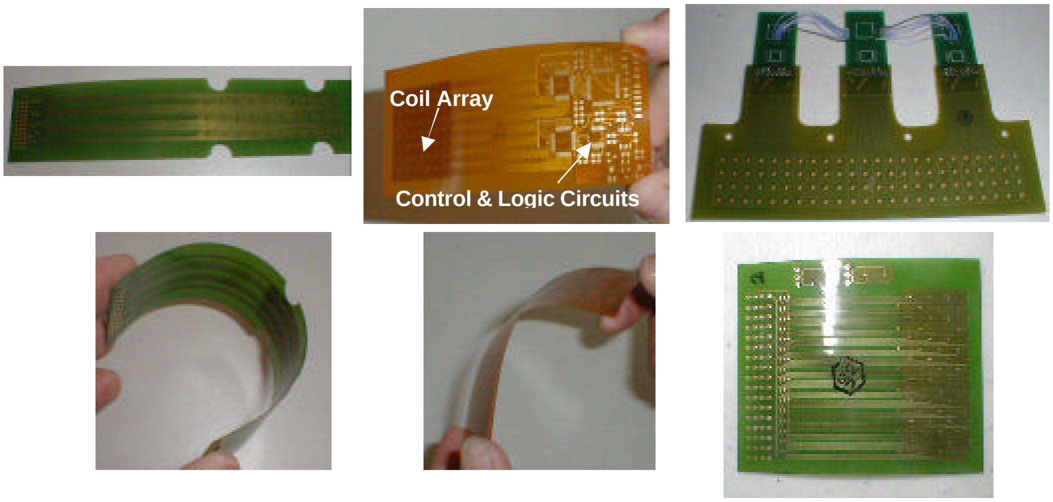


FIGURE 1. Photos of a few flex circuit portion of recently developed MCP.

Recent test results show that MCP can detect 0.030 x 0.016" EDM notches on a Titanium standard, 0.024" ~ 0.036: real cracks on titanium standards, as well as penetrate through a 0.040" aluminum layer for corrosion detection.

The advantages of the MCP technique include:

1. Absolute static inspection:
   a. No mechanical noise – ensuring high sensitivity;
   b. Electronic and magnetic scan – ensuring high speed, or instant, inspection of large area;
   c. No mechanic parts/components, a pure electronic device – ensuring
      - Simplicity, robustness, light weight and reliability;
      - Easy in use and low cost.
2. Thin and flexible 2-Dimensional sensor array – providing capabilities in
   a. Conforming to curved surface;
   b. Being attached to inaccessible or difficult accessible areas for NDI or heath monitoring;
   c. Possibility for future remote control of NDI and heath monitoring through networking and/or wireless techniques.
3. Software controlled call/reject action. Minimum human factor involved.

FOUNDATIONS AND WORKING PRINCIPLES

MCP technique is a new development of the conventional eddy current (EC) NDI technique. The foundations for the new development are:

1. Advances of Flexible Printed Circuit (Flex Circuits) technique allow building very thin copper traces and spacing in very thin material 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.
2. Advances in digital electronic devices have enabled control of complex and high speed electronic and electromagnetic scan over a coil array with a large number 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.

The working principle of an MCP can be summaries as follows:

1. Densely populated 2-D coil elements, coil array, built in flex circuit and covering a wide area of inspection;
2. Connection of each coil element of the coil array to an eddy current instrument through multiplexers. The new instrument can be a conventional EC instrument with minimum modifications;
3. Electronic control of high speed electromagnetic scan over the entire area of inspection.
4. Automatic image, crack/corrosion identification, and display.

Figure 2 shows a diagram of an MCP. A 2-dimensional coil array is placed on top of a metallic surface under inspection. Drive current generated by SSEC system goes to each element of the coil array through multiplexes in a sequence controlled by the programmable logic control chip. The crack/corrosion signals collected by each element of the coil array are sent back to the Super-Sensitive Eddy Current (SSEC) system for display and record. Figure 3 shows a typical screen display from an MCP.

The common used programmable logic chip can be an FPGA or CPLD. 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.

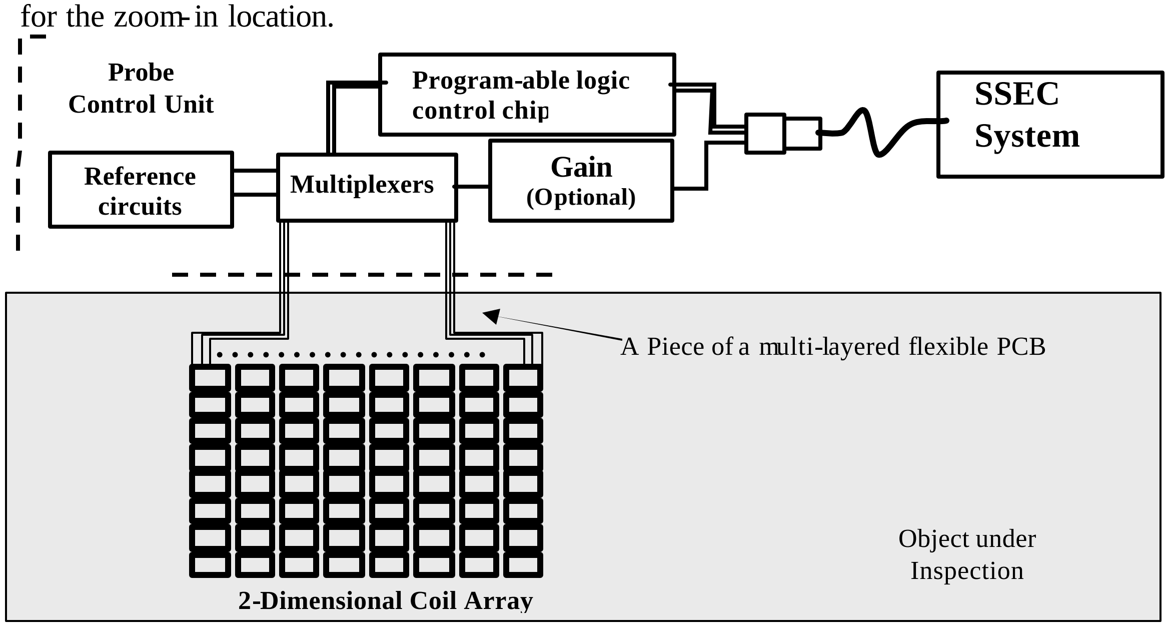


FIGURE 2. Diagram for an MCP, Version MCP-1 V.2.

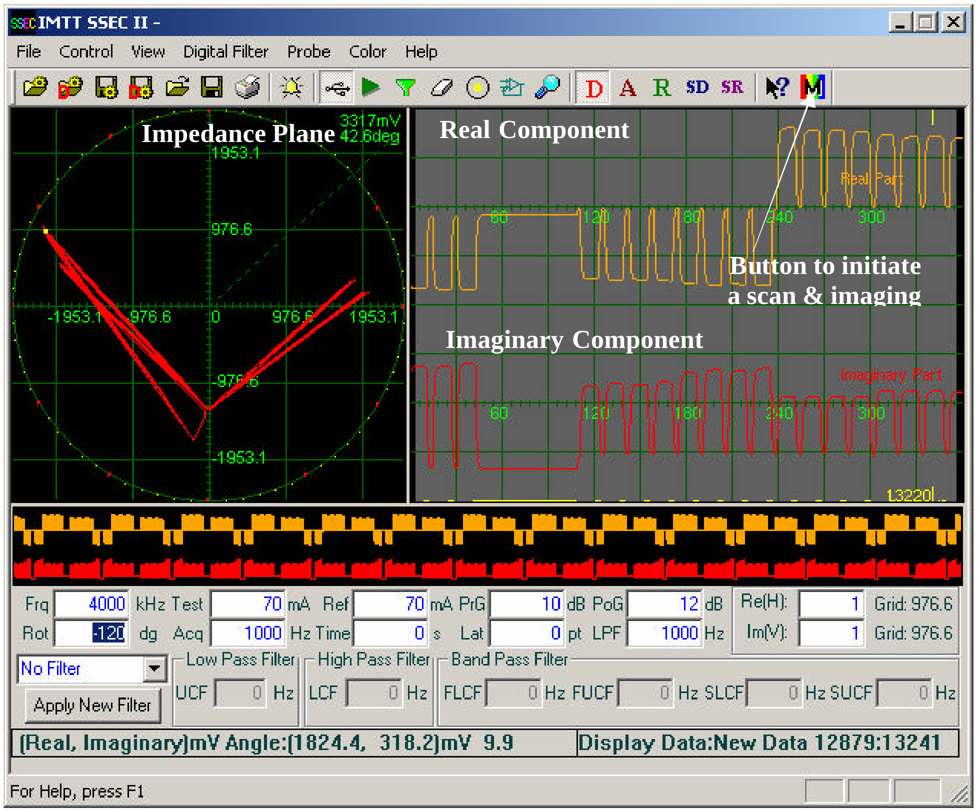


FIGURE 3. Major screen of an MCP.

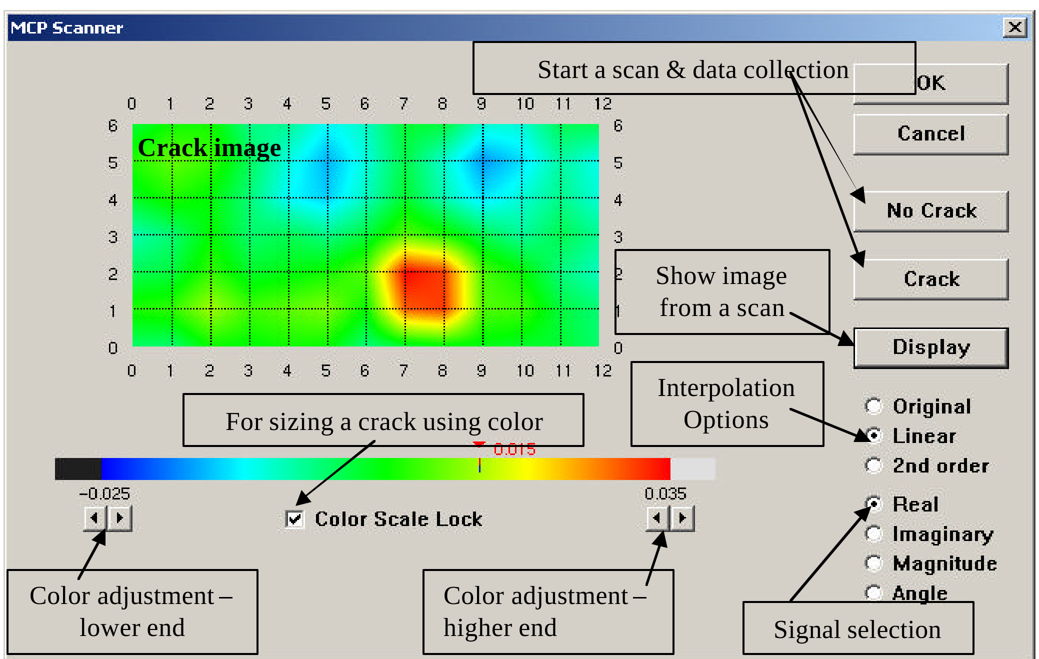


FIGURE 4. Image screen of an MCP

TEST PROCEDIRE

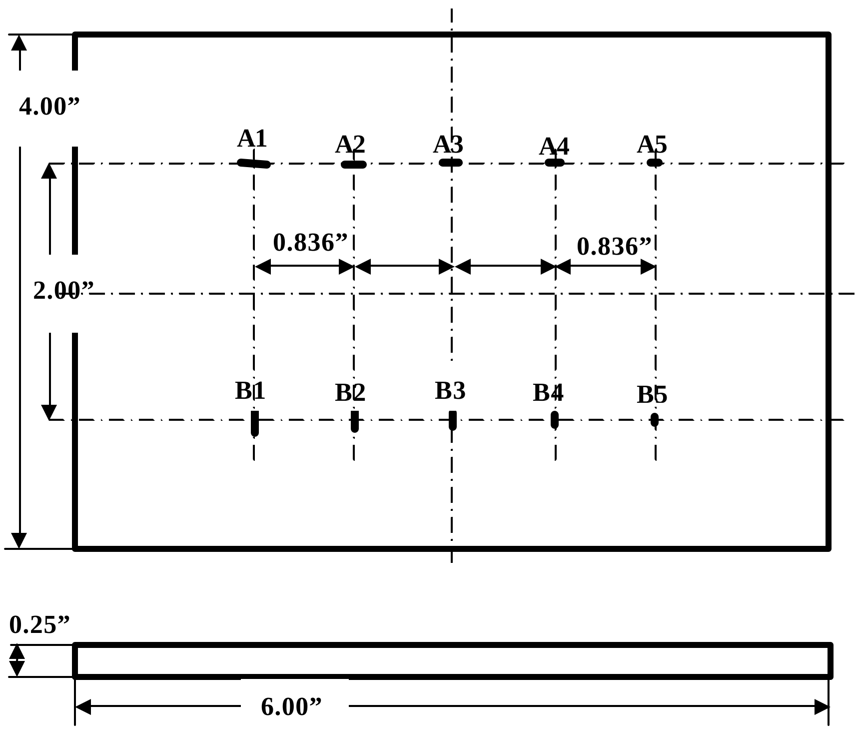
1. Firmly place MCP on a no-defect area;
2. Click “**M**” to get the Image Screen.
3. Select the display options and set the color adjustment values.
4. Click “**No Crack**”. No-defect data are collected and processed practically in a few seconds. Note: we need to do 4 only once per an inspection.
5. Firmly place MCP on the area of inspection.
6. Click “**Crack**”. Crack/corrosion data are collected and processed practically in a few seconds.
7. Images immediately appear on the Crack Image screen.

TEST RESULTS (1) – DETECTING EDM NOTCHES ON A TI SPECIMEN

A few typical test results on detecting EDM notches made a titanium calibration standard, shown in Figure 5, are shown on Figure 6 A and B. The notches are clearly detected using the red color of the image. Note: the red color at the two figures represents different signal levels: on Figure 6 A the signal was obtained from EDM Notch #B2 – a 0.060” × 0.030” notch, the maximum signal was 56 mv; on Figure 6 B – from EDM Notch # B3 – a 0.30” × 0.015” notch, the maximum signal was 35 mv.

There is another option to show a detected notch using color scale. That is to lock the higher and lower end of the color scale to pre-determined values. Then the color of a crack image tells the size of the crack.

In the current images the signal real component value is used to identify a notch/crack. However, there are multiple choices can be made in the software. One can use any component of the signal for the crack identification: real, imaginary, magnitude or phase angle



ED	L × D
A	.100” × .050”
A	.060” × .030”
A	.030” × .015”
A	.020” × .010”
A	.010” × .005”
B	.100” × .050”
B	.060” × .030”
B	.030” × .015”
B	.020” × .010”
B	.010” × .005”

Material: Ti-6-4

FIGURE 5. Titanium EDM calibration standard

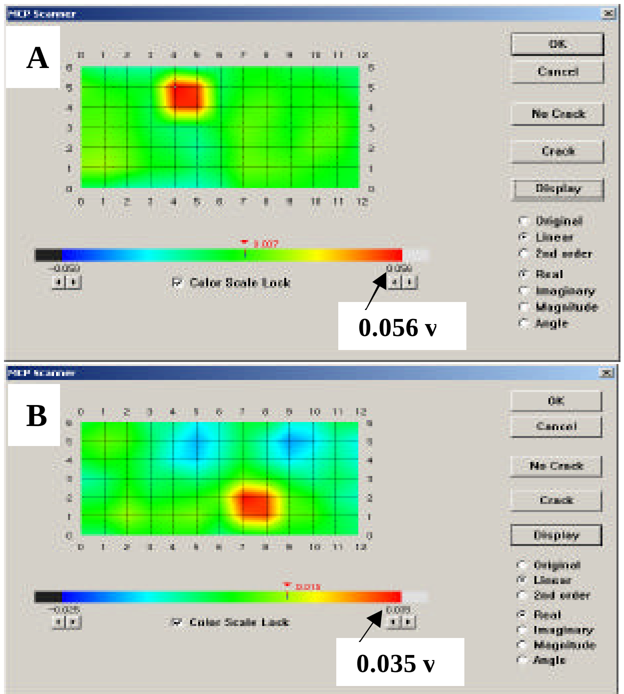


FIGURE 6. Images showing the detected EDM notches from the EDM calibration standard: A. from Notch B2 - a .060” × 0.030” notch; B. from B3 - a 0.030” × 0.015” notch.

TEST RESULTS (2) – DETECTING FATIGUE CRACKS ON TITANIUM SPECIMENS

Four 6.0” × 1.0” × 0.25” Titanium fatigue crack standards were provided by Mike Bode, FAA AANC, Sandia, as shown on Figure 7. The images obtained by using an MCP are shown in Figure 8.

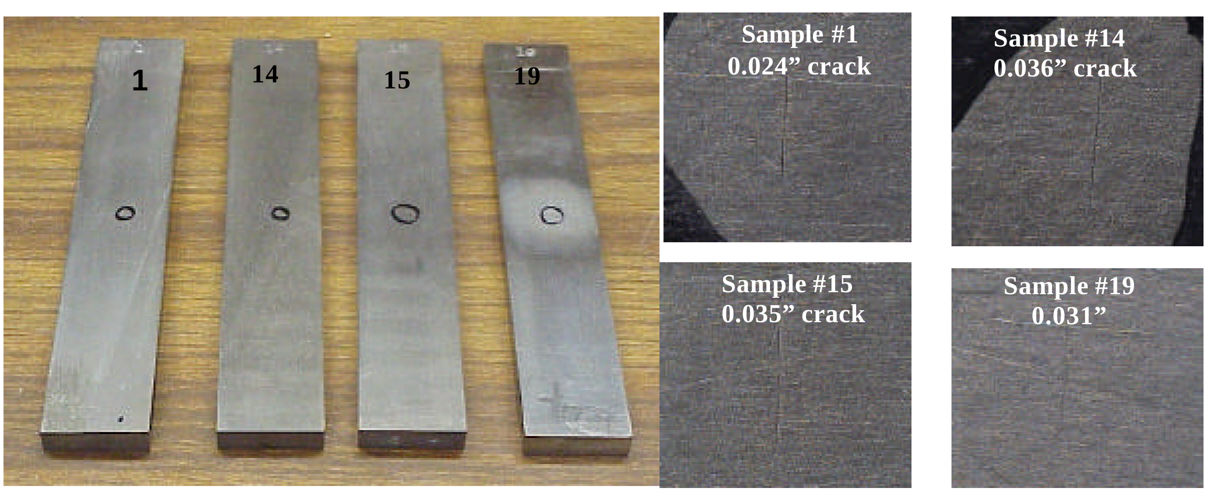


FIGURE 7. Fatigue crack standards provided by Mike Bode, Sandia .

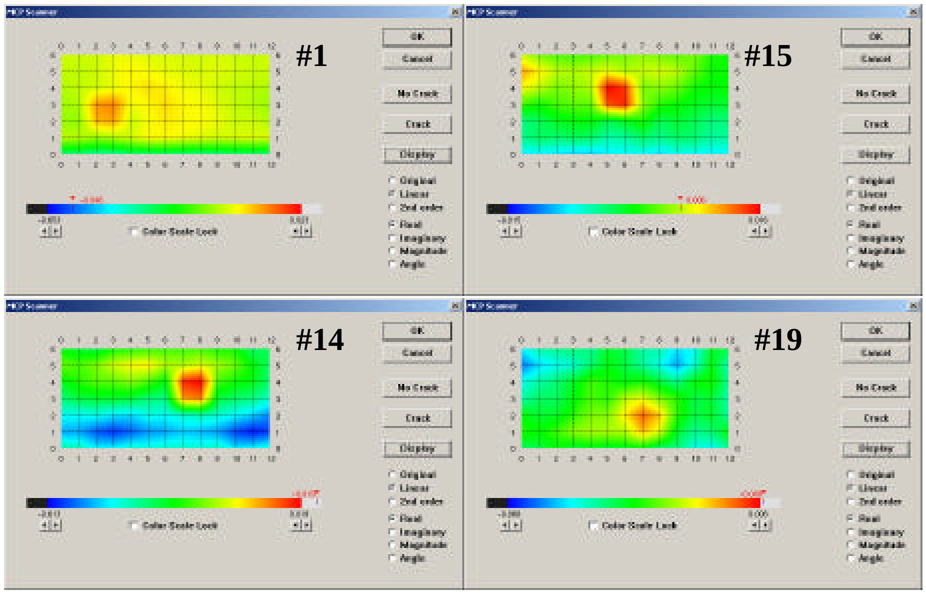


FIGURE 8. Images obtained from the fatigue crack standards.

TEST RESULTS (3) – DETECTING CORROSION ON ALUMINUM SPECIMENS

A 0.024” thick simulated corrosion standard, see Figure 9, was provided by Dennis Roach, Sandia. Three corrosion sites, 10%, 20%, and 30 %, were made on the bottom side of the standard. A MCP, version MCP-1 V.7, was placed on the top surface on top of each of the three corrosion sites, as shown in Figure 10. The image showing the corroded and un-corroded areas is shown in Figure 11.

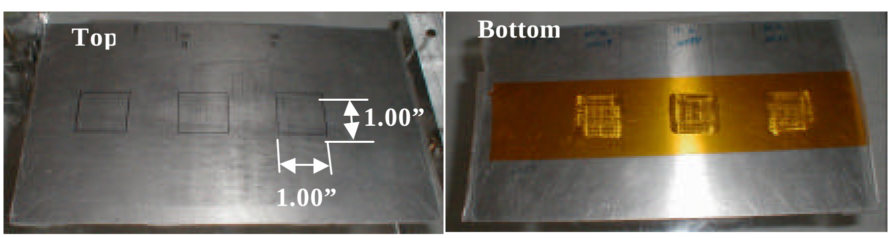


FIGURE 9. A 0.024” thick aluminum corrosion standard provided by Dennis Roach, Sandia.

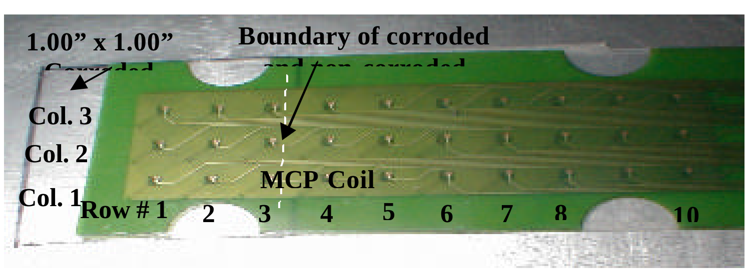


FIGURE 10. Place an MCP on the top surface above a corrosion site.

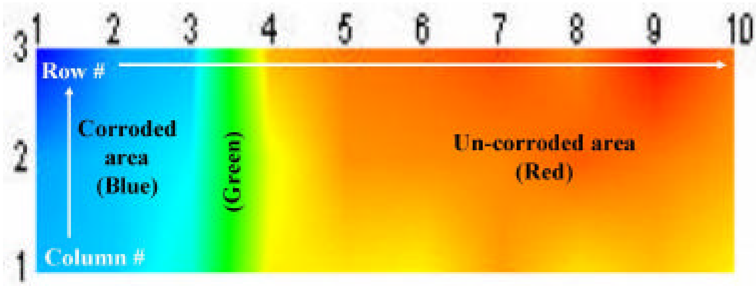


FIGURE 11. Image showing the corroded and un-corroded areas.

One more test has been carried out to check the penetration ability of the MCP. Figure 12 shows the MCP penetrating a 0.040” thick aluminum sheet.

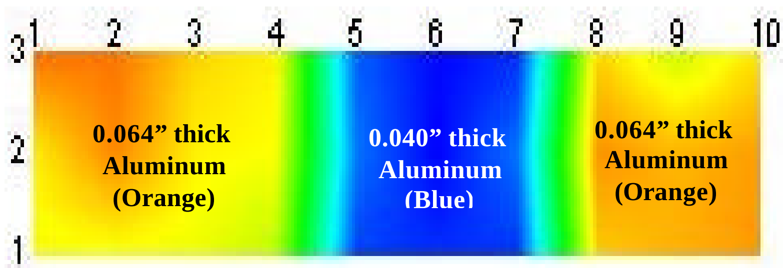


FIGURE 12. MCP penetrating a 0.040” thick aluminum sheet.

CONCLUSION

1. A new NDI method for large-area and instant inspection of surface and sub-surface flaws, MCP Technique, has been developed. A number of prototypes have been made and tested.
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 NDI of possible health monitoring;
   - Software controlled call/reject actions, minimum human factor.
3. Future work
   - Further improve its performances
   - Apply the technique in real NDI and health monitoring applications

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