Detection of cracks in Multi-Layer Aircraft Structures with Fasteners Using Remote Field Eddy Current Method

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ABSTRACT

The remote-field eddy-current (RFEC) technique has been shown to be highly sensitive to cracks and corrosion that are embedded deep in multi-layer aircraft structures. This paper shows the effectiveness of the approach in detecting cracks in double-layered specimens with fasteners, as well as corrosion specimens.

The crack specimens, made by Lockheed George Company in 1980, had two layers held together with ten fasteners. The total thickness is 0.356” for Group A and 0.446” of Group B, respectively. Fatigue cracks were made on different layers and at different depths. The corrosion specimens are of 0.063” thick with 0.006” or 0.002” corrosion wall thinning. Another one or two much thicker plates of aluminum are placed on top of one corrosion specimen during a test. All tests were conducted using a newly developed RFEC system that includes a probe specified for inspecting thick plates.

The effect of different parameters, such as excitation frequency, excitation to pick-up coil separation distance, and probe to fastener distance, were studied to determine the optimal test parameters. The system will be demonstrated along with the presentation.

1. INTRODUCTION

Eddy current NDE technique (ECT) has been used extensively for aging aircraft inspection. However, it is evident that significant improvement must be made to existing inspecting techniques and devices so as to meet the demand for enhancing the reliability of flaw detection. Recently, the remote-field eddy-current (RFEC) system has been developed for deeply hidden corrosion and cracks in multi-layered aircraft aluminum structures [1].

More careful study has been conducted after publication of [1]. With the help of Dr. Tom Moran, Wright Patterson Air Force Base (WPAFB), and Dr. Matt Golis, Advanced Quality Concept, Columbus, OH, dozens of crack specimens and several corrosion specimens are tested using the RFEC system and probe prototypes. Then, the test results were used as feedback for modifications of the RFEC system and probe design. Three iterations of such test-modification process have been made since spring last year. Significant improvements are achieved in the RFEC system and probe performances that will be demonstrated during this presentation.

The effects of probe parameters to probe sensitivity are also studied.

2. RFEC TECHNIQUE VERSUS ECT

In conventional ECT the primary parameter used to evaluate the specimen condition is either the impedance of the excitation coil or the induced voltage in the pick-up coil. Both two parameters are functions of the total magnetic flux linked by the coil. Deeply hidden corrosion/cracks contribute very little to the total flux variation so to the impedance or induced voltage of the coil because of the skin-depth effect. It is a challenge to separate an extremely small flaw signal from a huge unflawed signal.

In remote-field eddy-current technique the primary parameter used to evaluate the specimen condition is the induced voltage in the pick-up coil. The pickup coil is placed away, magnetically, from the excitation field and senses only the flux that has penetrated the specimen wall twice, from the front-side to the back-side at excitation position, then from the back-side to the front-side at the pickup coil position. In other words, in a proper designed RFEC probe the direct coupling between the excitation coil and the pickup coil is sufficiently blocked and the flux coming through the indirect path should be dominating the pickup coil area. The result is that the pickup coil of an RFEC probe senses only the flux which has penetrated the specimen twice and fully representing the wall condition of the specimen.

A very important feature of the RFECT is that the phase signal of an RFEC probe is independent of lift-off if the RFEC effect in the probe is complete. Because of the special underlying physics, the RFECT does not have limitation directly from skin-depth effect. Its limitation is the signal/noise ratio. Environmental and instrument noises should be the only things that bother an RFECT system.

3. SPECIMENS

The corrosion specimens, made by Center for Non-destructive Evaluation at Iowa State University (CNDE), are produced from 0.063"thick 12"x 12" 2042-T3 alclad sheets. Thinning of different sizes made by chemical milling is made on one side of each plate, refer Figure 1a. Two of such specimens, #1 and #5, were used in the testing and are going to be used for the demonstration. The depth of the corrosion thinning is 0.002" for Specimen #1 and 0.006" for Specimen #5. To see the effectiveness of the RFEC system in detecting deeply hidden corrosion thinning some thicker aluminum sheets are going to be placed on top of each of the specimens, refer Figure 1.

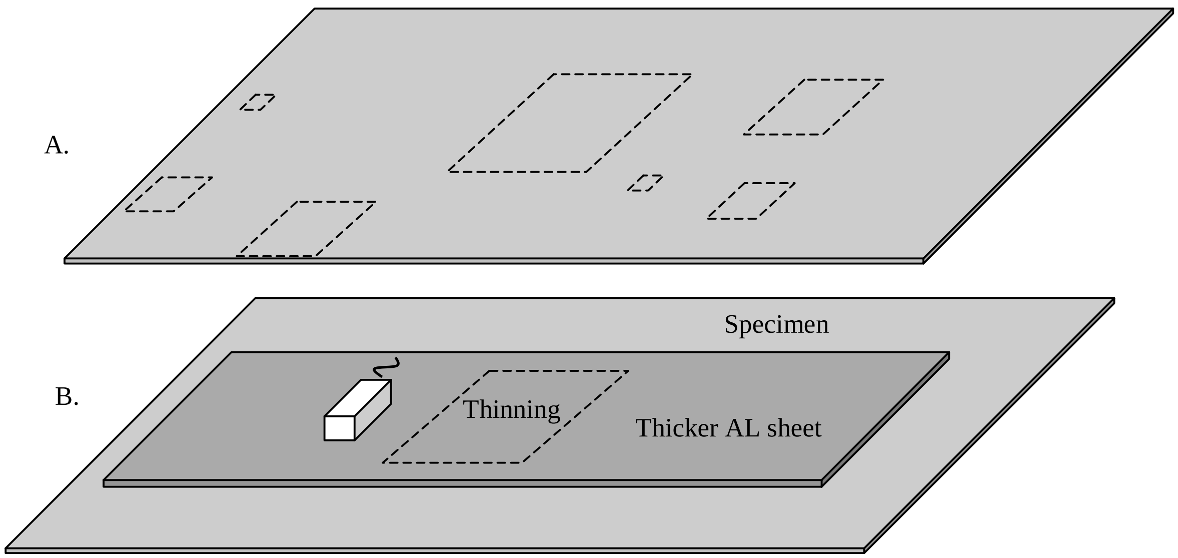


Figure 1. Corrosion thinning detection. A - corrosion specimen; B. Detecting deeply hidden corrosion.

The crack specimens, made by Lockheed Georgia Company in 1980, had two layers held together with ten fasteners. Most fasteners were made of titanium, but often, one out of the ten was made of carbon steel. The total thickness for the specimens is 0.356" for Group A and 0.446" of Group B, respectively. Fatigue cracks were made on fastener holes using a professional way at specified layers and at specified surfaces of the layer. A typical example of the Group B specimens, B4-1, is show in Figure 2.

All tests were conducted using a newly developed highly sensitive RFEC system that includes a probe specified for inspecting thick plates.

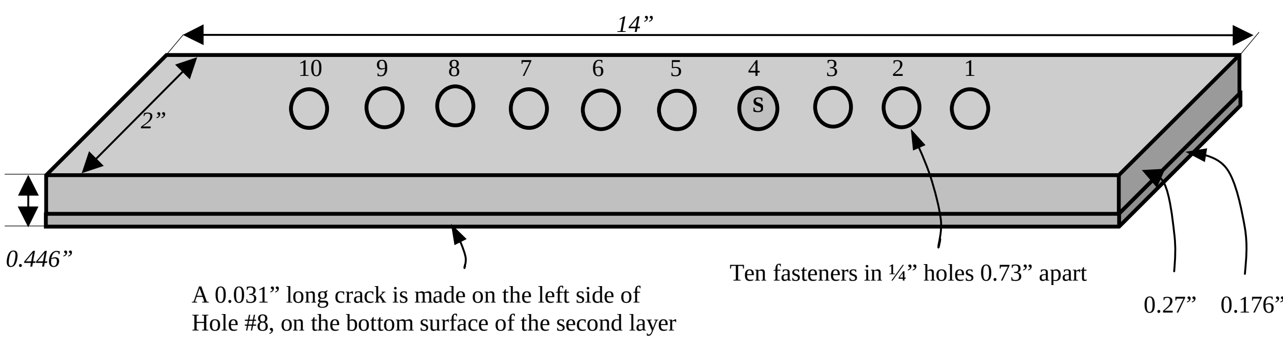
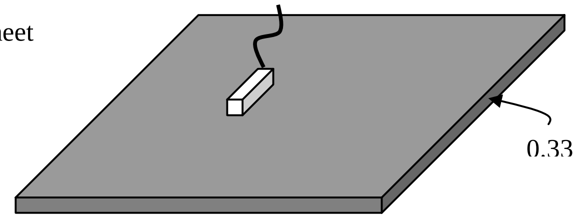


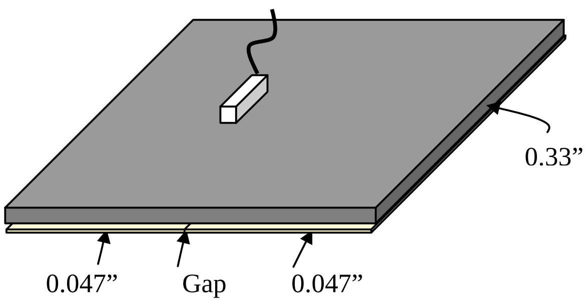
Figure 2. A typical Lockheed Georgia Specimen of Group B: Specimen #B4-1:

4. LIVE DEMO #1
DETECTING MATERIAL DISCONTINUITY THAT IS FAR BELOW SURFACE

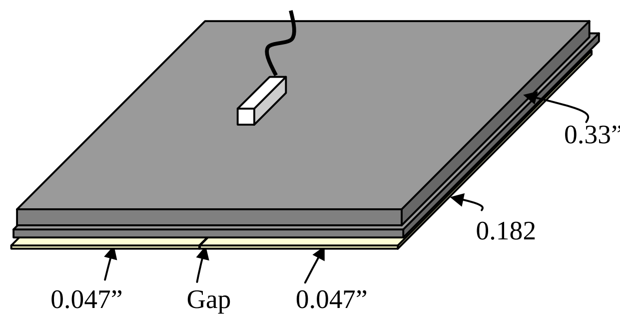
A. DEMO#1-1 Scanning on a 0.33” thick clear aluminum sheet



B. DEMO#1-2 Scanning on a 0.33” aluminum sheet with a discontinuity below



C. DEMO#1-3 Add a 0.182”thick plate to make total thickness to be 0.51”



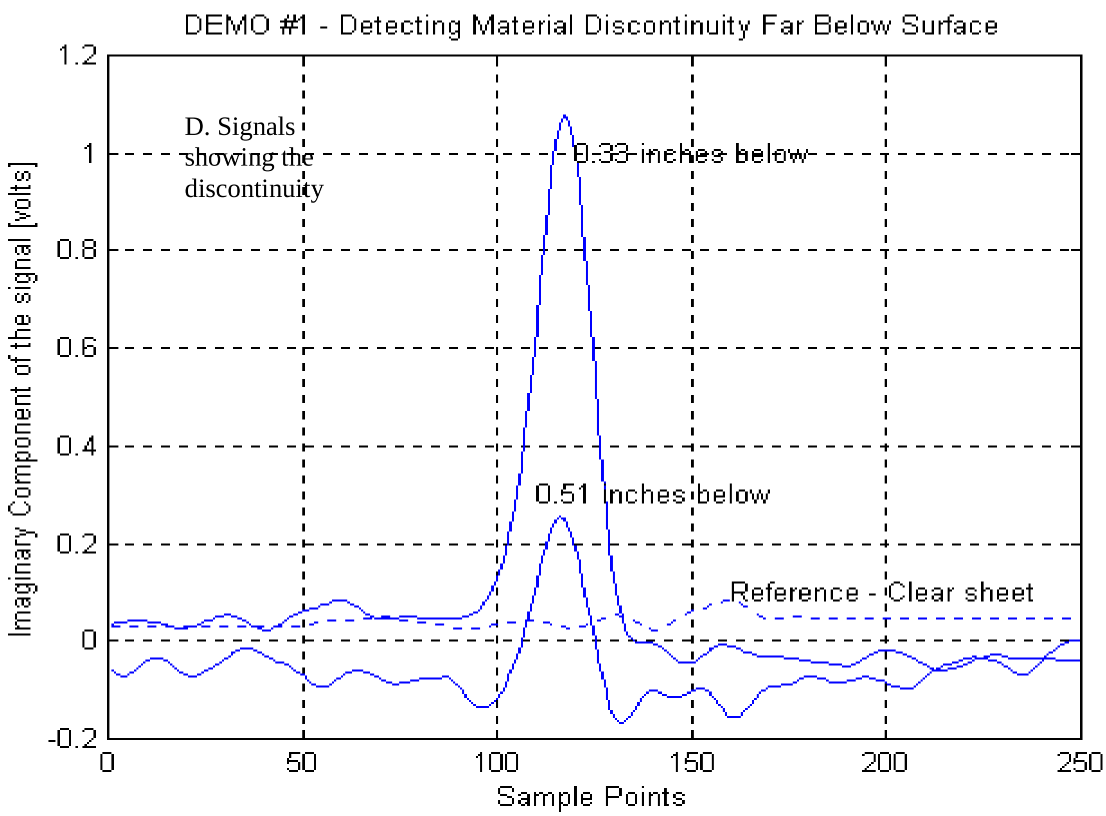


Figure 3. DEMO #1 – Detecting material discontinuity far blow surface - f - 200 Hz

5. LIVE DEMO #2 - DETECTING CORROSION THINNIG ONSPECIMEN #5

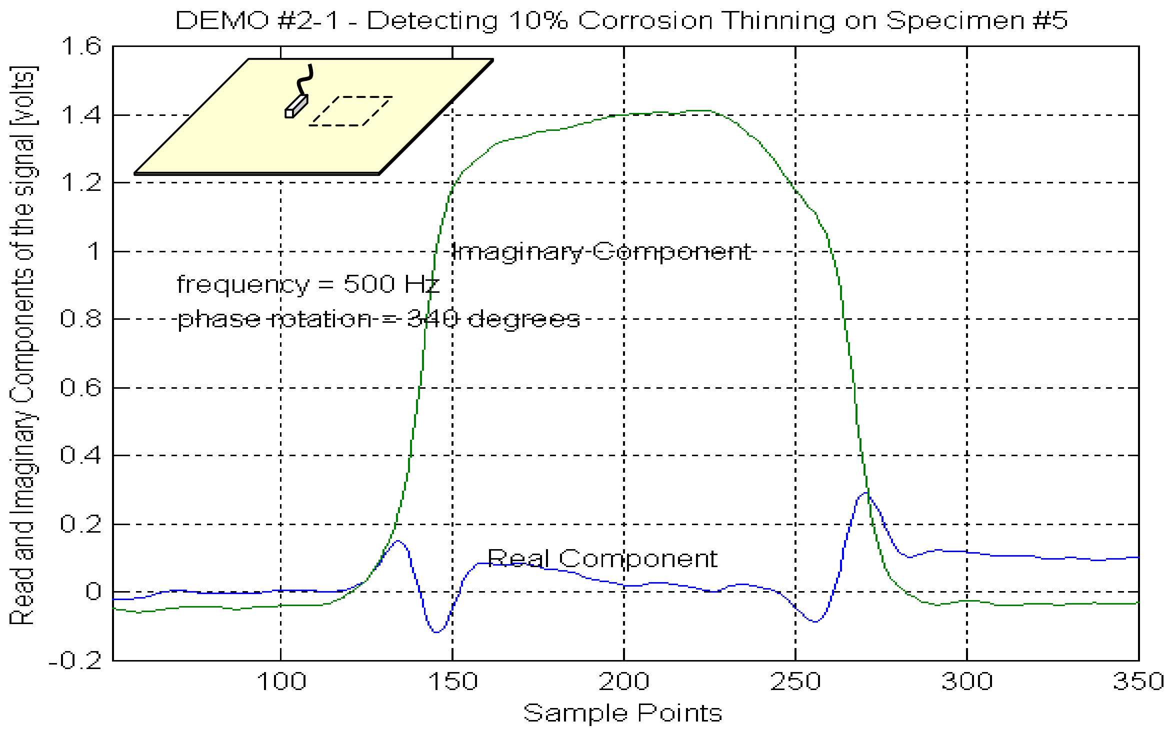


Figure 4. DEMO #2-1 - Thickness = 0.063”, Corrosion Depth = 0.006”, Relative Depth = **10 %**

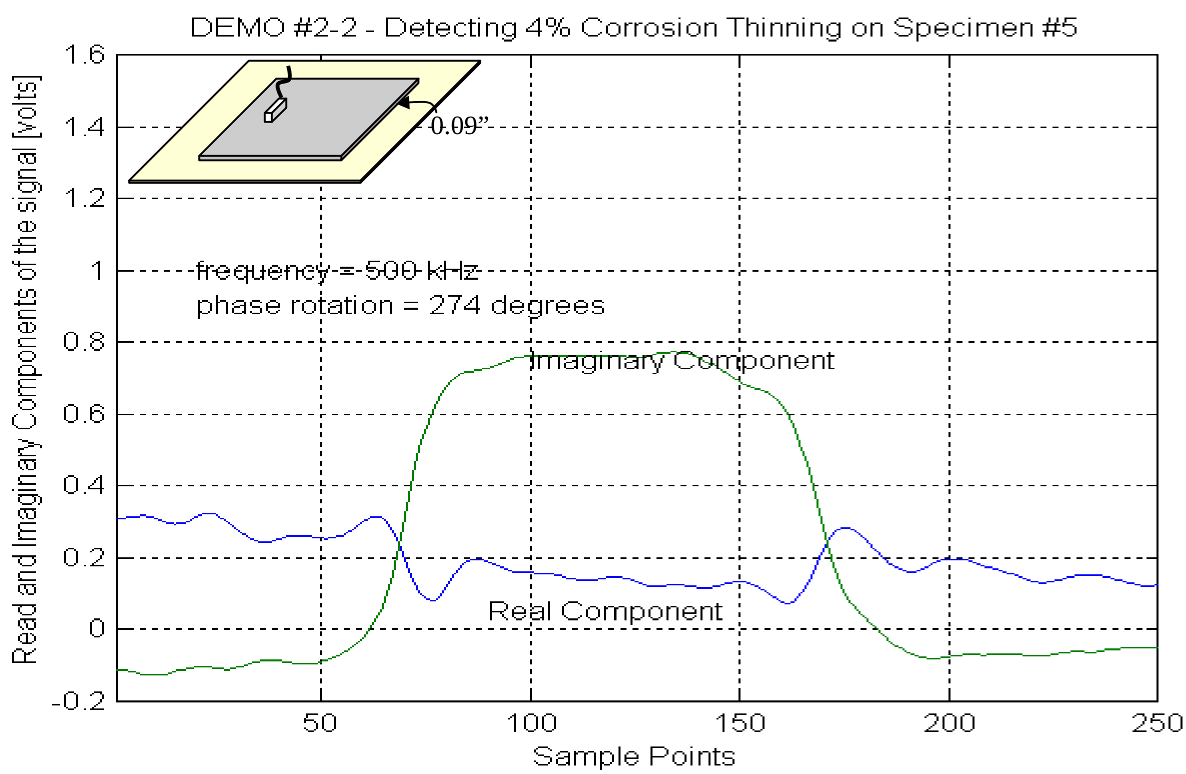


Figure 5. DEMO #2-2 - Thickness = 0.153”, Corrosion Depth = 0.006”, Relative Depth = **4 %**

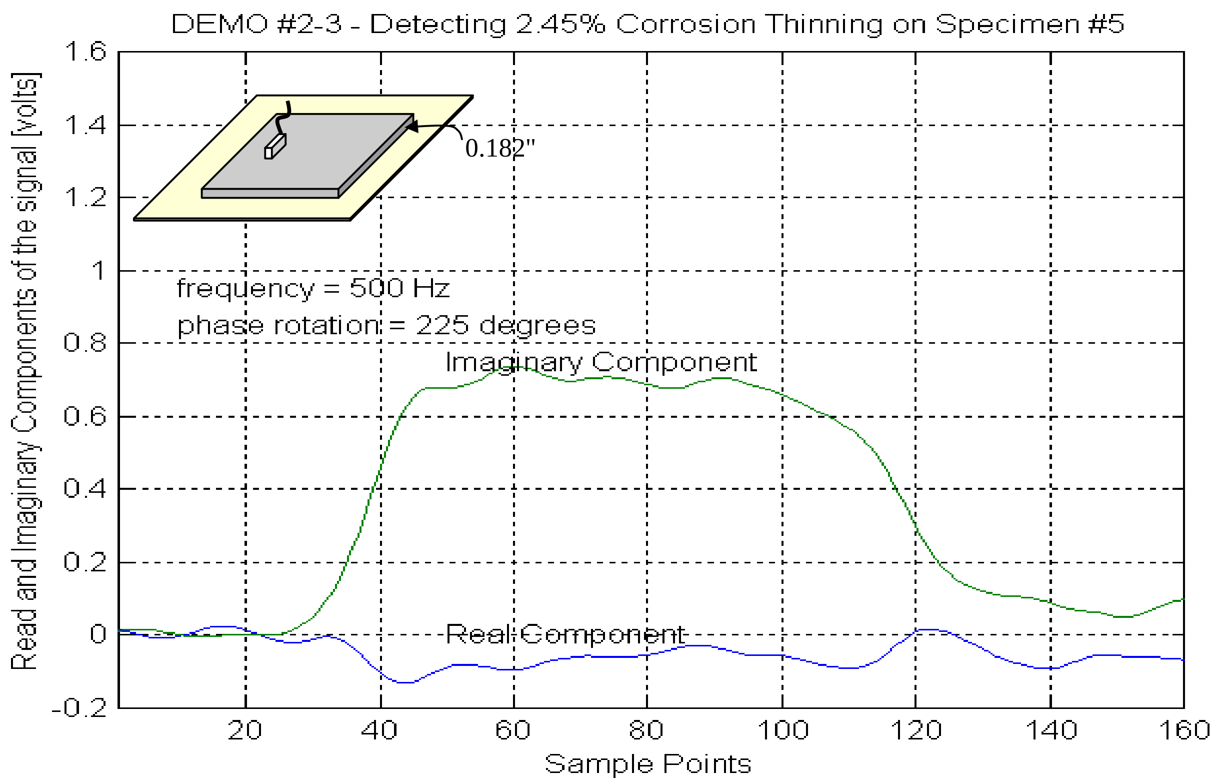


Figure 6. DEMO #2-3 - Thickness = 0.245", Corrosion Depth = 0.006", Relative Depth = **2.45 %**

6. LIVE DEMO #3 - DETECTING CORROSION THINNIG ONSPECIMEN #1

Figure 7. DEMO #3-1 - Thickness = 0.063", Corrosion Depth = 0.002", Relative Depth = **3.17 %**

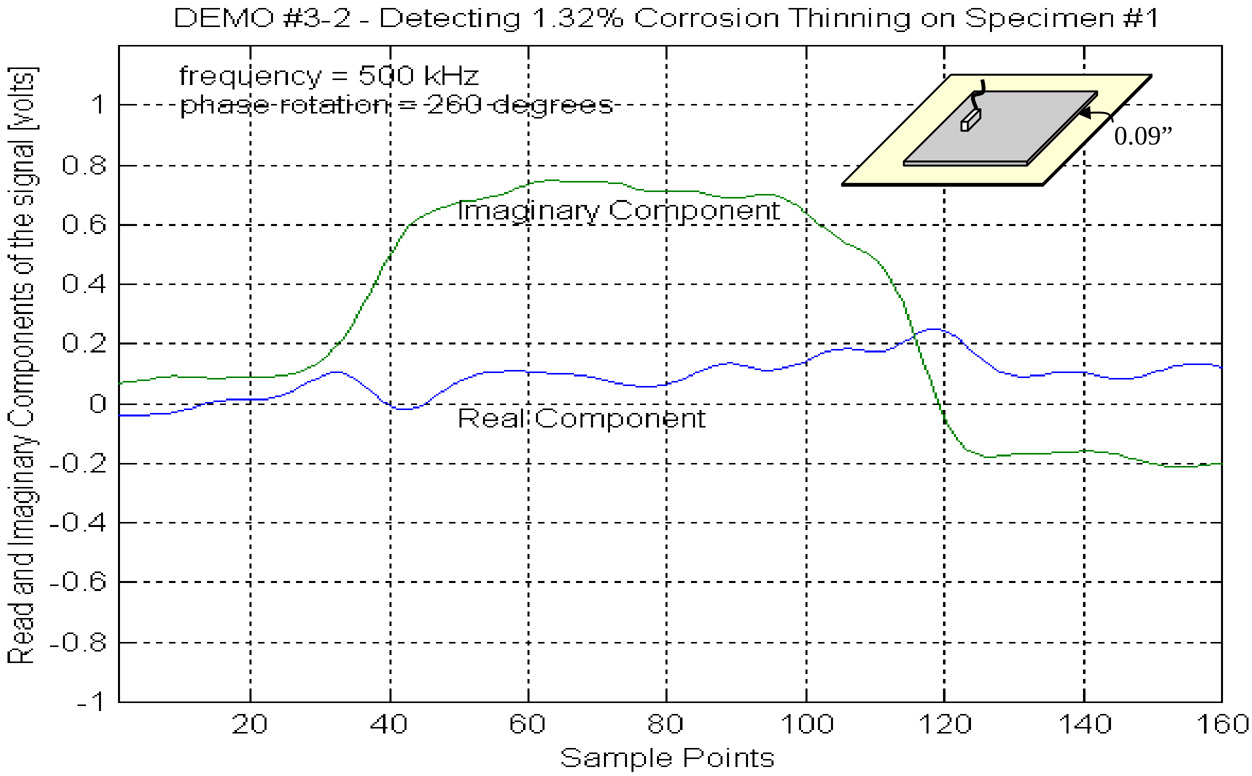


Figure 8. DEMO #3-2 - Thickness = 0.153”, Corrosion Depth = 0.002”, Relative Depth = **1.32 %**

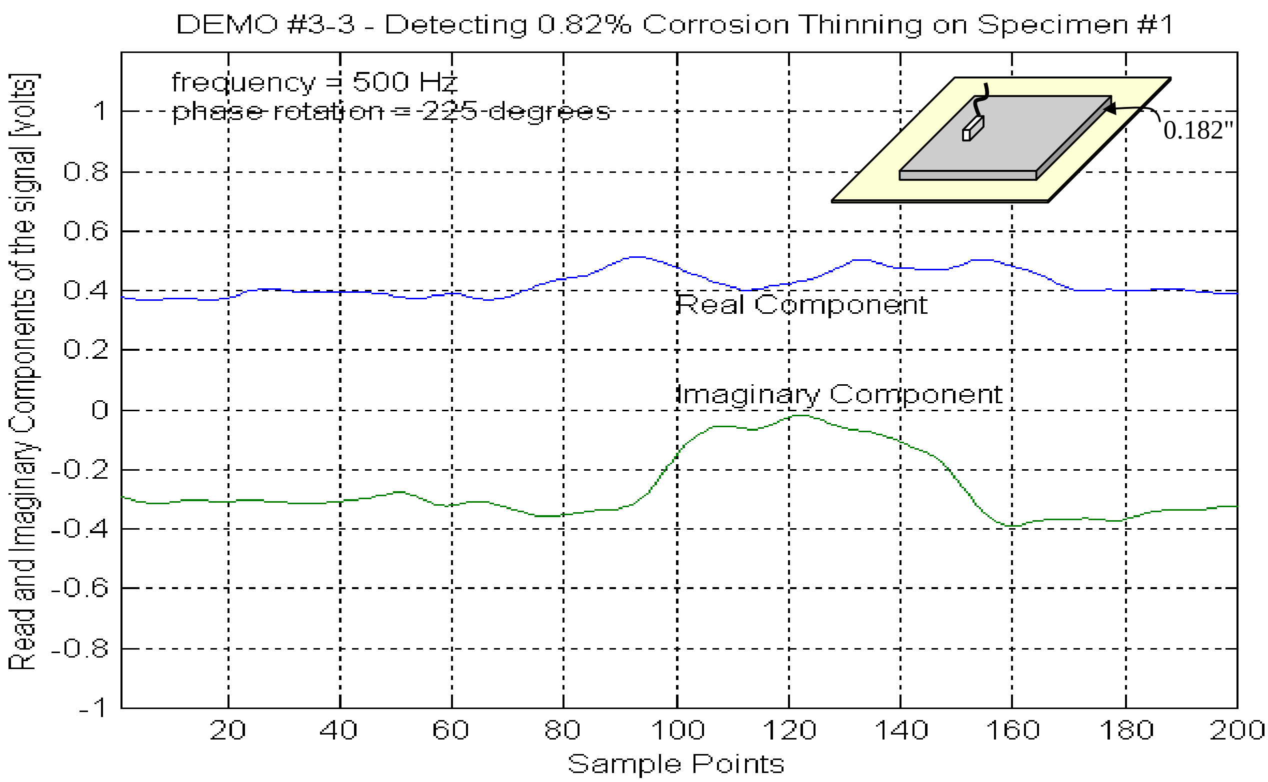


Figure 9. DEMO #3-3 - Thickness = 0.245”, Corrosion Depth = 0.002”, Relative Depth = **0.82 %**

7. LIVE DEMO #4 - DETECTING CRACKS ON LOCKHEED SPECIMEN #B4-1

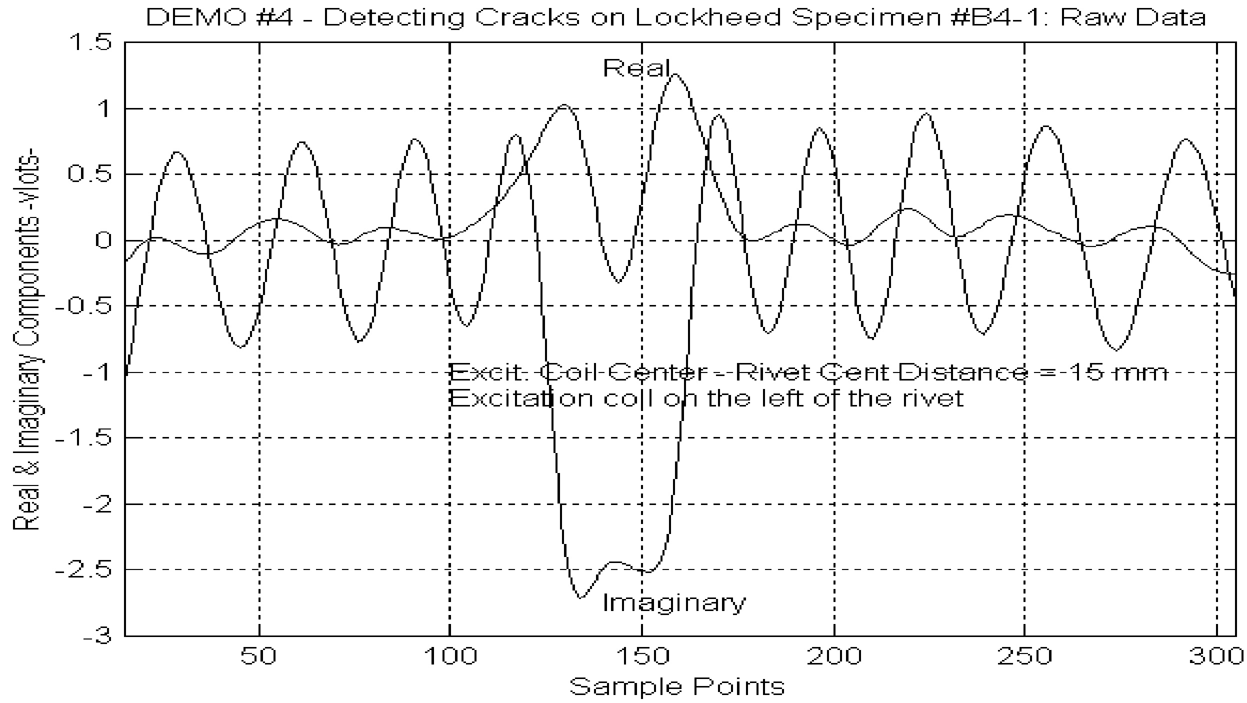


Figure 10. DEMO #4 - Total thickness = 0.446", Crack length = 0.031", Crack location - bottom surface of 2nd layer (Raw Data)

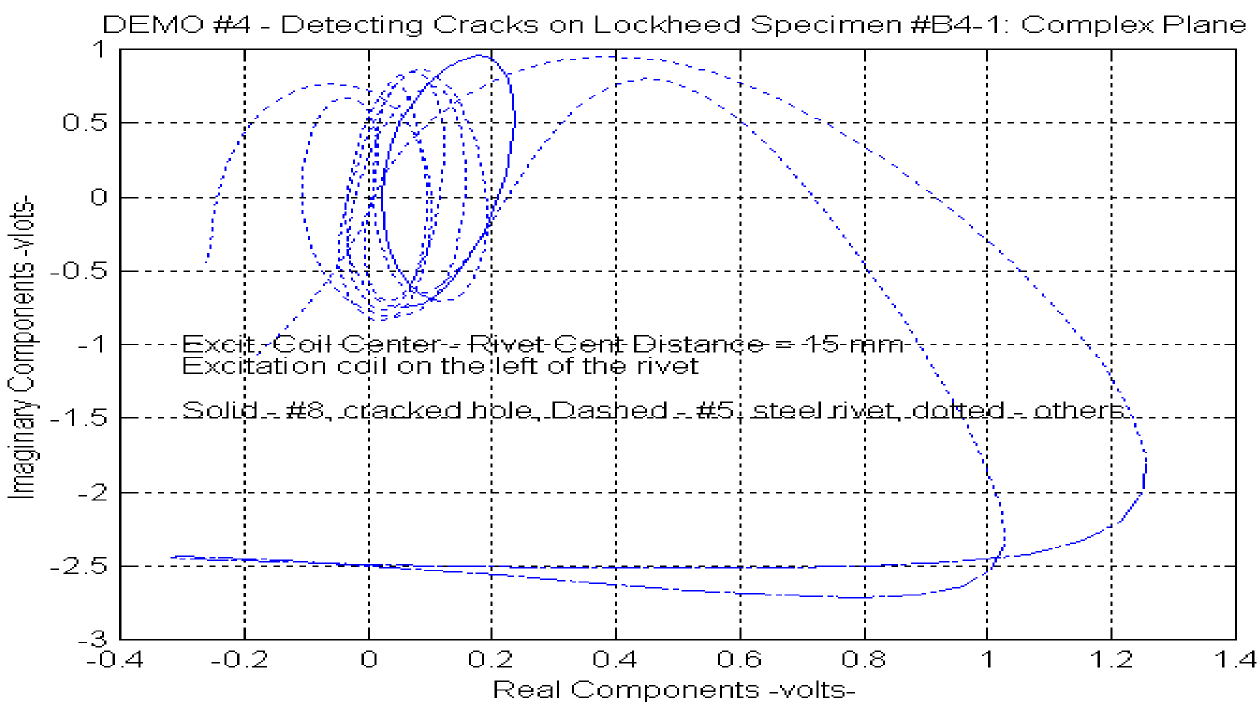


Figure 11. DEMO #4 - Total thickness = 0.446", Crack length = 0.031", Crack location - bottom surface of 2nd layer (Complex Plane)

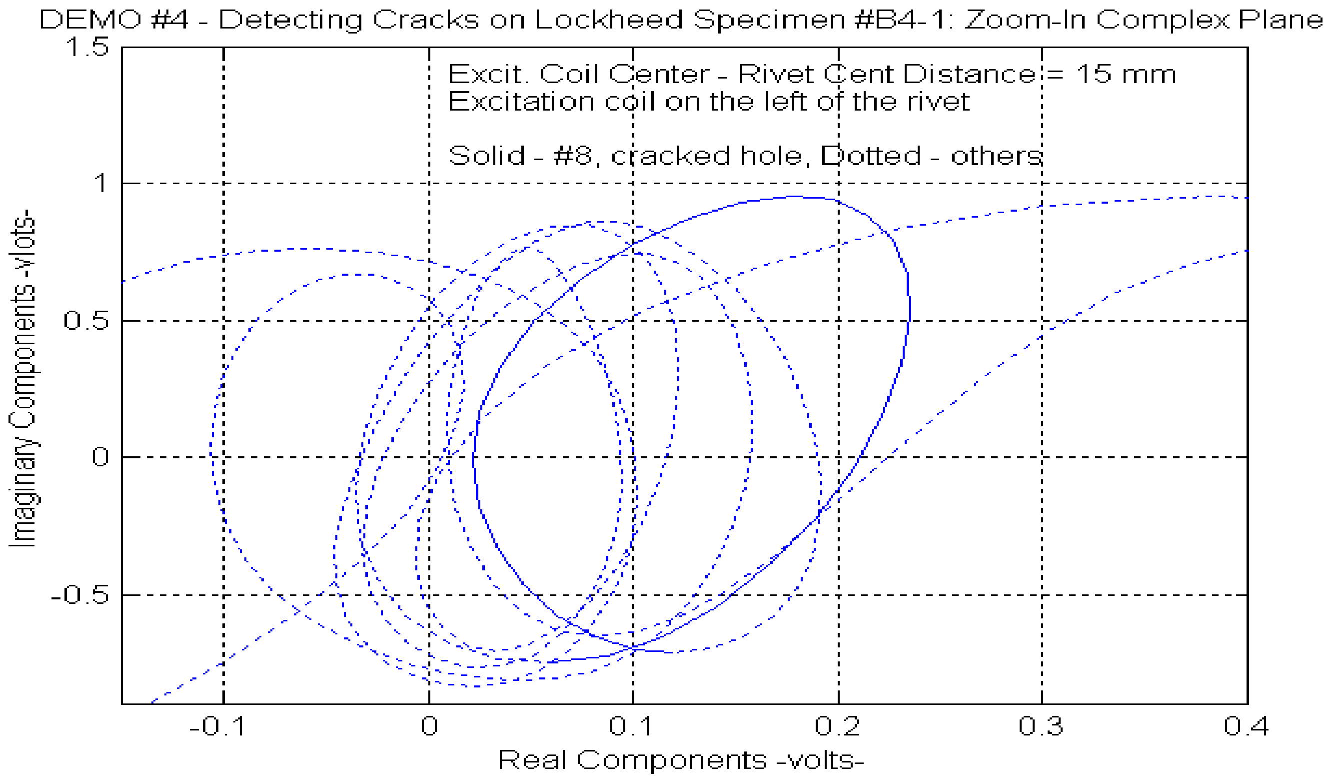


Figure 12. DEMO #4 - Total thickness = 0.446", Crack length = 0.031", Crack location - bottom surface of 2nd layer (Zoom-In Complex Plane)

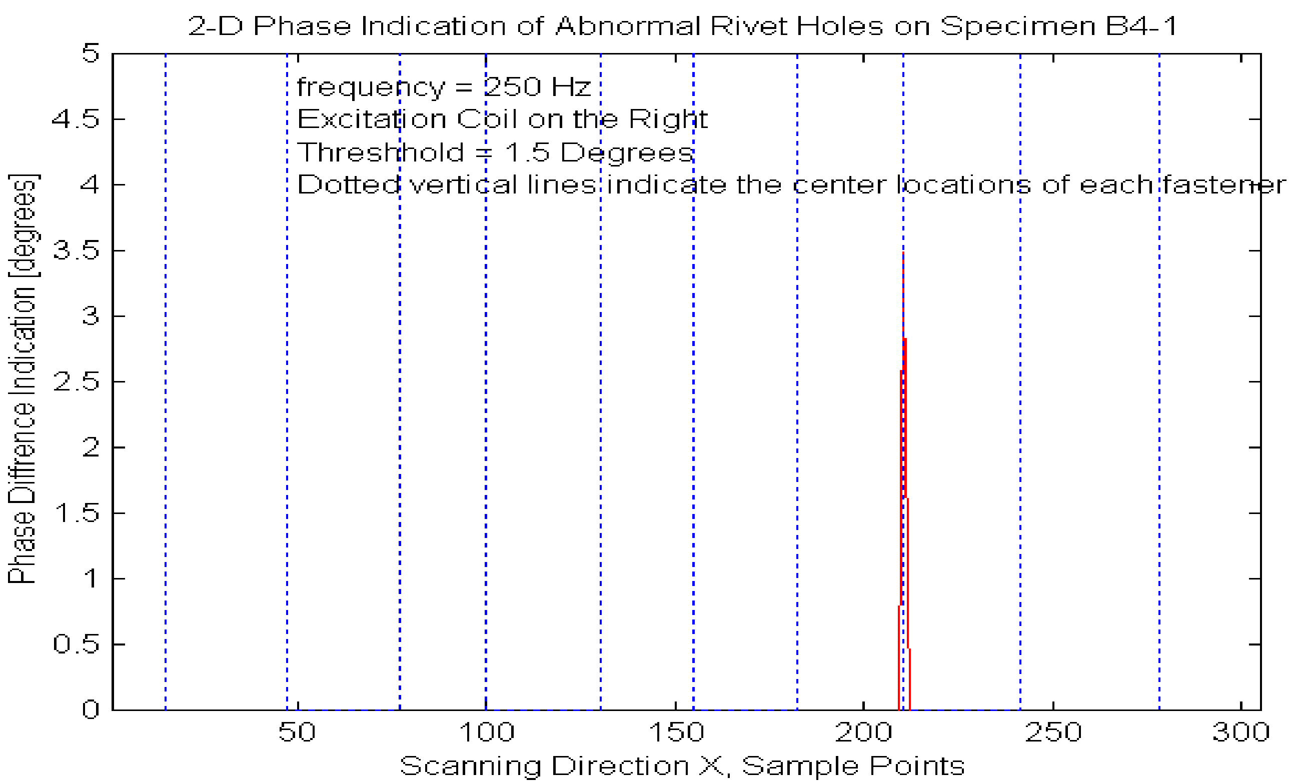


Figure 13. DEMO #4 - Total thickness = 0.446", Crack length = 0.031", Crack location - bottom surface of 2nd layer (The cracked hole is identified by its phase angle derivation)

BRIEF SUMMARY OF THE DEMO

The RFEC system is capable of detecting:

1. Materials break that is about half a inch below the surface where the probe is scanning on.
2. Corrosion that is about 1/4" below the surface with accuracy around 1% or 2%.
3. A 0.031" long crack that is 0.446" below the surface on a fastener hole.

8. PARAMETER STUDY

FREQUENCY SELECTION

1. For an RFEC probe with a coil pickup sensor, the higher the frequency is used the shallower the penetration is expected. However, the higher induced voltage is received from the some amount of flux and the shaper edge indication is seen in the signals. Therefore, there is an optimal frequency range for each application.
2. Recommended frequency ranges for detecting corrosion that is
   - Around 0.063" below the inspecting surface and higher accuracy is required: 1,000 Hz - 3,000 Hz;
   - More than 0.063" below the inspecting surface and lower accuracy is required: 500 Hz - 1,000 Hz;
   - More that 0.15" below the inspecting surface: 200 Hz - 800 Hz.
3. Recommended frequency ranges for detecting fastener hole cracks that are
   - On the counter-sink surface of fastener holes: 2,000 Hz - 5,000 Hz;
   - More that 0.2" below the inspecting surface: 200 Hz - 1,500 Hz.

   Figure 14 shows an example of detecting a crack that is located on the counter sunk surface of a fastener hole.
4. A steel fastener gives much greater indication. It alters the signals of its two adjacent fastener signals, see Figures 10 and 11. This brings difficulty in identifying possible cracks on these two holes. Fortunately, the influence from a steel fastener to its neighbors varies with frequency. It is possible to find a frequency that applies minimal influence to its neighbors. Figures 15 and 16 show the complex planes obtained from the same Lockheed Specimen #B4-1 but with different frequencies, 250 Hz and 600 Hz. It is seen clearly that minimal influence is observed in the plot which is obtained at f = 600 Hz.

EXCITATION COIL - PICKUP COIL DISTANCE

Experiences have shown that a smaller excitation coil center to pickup coil center distance, EPD, allows an RFEC probe to have higher sensitivity to shallower cracks and a greater EPD must be used if one need to detect a deeply hidden crack. In other words, if one needs to detect corrosion and/or cracks in a thick multi-layered structure, it is preferable to use two RFEC probes with different EPD values. Each probe is excited with a selected group of frequencies.

EXCITATION COIL - FASTENER DISTANCE AND PICKUP COIL - FASTENER DISTANCE

Experiences repeatedly showed that more pronounced signals are seen when the excitation coil of an RFEC passes by a defect. However, when detecting a deeply hidden crack on a fastener hole, the best position is to have the excitation coil on one side of the fastener and the pickup coil on the other side of the fastener. The deeper the crack is located, the farther the excitation coil - fastener distance is suggested to use, but keep the pickup coil slightly away from the fastener edge.

CONCLUSIONS

A novel RFEC system has been introduced and demonstrated. Th new technique shows great superiority over the conventional ECT in the detection of deeply hidden corrosion and cracks. A brief description of the selection of RFEC probe parameters have also been introduced.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Yushi Sun, Tianhe Ouyang, and Satish Udpa, "Recent Advances in Remote Field Eddy Current NDE Techniques and Their Applications in Detection, Characterization, and Monitoring of Deeply Hidden Corrosion in Aircraft Structures", *Proceeding of SPIE Volume 3586, Nondestructive Evaluation of Aging Aircraft, Airports, and Aerospace Hardware III*, Chair/Editor Ajit K. Mal, 3-5 March 1999, Newport Beach, CA.

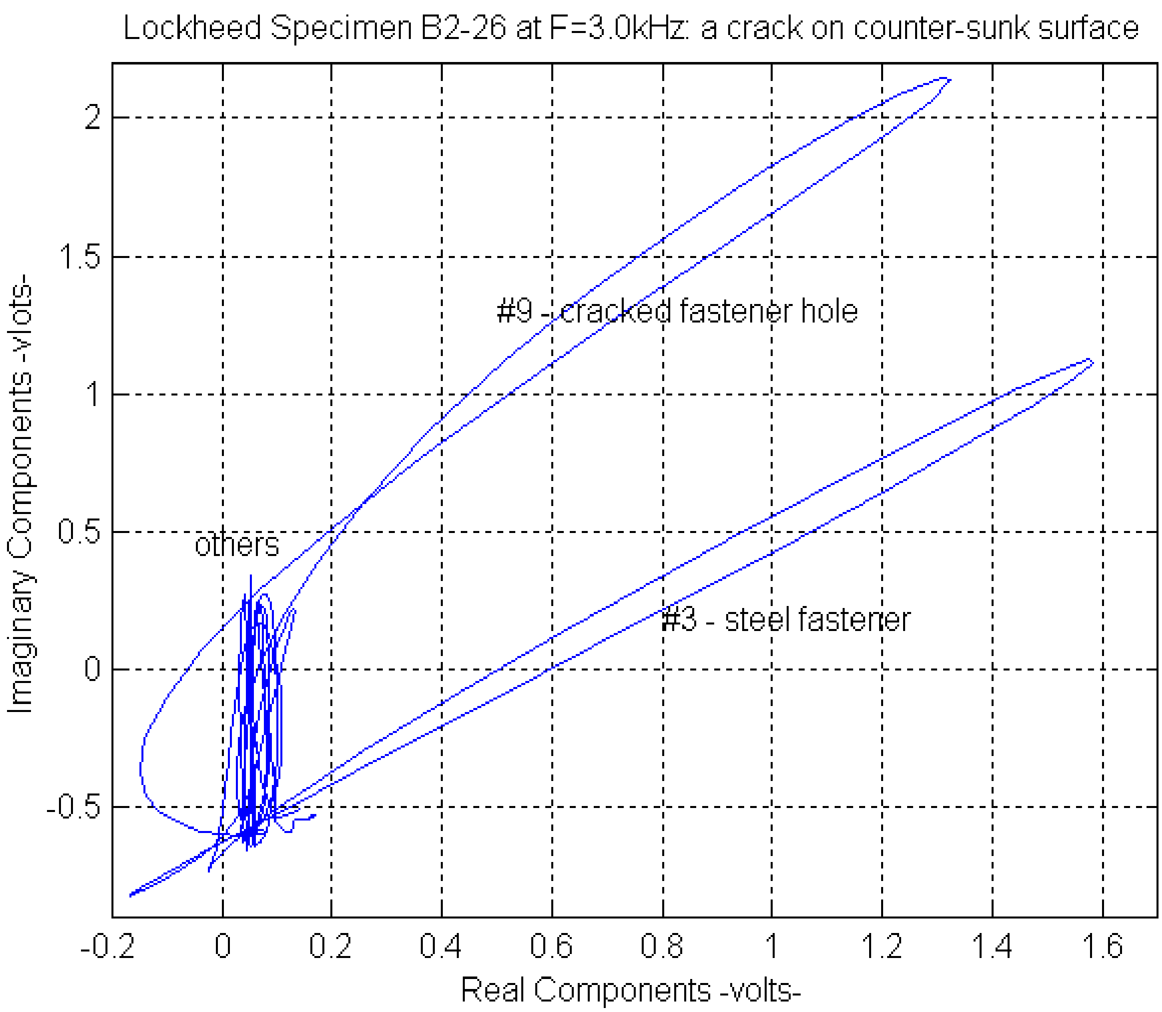
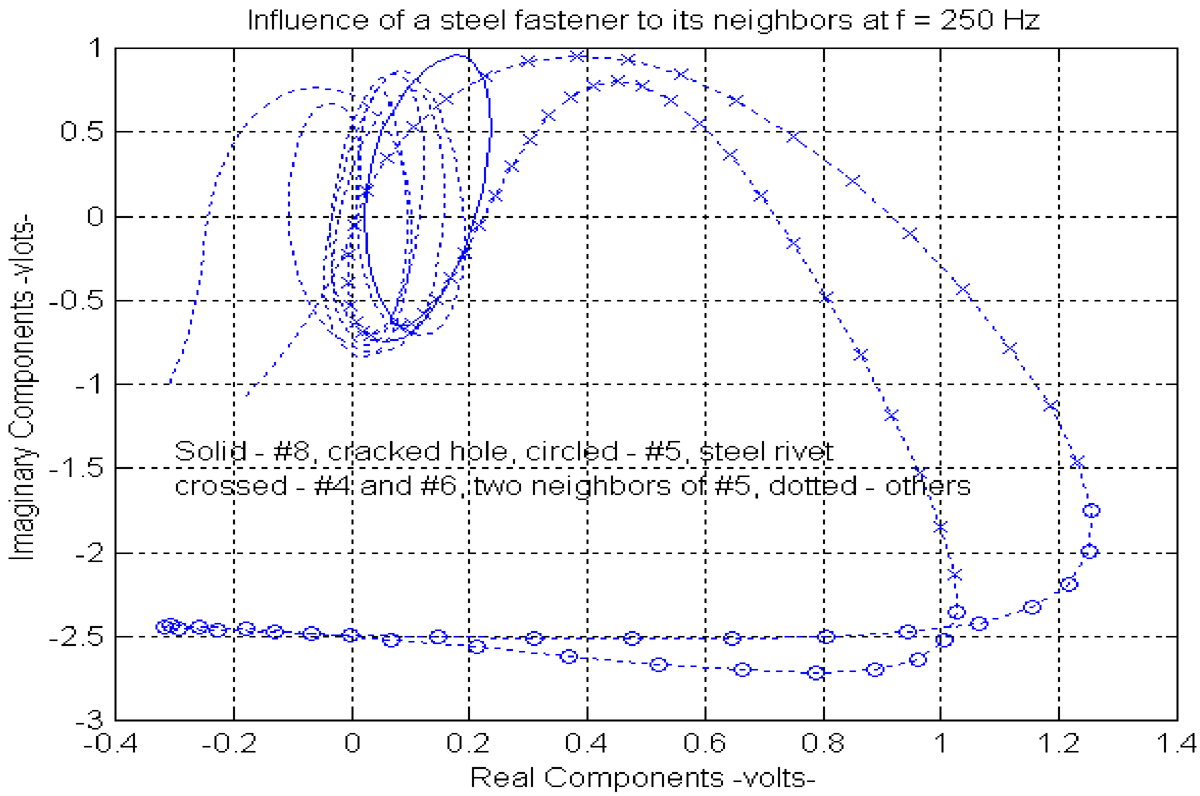
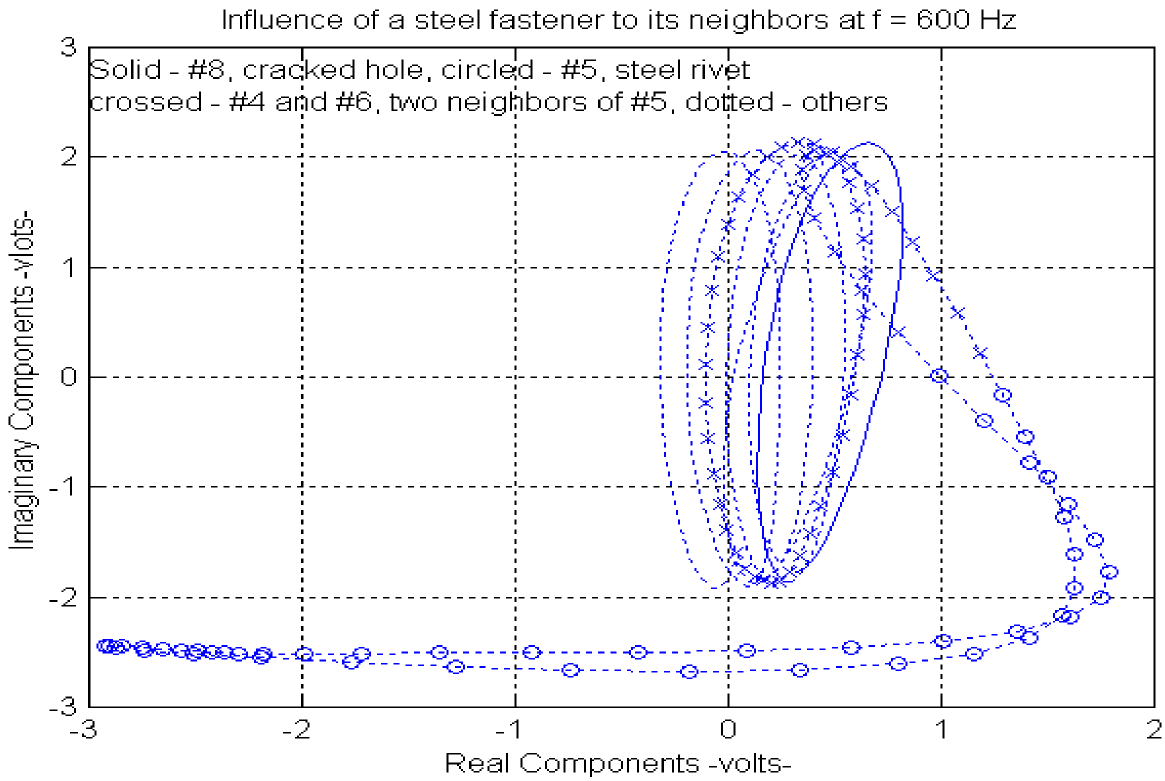


Figure 14. Signal from a crack that is located on the counter sunk surface of a fastener hole.



Figures 15. Influence from a steel fastener to its neighbors at 250 Hz.



Figures 16. Influence from a steel fastener to its neighbors at 600 Hz.