Structural Health Monitoring Application on Chemical Mill Line Cracking

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ABSTRACT

The FAA's Structural Health Monitoring (SHM) research program is integral in the FAA's regulatory policy and guidance development for the implementation of SHM in civil aircraft. It also assists the FAA's Emerging Technology Research program in numerous test scenarios. Various SHM technologies get real structure testing and provide the FAA with inspection results. Further, the SHM research team also participates in the SAE Aerospace Industry Advisory Committee (AISC) for SHM. This paper will provide a brief history of the SHM research program and its assistance in FAA certification of SHM use. It will provide results from one of the Emerging Technology test programs at the FAA William J Hughes Technical Center focused on the evaluation of two SHM technologies and their ability to detect chemical mill line cracking on a full-scale test panel.

BACKGROUND

Chemical milling is a process used in aircraft manufacturing to remove material from the surface of metal components, such as skin panels, to achieve a specific shape or thickness. The process involves immersing the component in a chemical solution which selectively dissolves unwanted material from the surface of the metal while leaving the underlying material intact. Compared to traditional machining techniques, this can allow manufacturers to produce lighter and more aerodynamic components which can improve the performance and fuel efficiency of the aircraft [1]. However, chemical milling has also been associated with several incidents of cracking at the edges of the milled areas, leading to the issuance of a number of Service Bulletins [2] and Airworthiness Directives [3] requiring inspection at the mill line. These additional inspection requirements can be lengthy and costly, as they often require significant teardown of the aircraft's interior. As a result, operators have expressed interest in pursuing Structural Health Monitoring (SHM) solutions in these areas of known potential cracking as an alternative to the traditional non-destructive inspection (NDI) techniques currently being used for detection. In anticipation of these applications and in recognizing the challenges involved with the implementation and certification of new aviation technologies, the FAA conducts research to fill in knowledge gaps integral to developing policy and guidance to promote aviation safety.

In a multi-year, multi-phased research program, the FAA in partnership with Arconic and Embraer are investigating the safety and structural performance associated with emerging metallic structures technology (EMST) applied to fuselage structure using the FAA's Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) fixture [4-5]. The current fuselage test panel utilizes a traditional structural design approach enhanced by the use of advanced aluminium alloys and integral frames. As is common on modern aircraft, such as the Boeing 737, the panel skins are thicker where the internal structure is riveted. In the areas between the stiffeners, the skin has been chemically milled down from 0.065" to approximately 0.050 inches as shown in Figure 1. In order to evaluate the capability of SHM sensors in detecting cracks along the mill line, a test segment including a notch oriented along the mill line was introduced to evaluate SHM applications on the mill line inspection. Two SHM manufacturers, Acellent Technologies and Metis Design, agreed to participate in a cost sharing arrangement.

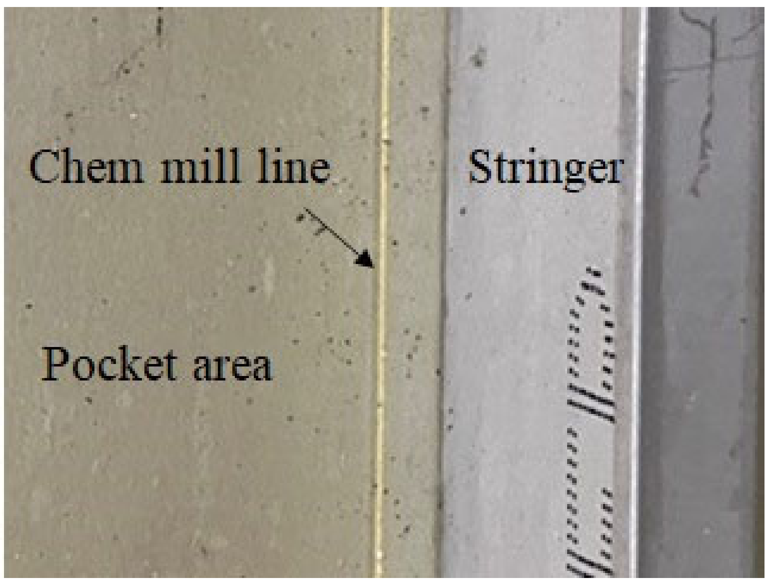

Figure 1. FASTER panel chemical mill line

TEST PROGRAM

A 4.0" long mill line notch was cut into the test panel, with a Metis Design/Analog Devices, Inc. carbon nanotube (CNT) sensor installed on one side of the notch and Acellent piezoelectric transducer (PZT) sensors installed on the other side, as shown in Figure 2. The CNT sensor data was taken every 250 cycles up to a 0.5" crack extension, and Acellent PZT data was taken at 500 cycle intervals up to a 1.0" crack extension. There were a total of 11,700 simulated flight cycles completed for this study. During these cycles, a total of 29 data points were taken with the Metis Design CNT sensor and 24 data sets were taken with the Acellent PZT sensors. The cracks, which extended from either side of the cut, grew at least 1.0" on both sides as shown in Figure 3. FAA also collected crack growth data using high-frequency eddy current (HFEC) and visual inspection to measure the crack length.

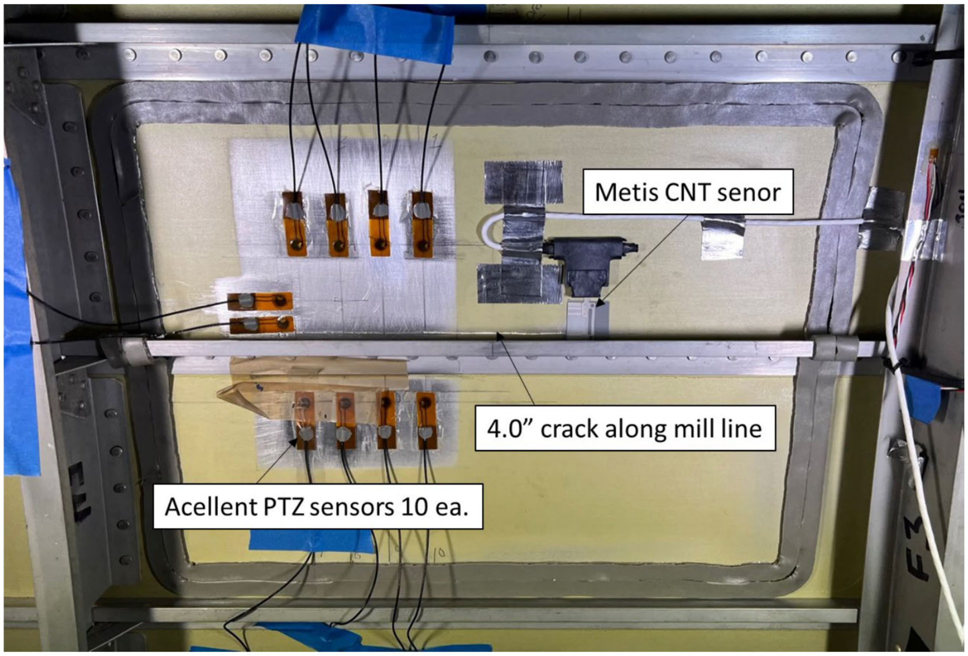

Figure 2. Sensor layout on both sides of 4" sawcut

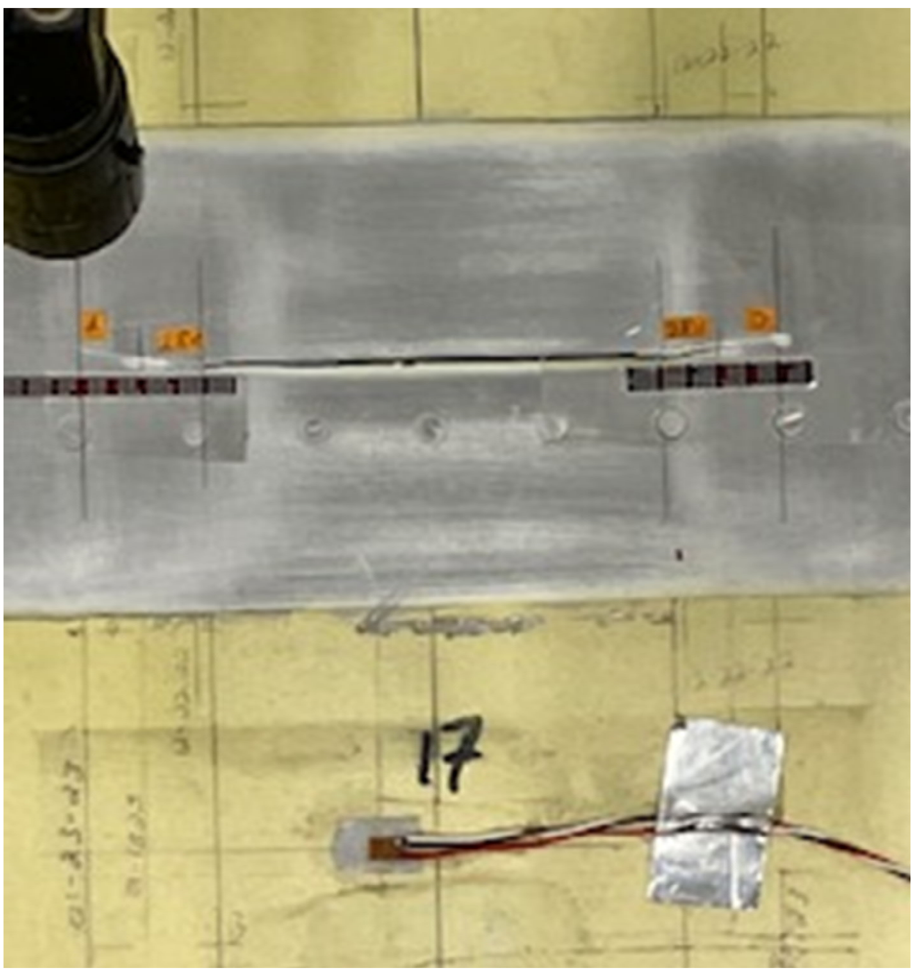

Figure 3. Crack growth on each side of the saw cut notch

Sensor data was returned to each SHM manufacturer in a "blind" fashion, meaning that they were not given the visual inspection crack lengths that corresponded to the collected sensor data until after initial analysis of the sensor data was completed. The collected inspection data of crack length at different cycles is shown in Figure 4.

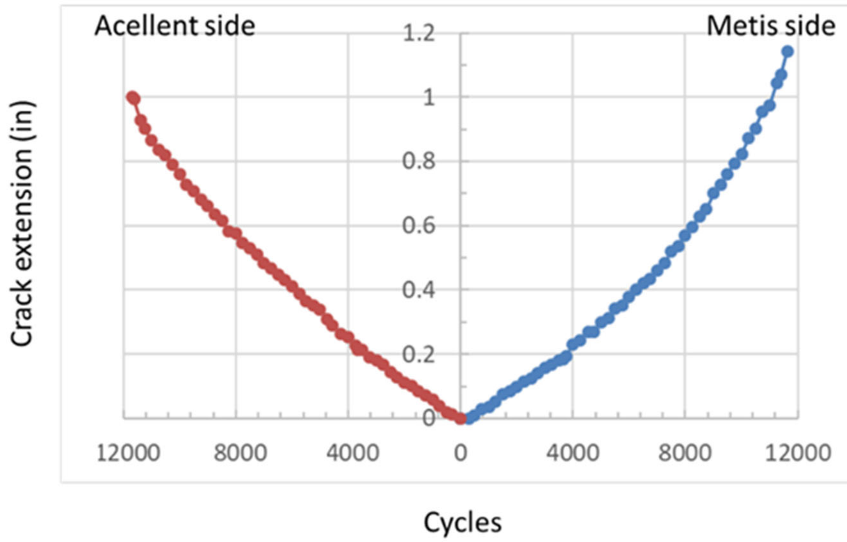

Figure 4. Crack growth by cycles

Figures 5 shows the crack growth through the Metis Design CNT sensor from the internal side of the FASTER panel. It was noticed that as the crack grew, it turned away from the chemical mill line similar to what has been noticed in field cracking incidents. This behavior of the crack straying towards the interior of the bay was also predicted by the FAA finite element model prior to sensor installation.

Figure 5. Crack through Metis Design sensor

RESULTS

Figure 6 shows the CNT sensor results from Metis Design which displays the visual inspection results, no-load sensor results, and no-load results with a correction/calibration factor (applicable up to half the gauge length which in this case is 0 to 0.25”). It is noted that this particular installation used a commercial-off-the-shelf version of the sensor due to quick turnaround times to begin testing. Normally, a custom form-factor sensor would be designed specific to the application. As such, the CNT sensor installation required custom bonding using an area of thick adhesive about 25x that of the normal bondline thickness in order to compensate for the height difference between the chem mill pocket and pad-up region. This atypical installation allowed the sensor to lie flat but caused uncharacteristic performance issues requiring a correction factor to accommodate the shear lagging due to additional adhesive.

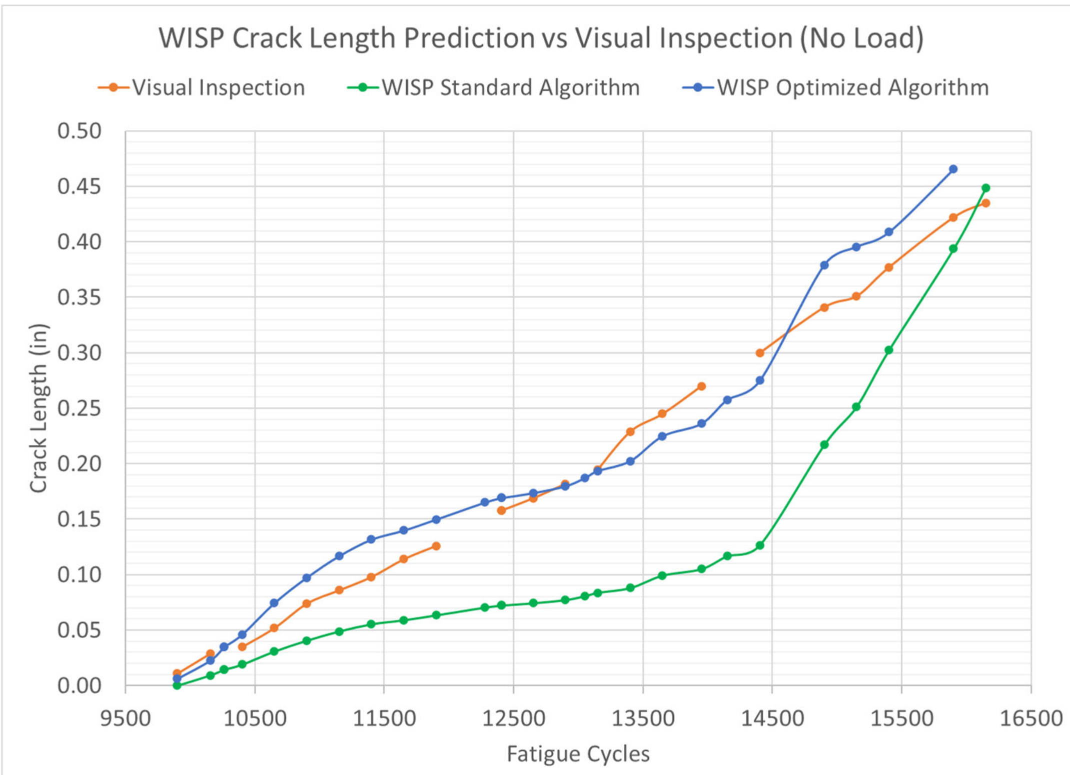

Figure 6. Metis Design CNT sensor results compared to visual inspection

Acellent PZT sensor inspections gathered data from frequencies ranging from 200-500 kHz at 25 kHz increments. Figures 7 and 8 shows the PZT sensor paths as well as a sample of results at 250 kHz and 500 kHz. The sensor output provides a damage index (DI) for each path and frequency combination for each inspection. Data shown from 500 kHz provides an example of crack detection with a DI threshold set at 0.2. The data that remains are paths that have consistently risen above the selected threshold, signalling detection of a crack. Path 1-10, the path closest to the tip of the initial chem mill cut, was shown to be the most sensitive across all frequencies. Paths 1-9 and 2-10 performed well once the crack reached approximately 0.5” as shown in Figure 9.

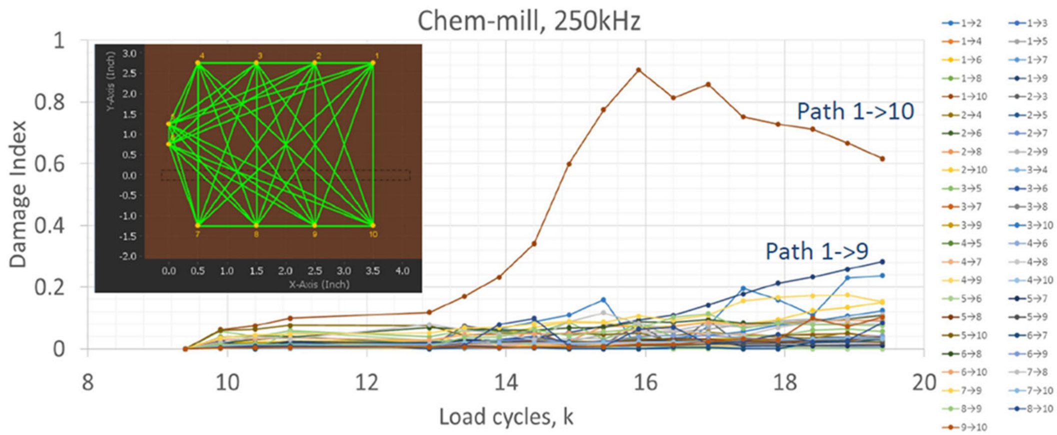

Figure 7. Acellent PZT sensor paths and all path results at 250 kHz

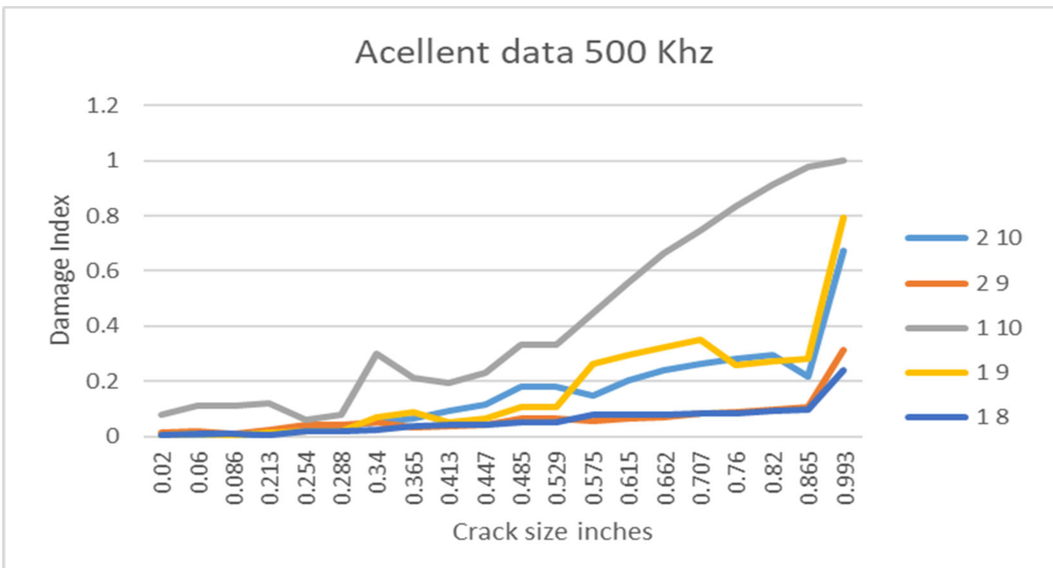

Figure 8. PZT data at 500 kHz showing indications above Damage Index of 0.2

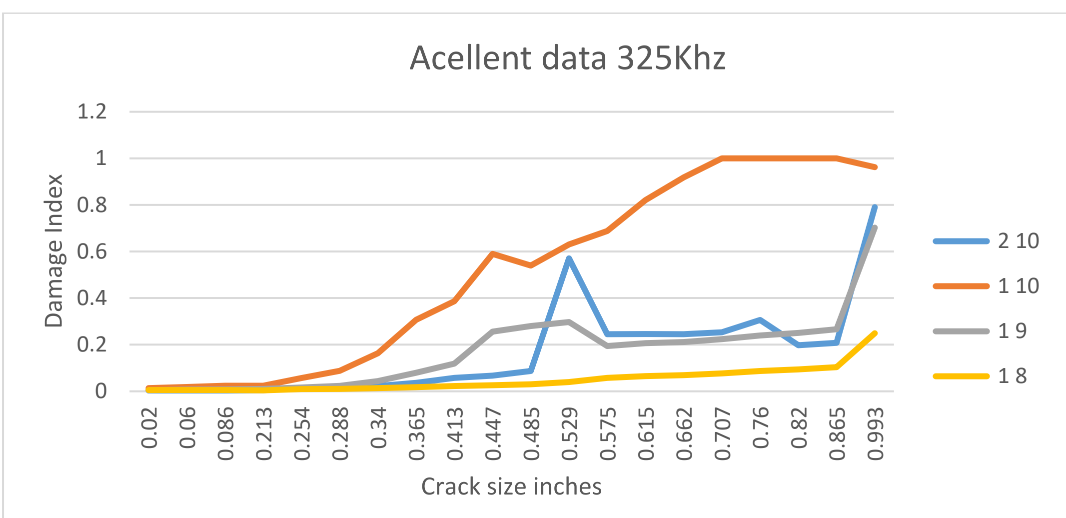

Figure 9. PZT data at 325 kHz showing indications above the Damage Index of 0.2

CONCLUSION

Within the FASTER panel test setup, both technologies demonstrated that they were capable of identifying a crack located at the mill line of the chemically milled geometry. However, more tests should be undertaken to further determine each systems' sensitivity and reliability as well as to evaluate the variables that can affect these sensors' readings. For example, in-service chem mill cracking does not necessarily originate "neatly" in one area, but instead has the potential to form multi-site cracking which coalesces into a large crack. The data collected through this test program will be used towards the evaluation of the capability and reliability of SHM systems in mill line crack scenarios, and towards addressing necessary changes to standards and guidance for operators seeking to use SHM inspection methods.

REFERENCES

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