Structural Condition Monitoring of Helicopter Components

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ABSTRACT

This paper will review the ongoing Structural Health Monitoring (SHM) work being done for the Aviation & Missile Research, Development, & Engineering Center (AMRDEC) Diagnostics and Prognostics Laboratory (DPL) located at the Redstone Arsenal in Huntsville, AL. The focus of DPL activities is to examine various techniques to enhance the diagnostic capability of Army aviation, ground, and missile systems. An area the DPL is involved in is structural health monitoring of critical structures of our aviation fleet. This work involves detecting and, in some cases, localizing damage on various air and rotor craft parts. Many of these applications are currently displayed as demonstrations in the DPL.

Two laboratory demonstrations were developed to demonstrate the importance of optimizing sensor locations by comparing the results of a group of sensors that have been optimized to a group of twice as many sensors that had been heuristically placed. This is demonstrated on two very different parts; a Black Hawk drag beam tested in free-free boundary conditions and a Kiowa Warrior roof strap tested with many complex boundary conditions. The drag beam demonstration detects a simulated mass removal such as pitting or corrosion where as the roof strap demonstration detects simulated cracking and bolt loosening.

Another demonstration involves detecting damage such as pitting and corrosion on an Apache tail rotor blade. Although the demonstration uses external sensors and actuators, the end goal would be to have the sensors and actuators integrated into the part during manufacturing. The correlation between the damage metric and corrosion are demonstrated on steel plates subjected to a salt fog chamber.

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INTRODUCTION

The majority of the demonstrations discussed herein utilize an optimal sensor location strategy which is a model based method of optimally placing sensors to detect and locate damage. Details of this method can be found in papers published previously by the authors [1]. These methods, along with advancements such as automating current NDI techniques, are being set up as demonstrations in the DPL to show current SHM capabilities and how they can be integrated into the Army's aviation, ground, and missile systems.

BACKGROUND

There are many ways to improve the current methods of health monitoring. Most of the work presented previously by the authors has been focused on the method of developing optimal locations for sensors and actuators on the structures of interest. Optimizing these locations has many advantages. By minimizing the number of sensors and actuators added to a structure, this greatly reduces the added weight, reduces the amount of data collected, maximizes sensitivity to damage and ensures global coverage of detecting damage anywhere on the structure.

Another method is to simply automate current NDI techniques. This will reduce the total inspection time and eliminate human error. This will also allow any delamination to be tracked over time if it has not met the critical size when first detected.

OPTIMAL VS. HEURISIC DEMO RESULTS

The focus of this demonstration was to compare the results of a group of sensors that had been optimized to specific design criteria to a group of twice as many sensors that were heuristically placed on the structure. To achieve this comparison, it was decided that the optimal group would contain one actuator (piezoelectric disc bender) and two sensors (accelerometers) while the heuristic group would contain four sensors. All groups responded to the same actuator on each part.

The structures under test were a Bell OH-58D Kiowa Warrior roof strap beam and a Black Hawk drag beam. The test results for these demonstrations are shown below. A more in depth review of the results of these demos can be found in the authors' previous paper [2].

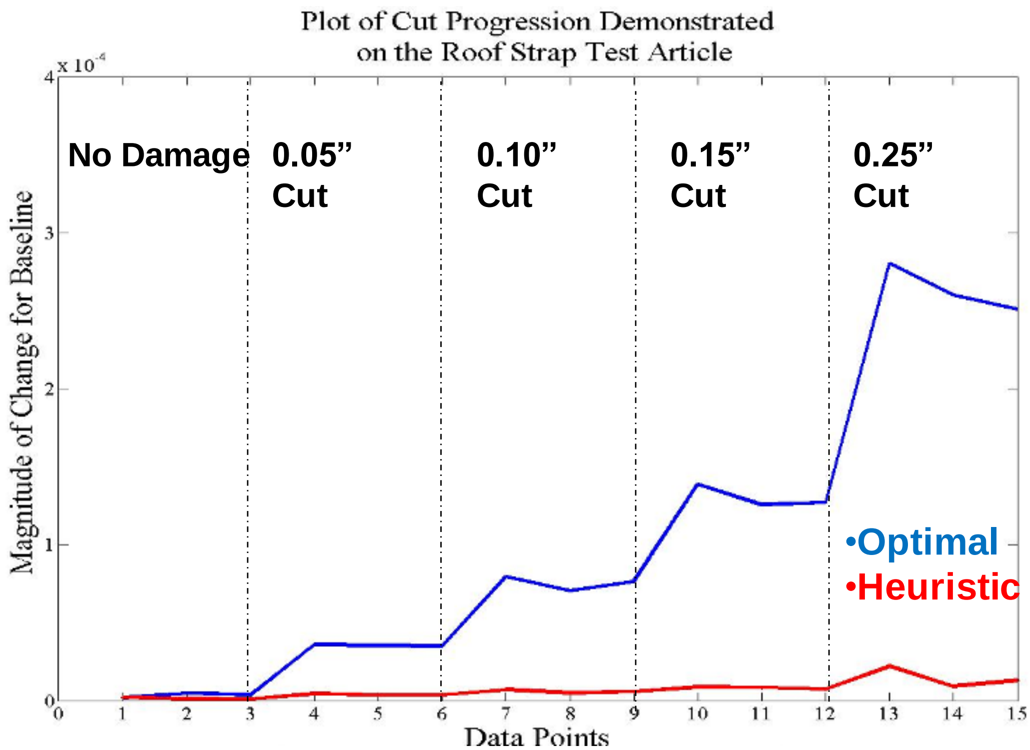

Figure 1. Results of the Cutting Demo on Kiowa Warrior Roof Strap

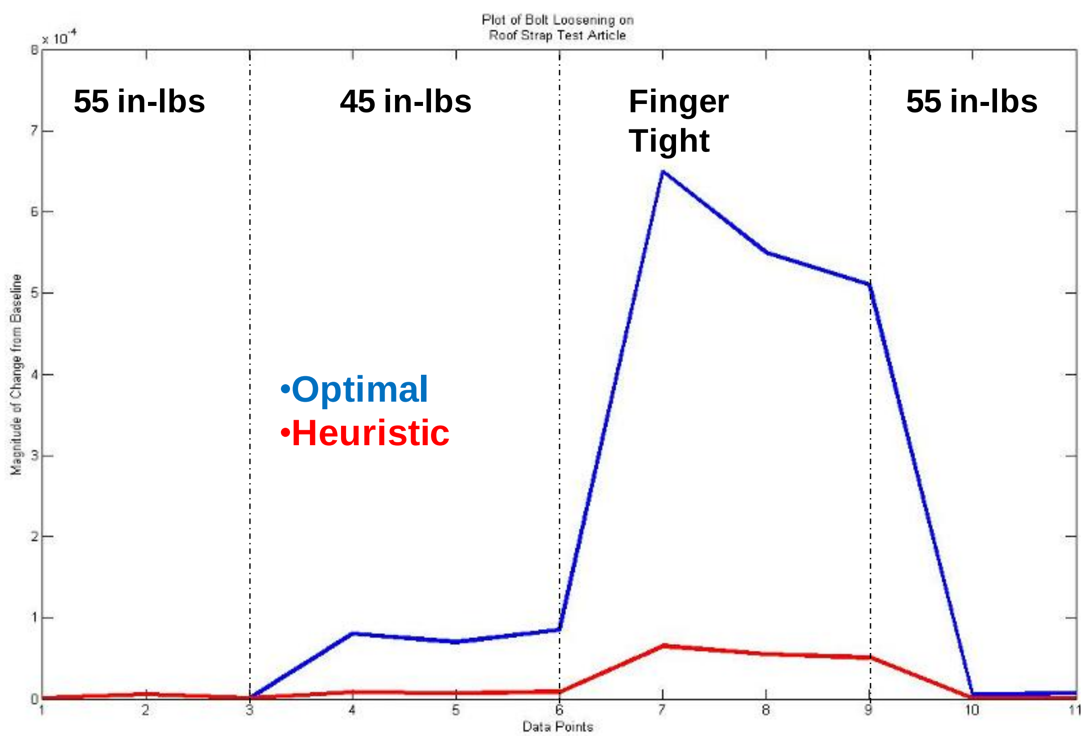

Figure 2. Results of the Bolt Loosening Demo on Kiowa Warrior Roof Strap

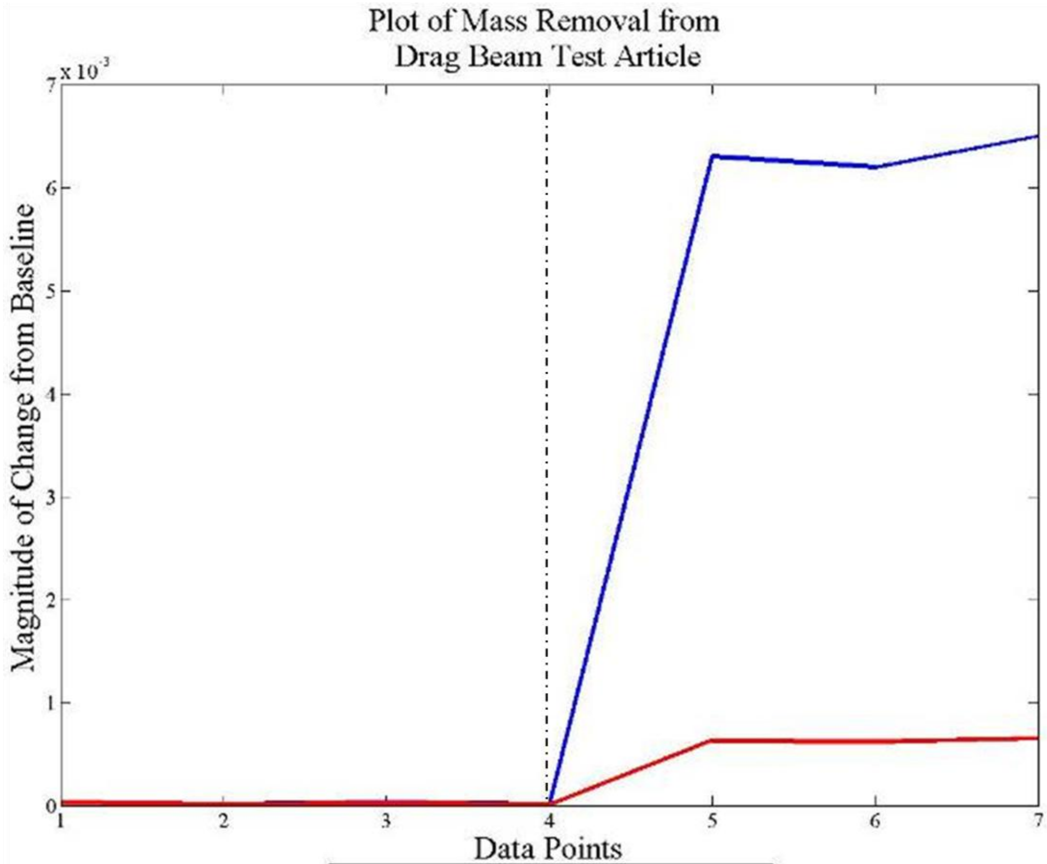

Figure 3. Plot of Damage Detection on the Black Hawk Drag Beam. Optimal in blue, Heuristic in red

APACHE TAIL ROTOR BLADE DEMO RESULTS

An Apache tail rotor blade weighing 5.65 kg was acquired, and a mount was designed and fabricated to support the blade in a cantilevered position. Various optimal sensor designs were found ranging from one to four sensors, and the three sensor case was chosen for this experiment. Two sensors were located on the front of the blade and one was located on the back. This demonstration is presented to viewers as a step toward integrating the sensors and actuators into the manufacturing process. The test set up is shown below in Figures 4 and 5.

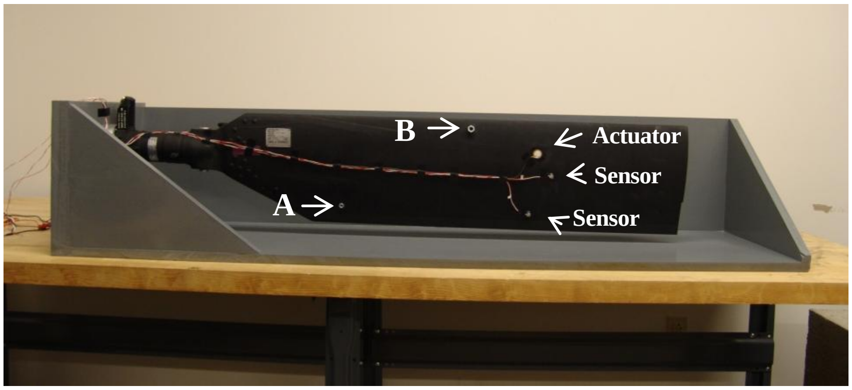

Figure 4. Test Assembly of Tail Rotor Blade – Front View

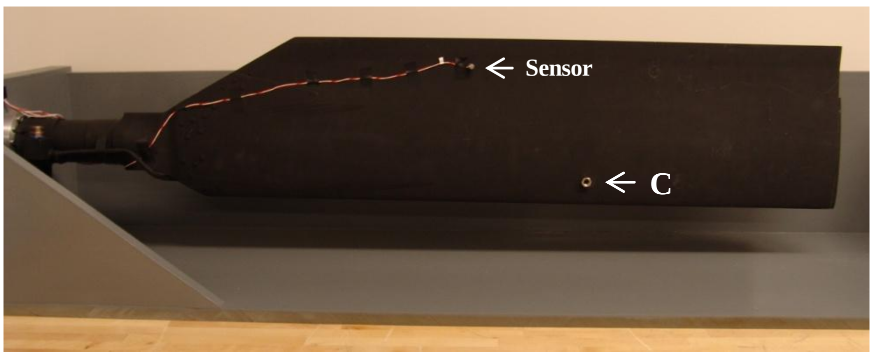

Figure 5. Test Assembly of Tail Rotor Blade – Back View

The baseline was taken with masses (nuts) on the structure which allows for pitting or mass removal to be simulated. The masses are shown next to the letters “A” and “B” in Figure 8. Mass “C” is located on the back side of the rotor blade to the right of mass B. The masses were removed one at a time in alphabetical order and weighed 3.1, 6.9 and 6.9 grams respectively. A baseline is shown in the first three points in Figure 7. Mass A was removed at point 4, mass B at point 7, and mass C at point 10 in the same figure. The damage for each case was detected, and the progression can be seen in the screen shot below in Figure 6.

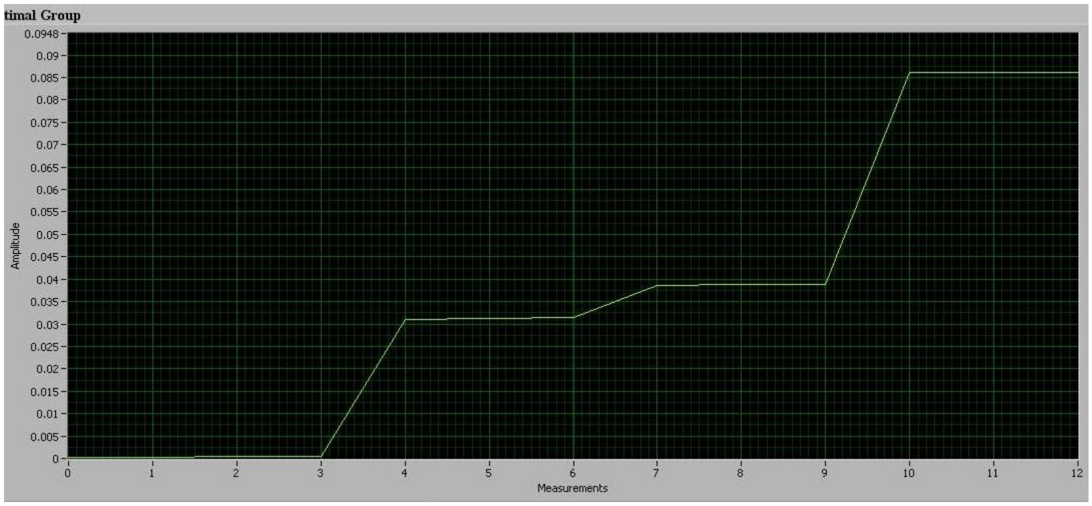

Figure 6. Screen Shot of Damage Detection of the Apache Tail Rotor Blade

CORROSION DEMONSTRATIONS

To demonstrate the correlation between the damage metric and actual corrosion (as opposed to mass changes) two test coupons were instrumented and subjected to a salt fog chamber. The coupons were 3" x 5" unprotected sheets of steel. On each coupon three uni-axis accelerometers and one piezo were bonded. They were then placed in a salt fog chamber for 69 hrs under salt mix conditions of ASTM G85-A5 and spray conditions of ASTM B117. Data were collected and processed every two minutes during the test. A clear correlation between the damage metric and corrosion can be seen in Figure 7. The spikes shown in the figure are due to the test being stopped and the chamber opened so pictures could be taken of the samples at various times.

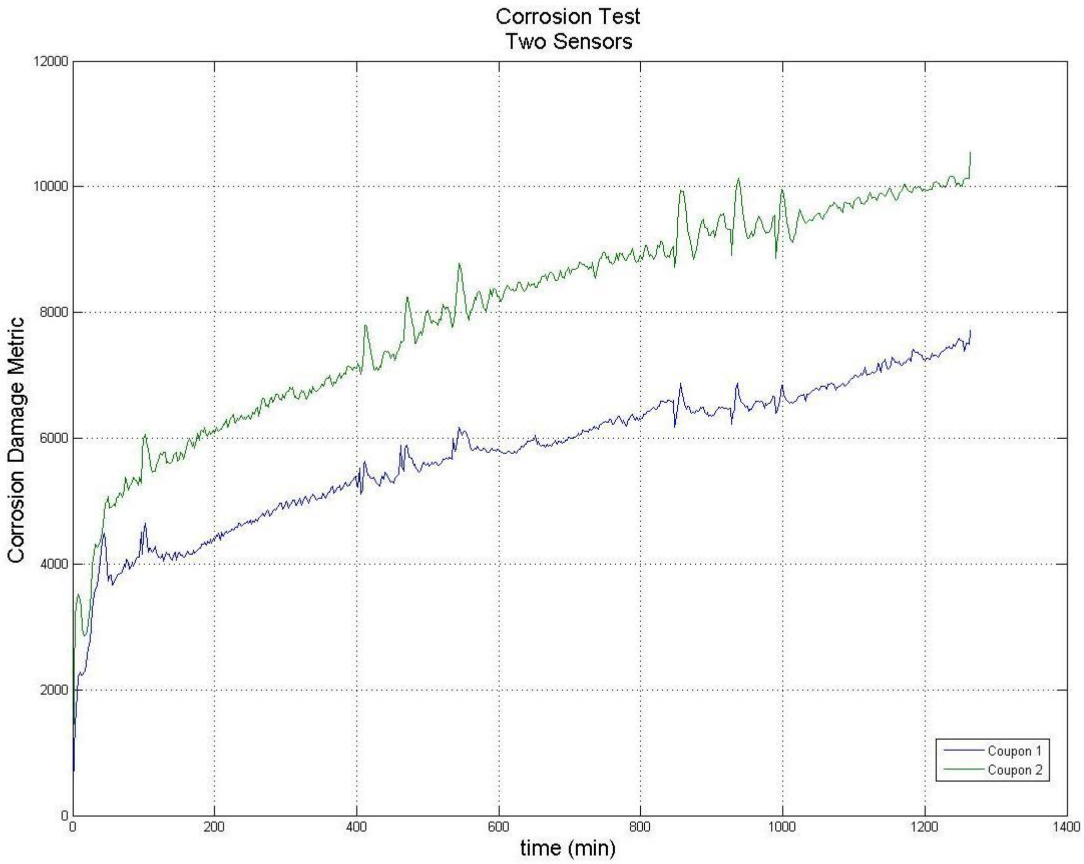

Figure 7. Damage Metric vs. Time for Coupons in Salt Fog Chamber

CONCLUSIONS

There are many advances being made in structural health monitoring. Optimal sensor placement is very useful on many different structures with simple and complex boundary conditions. By minimizing the number of sensors and actuators added to a structure, this greatly reduces the added weight, reduces the amount of data collected, maximizes sensitivity to damage and ensures global coverage of detecting damage anywhere on the structure. The end goal for many of these parts would be to have the sensor and actuators integrated into the fabrication of each part. This will allow for data to be collected and monitored over the life of the part. Not only can the data tell you when damage occurs, it can also reassure you that nothing has changed. This will allow for a shift from time interval inspections to a more condition based method.

REFERENCES

1. Danny L. Parker, William G. Frazier, Hank S. Rinehart, Pamela S. Cuevas, “Experimental Validation of Optimal Sensor Placement Algorithms for Structural Health Monitoring", Third European Workshop on Structural Health Monitoring, Granada, Spain, 2006.

2. Pamela S, Cuevas, Danny L. Parker, William G. Frazier, Duane D. Weatherford, "Structural Damage Detection: A Study of Optimal Sensor Locations", 2nd Asia-Pacific Workshop on Structural Health Monitoring, Melbourne, Australia, 2008