NEW TECHNOLOGICAL CHALLENGES FOR GUIDED WAVE NDE

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ABSTRACT

This paper summarizes the current research effort focusing on development of ultrasonic guided wave technology suitable for condition based maintenance (CBM) of military aircraft. Early detection of fatigue cracking in the transmission support beam of the SH-60 helicopter is an example of a problem that can be tackled using guided waves. New developments in sensor technology and guided wave instrumentation have made the possibility of embedding sensors permanently on the beam. The sensor can be controlled remotely and valuable information on the condition of fatigue cracking can be obtained using a portable personal computer. The current research thrust is concentrating on integrating wireless communication into the system.

KEYWORDS

Ultrasound, guided waves, sensors, condition based maintenance.

INTRODUCTION

Ultrasonic guided wave technology has been applied to many aircraft inspection applications and is now ready to be implemented as a tool in maintenance of the military's aging aircraft. The challenge now is to integrate sensor technology, wireless communication, and portable data acquisition and analysis hardware into one complementary technology. Although there are many conventional and new innovative NDE technologies that maintenance personnel may select to monitor for damage [1-3] guided waves have emerged as a natural choice for some aircraft applications due to their ability to propagate over long distances, multi-layer inspection capability, and dispersive characteristics [4-9]. In the past, a significant amount of research has been devoted to developing guided wave sensors, instrumentation, and the associated wave mechanics for a given structure. Very little work has actually focused on integrating the complimentary technology. The following discussed the motivation for developing guided wave technology for CBM and the sensors and instrumentation required for realization.

SH-60 TRANSMISSION SUPPORT BEAM MAINTENANCE

The fatigue cracking (Fig.1) in the SH-60 transmission support beam generally initiates close to the middle of the beam and grows outward axially. Table 1 shows the transmission beam cold working chart. Note that repairs occur in 1/64" increments. If the crack is detected early enough, it can be milled out. Currently, the aircraft is inspected every 200 flight hours or 6,000 landing cycles and can be unnecessary since cracking may not be present. By using a condition based maintenance (CBM) approach instead of a time based maintenance (TBM) approach, unnecessary inspections and the associated costs can be avoided. Fig. 2 shows that the current one day inspection of the beam contributes to only 1% of the total maintenance cost of the beam which includes the tear-down, replacement, and parking costs.

COMB SENSOR DEVELOPMENT

Piezocomposite comb sensors were used for the feasibility study since they were readily available from the manufacturer and also because their performance could be easily predicted. The final sensor, however, will use a piezopolymer as the substrate since this material is 10-100 times cheaper than the piezocomposite. A typical prototype piezocomposite sensor can cost up to $500 while in high volume applications the unit cost can be potentially reduced to $100. Prototype PVDF transducers can be manufactured for less than $100 and for high volume applications it may be possible to develop individual sensors for $25-50. See Fig. 3 for a cost comparison of the different sensors that can be used to excite guided waves. Notice that the piezopolymer sensor is the only viable candidate for high volume applications.

AUTOMATED INSPECTION DEVELOPMENT

Each helicopter has transmission beam 16 critical zones, 8 on each beam, where monitoring for cracks is required. The controlling instrumentation can record data from 8 sensors by using a built in multi-plexer to switch from sensor to sensor. This approach minimizes the inspection setup time since only one cable connection is required for 8 transducers. Special built-in software gates are used to analyze the data with analysis tools including real time peak detection, real time signal profile extraction, and real time reference signal correlation analysis. Built-in alarms can then be implemented for each feature. Fig. 4 shows the gate concept.

It was also necessary to develop a protocol for transducer performance and transducer coupling diagnostics. Since it is possible for the sensors to become damaged and/or unattached during flight it is required to perform a pre-inspection test to verify that the transducer is still attached to the beam and functional. This is accomplished by recording the transducer response before installation and after it is bonded to the structure. The correlation of these two signals will serve as a reference for future data taken from the bonded sensor when compared to that from the initial installation. Any significant deviation from the correlation of the reference signals will alert the operator

Phase 1 of the work focused on the detection of severe cracking and the supporting instrumentation. The instrumentation was developed such that little or no modification would be needed to upgrade the system for smaller crack detection as outlined in the cold work chart above. The only major difference between the systems is the transducer used to inspect for cracking and the detection gates. As a result, the hardware, software, and inspection routines are applicable to both types of crack detection.

The transducer position and wave propagation direction are shown in Fig. 5. The thinner section of the beam is 2.5 mm thick and the 30 mm long. The comb transducer finger spacing was 0.7 mm which closely matched the wavelength of the A_0 in the thinner section at 2 MHz (see Fig. 7). Experimental measurement of the group velocity gave a value of 2.85 mm/us which closely matched the theoretical value of 2.93 mm/us shown in Fig. 6. Tests were performed using the HELIUS system developed jointly by Penn State Ultrasonics Lab and TISEC Inc. The system outputs a gated sinusoid in the 50 kHz to 15 MHz frequency range at a maximum voltage of 300V. The receiver has an output level of 4V and a dynamic range of 70 dB. Sample RF waveforms are provided in Fig. 4 from a crack free and cracked zone. The critical information is found in the 20-24 *u*s and 29-35 *u*s windows corresponding to the crack gate and back edge gates, respectively. As the crack propagates from hole to hole the echo from the back edge diminishes while that from the crack increases.

FUTURE WORK

The next phase of work will focus on the development of wireless sensors and the supporting instrumentation. One approach to implementing wireless technology is shown in Fig. 8. The signal from the local comb transducer is conditioned and amplified then digitized. Following digitization the signal is acquired by a digital signal processor and stored. The stored waveform is then processed as discussed above and the results are transmitted back to the host PC via a telemetry link notifying the operator on the condition of the beam.

CONCLUSION

An ultrasonic guided wave system for the condition based monitoring of the SH-60 Sea Hawk helicopter was presented. It was shown that it is possible to monitor for cracking in the transmission support beam using embedded guided wave comb transducers. The design and installation is strongly influenced by the local geometry and access of the beam adjacent to the cracking. The supporting instrumentation development was discussed focusing on the detection gates, real-time feature analysis, pre-inspection diagnostics, and inspection automation. The building blocks for a wireless system that is currently being developed was also presented.

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Table 1. Cold Work Chart for Navy H-60 Aircraft

Fastener	Starting Hole Diameter	Initial Ream Diameter	Cold Expanded Hole Diameter	Final Hole Diameter	Mandrel
	Range	Min./Max			
HL20PB-6-X	0.171-0.180	0.177-0.180	0.181-0.183	0.184-0.187	CX6-0-N
HL64PB-6-X	0.180-0.195	0.192-0.195	0.197-0.199	0.199-0.201	CX6-1-N
HL220PB-6-X	0.195-0.212	0.209-0.212	0.213-0.215	0.215-0.217	CX6-2-N
HL224PB-6-X	0.212-0.228	0.225-0.228	0.229-0.231	0.230-0.233	CX6-3-N
HL20PB-8-X	0.228-0.238	0.235-0.238	0.241-0.243	0.244-0.247	CX8-0-N
HL64PB-8-X	0.238-0.253	0.250-0.253	0.255-0.257	0.261-0.264	CX8-1-N

Figure 1: Close up of SH-60 transmission beam fatigue crack

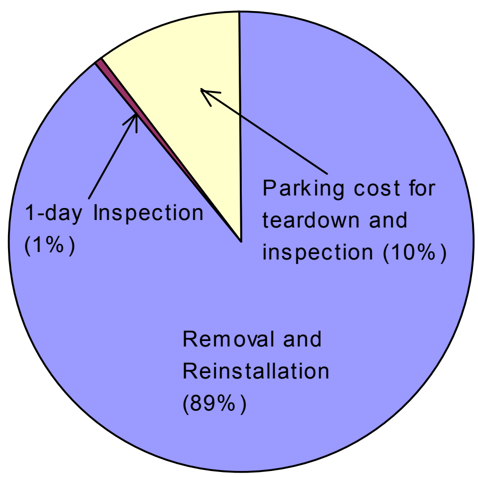

Figure 2. Current maintenance cost breakdown.

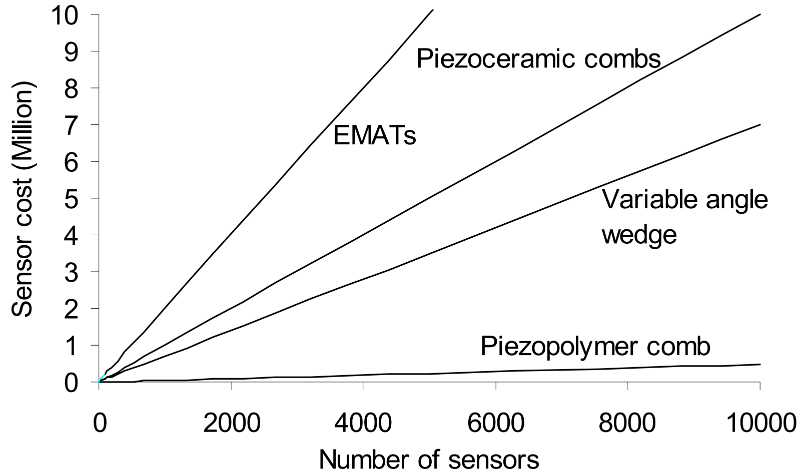

Figure 3. High volume application of guided wave sensors

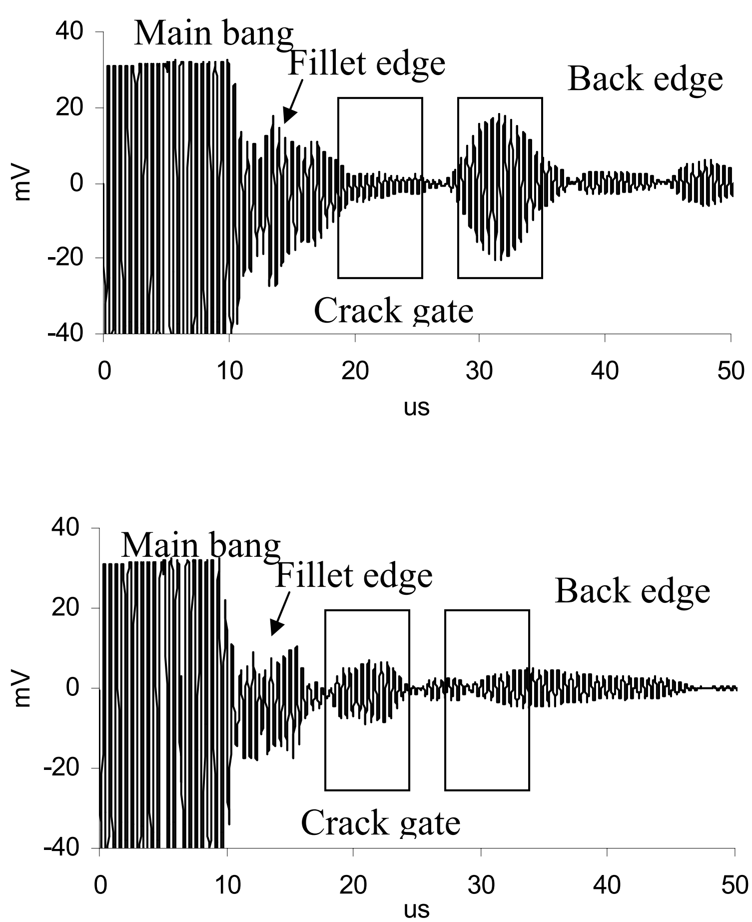

Figure 4. Example software gates for analysis of data.

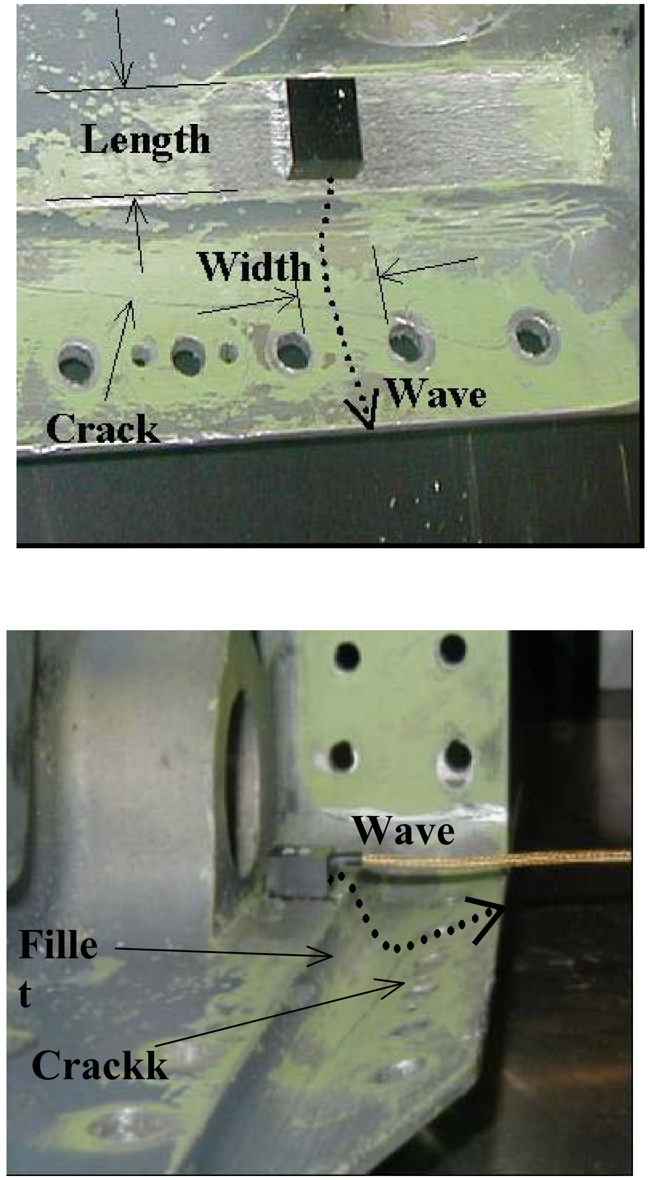

Figure 5. Transducer position and wave propagation direction.

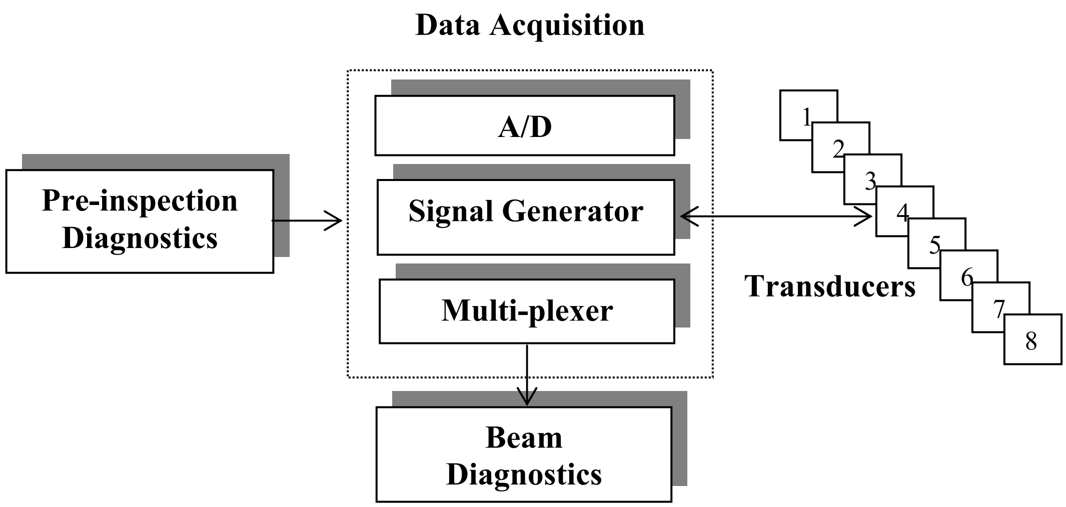

Figure 6. Inspection routine.

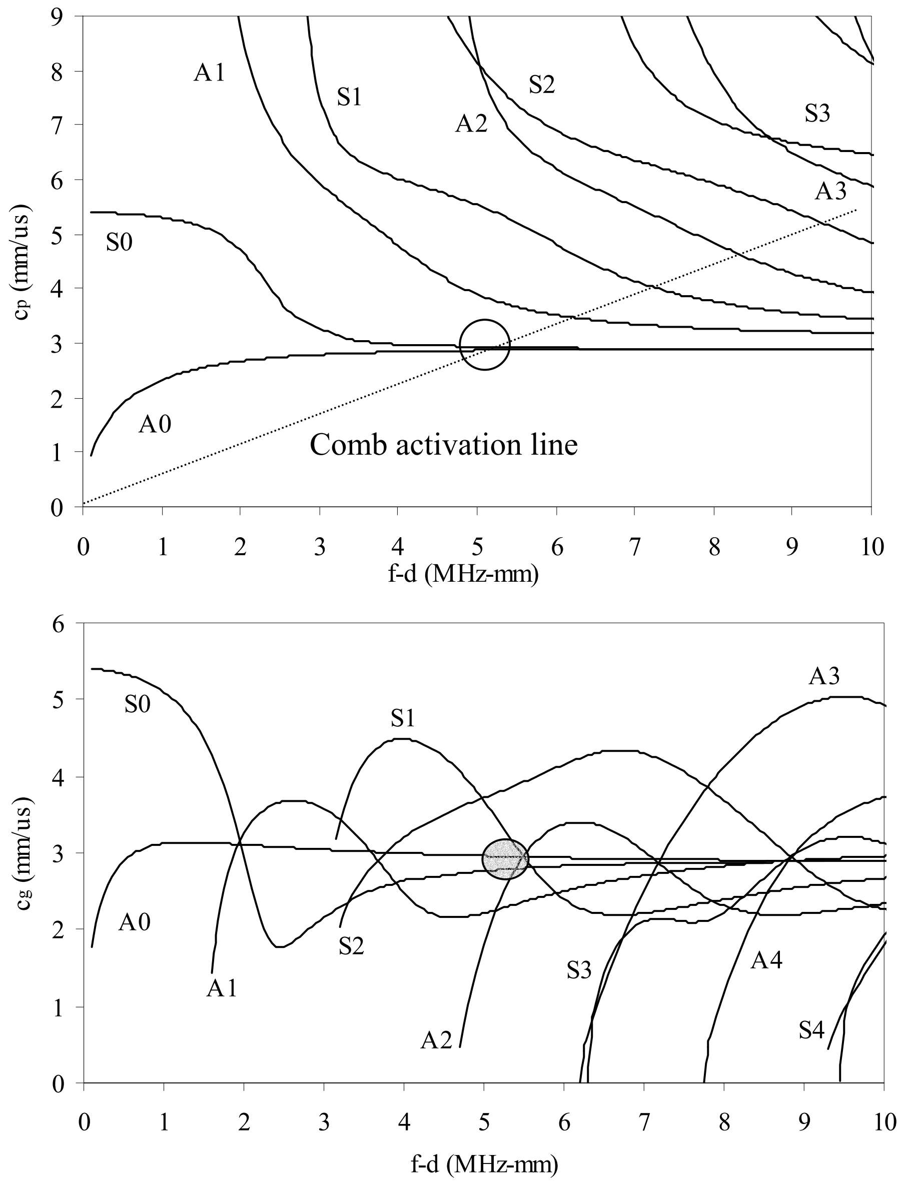

Figure 7. Phase (top) and group (bottom) velocity curves for an aluminum plate.

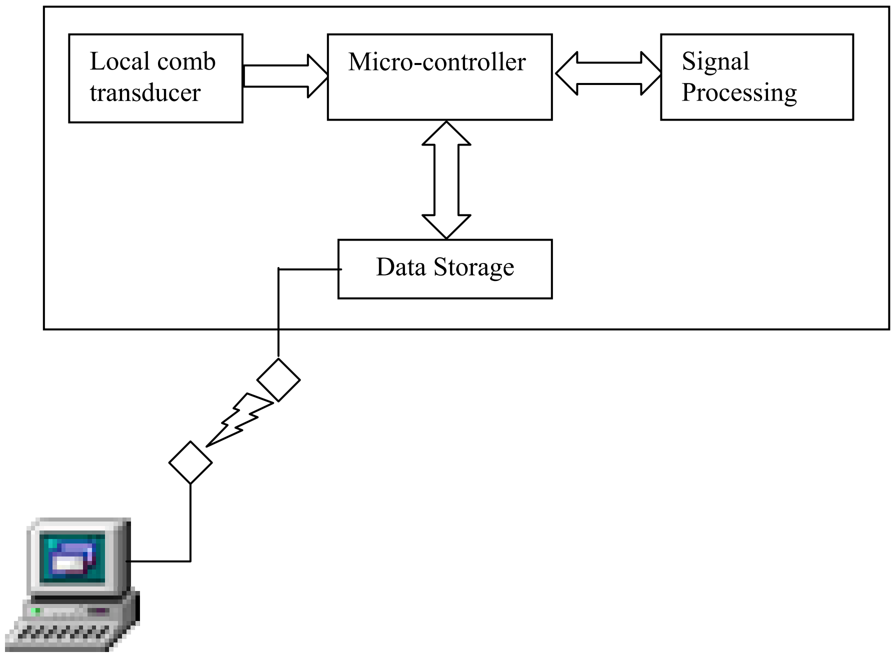

Figure 8. Wireless communication with guided wave sensor.