NON-DESTRUCTIVE EVALUATION OF AIRCRAFT CABLES USING ULTRASONIC GUIDED WAVE TECHNIQUE

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Abstract

The degradation of aircraft wire structure over time due to environmental and operational conditions can potentially become a source of electrical unreliability. This consequently compromise the functionality of instruments and safety of the aircraft. Therefore, it is essential to develop an inspection technique to accurately determine the health of electrical wiring, in particular to inspect the condition of the insulation during maintenance efficiently. Recently, the use of Ultrasonic Guided Wave (UGW) has gained wide attention in the field of Non-Destructive Testing (NDT) notably in the application for pipeline inspection. In this paper, a mobile UGW system is developed by utilizing transducer based on Macro Fibre Composite (MFC). Numerical studies using Finite-Element Method (FEM) have been used to study the frequency and transient characteristics on the modes of wave propagation in wire structures. Representative aircraft cables with well classified insulation defects were subjected to the UGW inspection system operating at frequencies range of 10 – 20 kHz. The data acquired by the pulser/receiver unit was further processed with a Hybrid Defect Detection (HDD) algorithm in order to automate the result analysis. The results yield a standard deviation of 0.25 m which provides an indication on the applicability of the proposed system to inspect small insulation defects for a length of 6 m cable bundle.
Project overview

Problems in aircraft wiring

- Aging of wires (due to environmental & operation conditions).
- Arcing.
- Difficult to access certain part of the wire (i.e. not exposed).
- Massive cable looms.

Proposed solution.

- Feasibility study for novel wiring inspection technique based on the use of Ultrasonic Guided Wave (UGW).
- Wires act as wave guides.
- Insulation damage will be characterized by defect detection algorithm.

Typical inspection of wiring

Method: Visual inspection

- Prone to error
- Need full access of wire
- Accidentally causing damage
- Only to test metallic core
- Complexity increases due to scalability

Method: Pulse Arrested Spark Discharge
(Ref: Astronics test system)

- Suitable only for fibre optic cable
- Complex data interpretation

Method: Infrared thermography
(Ref: Infrared imaging services LLC)

- Only to test metallic core
- Need full access of wire
- Complexity increases due to scalability

Method: Optical Time Domain Reflectometry
(Ref: KITCO System)

- Suitable only for fibre optic cable
- Only to test metallic core
- Complexity increases due to scalability

Method: Frequency Domain Reflectometry (FDR)
(Ref: MOHR System)
Introduction on Ultrasonic Guided Wave (UGW)

• Also known as Long Range Ultrasonic Test (LRUT)
• Typical operating frequencies around 10 – 100 kHz

An example of ultrasonic guided wave testing performed on a pipe using Teletest System.

Numeral modelling software: Finite Element Method (FEM)

• COMSOL® Multiphysics was used to validate the work performed in disperse® and model complex geometry (i.e. insulation/multiple cores).
• COMSOL® is an FEM based software which subdivides a complex geometry domain into several elements, and provides approximate solutions to Partial Differential Equations.
Cont. FEM

- Eigenfrequency analysis** used to determine natural frequencies and mode shapes using COMSOL.


Governing equation:

\[
\nabla \cdot \left( -c_a \nabla u - \alpha u \right) + \beta \nabla u + \alpha u = \lambda_{eigen} d_a u - \lambda_{eigen}^2 e_a u
\]

- Eigenfrequencies \( f_{eigen} \) in the structural mechanics field is related to the eigenvalue \( \lambda_{eigen} \) returned by the solver through:

\[
 f_{eigen} = \frac{\text{Imag}(\lambda_{eigen})}{2\pi}
\]

- Input parameters for the material properties that are necessary for COMSOL model:
  - Density, Poisson’s ratio & Young’s Modulus

Cont: Modelling Benchmark (FEM)

- Wire diameter: 2.4 mm
- Fixed constrained on the edge boundaries
- E = 110 GPa
- \( \nu = 0.35 \)
- \( \rho = 1700 \text{ kg/m}^3 \)
  - Tetrahedral mesh.
  - No. of elements: At least 10 elements per wavelength (max. element size = 8 \times 10^{-12}).
  - Freq sweep: 10 kHz to 200 KHz.
Cont: Results for the modelling Benchmark (FEM)

Post processing of COMSOL® results to obtain dispersion curve.

\[ \lambda = \frac{L}{n} \]

\[ c = f\lambda \]

- Longitudinal mode @ 21341 Hz
- Flexural mode @ 21054 Hz
- Torsional mode @ 23089 Hz

Dispersion curve data between COMSOL® and Disperse® agree well for our application!

Transitory analysis (FEM)

Source: 16 kHz, 5 cycle sine hanning window.
Simulation time: 0 – 0.6 ms (steps: 6µs)
Time to compute: ≈ 45 mins.
Transducer holder design (prototype)

- Adjustable compression
- Non-conductive material (around transducers).

Ref: http://www.smart-material.com/MFC-product-main.html

Hardware

Safewire system testing on bundle of cable

Experiment setup

Cont. Safewire system testing on bundle of cable

End of 6 m cable loom

Cross section of cable (55D0211-10-9, AWG size 10)

Material of cable illustrated using 55D0211-22-9, AWG size 22)
Slit defect at 4.5m (Defect 2) on wire 1

Quarter slit (insulation) defect at 4.5 m (i.e. defect 2)

Cross-section of wire showing the insulation defect segments

Defect detection algorithm using Hybrid Defect Detection (HDD)

Row PE data

Baseline subtraction

Anti cross-correlation

HDD

Results showing for 13 kHz
Green line: Signal for defect-free (baseline)
Red line: Signal for defect 2

Developed by project collaborator (CERTH)
Hybrid Defect Detection (HDD) metrics for the defect Slit at 4.5 mm using channel 2 computed at each single frequency.

Defect detection algorithm using Hybrid Defect Detection (HDD)

Level 2 HDD data fusion termed as Combined HDD (CHDD)
Combined Hybrid Defect Detection (CHDD)

Final result clearly shown the defect at ca. 4.58 m

Larger slit defect at 5.5 m on wire 2

Standard Deviation,

\[
\sigma = \sqrt{\frac{\sum (\text{Deviation}^2)}{n-1}}
\]

\[\sigma = \text{ca. } 0.25 \text{ m}\]

Final result clearly shown the defect at ca. 5.75 m
Conclusions

i) Feasibility study of utilizing UGW for inspection of insulation defect on aircraft cable (type 55D0211-10-9, AWG size 10) in a wire bundle has been performed.

ii) Numerical studies using Finite-Element Method (FEM) have been used to study the frequency and transient characteristics on the modes of wave propagation in wire structures.

iii) UWG system prototype have been developed based on commercially available Macro Fibre Composite (MFC) transducers.

iv) UWG is well applicable to detect the defect (small slit) on the insulation for a representative aircraft cable bundle of length 6m.

v) According to these results, insulation defect can be distinctively observed with HDD algorithm. Standard deviation calculated to be ca. 0.25 m for a 6 m cable length inspection.

Future work

i) To investigate different types and extended length of aircraft cable loom.

ii) A better understanding of the influence of multiple insulation defects at different locations in the wire.

iii) Investigate further defect detection algorithm to improve accuracy on defect localization

iv) To investigate different mode of testing operation such as online condition monitoring to improve reliability of results.

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Thank You!!

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Safewire project website: http://www.safewire.eu