Multi-element piezo-composite transducers for structural health monitoring

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Outline

- Short company presentation
- Introduction to structural health monitoring and the AISHA II project
- Lamb waves and array transducers
- Development of piezo-composites
- FEM modelling
- Integration and testing of array transducers
- Conclusions and outlook
Meggitt Sensing Systems

Meggitt Avionics
Flight Deck Avionics

Ferroperm Piezoceramics
Piezoelectric Components

Insensor®

PIHER
Automotive Potentiometers

Wilcoxon Research
Industrial Sensors

Endevco
Acceleration/Pressure Sensors

Sensorex
Displacement Sensors

Vibro-Meter
Aerospace Sensors

MEMS
Meggitt Electronics Micro Structures

Structural health monitoring
Structural health monitoring

- A collective term for advanced technologies using sensor networks for monitoring of structures of high importance
  - Bridges
  - Buildings
  - Aircraft
- For aircraft, SHM is closely linked to the Maintenance, Repair and Overhaul schedule
  - Light maintenance (A-check, duration < 24 h, interval 2 months)
  - Base maintenance (C- and D-checks, duration 1 – 5 weeks, interval 2 – 10 years)
- Main benefits of SHM:
  - Cost savings by reduction of inspection costs and possible weight reduction in the design phase
  - Enhancement of safety by more frequently applied automated inspections
  - Increase of passenger throughput by reduction of maintenance time and by better maintenance planning

AISHA II project

- Aircraft Integrated Structural Health Assessment II
- FP7 Theme TRANSPORT (incl. AERONAUTICS)
- 5 full-scale parts selected as cases for SHM:
  - fatigue cracks in slat tracks of Airbus A320 and A380
  - impact damage in the tail boom of the helicopter Eurocopter EC135
  - fatigue cracks in the helicopter tail boom of a MIL Mi-8
  - corrosion in floor beams of Airbus A340
  - fatigue damage in doubler repairs of Airbus A340
- Focus on hot spots
- Examples of sensing technologies:
  - piezoceramic transducers for ultrasonic Lamb waves
  - EMAT sensors for ultrasonic Lamb waves
  - electrochemical sensors
  - optical fibre sensors
AISHA II full-scale parts
AISHA II consortium

- Katholieke Universiteit Leuven, MTM & ATF (BE)
- METALOGIC nv (BE)
- Deutsches Zentrum für Luft- und Raumfahrt, DLR (DE)
- CEDRAT Technologies SA (FR)
- EUROCOPTER - Marseille (FR)
- Riga Technical University (LV)
- CENTRO DE TECNOLOGIAS AERONAUTICAS, CTA (ES)
- Meggitt Sensing Systems (DK)
- ASCO Industries nv (BE)
- Fraunhofer Institute for Manufacturing Technology and Applied Materials Research, IFAM (DE)
- Universität Leipzig (DE)
- LUFTHANSA Technik (DE)
- Vrije Universiteit Brussel (BE)
- University of the Basque Country (ES)
Lamb waves
Lamb waves

- A type of guided waves also known as plate waves
- For frequencies in the range of a few hundred kilohertz, only the lower-order Lamb waves, $S_0$ and $A_0$, will be significant
- $S_0$ and $A_0$ are called the symmetric and antisymmetric modes, respectively
- $S_0$ is the fastest of the two and the one most sensitive to defects
Lamb waves for SHM

- The main challenge in using Lamb waves for SHM is the multitude of interfering echoes leading to a heavy burden of signal processing.
- A convenient solution is to apply mode and direction selectivity by means of a linear array piezoelectric transducer.
- In the linear array, the elements are separated by a fixed pitch.
- By simple signal processing, waves propagating at different velocities can be distinguished:
  - Undesired waves are filtered out by virtually creating destructive interference.
  - The interesting wave is amplified by virtually creating constructive interference.
- Mode selection delay:
  \[ t_{\text{delay}} = \frac{\text{pitch}}{\text{velocity}} \]
Piezo-composite transducers
2-2 composites as linear arrays

- Composite transducers have very interesting acoustic properties (damping of transverse modes, possibility of electronic scanning, focusing and beam steering)
- 2-2 composites have a multilayer structure (2D connectivity for both the ceramic (active) phase and the polymer (passive) phase)
- Ferroperm soft PZT (Type 100) has been chosen as the piezoceramic
Characterisation of 2-2 composites, 1st generation

- Impedance spectrum shows difference seen between inner and outer elements

**1G, outer element**

**1G, inner element**
FEM modelling
FEM modelling of 2-2 composite

- An FEM model has been set up in COMSOL Multiphysics in order to investigate the uniformity of response over the piezoceramic elements

- Dimensions of composite part:
  - piezoceramic: 8 elements of $L$ 30 mm * $W$ 0.55 mm * $h$ 3 mm
  - polymer: 7 elements of $W$ 0.55 mm
  - wrap-around electrode not considered

- Model definition and input data (preliminary):
  - piezoceramic: standard soft PZT
  - polymer: density 930 kg/m$^3$, elastic modulus 1 GPa, Poisson ratio 0.33
  - the part is fixed on the bottom side (~ glue with ideal clamping)
  - rectangular meshing used (34 * 30 * 4 elements)
Static displacement

- A plot of the displacement shows higher values at the ends of the element.
- Similarly for outer elements (z-displ., end view and central cross section).
2-2 composites manufactured, 2\textsuperscript{nd} generation

- A different polymer was selected
- A number of improvements were made to the process
- 2\textsuperscript{nd} generation devices show improved quality and uniformity
Characterisation of 2-2 composites

- Impedance spectrum shows enhanced resonance
Reproducibility of 2-2 composites

- Resonance very reproducible between elements

3G-14, all elements

3G-15, all elements
Integration and testing of array transducers
Integration and testing

- Arrays mounted with flex PCB by soldering
- Two arrays glued to an aluminium plate
- Both arrays connected to a dedicated SHM electronics module
  - High-frequency excitation (bandwidth up to 2 MHz)
  - PULSECHO functionality (emission and reception on same piezoelectric patch)
  - 4 channels per daughter board
Selective reception

Selective reception on A0 mode

Amplification of A0 mode

Amplitude [V]

Time [s]

No mode selection
With selective reception

Mode and direction selection

Selective emission and reception of the A0 mode

Attenuation of S0
Conclusions and outlook

- Ultrasonic inspection using Lamb waves is an important method for SHM.
- By using arrays instead of single patches it is possible to perform mode selection in a very efficient manner.
- 8-element linear arrays for SHM have been manufactured successfully in the form of 2-2 composites, obtaining a high degree of reproducibility.
- Mode selection in reception of either the $S_0$ or $A_0$ mode has been demonstrated.
- The selectivity of either mode can be further enhanced by combining selective emission and selective reception.
- In the near future, similar 8-element arrays in the form of thick films will be tested.
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