HEALTH MONITORING OF AIRCRAFT
BY NONLINEAR ELASTIC WAVE SPECTROSCOPY

AERONEWS

EC SIXTH FRAMEWORK PROGRAMME
PRIORITY 4: AERONAUTICS AND SPACE
SPECIFIC TARGETED RESEARCH: AST3-CT-2003-502927
PROJECT WEBPAGE: http://www.kuleuven-kortrijk.be/aeronews/
PROJECT COORDINATOR: Prof. KOEN VAN DEN ABEELE

Deliverable D13

Design and manufacturing of advanced smart aircraft components with integrated transducer and sensing systems, satisfying NEWS application demands

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Period covered: March 1, 2004 to February 29, 2008

Date of preparation: April 15, 2008

Start date of project: March 1, 2004 Duration: 4 years (February 29, 2008)

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Project coordinator organization name: KULeuven
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Partners: UNOTT, VUB, ASCO, GIP-U, NDTE, IZFP, UNI-Na, BR&TE, UNEXE, UNIVBRIS, CU, CSIC,

Final version (confidential)

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1. Overview of the tasks, deliverables, and milestones of WP3

WP3: Adaptation of smart transducers and sensors for NEWS

Workpackage leaders: ZD Rpety-Diagnostic Centre, Czech Republic (DAKEL)
University of Nottingham, UK (UNOTT)
Partners: VUB, ASCO, GIP-U, NDTE, IZFP, UNI-Na, CSIC, BR&TE, UNEXE, UNIVBRIS, CU

The **overall objectives** of WP3 are:

- Survey of currently available transducers and smart sensors which can be used for continuous health monitoring and choice of a limited number of transducer candidates.
- Extend existing methods of transducer integration for application in the NEWS applications into new design of smart components with integrated sensing devices.
- Develop methods for rapid experimental prototyping of transducer configurations in NEWS systems.
- Make a fully functioning sensor and excitation system with smart transducers that can be used in a noisy environment (suitable for in-flight operation).

To enable these objectives to be achieved sub-tasks, deliverables, and milestones were defined.

Sub-tasks and Milestones:

- **WP3.1:** Analysis of existing transducers. Choice of new excitation and sensing devices (months 0-6 (36)),
- **WP3.2:** Design of transducer systems and manufacturing of smart aircraft components (months 0-48),
- **Milestone 4:** Report the decision and integration of the most appropriate sensor technology including smart sensor design for selected aeronautical components
- **WP3.3:** Testing of complex structures (months (12)24-48)

Deliverables and Milestones:

- **D11:** Description, critical evaluation and adaptation of available smart transducers on the market. (delivery dates at months 6 and 36),
- **D12:** Requirement identification, adaptation and development of an advanced smart transducer package for implementation in the complete inspection system, satisfying the NEWS application demands (delivery dates at month 36, milestone 4),
- **D13:** Design and manufacturing of advanced smart aircraft components with integrated transducer and sensing systems, satisfying NEWS application demands (delivery dates at months 36-48)

2. Overview of Deliverable 13 (D13)

D13: ***Design and manufacturing of advanced smart aircraft components with integrated transducer and sensing systems, satisfying NEWS application demands***

D13 is due in month 48 and the bulk of the work related to this deliverable started being a major activity of WP3 after month 24.

D13 is a deliverable within WP3.3 whose objective concerns the development optimisation of the designed transducer system.

The optimisation task in WP3 includes:

- Concept verification with feedback from WP4.
- Optimise the transducers system design and adjust the NEWS equipment to various conditions using novel experimental procedures.
- Optimise the transducer and sensor requirements and placement in connection with recommendations from WP2.

This WP involves later stage engineering of the concepts developed earlier in this WP. All partners involved in WP3.2 will develop optimum technologies for permanent mounting/integrating at particular aircraft components specified in WP1.1 to cover a wide spectrum of critical nodes. Optimisation design reflects specific structural requirements from WP1.4, WP2 and WP4 and possible in-flight operation

Outputs from WP3.2 , WP3.3, WP4 and WP5 formulate the requirements with the proposals of solutions, that is described in D13

The final result of this work package aims at providing a methodology for sensor/transducer selection and placement together with a standardised set of sensors for NEWS techniques. This encompasses fabricating and embedding transducers to make smart aeronautical structures for on-ground health monitoring and the use of external sensors/transducers to precise defect localisation and smart NDE. The selection and optimization methodology is fed by the studies conducted in WP1, WP2 WP3.1 WP3.2 and WP4.

Section 3 of the present document describes the efforts of partners on developing service transducers. While working on the project, the AERONEWS partners decided that in addition to the built-in transducers it is necessary to develop a family of transducers for service measuring.

Section 4 presents the work done in producing transducers suitable for permanent mounting on components.

Finally, section 5 summarises the results presented in the previous sections.

3. Service Transducers

While working on the project, the AERONEWS partners decided that in addition to the built-in transducers it is necessary to develop a family of transducers for service measuring

There are following requirements to be met for these transducers:

- simple attaching to measuring object
- wearproof system of transducers
- small dimensions, small weight
- adapted transducers to some specific objects (curved surfaces)
- transducers with minimal influence on the measuring objects
- simple connection to measuring devices
- low cost of measuring units
- interference imunity
- aging resistance

DAKEL developed, produced, and presented several types of adapted transducers with active piezoelectric elements.

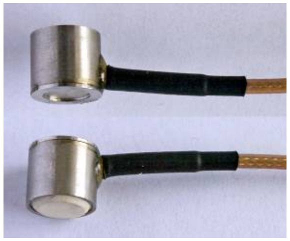
Model **IDK 09** is a small wideband transducer, suitable for active low power excitation and high sensitivity scanning in the frequency range 20 kHz up to 1 MHz. Measuring system is electrically insulated from the measuring object. The unit can be connected to the measuring object by an adhesive bonding.

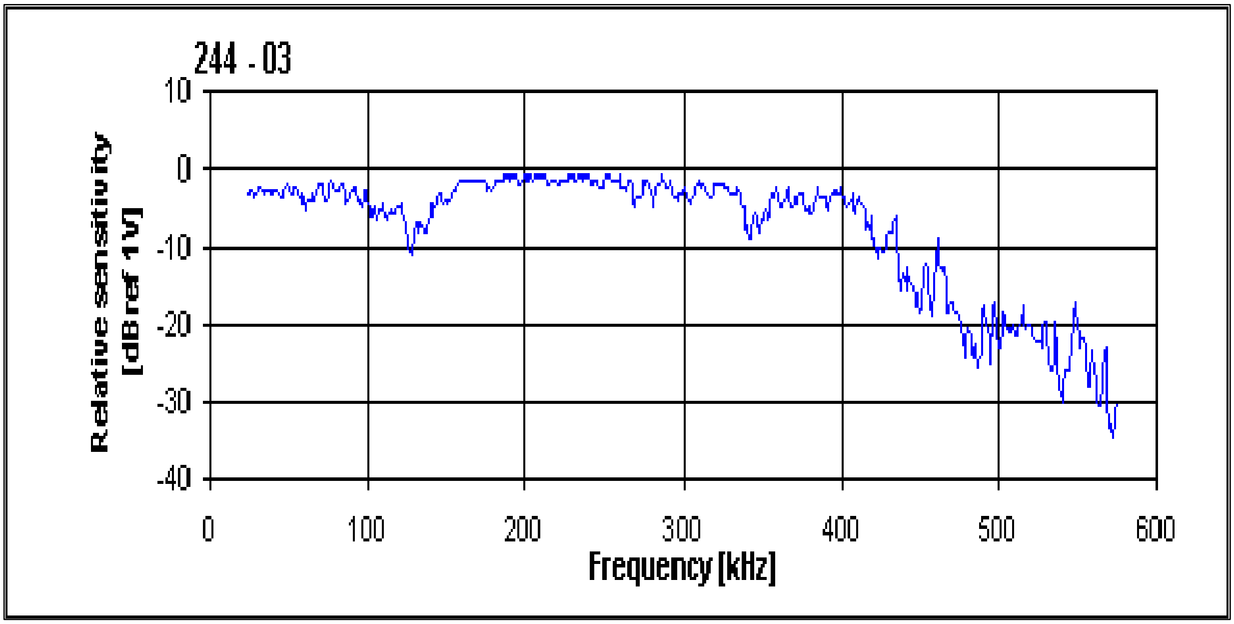
Model **MDK 13a** is a wideband transducer, suitable for active low power excitation and high sensitivity scanning in the frequency range 20 kHz up to 1 MHz. The unit is self-acting on magnetic steel or on a glued metal foil.

Model **MDK 17a** is a wideband transducer, suitable for active medium power excitation and high sensitivity scanning in the frequency range 20 kHz up to 1 MHz. The unit is self-acting on magnetic steel (bigger pressure force than MDK13a) or on a glued metal foil.

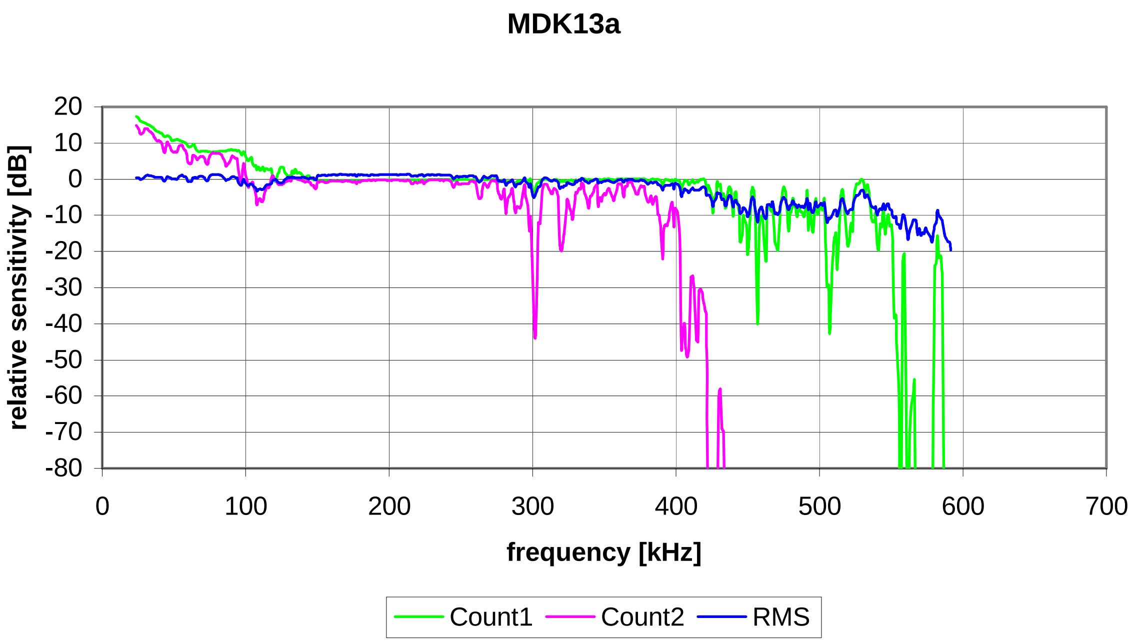
Model **MDKR xx** is a wideband robust transducer, suitable for active medium power excitation and high sensitivity scanning in the frequency range cca 20 kHz up to 1 MHz. The unit is self-acting on magnetic steel. This model was developed for measuring objects with a circular contact surface with the diameter xx.

Model **MDK 14AS** is a small wideband high sensitivity sensor for the frequency range 20 kHz up to 1 MHz. This unit contains a 35 dB preamplifier. The low profile of the sensor is suitable for build-in applications. Measuring system is electrically insulated from measuring object, the unit can be connected to measuring object by an adhesive bonding.

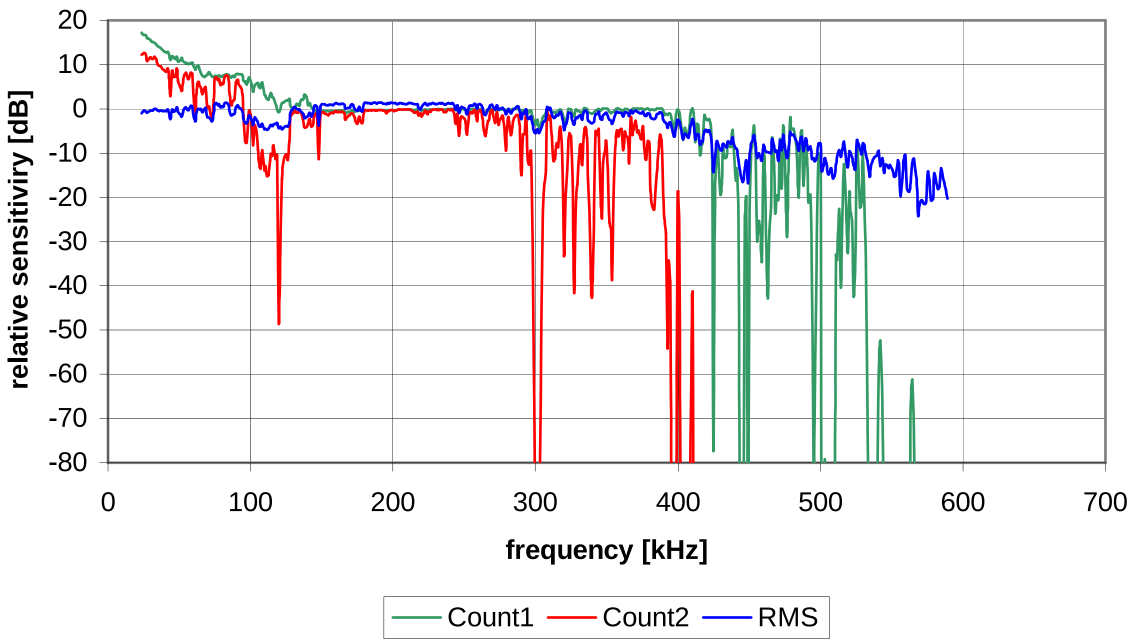
MODEL	**DAKEL IDK-09**	
 	Dimension	Diam. 9 mm, height 9 mm
	Case material	stainless steel
	Wear plate	Alumina sintered, contact area diam. 6mm
	Output	Coaxial cable diam.: 1.7 mm BNC connector
	Piezoceramic material	DAK 432
	Temperature range	DAK 432 … - 20 to + 75 ^{o}C
	Application	Laboratory using
		External coaxial impedance converter & preamplifier.
	Mounting methods	Glued joint

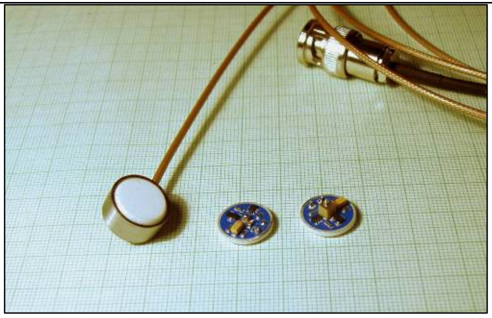


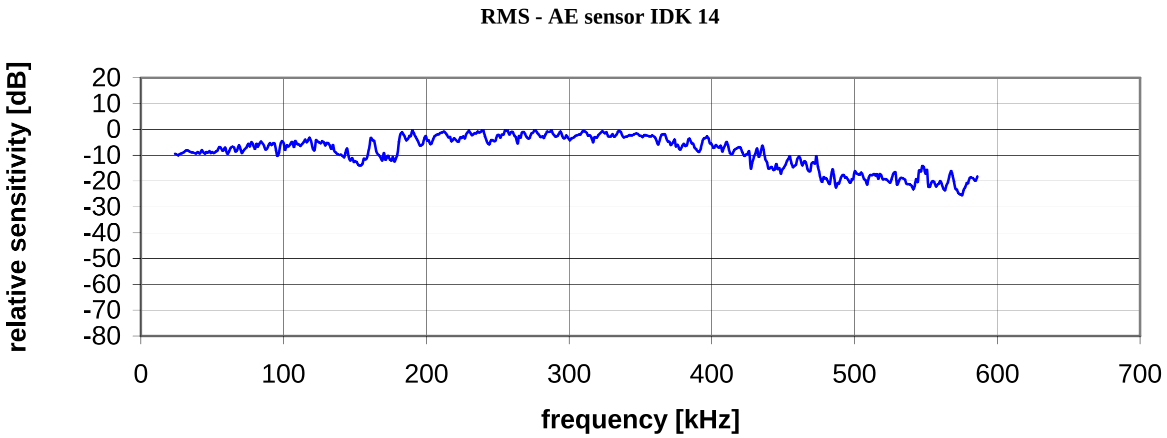
MODEL	**DAKEL MDK 13a**	
	Dimension	Diam. 13 mm, height 11 mm
	Case material	stainless steel
	Wear plate	FeNdB magnetic disc, contact area diam. 12mm
	Output	Coaxial cable diam.: 1.7 mm BNC connector
	Piezoceramic material	DAK 432
	Temperature range	DAK 432 … - 20 to + 75 ^{o}C
	Application	Laboratory and industry using
		External coaxial impedance converter & preamplifier.
	Mounting methods	self-acting on magnetic steel



MODEL	**DAKEL MDK17A**	
	Dimension	Diam.: 17 mm, height 12,5 mm
	Case material	Stainless steel
	Wear plate	FeNdB magnetic disc, contact area diam. 15mm
	Output	Coaxial cable diam.: 1.7 mm BNC connector
	Piezoceramic material	DAK 432
	Temperature range	DAK 432 … - 20 to + 75 °C
	Application	Laboratory and industry using
		External coaxial impedance converter & preamplifier.
	Mounting methods	self-acting on magnetic steel

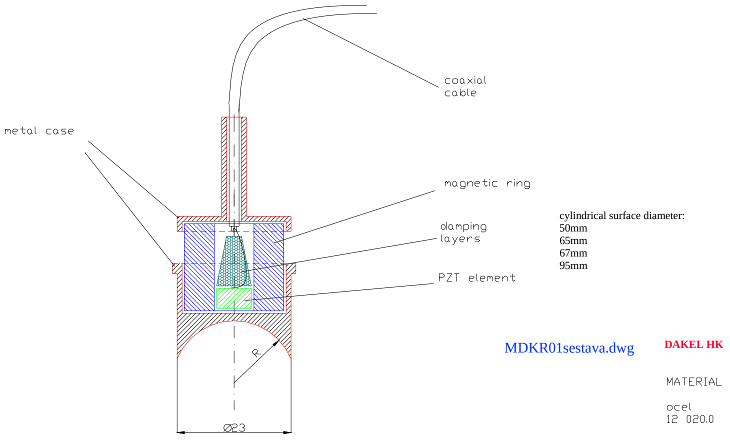


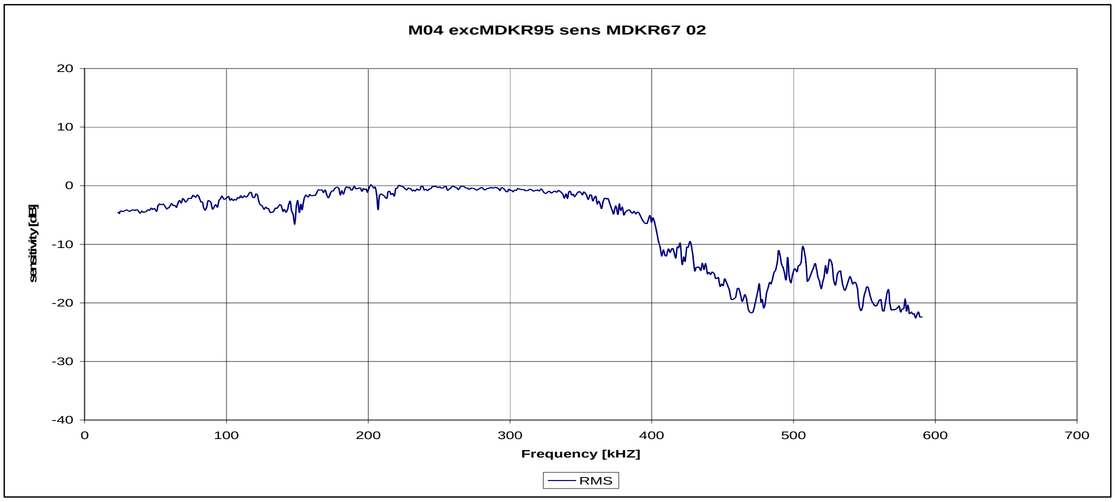
MODEL	**DAKEL IDK-14**	
	Dimensions	Diam. 14 mm, height 6 mm
	Case material	Stainless steel
	Contact plate	Alumina sintered , contact area dim. 11mm
	Output	Coaxial cable diam.: 1.7 mm BNC connector
	Piezoceramic material	DAK 274 DAK 15 B
	Temperature range	- 20 … + 75 ^{o}C
	Application	Laboratory and industry using
		Internal impedance converter & preamplifier cca 35 dB
	Mounting methods	Glued joint, magnetic holder



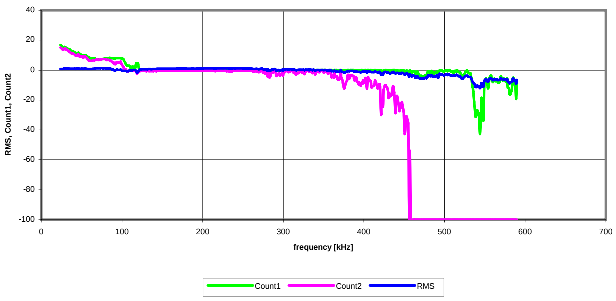
MDKR xx Sensor &. Exciter

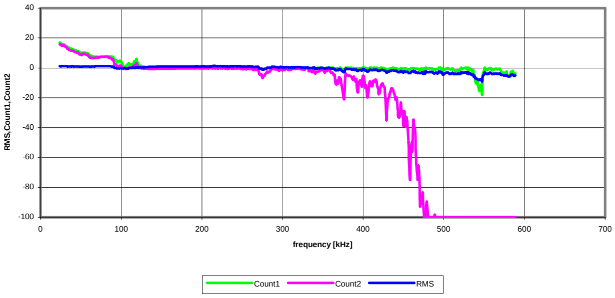
- piezoceramic disc - PZT material DAKEL - class 200
- dimension of PZT element : diameter 4 mm, thickness 3 mm
- capacity of piezoelement : 66 pF, diel. loss : 160E-4
- output - coaxial cable - diam. 3 mm – BNC connector
- metal case – stainless steel - diam. 23mm, thickness 35 mm
- wear plate – Steel contact plate with curved wall :
    - -MDKR50 - contact diam. 50mm
    - -MDKR65 - contact diam. 65mm
    - -MDKR67 - contact diam. 67mm
    - -MDKR95 - contact diam. 95mm
- damping layer
- recommended length of cable : max 1m
- external coaxial impedance converter & preamplifier ASII
- mounting methods - self-acting on magnetic steel





Experimental Comparison of the Magnetic Case Sensor MDK and the Standard DAKEL Sensor IDK09


IDK 09

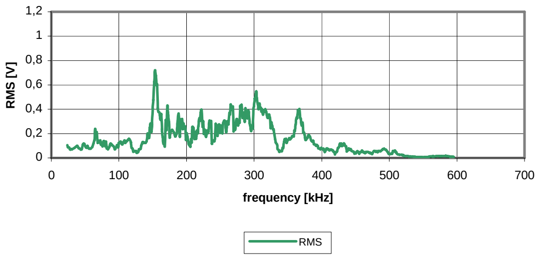

MDK13a

Measuring configuration
- duralumin block 300x10x40 mm
- exciter – MDK17a, sinusoidal sweep signal
- sensor : MDK13a,
- sensor IDK09 (glued)
- contact plate – Permalloy 76 foil 0.2 mm thickness
- coupling medium – Ultragel II

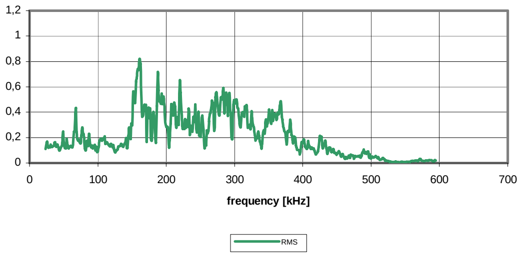
Experimental Verification of the US Signal Transmission Bandwidth Through the Steering Actuator Bracket

IDK09

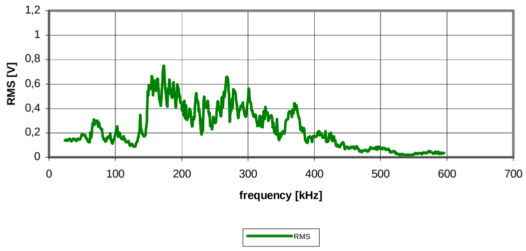
IDK09 exciter B sensor A



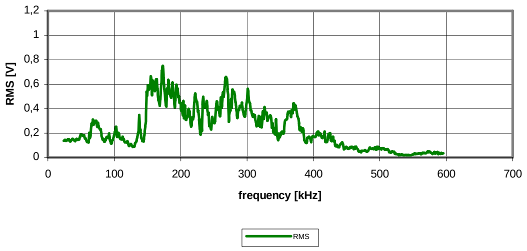
IDK09 exciter C sensor A



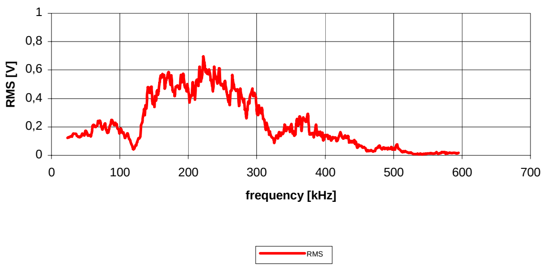
IDK09 exciter C sensor B



IDK09 exciter B sensor C



IDK09 - IDK09 face to face

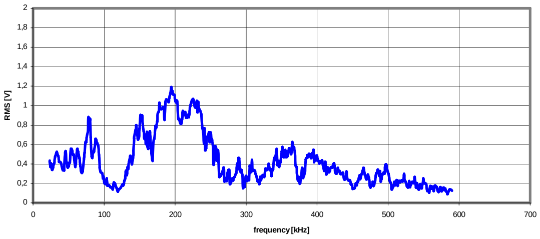


Measuring conditions:
Exciter – IDK09, glued by cyanoacrylate
Electrical source – continual sine wave, Voltage – 0.6 V RMS, wobbled frequency 20-600 kHz
Coaxial cable 1 m,
Coaxial preamplifier 35 dB,
XEDO voltage gain 0 dB
Measuring device – DAKEL XEDO 5, evaluation by DAKEL DAEMON SW

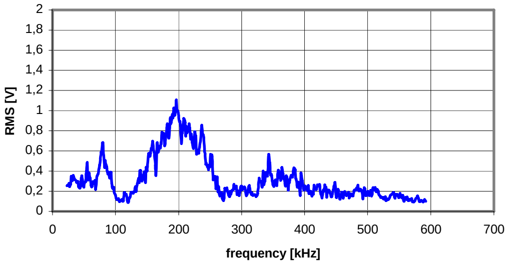
Experimental Verification of the US Signal Transmission Bandwidth Through the Steering Actuator Bracket

MDK13a

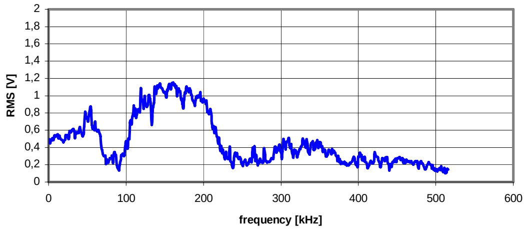
MDK13a exciter B sensor A



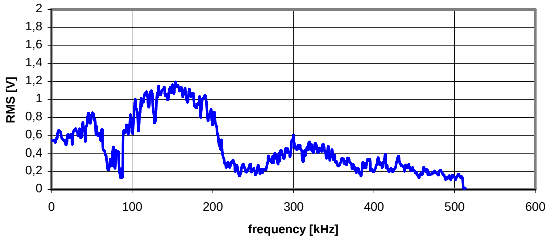
MDK13a exciter C sensor A



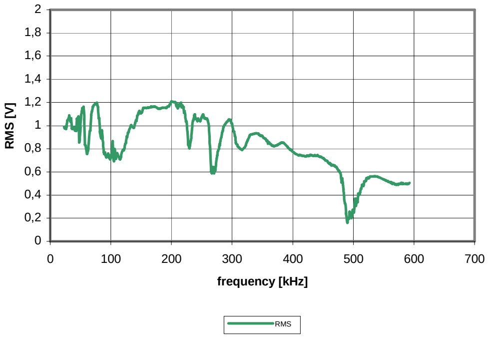
MDK13a exciter B sensor C



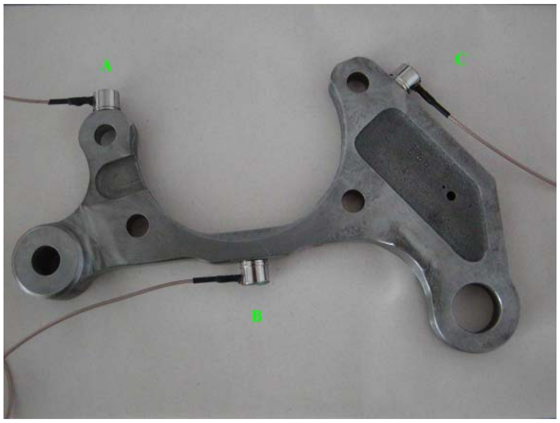
MDK13a exciter C sensor B



MDK13a - MDK13a "face to face"

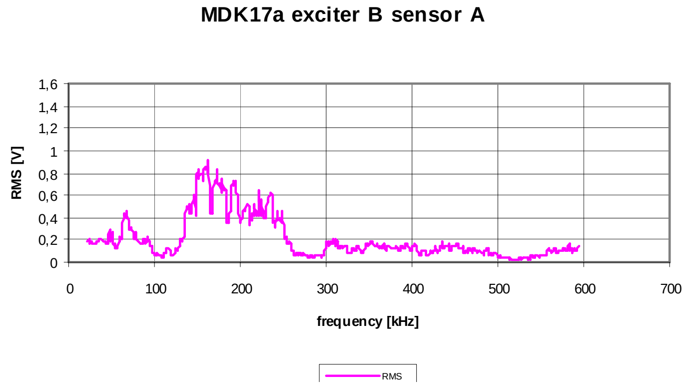


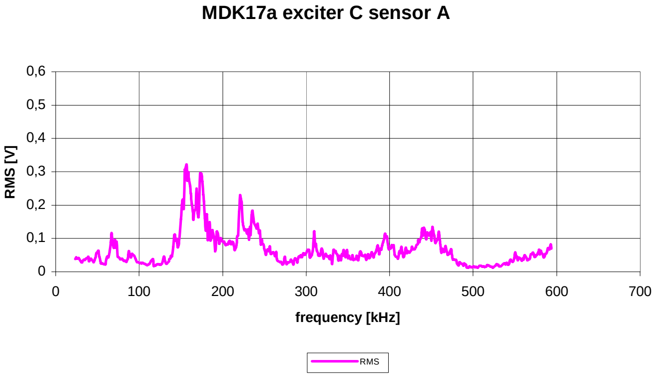
Measuring conditions:
Exciter – MDK13a
Electrical source – continual sine wave,
Voltage – 0.6 V RMS, sweeped frequency 20-600 kHz
Coaxial cable 1 m, coaxial preamplifier 35 dB,
XEDO voltage gain 0 dB
Measuring device – DAKEL XEDO 5,
evaluation by DAKEL DAEMON SW

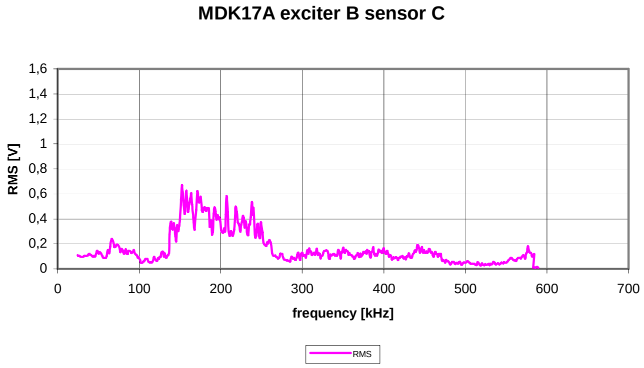


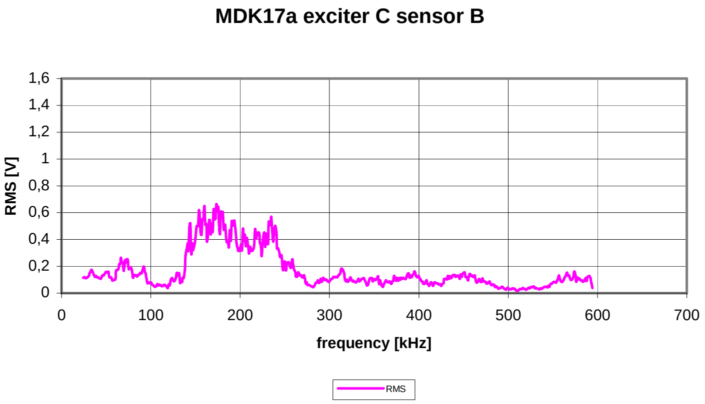
Experimental Verification of the US Signal Transmission Bandwidth Through the Steering Actuator Bracket

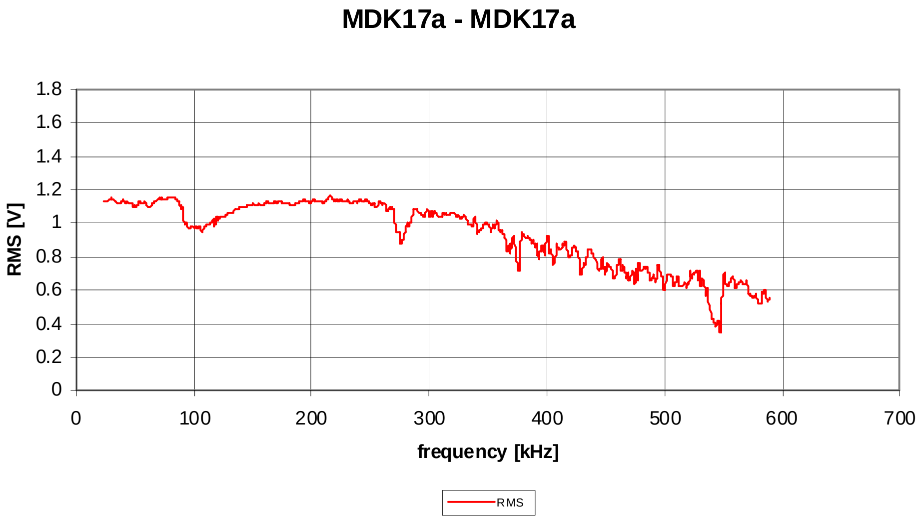
MDK17a


MDK17a exciter B sensor A


MDK17a exciter C sensor A


MDK17A exciter B sensor C

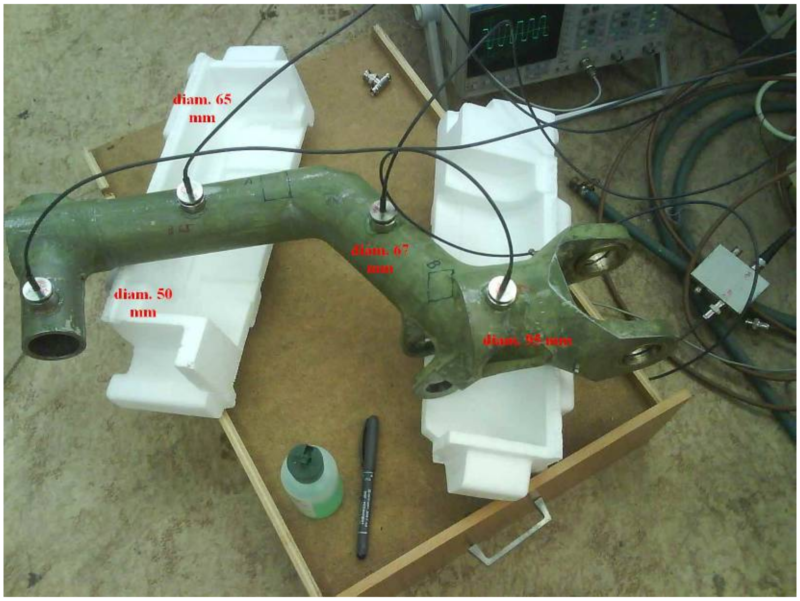


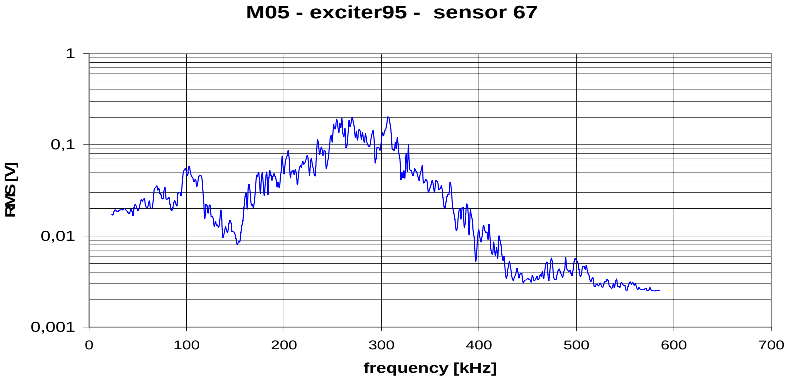


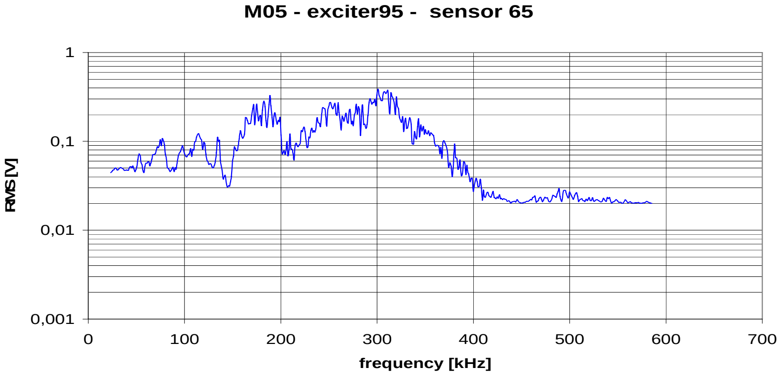
Measuring conditions:
Exciter – MDK17a
Electrical source – continual sine wave, Voltage – 0.6 V RMS, wobbled frequency 20-600 kHz
Coaxial cable 1 m,
coaxial preamplifier 35 dB,
XEDO voltage gain 0 dB
Measuring device – DAKEL XEDO 5, evaluation by DAKEL DAEMON SW

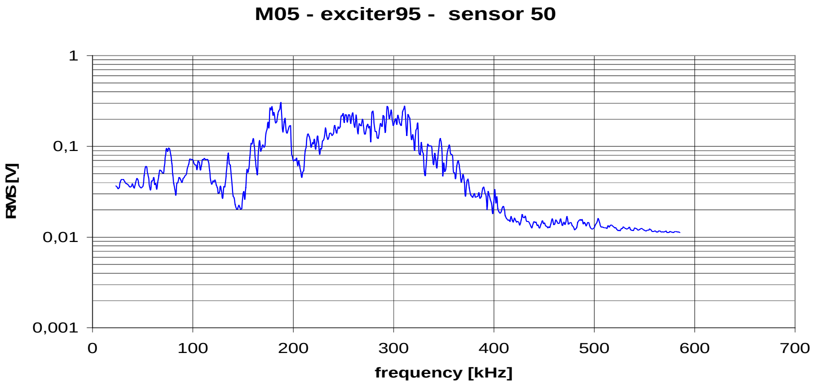
Experimental Verification of the US Signal Transmission Bandwidth Through the Fork Leg

EXCITER MDKR95-01 sensors MDKR67-01, MDKR65-01, MDKR50-01









Measuring conditions:
Exciter – MDKR95
Electrical source – continual sine wave, Voltage – 0.6 V RMS, sweep frequency 20-600 kHz
Coaxial cable 1 m,
coaxial preamplifier 35 dB,
XEDO voltage gain 10 dB
Measuring device – DAKEL XEDO 5, evaluation by DAKEL DAEMON SW

4. Permanent Transducers

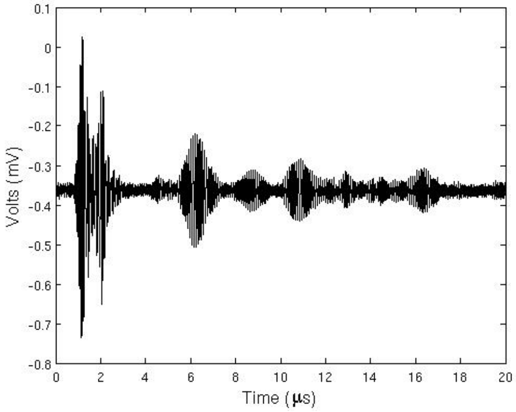
UNOTT - CHeap Optical Transducers (CHOTs)

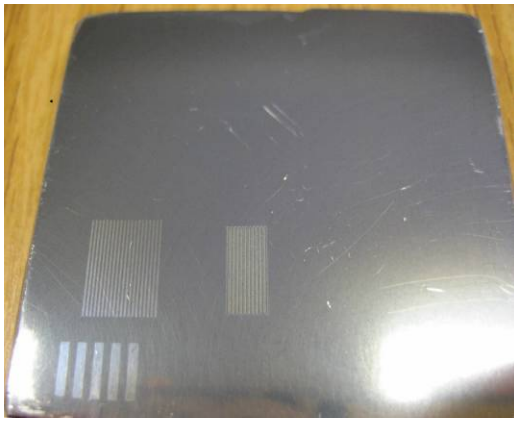
CHOTs (Cheap Optical Transducers) are an innovative ultrasonic transducer system developed by **UNOTT** which are optically activated both for generation (g-CHOT) and detection (d-CHOT). Lasers are used as actuators providing remote and couplant free operation. One of their many advantages is that they are low profile (minimal weight and size <1cm^2) allowing minimal impact to the inspected sample. They can be permanently attached to the sample to provide reliable and repeatable measurements. In addition, they have the potential of becoming very cheap.

The g-CHOT is used for generation and in essence it is a structure deposited, printed or somehow attached onto the surface of the sample By changing the geometrical characteristics of the CHOT structure one can control the mode and frequency content of the generated wave as well as its directivity.

Several examples of CHOTs have been fabricated. The manufacturing procedures used were either photolithography or laser etching. The substrates tested were made of BK7 glass, Fused Silica, Silicone Nitride and Aluminium.

One of the challenges with CHOTs is their application onto real samples. During the previous stages of the research we have shown their efficiency in glass samples and samples that are relatively small. The limitations were posed by the manufacturing (photolithography). During the last year we have been experimenting with testing of aluminium samples using CHOTs. We have set up a laser marking station that can "draw" structures with a resolution of 40μm. With this system we were able to produce g-CHOTs on aluminium samples. The difference in absorption required for the operation of the g-CHOT is provided by the fact that the laser etched section of the g-CHOT is more rough compared to the relatively flat and reflective surrounding material. Experimental results from a g-CHOT manufactured using this method is shown in Figure 1(a). The d-CHOT in this case was manufactured using photolithography but we envisage to overcome this step by manufacturing aluminium masks using the laser etching system, in which case the sample can go straight into the evaporator for the deposition of the d-CHOT. A picture of the manufactured sample is shown in Figure.1(b).





GIP-U - Piezoelectric disk embedment in composite samples

Piezoelectric disks furnished by Dakel's Company have been embedded into composite plate structures. Significant differences between electrical impedances measured before and after embedment show that the contact between the piezoelectric disks and the composite plate is well ensured. Further, the ability to generate and to receive Lamb waves is verified. Such a technique is thought to be a useful way to emit/receive acoustic signals from/at non-accessible locations, as soon as the piezoelectric inclusion (and also the electric wires) does not alter the safety.

In aeronautics, composite plane and curved structures are nowadays frequently used structures due to their weight and their interesting properties, in comparison with metallic structures. Further, the performances can be improved and adapted by adjusting the choice and the proportion of both the tissue and the surrounding matrix. In this work, the possibility to include piezoelectric disk in a composite plate structure is investigated. In the first part, five piezoelectric disks are embedded at various depths and in the second part, emission/reception tests are conducted with two disks embedded in the same plate.

Composite plate manufacturing process

The piezoelectric disks have been embedded in composite plates made of glass fiber tissue (300 g/m^2) and phenolic resin. Samples are done layer by layer (1/4 mm each). Circular holes are made in the tissues to match the disks across their thicknesses (1mm and 3mm). The plates are made manually at ambient temperature.

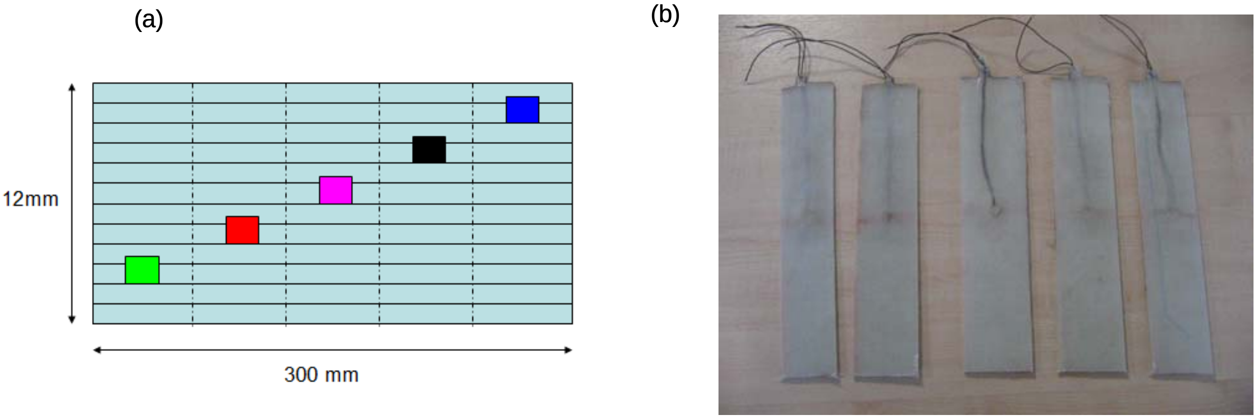


Figure 1

Embedment sensitivity

A first set of five plates (300x50x12mm^3) is manufactured. In each plate, a 1mm thick piezoelectric disk is embedded at a particular depth (Figs. 1a-b). The electric impedances of the disks are measured before and after embedment, showing a good reproducibility for any depth. A typical result is shown in Fig 2: both the first radial and thickness modes are observed. As typical effects of the load (embedment), the sensitivity is weaker and the peaks are enlarged.

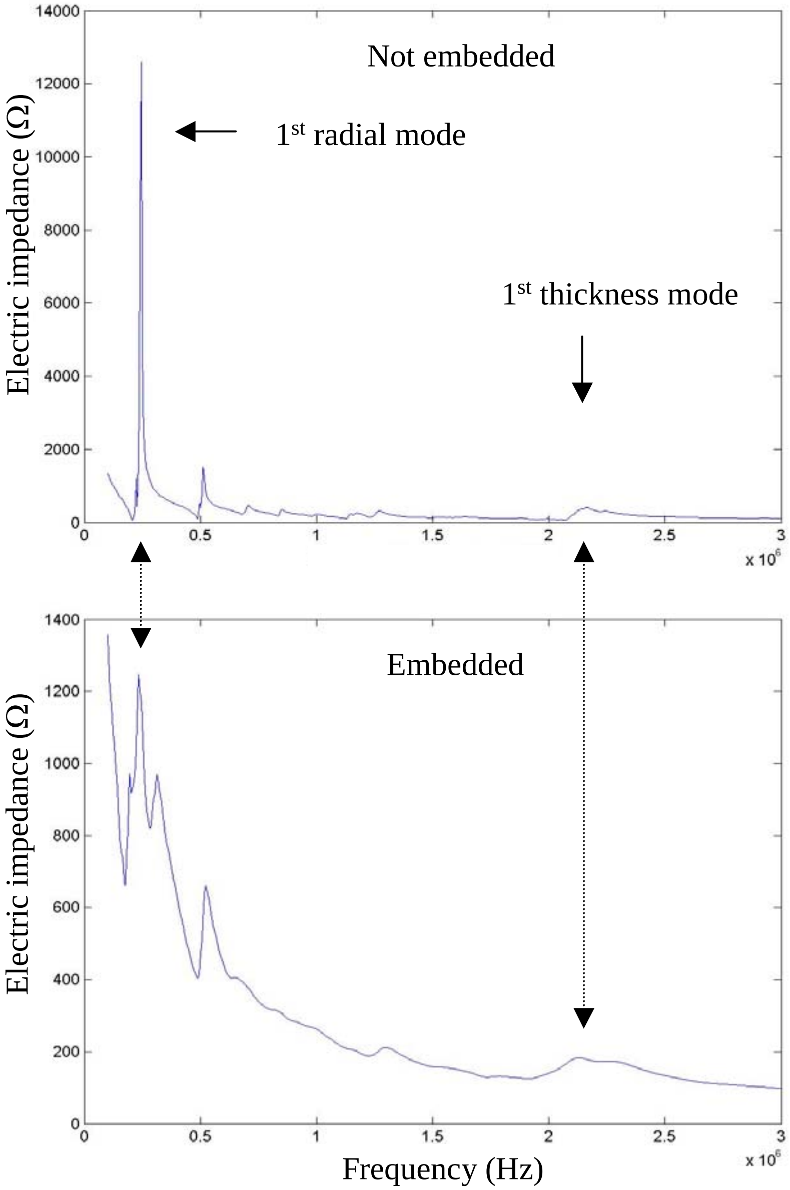


Figure 2

Emission and reception of acoustic signals

The second test concerns the ability to generate and receive acoustic signal using embedded piezoelectric disks. A plate ($500x500x8mm^3$) is made. Two 3mm thick disks (Fig. 3a) are embedded on the diagonal, at 200mm from opposite corners. The electrical wires are glued on the plate between the disks and the back corners (Fig. 3b). The finished plate with the coaxial connections is shown in Fig. 3d. The electrical impedances are displayed in Fig. 4. The main differences with Fig. 2 are due to the thickness of the piezoelectric element, leading to a shift of the resonance frequency of the first thickness mode, 700 kHz approximately.

The setup used to achieve the acoustic propagation test is shown in Fig. 5a. A short electric pulse is applied to one of the disks and a time domain signal is received by the second disk and turn into a spectrum by Fast Fourier Transform (Fig. 5b). It mainly highlights that waves transmitted through the plate are at frequencies far below the thickness mode. In the frequency range considered here, the weak attenuation during the propagation is not responsible for that. Rather, a too large distance to be covered by the wave generated by the thickness mode can explain the lack of signal around 700 kHz.

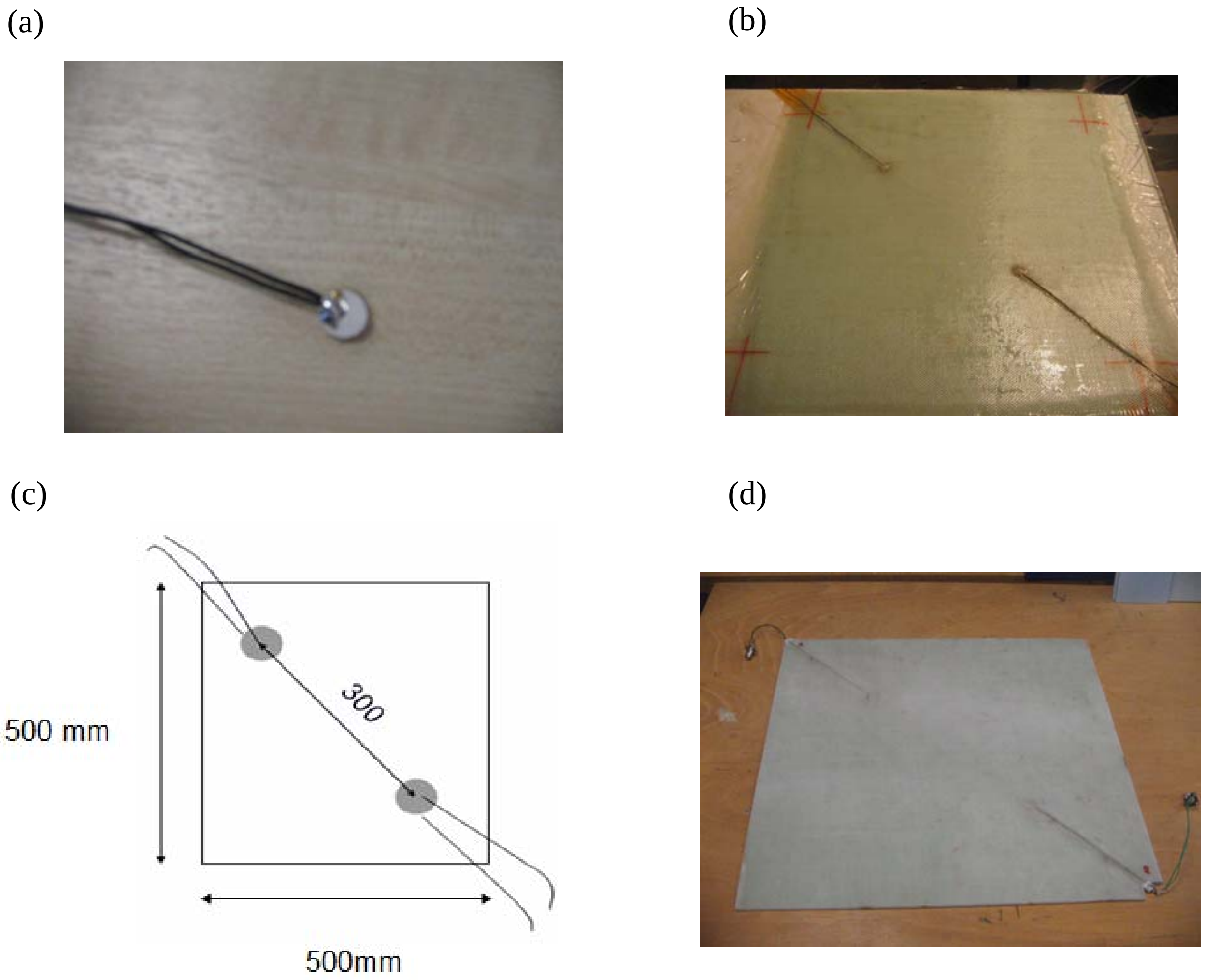
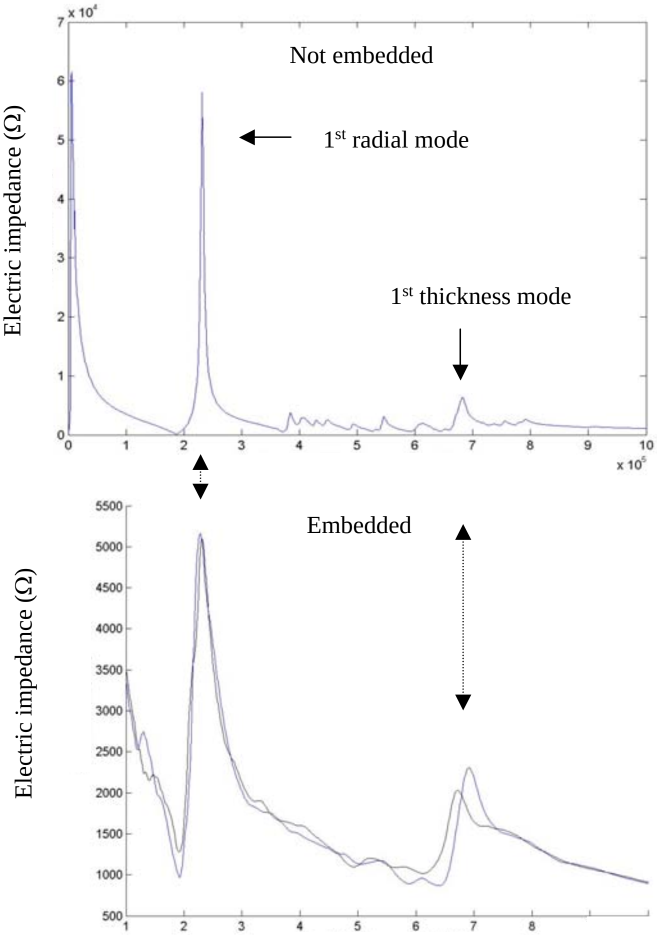
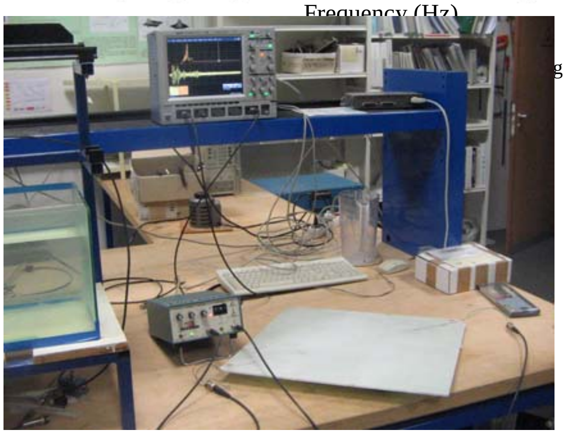


Figure 3


x 10⁴
Not embedded
1st radial mode
1st thickness mode
Electric impedance (Ω)
0
1
2
3
4
5
6
7
8
9
10
x 10⁵
Embedded
Electric impedance (Ω)
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
Frequency (Hz)



g (a)

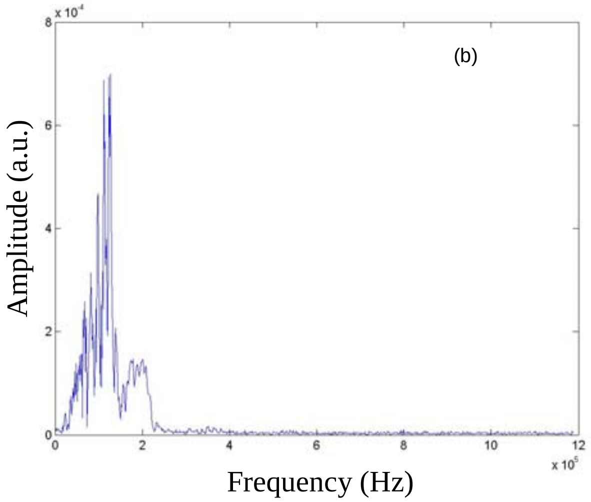

x 10⁻⁴
(b)
Amplitude (a.u.)
0
2
4
6
8
10
12
x 10⁵
Frequency (Hz)

Figure 5

Conclusions – Perspectives

This work shows that piezoelectric disks can be embedded into composite plates during the manufacturing process to obtain efficient acoustic coupling. Large propagation distances can be reached using the lowest radial vibration modes of the disk.

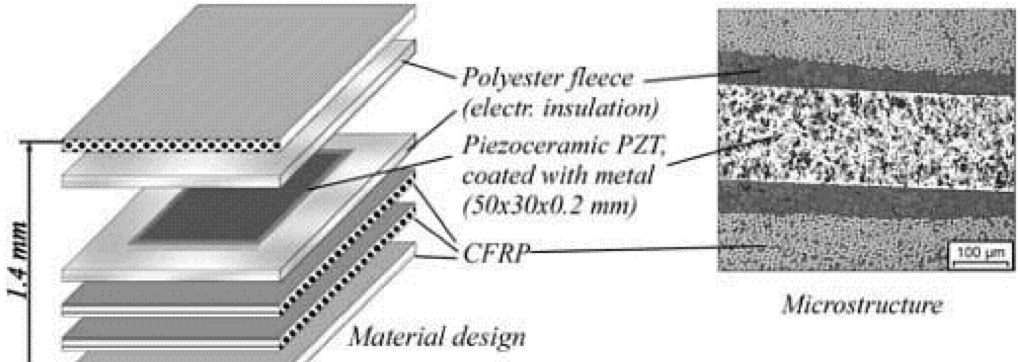
In the study, the depth of embedment does not perturb the coupling. However, fatigue tests on the five samples could bring crucial data concerning the behavior of the mechanical impedance breaking between the disk and the plate, for ageing samples.

EXETER University - associated embedded electronics

EMBEDDED TRANSDUCERS (SMART LAYERS)

The NEWS system can be realized by having transducers permanently embedded within the composite material making up the aircraft structure, the sensors and actuators can be either activated independently whilst the aircraft is in flight, or used in-conjunction with surface testing probes, when the aircraft is undergoing periodic ground tests.

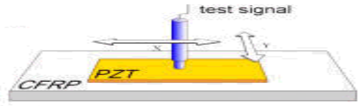
Techniques involving this principle are outlined from the following paper:-
Non-destructive Inspection of Smart Materials
Gerhard Mook, Juergen Pohl, Fritz Michel, Thomas Benziger
Institute of Materials Engineering and Materials Testing (IWW)
The Otto-von-Guericke-University, Magdeburg, Germany.



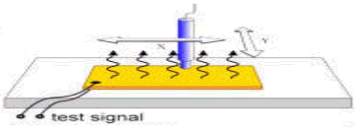
Material design

Microstructure

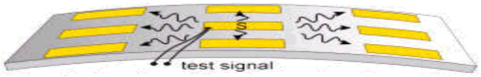
external transmitter, external receiver



internal transmitter, external receiver



internal transmitter, internal receiver



Adaption to the NEWS system, would involve either of the following:-

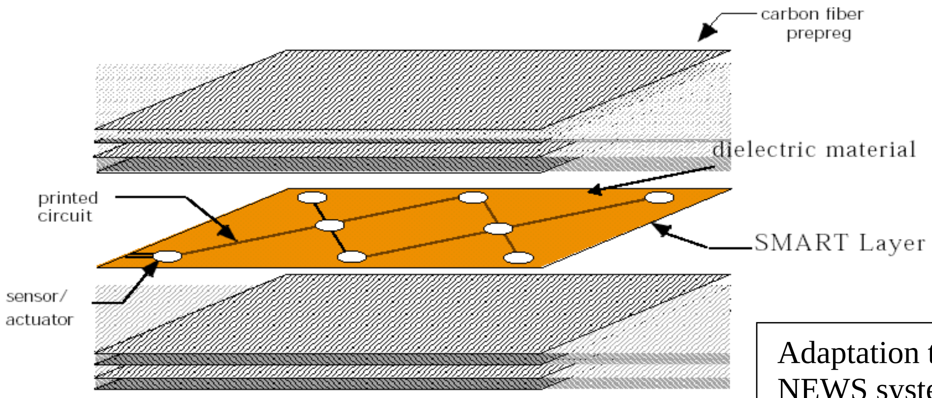
1) high power transmission using one transducer and sensing the harmonics and overtones produced by non linearity.

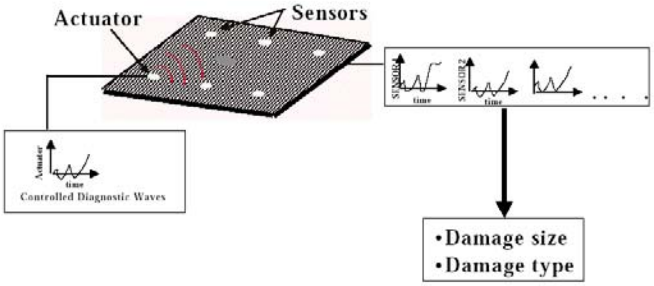
2) Two lower powered transmitters, sending two separate frequencies, and measuring the sum and difference components generated by non linearity.

The following paper describes how transducers can be embedded into panels and small components to make smart structures for use in air craft production.

Demands and Challenges for Structural Health Monitoring
Fu-Kuo Chang, Dept. of Aeronautics and Astronautics
Stanford University
The First Australia Structural Health Monitoring Workshop
Nov. 25-26, 2002

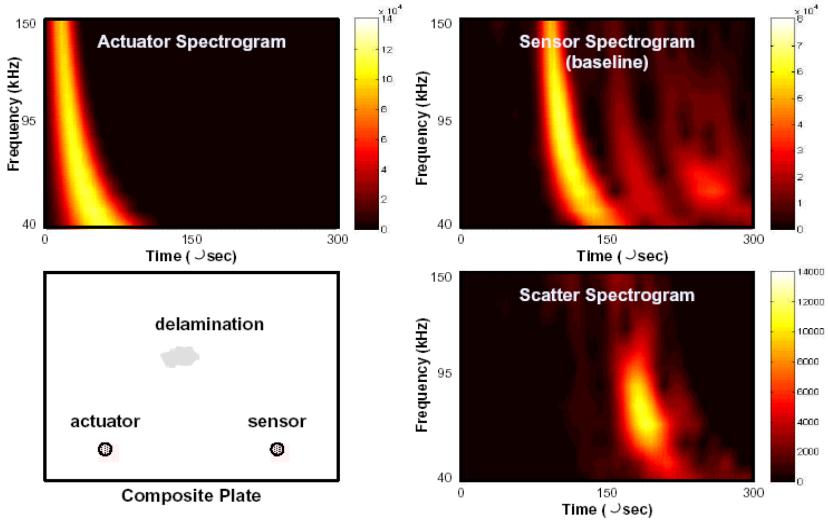
❑ FLEXIBLE PRINTED-CIRCUIT BOARD TECHNIQUE

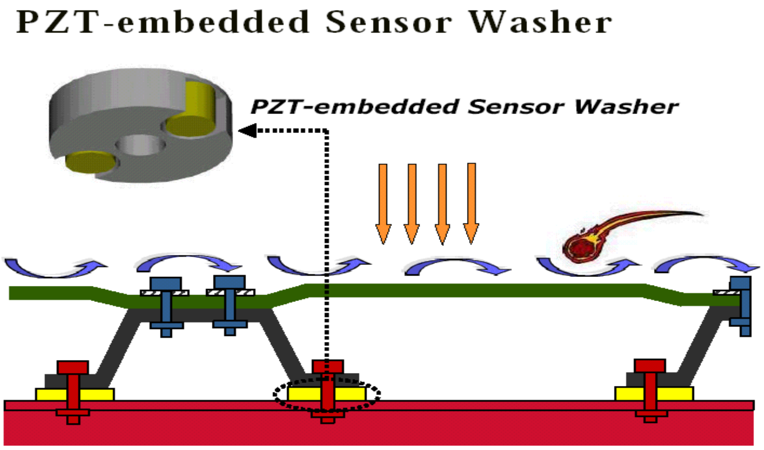




Adaptation to the NEWS system.

Two actuators would be used, transmitting two different frequencies. The spectrum of the sum and difference products due to non linear properties in a defective composite material will then be displayed or analyzed by computer.

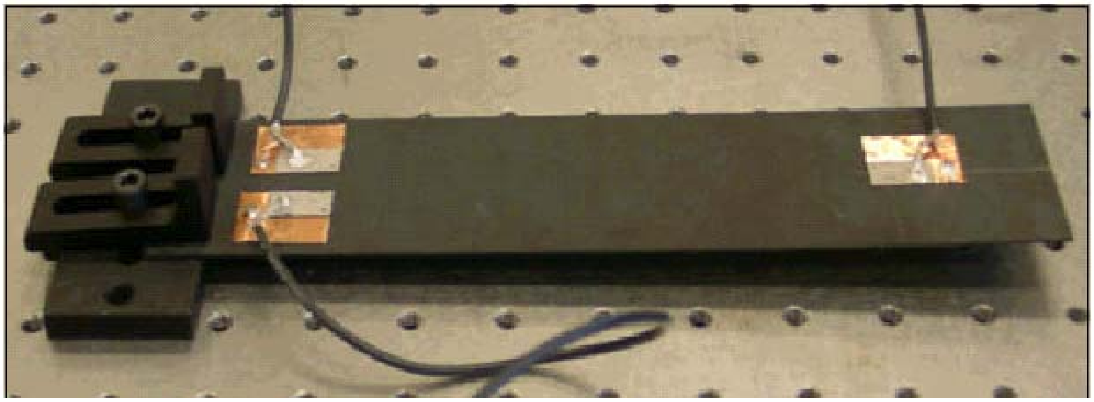




The above sensor described in this paper, is a PZT transducer embedded into a washer that is used in the assembly of aircraft structures. Again this can be adapted to the NEWS technique by including a third PZT transducer. Two for transmission one for receiving.

In the following paper there is described how sensors can be embedded in an aircraft component. Since the component is thin, Lamb waves are used to perform the test.

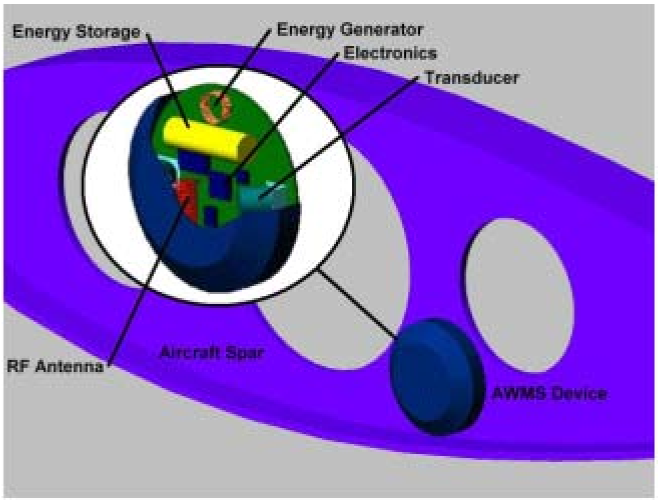
Kessler S.S., Spearing, S.M. and C. Soutis. “Damage Detection in Composite Materials using Lamb Wave Methods.” Proceedings of the American Society for Composites, 9-12 September 2001, Blacksburg, VA.



For adaptation to the NEWS technique, a three transducer arrangement is used. Two actuators, transmitting two different frequencies and one sensor.

EXAMPLES OF SMART SENSORS IN DEVELOPMENT

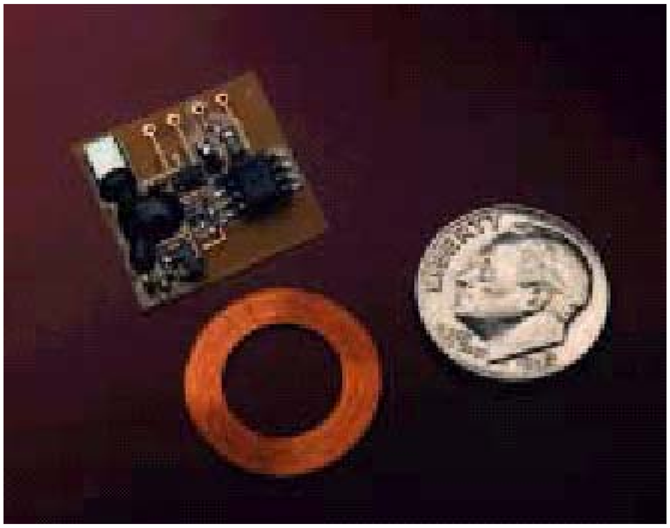
Strictly, materials that have just have transducer active elements embedded within them are called smart materials.
If the transducer's active element has additional electronics, such as a microprocessor, and communication can be established (usually digitally) between the active element and a remote device (eg, data logger and display) the transducer will be termed a smart sensor or a smart actuator.
Examples of such devices are illustrated below:-



AIRCRAFT SMART SENSOR

Source:- TenXsys Inc

Radio link for data, induction loop for power.

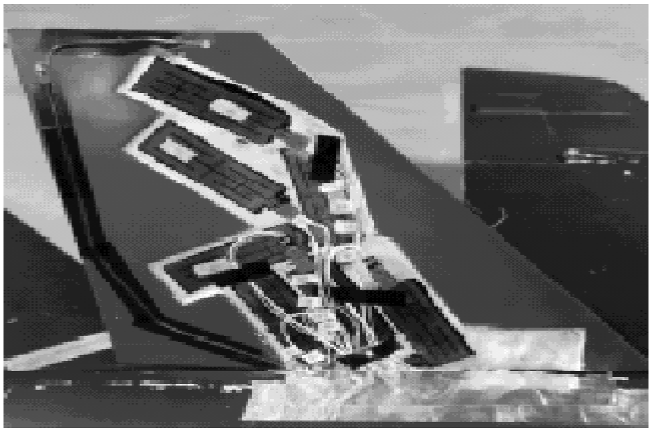


Induction loop for power and data communication.

Source:- Applied Research on Remotely-Queried Embedded Microsensors
Donald Krantz(1), John Belk(2), Paul J. Biermann(3), Joel Dubow(4), Lee W. Gause(5), Ramesh Harjani(6), Susan Mantell(6), Dennis Polla(6), Philip Troyk(7)
1 MTS Systems Corporation, 2 The Boeing Company, 3 Applied Physics Laboratory of Johns Hopkins University,
4 University of Utah, 5 Naval Research Laboratory, 6 University of Minnesota, 7 Illinois Institute of Technology

USING EXISTING SMART SENSORS and ACTUATORS

Smart aircraft structures containing sensors and actuators that can be used in conjunction with computer control systems are being developed to control flight surfaces, reduce engine noise and vibration. They are also being used to reduce turbulence induced panel skin vibrations, which in time causes fatigue of critical aircraft parts. The NEWS technique could be made to utilise these existing devices.



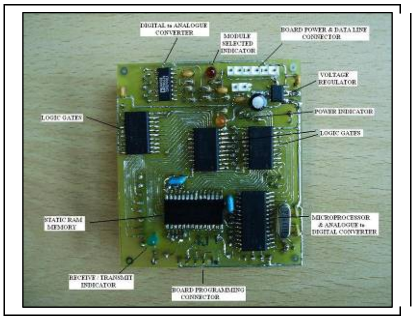
Piezoelectric actuator arrangement on aircraft flexible tail.

Source:-
Robert W. Moses
Aeroelasticity Branch
NASA Langley Research Center

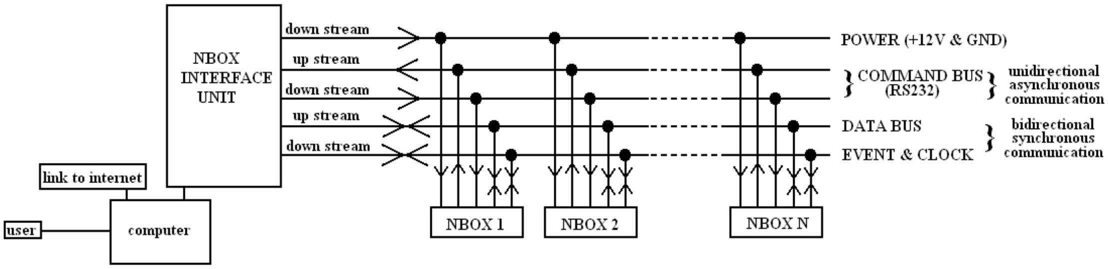
Presented at SPIE's 4th Annual Symposium on Smart Structures and Materials, Industrial and Commercial Applications of Smart

EMBEDDED NBOX ELECTRONICS

The NBOX series of modules were originally designed to function within a self contained unit that included a spring loaded transducer and mechanical box structure for assembly into a large array. The electronic boards themselves can be used independently and embedded or incorporated into aircraft structures. In these applications separate embedded sensors and actuators are connected to both the analogue and digital boards that make up an NBOX unit.



The schematic below shows the required interconnection. For simple NEWS testing methods, for example harmonic generation, where large amounts of data need not be transferred between devices the Data Bus, Event & Clock may be omitted. Data from measured information being transferred along the Command bus line. This would allow for a simpler wiring arrangement between devices.



PROBLEMS ASSOCIATED WITH EMBEDDING SENSORS

Two of the main problems with embedded smart sensors are :-

1) How do we get signals from the sensor to the acquisition, processing and recording apparatus?
2) How do we get power to the sensors and actuators?
3) Does embedding weaken structural integrity?
4) What if the embedded devices fail (how many redundant components)?
5) Does the embedded devices add significantly to the weight payload?

For a ground inspection system with sensors only embedded in the composite material, power requirements may be lower as the high power actuators can be supplied externally in a moving contact probe.
For in flight health monitoring, both actuators and sensors will need to be powered.

The possible ways to power the transducers:-

1) Illuminate with Radio waves or Radar, convert this RF power to DC supply
2) Supply power through embedded cables
3) Supply power through embedded structure (eg, use existing carbon fibre layers)
4) Apply an alternating magnetic field (induction loop)
5) Use vibration to generate power
6) The sensor itself provides power (piezoelectric generation)
7) Light or Thermal power extracted from surroundings.

The possible ways to connect the sensors to the data acquisition instrumentation:-

1) Embed wires
2) Route signals through embedded structure (eg, use existing carbon fibre layers)
3) Radio links (eg, Bluetooth, WI-FI, Zigbee or other radio modules).

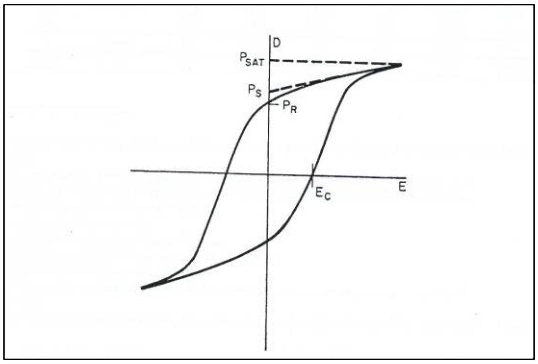
DAKEL – Transducer for built-in applications

DAKEL developed and produced several types of transducers, suitable for built-in applications. These units have a very low thickness (typically < 2 mm) and low weight (up to 2 g without coaxial cable).
These sets of the transducers were tested separately. After comparison of the results several models were measured on the real aircraft parts (fork leg, wing).
Various piezoelectric materials were tested – PVDF foil, PZT composite 1-3, PZT disc, thin layer PZT.
Sensitivity of the sensors

~ dij … piezoelectric charge constant
~ F … applied force (vibration)
~ y … amplitude of vibration
~ 1/C … 1/total capacity (sum of capacity piezoelectric element, capacity of cable, capacity of preamplifier input)
~ suit of acoustic impedance

~ dij … piezoelectric charge constant
~ Usig… applied voltage (electric field)
~ A … area of piezoelectric element
~ suit of acoustic impedance

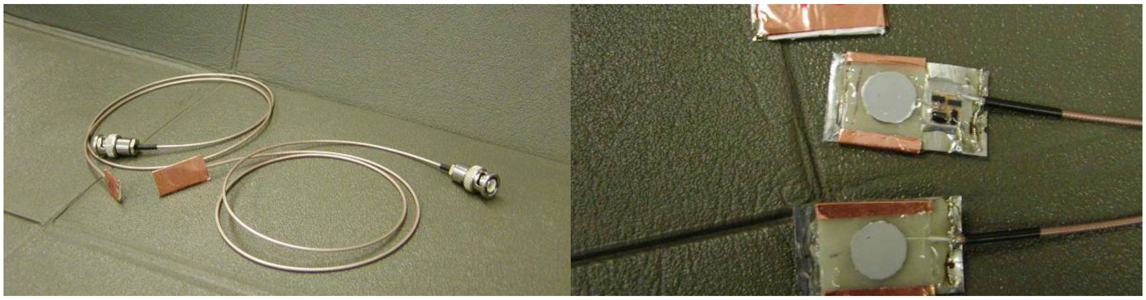
Piezoelectric material	Relative permitivity Eps33	Piezoel. Charge constant d33 *10E-12 [C/N]	Curie temperature [C^{o}]	Acoustic impedance *10E6 [kg/m2s]
PZT pure ceramic	800	200	330	25
PZT ceramic class 200	1900	500	320	30
PVDF	10	22	90	7
PMN-PT	5000	2000	180	

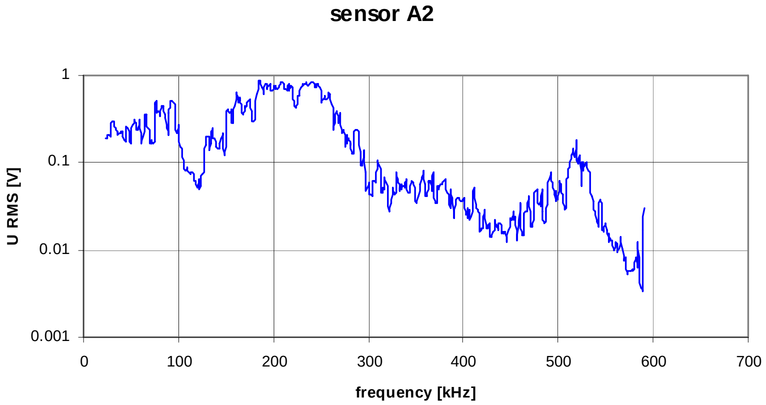


Typical P-E curve of PZT ceramic
Ec … typical 0.5 – 1 kV/mm (by the class of ceramics)
Eb … 3 – 5 kV/mm (breakdown)

Thin flat detachable PZT bulk ceramic sensor &. Exciter

- piezoceramic disc - PZT material DAKEL - class 200
- dimensions of unit :
    - with Permalloy plate : 30 x 20 x 2.5 mm
    - with Cu plate : 30 x 15 x 2 mm
- dimension of PZT element : diameter 10 mm, thickness 1 mm
- capacity of piezoelement : 1160 pF, diel. loss : 170E-4
- output - coaxial cable - diam. 1,7 mm – BNC connector
- wear plate
- Permalloy thickness 0.1 mm
- Cu foil 0.035 mm
- damping layer, insulating layer, metallic shield by Cu foil
- recommended length of cable : max 1m
- external coaxial impedance converter & preamplifier ASII
- viable internal impedance converter & preamplifier ASII
- mounting methods - glued joint, magnetic flat unit, spring-loaded unit





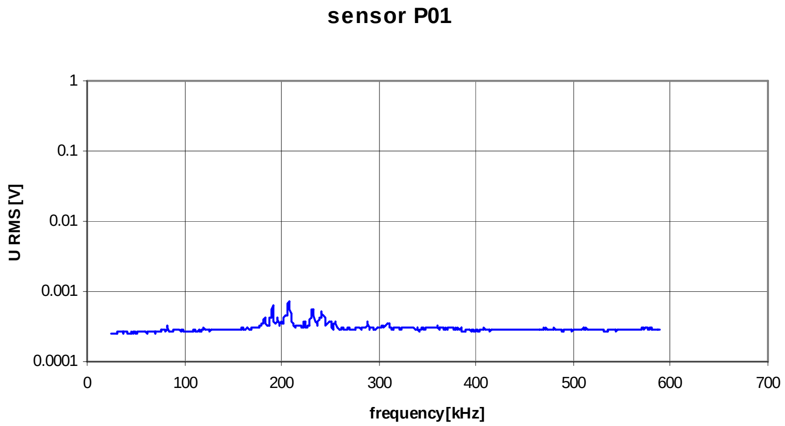
Measuring conditions:
Exciter – conical PZT unit
Electrical source – continual sine wave, Voltage – 1V RMS,
sweep frequency 20-600 kHz
Coaxial preamplifier 35dBMeasuring device – DAKEL XEDO 5, evaluation by sw DAKEL DAEMON

+ simple technology
+ sensor sensitivity is the highest of all thin detachable units
+ high efectivity of excitation US wave
+ high resistance to electrical overload (up to 200V RMS)
+ high reproducibility
+ high time stability of electromechanical parameters

- suitable only for flat surface of measuring objects
- higher noise (in comparison to standard sensor)

Thin flat detachable PZT thin layer sensor &. Exciter

- piezoceramic element - PZT thin layer
- dimensions of unit : 11 x 12 x 1.5 mm
- dimension of electrode : diameter 4 mm
- capacity of piezoelement : 1100 pF, diel. loss : 4170E-4
- output - coaxial cable - diam. 1,7 mm – BNC connector
- wear plate - steel thickness 0.3 mm
- damping layer, insulating layer, metallic shield by Cu foil
- recommended length of cable : max 1m
- external coaxial impedance converter & preamplifier ASII
- mounting methods - glued joint, magnetic flat unit, spring-loaded unit



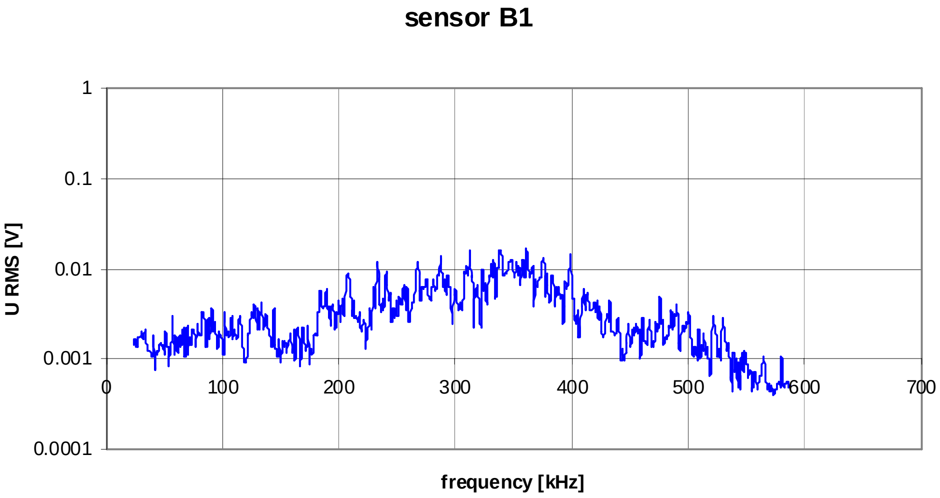
Measuring conditions:
Exciter – conical PZT unit
Electrical source – continual sine wave, Voltage – 5V RMS,
sweep frequency 20-600 kHz
Coaxial preamplifier 35dBMeasuring device – DAKEL XEDO 5, evaluation by sw DAKEL DAEMON

+ very low cross-section of units
+ compact structure

- very low sensitivity
- complicated technology
- low voltage resistance – risk of depolarization or breakdown

Thin detachable flexible PVDF sensor &. Exciter

- piezoelectric disc – PVDF foil – 1 pc
- dimensions of unit :
    - Permalloy plate : 30 x 20 x 2 mm
    - Cu plate : 20 x 10 x 1 mm
- dimension of PVDF element : diameter 6 mm, thickness 0.025 mm
- capacity of piezoelement : 45 pF, diel. loss : 270E-4
- output - coaxial cable - diam. 1,7 mm – BNC connector
- wear plate
- Permalloy thickness 0.1 mm - Cu foil 0.035 mm
- damping layer, insulating layer, metallic shield by Cu foil
- recommended length of cable : max 1m
- external coaxial impedance converter & preamplifier ASII
- viable internal impedance converter & preamplifier ASII (not flexible)
- mounting methods: glued joint, magnetic flat unit, spring-loaded unit



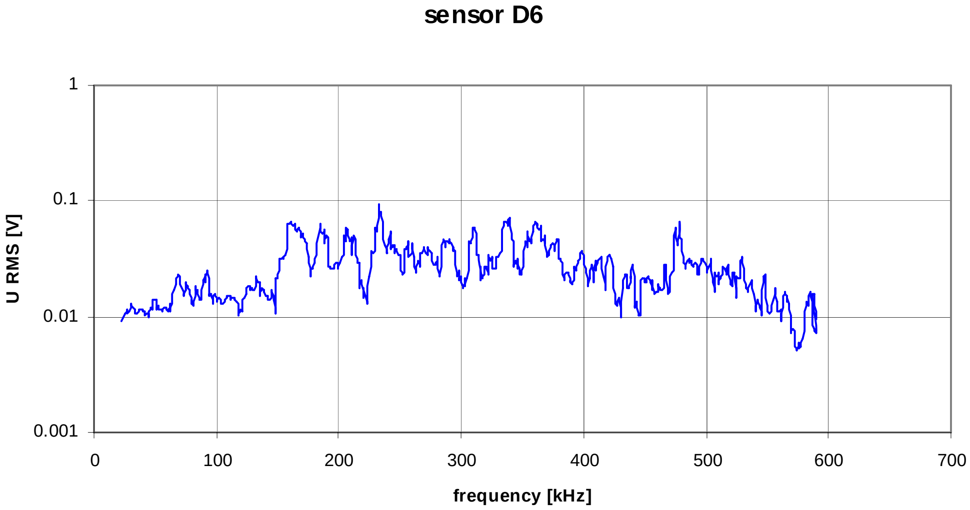
Measuring conditions:
Exciter – conical PZT unit
Electrical source – continual sine wave, Voltage – 5V RMS,
sweep frequency 20-600 kHz
Coaxial preamplifier 35dBMeasuring device – DAKEL XEDO 5, evaluation by sw DAKEL DAEMON

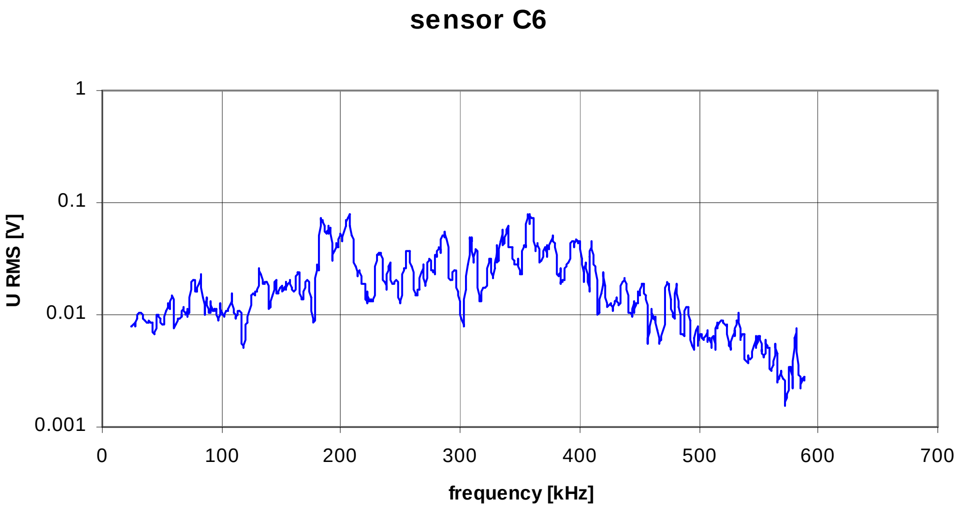
+ very low cross-section of units
+ highly flexibility

- low Curie temperature – using up to 60C
- low sensitivity
- lower long time stability of electromechanical parameters

Thin detachable semirigid PZT unit sensor &. exciter

- piezoceramic semirigid block – modified PZT class 200 unit
- dimensions of unit : 30 x 20 x 2 mm
- dimension of PZT systems :
- C samples - diameter 10mm, thickness 1
- D samples – 15 x 8 x 1 mm
-capacity of the piezoelement :
    C samples - 350 pF, diel. loss : 170E-4
    D samples - 950 pF, diel. loss : 220E-4
- output - coaxial cable - diam. 1,7 mm – BNC connector
- wear plate - Permalloy thickness 0.1 mm
- damping layer, insulating layer, metallic shield by Cu foil
- recommended length of cable : max 1m
- external coaxial impedance converter & preamplifier ASII
- viable internal impedance converter & preamplifier ASII (not flexible)
- mounting methods - glued joint, magnetic flat unit, spring-loaded unit





Measuring conditions:
Exciter – conical PZT unit
Electrical source – continual sine wave, Voltage – 1V RMS,
sweep frequency 20-600 kHz
Coaxial preamplifier 35dBMeasuring device – DAKEL XEDO 5, evaluation by sw DAKEL DAEMON

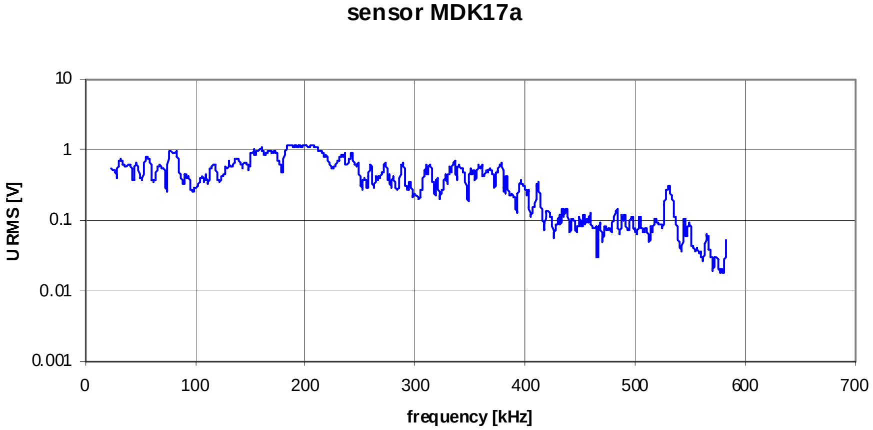
+ possible to application on surface with variable curvature
+ relative high sensitivity of sensors
+ relative high efectivity of exciters

- limited flexibility
- higher cross-section – thrust of contact foil on upper electrode

MDK17a – reference sensor & exciter

- piezoceramic disc - PZT material DAKEL - class 200
- dimension of PZT element : diameter 10 mm, thickness 3 mm
- capacity 380 pF
- output - coaxial cable - diam. 1,7 mm – BNC connector
- metal case – stainless steel - diam. 17mm, thickness 13 mm
- wear plate – magnetic disc FeNdB – diam. 15 mm, th. 4 mm
- damping layer
- recommended length of cable : max 1m
- MDK17AS - in-build preamplifier cca 35 dB

MDK17a unit



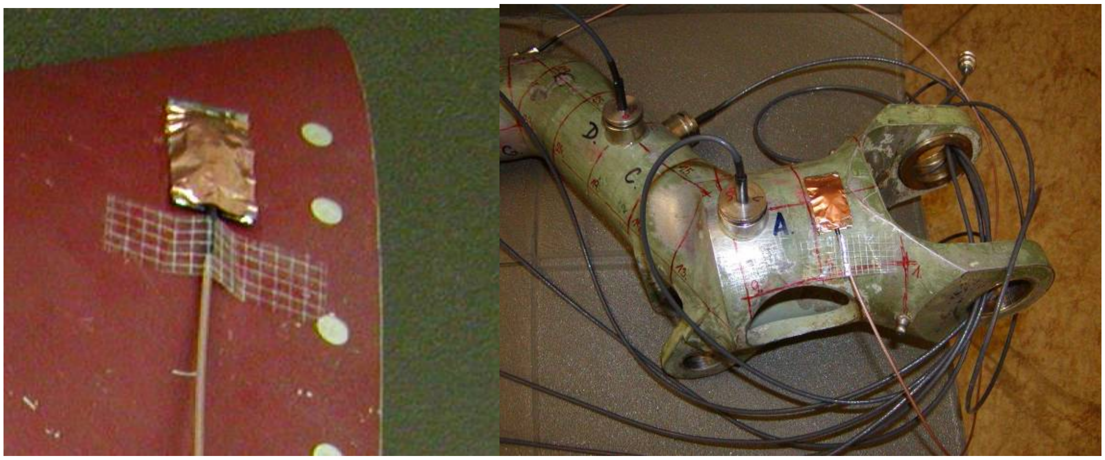
Exciter – conical PZT unit
Electrical source – continual sine wave, Voltage – 1V RMS, sweep frequency 20-600 kHz
Coaxial preamplifier 35dB
Measuring device – DAKEL XEDO 5, evaluation by sw DAKEL DAEMON

+very easy installation on the ferromagnetic object (or via glued ferromag.foil)
+ high sensor sensitivity
+high exciter efectivity
+ very low noise level

- suitable only for flat surfaces
- higher mechanical dimensions, higher weight

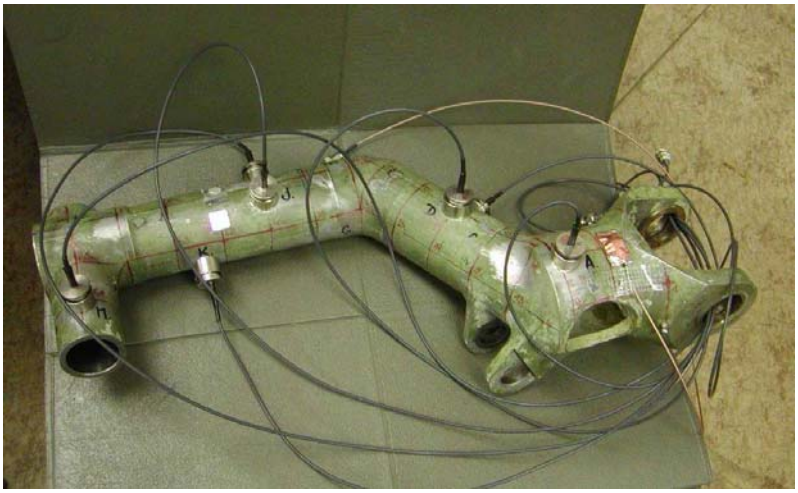
Thin built-in sensor &. exciter

- step by step assembly of piezoelectric units directly onto surface of measuring object
- relative easy technology of assembly
- technology is suitable in case of surface with variable curvature too
- technology permites to usig the hard adhesive (epoxy, …)
- minimal influence upon measuring object



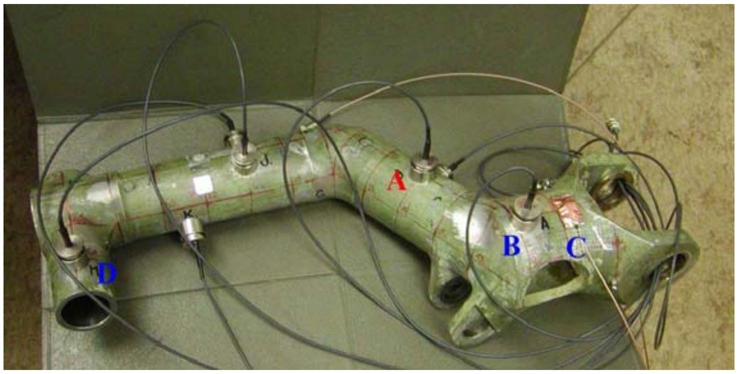
Jobsheet

1.Cleaning and coarsening of all surfaces
2.Splicing of contact membrane (Permalloy)
3.Splicing piezoelectric unit onto membrane
4.Splicing metal contact from upper electrode, damping layer
5.Coaxial cable connection
6.Coating with silicone paste
7.Electromagnetic screening

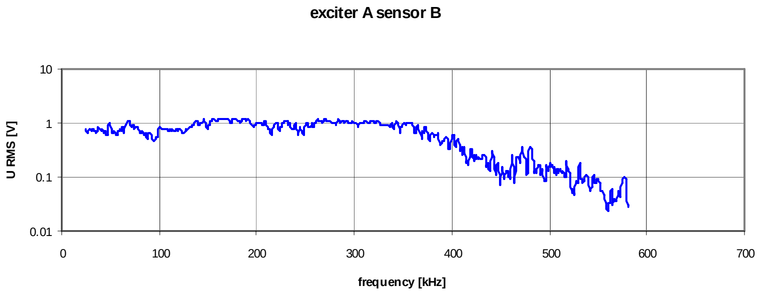


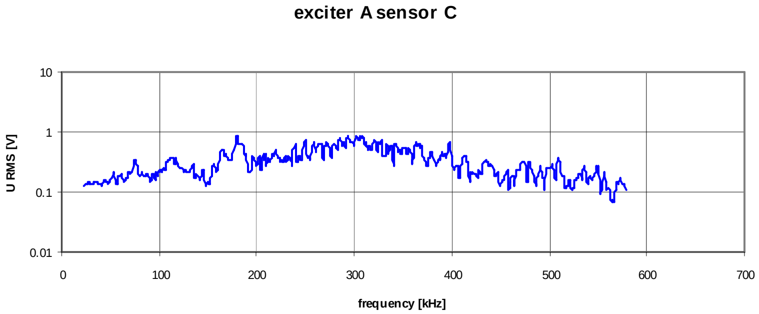
Fork leg L410 – measuring set of transducers

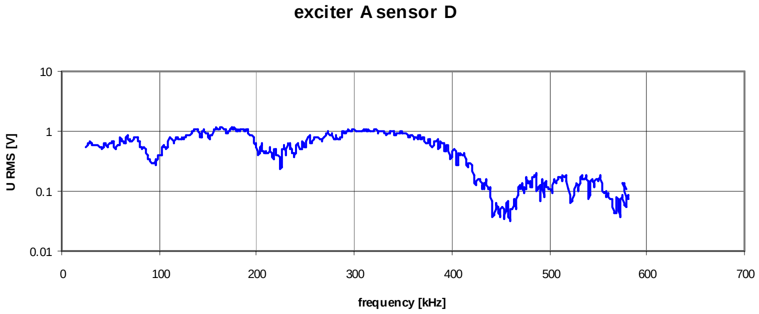
Thin build-in sensor &. exciter – fork leg – 1/2



A – exciter MDK17a
B – sensor MDK17a
C – slim built-in sensor type CC (PZT unit)
D – sensor MDK17a

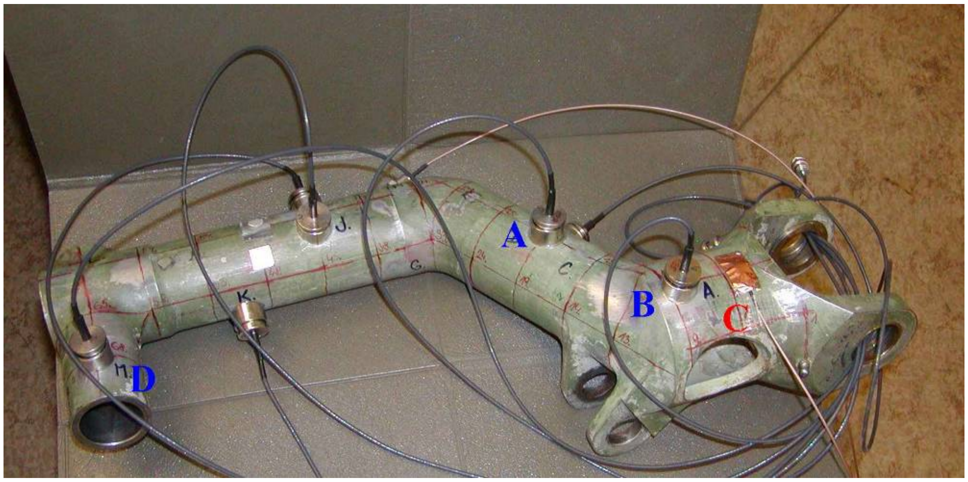

exciter A sensor B


exciter A sensor C

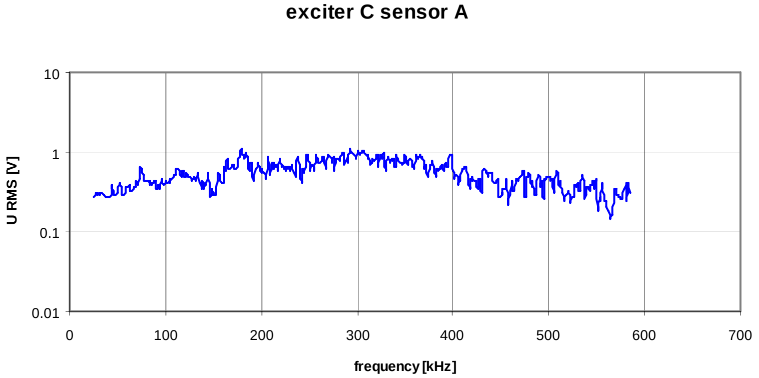

exciter A sensor D

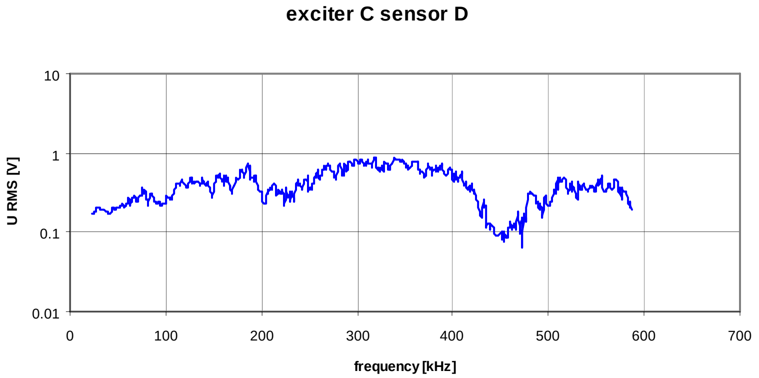
Measuring conditions:
Electrical source – continual sine wave,
Voltage – 10V RMS, sweep frequency 20-600 kHz
Coaxial preamplifier 35dB
Measuring device – DAKEL XEDO 5,
evaluation by sw DAKEL DAEMON

Thin built-in sensor &. exciter – fork leg - 2/2



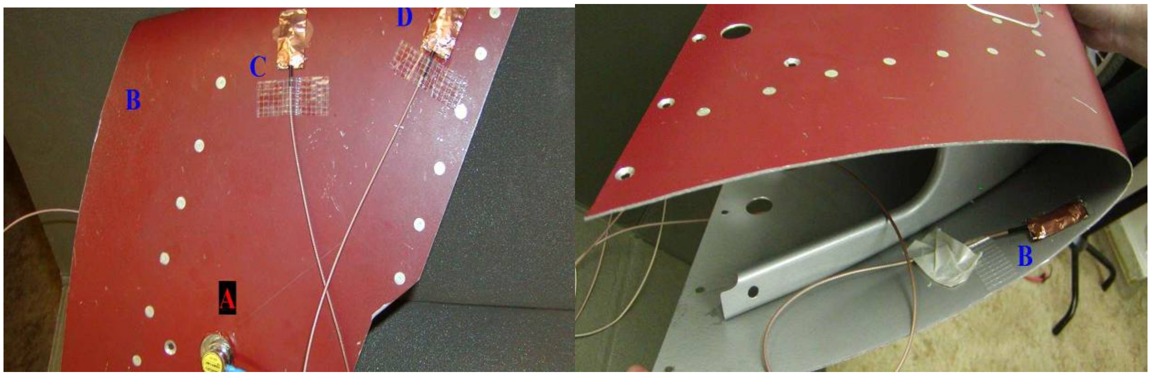
A – sensor MDK17a
B – sensor MDK17a
C – slim built-in exciter type CC (PZT unit)
D – sensor MDK17a



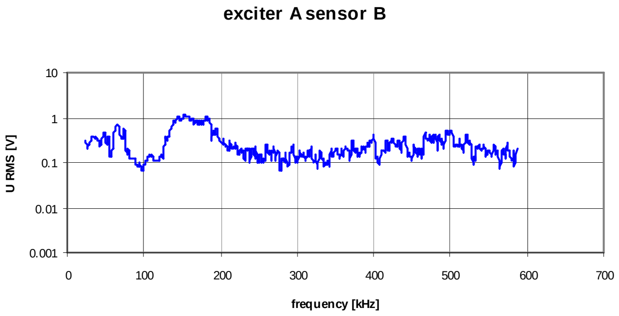


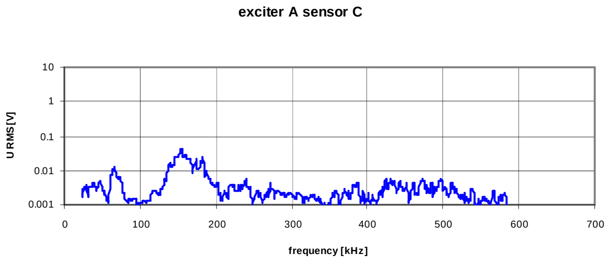
Measuring conditions:
Electrical source – continual sine wave,
Voltage – 10V RMS, sweep frequency 20-600 kHz
Coaxial preamplifier 35dB
Measuring device – DAKEL XEDO 5,
evaluation by sw DAKEL DAEMON

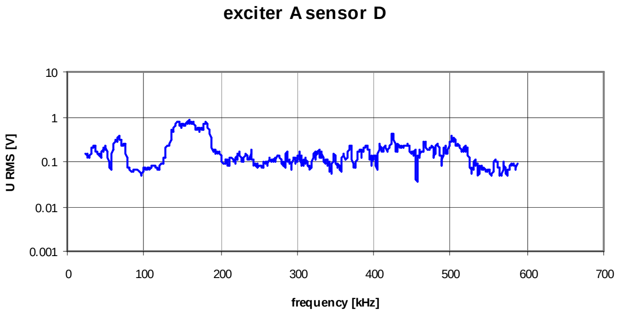
Thin built-in sensor &. exciter – wing - 1/2



A … exciter MDK17a
B … slim built-in sensor type CC (PZT unit) – inner surface
C … slim built-in sensor type BB (PVDF unit)
D … slim built-in sensor type CC (PZT unit) – outer surface

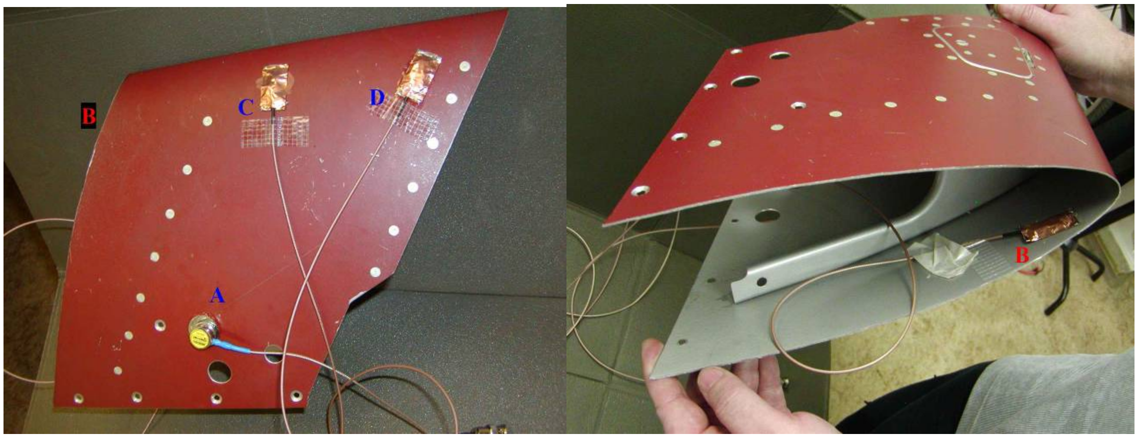




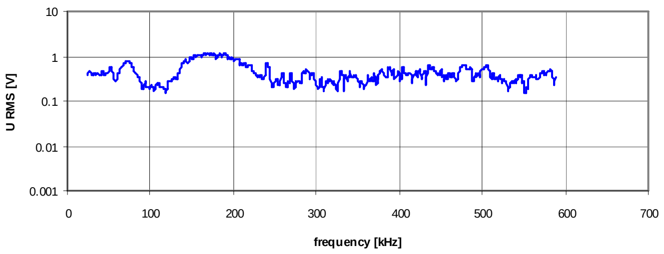


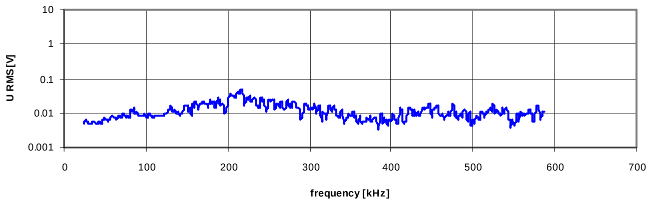
Measuring conditions:
Electrical source – continual sine wave,
Voltage – 10V RMS, sweep frequency 20-600 kHz
Coaxial preamplifier 35dB
Measuring device – DAKEL XEDO 5,
evaluation by sw DAKEL DAEMON

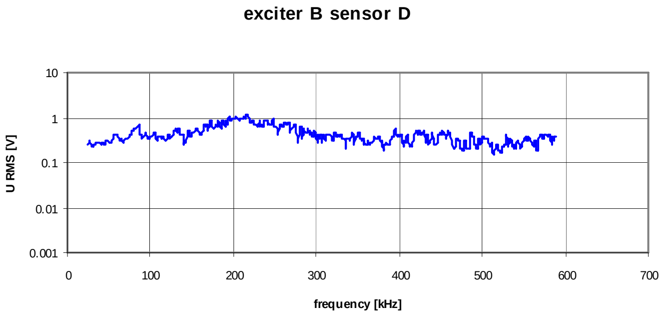
Thin built-in sensor &. exciter – wing - 2/2



A … sensor MDK17a
B … slim built-in exciter type CC (PZT unit) – inner surface
C … slim built-in sensor type BB (PVDF unit)
D … slim built-in sensor type CC (PZT unit) – outer surface


exciter B sensor A


exciter B sensor C



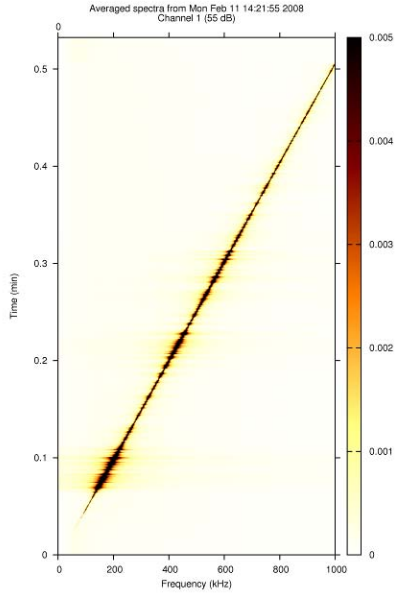
exciter B sensor D

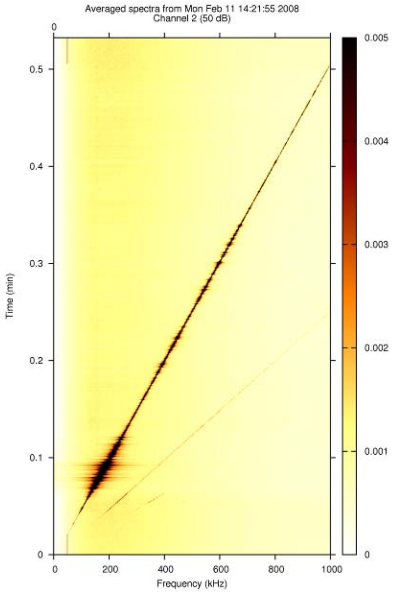
Measuring conditions:
Electrical source – continual sine wave,
Voltage – 10V RMS, sweep frequency 20-600 kHz
Coaxial preamplifier 35dB
Measuring device – DAKEL XEDO 5,
evaluation by sw DAKEL DAEMON

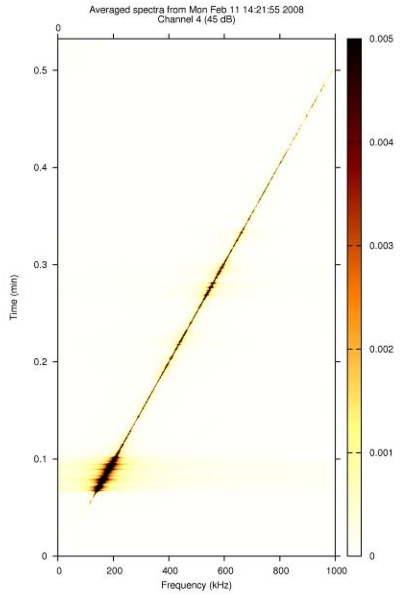
Thin built-in sensor &. exciter – wing

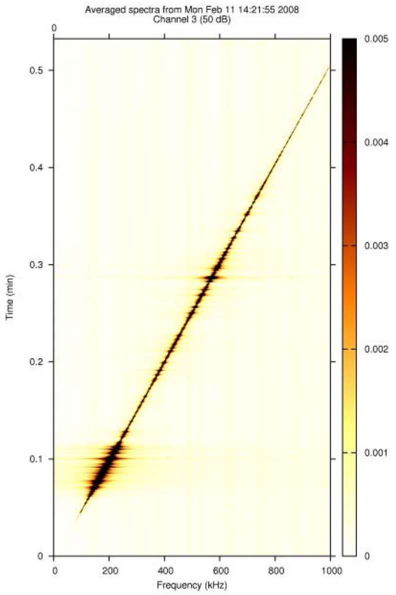
Measuring conditions:
Electrical source – continual sine wave,
Exciter – MDK17a – position E
Voltage – 0.9V RMS, sweep frequency range 20-1000 kHz
Measuring device – DAKEL CONTI

D … slim built-in sensor type CC (PZT unit) – outer surface
C … slim built-in sensor type BB (PVDF unit) with preamplifier 35 dB
B … slim built-in exciter type CC (PZT unit) – inner surface
A … sensor MDK17a


Averaged spectra from Mon Feb 11 14:21:55 2008
Channel 1 (55 dB)
Time (min)
Frequency (kHz)
0
0.1
0.2
0.3
0.4
0.5
0
200
400
600
800
1000
0.005
0.004
0.003
0.002
0.001
0


Averaged spectra from Mon Feb 11 14:21:55 2008
Channel 2 (50 dB)
Time (min)
Frequency (kHz)
0
0.1
0.2
0.3
0.4
0.5
0
200
400
600
800
1000
0.005
0.004
0.003
0.002
0.001
0


Averaged spectra from Mon Feb 11 14:21:55 2008
Channel 4 (45 dB)
Time (min)
Frequency (kHz)
0
0.1
0.2
0.3
0.4
0.5
0
200
400
600
800
1000
0.005
0.004
0.003
0.002
0.001
0


Averaged spectra from Mon Feb 11 14:21:55 2008
Channel 3 (50 dB)
Time (min)
Frequency (kHz)
0
0.1
0.2
0.3
0.4
0.5
0
200
400
600
800
1000
0.005
0.004
0.003
0.002
0.001
0