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Groupe d'Acoustique Physique,
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Arcachon, 8-10 décembre 2008

Program of the eighth
Anglo-French Physical Acoustics Conference
Arcachon, 8-10 December 2008

Alain Lhémery, chairman and scientific organisation
Christophe Aristégui, co-chairman, scientific and local organisation
Nader Saffari, co-chairman and scientific organisation
Sandrine Guit, local administrative, local organisation

Remarque pour les auteurs

Pour la première fois dans l'histoire (courte) de cette conférence, la possibilité vous est donnée de soumettre une publication à paraître dans le ***Journal of Physics: Conference Series***. Ce journal, publié en ligne par l'*Institute of Physics* présente plusieurs avantages qui nous ont semblé déterminants :

- il est accessible en ligne, à tous sans abonnement, assurant une large audience ;
- les articles ne sont publiés qu'après acceptation par un comité de lecture standard du Journal of Physics, si bien que vous pouvez les faire apparaître comme tels dans vos bibliographies personnelles ;
- il est référencé dans les principales bases de données bibliographiques ; votre *h*-index va croître !
- le coût de cette publication est limité (pas d'édition papier) ; ainsi, cela n'engendre qu'un faible surcoût à l'organisation de la conférence ce qui nous permet de maintenir les frais d'inscription bas ;
- les figures peuvent être faites en couleur sans frais supplémentaires ;
- c'est une façon écologique de publier pour toutes sortes de raisons (si l'on y réfléchit).

Pour que la publication d'un ensemble d'articles ayant fait l'objet d'une présentation lors de la conférence ait un sens, il vous est demandé de ne pas tarder à écrire le papier : la date limite pour soumettre votre contribution a été fixée au 16 janvier 2009. Sa longueur n'est pas contrainte puisqu'il n'y a pas d'édition physique des actes (l'option existe mais cette fois, le coût est significatif ; le surcoût occasionné rendrait cette conférence moins attractive). Cependant, il nous semble raisonnable de limiter la taille des manuscrits à un maximum de 8 pages équivalent journal.

Note for the authors

For the very first time in the (short) history of this conference, the possibility is given to you of submitting a paper to be published in the ***Journal of Physics: Conference Series***. This journal is an on-line publication of the Institute of Physics; it has several advantages that appeared very appealing to us:

- this is an on-line publication, with no subscription required, this ensuring a large audience;
- papers are published after acceptance under the standard referee process of the Journal of Physics; therefore, you can enter your paper in your publication list as being a refereed one;
- it is referenced in all the main abstract and bibliographic databases; Your *h*-index is going to grow!
- the cost of this publication is limited (no paper edition); thus, conference fees can be as low as we want them;
- colour figures are accepted, at no additional cost;
- this is an ecological way of publishing for all sorts of factors (if you think about it).

To give a sense to the publication of contributions that have been presented at the conference, you are asked to prepare your manuscript in a relatively short time from now: the dead-line for submission is the 16th of January 2009. The length is not constrained since proceedings will not be printed (the option exists though, but additional costs make this solution less attractive as far as conference fees are concerned). However, it appears reasonable to limit the size of manuscripts to the equivalent of 8 printed pages of the journal.

Lundi 8 (Monday, 8)

13:50 – 14:00 **A. Lhémery – C. Aristégui**
Welcome address

Invited talk:

14:00 – 14:30 **M. Castaings**
Non-Destructive Testing of composites

14:30 – 14:50 **E. Kostson and P. Fromme**
Fatigue crack growth monitoring in multi-layered structures using guided ultrasonic waves

14:50 – 15:10 **V. Baronian, A. Lhémery and A.-S. Bonnet-Ben Dhia**
Simulation of non-destructive inspections and acoustic emission measurements involving guided waves

15:10 – 15:30 **P. Belanger and P. Cawley**
Guided wave diffraction tomography

15:30 – 16:00 ***Tea – Coffee***

Invited talk:

16:00 – 16:30 **J. Vasseur**
Phononic crystals: Examples and applications

16:30 – 16:50 **S. Fletcher, M. Ratassepp, M. Lowe, C. Brett and J. Trelawny**
Reflection of the fundamental torsional guided wave mode from axially aligned defects in pipes

16:50 – 17:10 **D. Zakharov, W. Ke and M. Castaings**
Incorporating the 3D orthogonality of guided waves into FEM postprocessing

17:10 – 17:30 **R. Carandente, J. Ma and P. Cawley**
The reflection of the fundamental shear horizontal mode from tapered steps in plates

17:30 – 17:50 **F. Benmeddour, F. Treyssède and L. Laguerre**
Numerical study of guided modes scattering by non-axisymmetric cracks in cylinders

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Poster:

M. Cavaro, J. Moysan, C. Gueudré, G. Corneloup and F. Baqué
Towards acoustic characterization of the gaseous microbubbles applied to liquid sodium

AFPAC2008/9
Non-Destructive Testing of Composites

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After a brief remind of requirements in Non-Destructive Testing (NDT) of composite materials, a short review about existing NDT techniques used for composites is done, reminding their abilities and their limits. Then, some promising numerical or experimental tools developed either for mechanical characterization of anisotropic materials purposes or for defect detection purposes are presented. The potentiality of these tools will be emphasized through various examples. For example, the use of air- coupled transducers for evaluating the moisture content of a carbon-epoxy component wound around a Titanium liner of a high-pressure tank or for detecting a disbond-like defect between the liner and the winding, will be presented. Three-dimensional FE-based modelling will also be demonstrated for simulating the whole air-coupled NDT system, i.e. the transmitter, the structure including the defect and the receiver.

Number of words in abstract: 131
Keywords: Ultrasounds - NDT - Composites

AFPAC2008/7
Fatigue crack growth monitoring in multi-layered structures using guided ultrasonic waves

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Aircraft structures are subject to various types of loading conditions, mainly during take-off, landing, and manoeuvring. Such operating conditions can lead to the development of fatigue cracks in the aircraft structure. Due to the stress concentration fatigue cracks often initiate at the fasteners connecting multiple metallic layers. The detection of fatigue damage in the 2^{nd} layer of multi-layered structures using conventional techniques can sometimes be problematic. This contribution presents the application of low frequency guided ultrasonic waves for the monitoring of fatigue crack growth at fastener holes in the 2^{nd} layer of multi-layered structures. The model multi-layered structures investigated consist of two aluminium plate-strips adhesively bonded using a structural paste adhesive (Hysol 9394 EA). Guided waves were excited using multiple piezoelectric discs bonded to the surface of the multi-layered structure. The resulting wave field in the tensile specimen was measured using a laser interferometer and compared to numerical simulations. Experiments and 3D Finite Element (FE) simulations show a significant change in the scattered field around fastener holes caused by a defect in the 2^{nd} layer. Fatigue experiments were performed for several specimens and the amplitude of the guided ultrasonic wave field was monitored on-line at a single point using a laser interferometer. The measured changes in the amplitude of the ultrasonic signal at a single point due to fatigue crack growth agree well with numerical simulations.

Number of words in abstract: 226
Keywords: guided waves - multi-layered - crack-growth - scattering

AFPAC2008/20
Simulation of nondestructive inspections and acoustic emission measurements involving guided waves

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In a structure that guides elastic waves, the presence of a defect or a variation of its shape (local discontinuities) cause scattering. Modes incident on the discontinuity can be reflected, partially extinct or converted into new modes; transmission is therefore also modified. Two modal formulations have been developed to link separated models dealing with the calculation of modal decomposition, with the generation and reception of guided waves (GW), with their scattering. The first concerns configurations where a single transducer is used in the transmit-receive mode; the other concerns configurations where two separate transducers, an emitter and a receiver, are used. A new finite element (FE) method has been developed to compute the scattering by an arbitrary discontinuity of the guide. It is based on the modal decomposition of the wavefield. Specific boundary conditions are developed which are perfectly transparent, allowing the FE computation zone to be reduced to a minimum, depending on the number of inhomogeneous and evanescent modes taken into account in the computation. By including these new boundary conditions, a specific variational problem was obtained and then solved using classical FE tools. Moreover, elastic sources within the FE computation can be considered. By combining the modal formulations, the new FE scheme and tools for GW radiation, propagation and reception based on the Semi-Analytical Finite Element method, a new simulation tool has been developed able to address almost arbitrary configurations of interest for GW nondestructive testing. Thanks to the possibility of defining sources inside the FE computation zone, configurations typical of those encountered in acoustic emission (EA) testing can also be simulated. Here, this tool is used to deal with several configurations of industrial interest both in GW-NDT configurations and in EA-NDT.

Number of words in abstract: 283
Keywords: guided waves - finite element - modal decomposition - NDT

AFPAC2008/2
Guided Wave Diffraction Tomography

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Many aging pipelines and pressure vessels are suffering from corrosion and the corrosion patches are often inaccessible. Hence the majority of the conventional nondestructive evaluation techniques are compromised. There is therefore a need for a rapid, accurate, long range inspection technique to measure the remaining thickness in corrosion patches. Low-frequency guided wave tomography is a potentially attractive technique to rapidly evaluate the thickness of large sections of partially accessible structures. If the frequency is limited to below the cut-off of the higher order modes, only the three fundamental guided wave modes can propagate and thus the interpretation of the signals is easier. However in this frequency range diffraction becomes significant for realistic defect sizes and thus the straight-ray tomography algorithms leads to large reconstruction errors. Fortunately the diffraction effects can be taken into account with the more complex diffraction tomography algorithms. These algorithms were developed in ultrasonic medical and geophysical imaging and are here adapted to guided wave inspection of plates and pipes in the context of full view imaging. The reconstruction of a map of the remnant thickness is produced from the amplitude and phase of the scattered field generated by the defects in the area of inspection. The scattered field is assumed to have been generated from an inclusion in the background medium with all the properties of the background medium apart from a different the propagation velocity. Finite element simulations of a 64 element circular array on a plate have shown that when the scattered field is perfectly separated from the total field the reconstruction of the thickness is very accurate even when the area of inspection contains multiple defects. Moreover the amplitude of the artefacts in the reconstruction are minimised when a polychromatic field is used. Comparisons between finite element simulations and experimental results will be presented.

Number of words in abstract: 301
Keywords: Guided wave - Diffraction - Tomography

AFPAC2008/34
Phononic crystals : Examples and applications

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Phononic crystals are inhomogeneous materials made of periodic repetitions of inclusions in some different host material. These elastic periodic composites can exhibit large acoustic band gaps where the propagation of acoustic waves is forbidden. A phononic crystal can behave like a perfect mirror for the propagation of vibrations in some frequency range or like very efficient frequency filter when defects are inserted inside its structure. Phononic crystals allow the manipulation of the the acoustic waves and may have potential applications in transducer technology, filtering, guidance of acoustic waves, telecommunications devices technology and ultrasonic imagery.
We present some examples of phononic crystals, especially of two dimensional systems made of cylindrical inclusions embedded in a matrix. Then we review some of the applications of these composite materials.

Number of words in abstract: 125
Keywords: phononic crystals - acoustic band gaps - simulation - experiments

AFPAC2008/6
Reflection of the Fundamental Torsional Guided Wave Mode from Axially Aligned Defects in Pipes

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A study into the reflection of the T(0,1) mode from axially-aligned crack defects in pipes has been conducted. The purpose of this study is to evaluate the potential of using the long range guided wave non-destructive testing (NDT) method to locate such defects. Guided waves are being utilised as they can inspect over long distances and can therefore inspect large volumes of pipe work rapidly. Guided wave interactions in pipes are well understood for defects with large circumferential extent e.g. corrosion. It is also well known that axial defects are difficult to see as the reflection coefficient of guided waves is approximately proportional to the change in cross sectional area of a pipe. There is therefore a desire to investigate the nature of scattering from defects that produce very small or no changes in the pipe cross section. Ultimately it is hoped that this knowledge will enable improvements of inspection sensitivity to axially aligned defects.
A study was performed to address crack-like defects which were aligned axially on the pipe, employing guided waves in the frequency range 25-65kHz. The axial extents of the defects were of the same order as the wavelength of the incident mode. Finite element predictions have been produced and these have been validated with experimental data in certain cases. The FE models and experimental data show generally good agreement, although precise agreement was difficult to achieve because of the very low amplitude of the experimental measurements. The length, depth and width of the defects have all been considered. The experiments were performed on nominal 5 inch schedule 80 pipe work. Through-thickness and 80% depth notches were milled with the length of these notches being varied.

Number of words in abstract: 279
Keywords: Guided Waves - Torsional - Defect - Pipes

AFPAC2008/27
Incorporating the 3D orthogonality of guided waves into FEM pospro-cessing

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The direct FEM computation of the 3D dynamic field in waveguides is post processed in the frequency domain using modal analysis. Based on the generalized orthogonality of the guided waves the mode evaluation is incorporated. The coefficients of the coexistent modes under different sources are considered. The comparison of the results obtained by FEM calculation and by modal analysis is performed. The numerical error and stability of results with some parametrical analysis is discussed. As shown, the use of this algorithm permits one to apply the modal analysis at the relatively short distance to the source and may decrease the dimension of problem. The perspectives of the presented approach in context of the non-destructive evaluations are discussed

Number of words in abstract: 117
Keywords: guided waves - finite elements - orthogonality - postprocessing

AFPAC2008/8
The Reflection of the Fundamental Shear Horizontal mode from Tapered Steps in Plates

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Guided ultrasonic waves have been successfully applied to detect cracks and corrosion in plate and pipes; however, defect sizing still remains challenging due to the complex profiles of defects encountered in practice. It is thus crucial to understand the scattering behaviour of guided waves by defects with complex profiles. Much research has been done to understand the scattering behaviour of guided waves by defects with relatively simple geometries such as rectangular notches and flat bottomed circular holes, which assume uniform defect depth profiles. However, in reality corrosion defects usually have complex shapes and depth profiles, which may affect the strength and frequency dependence of the reflection.
In this work, a finite element study of the reflection of the fundamental shear horizontal (SH0) mode in plates from a tapered step is presented. Corrosion defects with gradually varying depth can be represented by a series of such steps. It is revealed that, for both up- and down-steps, the SH0 wave is reflected only at the start and end of the steps and the wave propagates at an unchanged velocity along the step. The mode shape remains constant through the thickness and the amplitude increases in inverse proportion to the square root of the local thickness, so that energy is conserved. The magnitude and phase of the reflections from the start and end of the step have been predicted and the frequency dependence of the overall reflection from the step has been studied. The reflections from successive down- and up-steps have been combined to predict the reflection from a V-shaped corrosion patch and the result has been compared with the result obtained from a direct model of the V-shaped defect.

Number of words in abstract: 277
Keywords:

AFPAC2008/14
Numerical Study of Guided Modes Scattering by Non-axisymmetric Cracks in Cylinders

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Environmental and operational conditions cause corrosions and fatigue damage in cables used in civil engineering. For their non-destructive testing, an appropriate method might be to employ guided ultrasonic waves since they can interrogate the entire section of cables for long distances. Cables are typically made of a central wire and several peripheral helical wires. Due to the complexity of such a geometry, only cylindrical waveguides are considered. The present work is dedicated to a numerical study of the interaction of guided waves with non-axisymmetric cracks in an infinite cylinder. The numerical computations are based on a hybrid method involving the Finite Element Method (FEM) and the Semi-Analytical Finite Element (SAFE) technique. The classical FEM is used to analyse the crack and its near field. Then, eigenmode expansions of the solutions at both inlet and outlet cross-sections of the FEM region are performed. The SAFE technique is used to determine the elastic guided modes for both inlet and outlet cross-sections of the volume. The amplitudes of the incident modes are enforced while the amplitudes of the scattered modes are determined by solving the global system of the hybrid FEM-SAFE model. Obtained results for the free-end cylinder compare favourably with results found in the literature. The interaction of the fundamental longitudinal Pochhammer-Chree mode with non-axisymmetric cracks are predicted and discussed.

Number of words in abstract: 218
Keywords: Guided waves - Cracks - Scattering - Cylinders

AFPAC2008/31
Poster : Towards Acoustic Characterization of the Gaseous Microbubbles Applied to Liquid Sodium

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Liquid sodium cooled fast nuclear reactors are considered as good candidates for the fourth-generation reactor system.
In these reactor design, the core is cooled by circulation of liquid sodium, with an argon cover gas. Different phenomenons such as gas dilution or gas entrainment can lead to microbubbles in the coolant, thus to core neutronic disturbances. Safety Authorities ask for the online core monitoring in order to control and detect this phenomenon.
In this context, acoustic technics are studied in order to allow us to characterize the presence of these microbubbles, i.e. determine the void fraction (volume fraction of free gas) and the histogram of bubbles radius. In this context, the measure of the low frequency celerity using the Wood's model is proposed in addition to nonlinear acoustic methods such as subharmonics and harmonics generation and frequencies modulation. Indeed the phenomena of bubbles resonance are very important and are nonlinear even in case of low acoustic pressure.
We present here the first-level experimental set-up in water: the bench MESANGE (MESure Acoustique de l'eNGazement en Eau). Similarities are expected in liquid sodium. A cloud of microbubbles is generated by relaxing a liquid enriched with dissolved gas by compression (aeroflottation). Bubbles are optically measured in order to have reference characteristics of the bubble cloud. The first results are promising.

Number of words in abstract: 216
Keywords: Bubbles - Nonlinear Acoustics - Liquid Sodium

Mardi 9 matin (Tuesday, 9 morning)

Invited talk:

08:30 – 09:00 **R. 'Dick' Hazelwood**
Noise issues in underwater acoustics – with particular attention to ship radiated noise, piling noise and ROV noise – and their possible environmental impact

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09:00 – 09:20 **N. Bertin, R. Wunenburger, E. Brasselet and J.-P. Delville**
Stabilisation of a liquid column by the acoustic radiation pressure of guided waves

09:20 – 09:40 **D. Sinden, E. Stride and N. Saffari**
Effects of nonlinear wave propagation on inertial cavitation

09:40 – 10:00 **B. Galaz, G. Haïat, N. Taulier, J.-J. Amman and W. Urbach**
Numerical study of the ultrasonic propagation in a solution of ultrasound contrast agent at high frequency

10:00 – 10:30 ***Tea – Coffee***

10:30 – 10:50 **S. Martynov, E. Stride and N. Saffari**
Numerical modelling of the dynamics of a microbubble in a blood vessel

10:50 – 11:10 **J. Chenot and D. Melodelima**
Ultrasound elastography by manual palpation for the visualization of ablations produced using a toroidial HIFU transducer: *in vivo* results

11:10 – 11:30 **R. Ellwood, T. Stratoudaki, S. Sharples, M. Clark and M. Somekh**
Investigation of the fatigue process using nonlinear ultrasound

11:30 – 11:50 **N. Leymarie, T. Fouquet, S. Mahaut and P. Calmon**
Semi-analytical-FEM hybrid tool dedicated to NDT in CIVA

AFPAC2008/33
Noise issues in Underwater Acoustics - with particular attention to ship radiated noise, piling noise and ROV noise - and their possible environmental impact

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A review will be made of some areas where underwater acoustics differ from acoustics in other media such as air. As well as the different reference pressure (1μPa) now widely accepted for decibel pressure levels, decibel source levels are more commonly used. Whilst there is a less well defined set of noise level criteria and frequency weightings, some recent proposals will be discussed.
Most 20th century work on noise concentrated on its effects on mechanical systems, but the environmental impact on other species has increased in importance. We need to take note of the techniques used for the protection of humans in air, and adapt procedures accordingly.
For example, the acoustic power rating, Lwa, has the same benefits underwater as it has in air and these will be discussed, particularly in relation to ship noise.

Number of words in abstract: 135
Keywords:

AFPAC2008/28
Stabilisation of a Liquid Column by the Acoustic Radiation Pressure of Guided Waves

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Acoustic radiation pressure is known to induce various deformations and instabilities at liquid-liquid interfaces (see Issenmann et al., Eur. Phys. Lett. 83, 34002 (2008) and refs. therein). It has also been recently used to stabilize liquid bridges (Marr-Lyon et al., Phys. Rev. Lett., 86, 2293 (2001)). We investigate a new, more efficient method for stabilizing a liquid column by injecting an intense acoustic beam into the column. Columns of length over diameter ratios close to 6 are observed, i.e. well beyond the limit of Rayleigh-Plateau instability. The measured column diameters are quantitatively predicted by using a guided mode theory and balancing Laplace pressure and acoustic radiation stress applying on the column.

Number of words in abstract: 111
Keywords: radiation pressure - hydrodynamics - guided modes

AFPAC2008/21
Effects of nonlinear wave propagation on inertial cavitation

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In the context of forecasting temperature and pressure fields in therapeutic high-intensity ultrasound accuracy in the model is critical for safe and efficient treatment.
Classically, estimations of cavitation thresholds have been based on the assumption that the incident wave at the surface of a bubble is sinusoidal, neglecting the effect of nonlinear wave propagation. By modelling the incident wave as a solution to Burgers' equation using weak shock theory, the effects of nonlinear wave propagation are investigated using both numerical and analytical techniques. From radius-time curves it is observed that there is a reduction in the maximum size of a bubble undergoing inertial cavitation and that the inertial collapse occurs earlier in contrast with the classical case. Corresponding stability thresholds for a bubble whose initial radius is slightly below the critical Blake radius are calculated. Bifurcation diagrams and frequency-response curves are presented describing the onset of broadband noise associated with the loss of stability.
The consequences and physical implications of the results are discussed with respect to the classical results.

Number of words in abstract: 170
Keywords: cavitation - Nonlinear wave propagation

AFPAC2008/15
Numerical study of the ultrasonic propagation in a solution of ultrasound contrast agent at high frequency

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Specific ultrasound contrast agents (UCA) offer new avenues in therapeutic treatment by allowing in situ drug delivery in combination with ultrasound imaging. However, high frequency acoustic wave propagation in solutions of UCA remains unclear due to the complex interaction between ultrasound and the coated particles (mode conversion, scattering, multiple reflections). The aim of this study is to assess the potentiality of 2-D numerical simulation tools to model the propagation is such medium around 50 MHz. We aim at deriving the sensitivity of the ultrasonic parameters to different physical parameters of UCA suspensions. A 2-D Finite Difference Time Domain numerical simulation code (Simsonic) was used to model the ultrasonic propagation in an aqueous solution with particles made of i) polystyrene and ii) fluid surrounded by a polymeric capsule. For each set of parameters, the results were averaged for 15 UCA solutions with randomly located particles. The numerical simulation tool is first validated by comparing the results with an analytical model derived from the Faran theory. A good agreement between the experimental and numerical results was obtained for the polystyrene particles. For the coated particles, the attenuation coefficient at 50 MHz (AC50) and the relative backscattered intensity (RBI) increases non-linearly with the concentration. When the membrane thickness increases, AC50 decreases whereas RBI decreases (respectively increases) for thin (< 1 μm) (respectively thick, > 1 μm) membranes. AC50 decreases (respectively increases) when the longitudinal (respectively transverse) wave velocity of the membrane increases. Mode conversion effects play a role in the ultrasonic propagation through a UCA solution. Multiple scattering phenomena may explain the variation of AC50 and of RBI as a function of the membrane thickness and of the concentration. This study therefore may have important implications in the conception of new particles used in UCA suspension.

Number of words in abstract: 293
Keywords: ultrasound contrast agent - heterogeneous medium - FDTD simulation

AFPAC2008/18
Numerical Modelling of the Dynamics of a Microbubble in a Blood Vessel

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Coated microbubbles have been extensively investigated as contrast agents for diagnostic ultrasound imaging and more recently for therapeutic applications such as targeted drug delivery. However, theoretical models for microbubble dynamics have previously been developed either for encapsulated bubbles in an infinite volume of fluid, or for uncoated bubbles in a confined volume. In the present study, a numerical model is developed to explore the effects of both encapsulation and confinement in a blood vessel upon the microbubble response in a pressure field. The bubble shell is modelled as a layer of homogeneous and isotropic linear elastic material of a finite or infinitesimal thickness, aiming to examine the dynamics of polymer-coated and surfactant-coated microbubbles. Elastic deformations of the vessel wall are described using a lumped-parameter model of the wall as a thin membrane. Results from the model will be compared with those from other theoretical models of oscillating bubbles, and the theory of buckling of a thin spherical shell. It will be shown that even at low acoustic pressures ($\sim$ 10 kPa), the radial oscillations of the bubble and the amplitude and spectrum of the radiated pressure field can be significantly modified as a result of confinement. Results showing the effects of vessel wall deformations and shape oscillations of a bubble (including buckling of the encapsulating shell) as predicted by the model will be discussed in the context of diagnostic and therapeutic applications of microbubbles.

Number of words in abstract: 234
Keywords:

AFPAC2008/5
Ultrasound Elastography by Manual Palpation for the Visualization of Ablations Produced Using a Toroidial HIFU Transducer: In Vivo Results

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The use of real-time surface palpation elastography for strain imaging was investigated. A toroidial HIFU transducer was used to produce large zones of ablation in in vivo pig livers. A conventional real-time ultrasound imaging probe was used and RF signals were obtained from a modified BK ultrasound scanner. The resulting strains were mapped using ultrasound correlation-based methods. Fourteen HIFU lesions produced in 4 pigs were analysed using the elastography by manual palpation. Fast algorithms have allowed producing elastograms at a rate of 60 images per second. The quality of the elastograms corresponding to the elastically inhomogeneous liver (normal tissues and ablated tissues) was assessed by computing the contrast-to-noise ratio (CNRe) and the signal-to-noise ratio (SNRe). In addition, a comparison of the lesions dimensions with the dimensions measured on sonograms and on elastograms was conducted. In most cases, sonograms and elastograms allowed to observe all lesions and dimensions were well-correlated. For all lesions, the average CNRe and SNRe were 4.7 ± 5.1 (0.1 - 24.7) and 2.7 ± 1.3(1.1 - 7.5) respectively. In two particular cases, elastograms allows a better evaluation of the ablation extends when compared with sonograms. A computation of the correlation between elastograms, sonograms and gross pathology by the Pearson's method highlight the importance of elastograms in complement of ultrasound scan (R^2_elasto/pathology = 0.97, R^2_sonogram/pathology = 0.91).

Number of words in abstract: 215
Keywords: elastography - ultrasound - liver - imaging

AFPAC2008/22
Investigation of the fatigue process using nonlinear ultrasound

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The aim of this work is to develop a non-destructive ultrasonic technique to monitor the residual lifetime / fatigue of engineering components. During usage, components undergo stresses, insufficient to cause a fracture but gradually cause fatigue, weakening the component. Linear ultrasonic methods are poor at detecting fatigue. However, strong evidence exists that accumulation of damage gives the material a non-linear elastic response which can be probed by ultrasound. The instrumentation we are developing will allow us to detect this and establish its link with the fatigue process.
Several methods detecting a material's non-linearity using acoustic waves have been proposed. We have had success with the collinear mixing technique[1]. It relies on propagating two waves of different frequencies (a pump low frequency and a probe high frequency wave) and measuring the subsequent mixing due to the non-linearity of the material. By arranging the frequencies and bandwidth of the waves we will measure the mixing as phase modulation of the probe wave (equivalent to a velocity change in the material) induced by the pump wave[2]. By measuring the phase change and the induced stress levels, a measure of non-linearity can be obtained. We intend to monitor this over several fatigue levels, to find a relationship between fatigue and non-linear response.
A transducer generates the pump SAW and a pulsed laser is used in conjunction with an amplitude grating to produce the probe SAW. Details about the design and construction of the instrumentation are given. We intend to monitor non-linear response as we fatigue specimens of titanium, stainless steel and aluminium. Early stage results are given with a discussion on the development of the technique.

Number of words in abstract: 300
Keywords: Nonlinear - Fatigue - Laser Ultrasonics - Surface Acoustic Waves

[1] IJ. Collison, T. Stratoudaki, M. Clark, M.G. Somekh Ultrasonics Vol 48 (2008) 471-477
[2] C. Barrière D. Royer IEEE transactions on Ultrasonics, Ferroelectrics and Frequency control Vol 48 (2001) 1706-1714

AFPAC2008/23
Semi-analytical-FEM hybrid tool dedicated to NDT in CIVA

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A hybrid model based on FEM code ATHENA developed by EDF and the pencil model implemented in the CIVA plat-form (CEA) will be available in the next CIVA version. This hybrid approach is combining the advantages of both methods by computing most of the propagation semi-analytically (CIVA pencil model) while the wave/defect interaction is computed numerically (ATHENA) in a small region surrounding the defect. In this presentation we summarize the coupling principle and give some examples for some canonical cases. We show the interest of the approach for the technical qualification of complex inspections such as irregular profiles cracks and array of cracks. The module also provides dedicated tools to visualize the elastodynamic field radiated and scattered inside the FEM box. Finally, we present the perspectives and works in progress which aim at improving time performance and developing some tools to help CIVA users with the definition and analysis of the coupling method.

Number of words in abstract: 153
Keywords: Finite Element Method - Semi-analytical ray based method - Coupling method - CIVA NDT simulation

Mardi 18 après-midi (Tuesday, 18 afternoon)

Invited talk:

14:00 – 14:30 **M. Bruneau**
Viscous and thermal boundary layers in fluid-filled acoustic cavities: fundamental and applications

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14:30 – 14:50 **P. Gélat and N. Joly**
Acoustic modelling in view of a determination of the Boltzmann constant within 1 ppm for the redefinition of the Kelvin

14:50 – 15:10 **B. Hosten, C. Bacon and C. Biateau**
FE modelling of the temperature rise due to the propagation of ultrasonic waves in viscoelastic materials and experimental validation

15:10 – 15:30 **E. Caplain, J.-Y. Le Huérou, S. Serfaty, N. Wilkie-Chancellier and P. Griesmar**
TSM resonators array for a broadband investigation of complex structures

15:30 – 16:00 *Tea – Coffee*

Invited talk:

16:00 – 16:30 **T. Kent**
Terahertz acoustics in semiconductor nanostructures

16:30 – 16:50 **Y. Guillet, C. Rossignol, B. Audoin, G. Calbris and S. Ravaine**
Vibrational modes of single 500 nm gold particle revealed by the picosecond ultrasonic technique

16:50 – 17:10 **L. Martinez, N. Wilkie-Chancellier, C. Glorieux, B. Sarens and E. Caplain**
Transient space-time surface waves characterization using Gabor analysis

17:10 – 17:30 **D. Ségur, A. Shuvalov and B. Audoin**
Acoustic waves generated by a laser pulse in an optically absortive isotropic cylinder

17:30 – 17:50 **A.-C. Hladky-Hennion, J. Vasseur, B. Djafari-Rouhani, E.H. El Boudouti and M. de Billy**
Numerical and experimental results on sonic bandgaps in 1-D phononic crystals with periodically grafted symmetric stubs

Conference dinner “Chez Diégo”

AFPAC2008/32
Viscous and thermal boundary layers in fluid-filled acoustic cavities: fundamentals and applications

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We ordinarily think of an acoustic wave in a gas as consisting of coupled pressure and displacement oscillations. However, temperature oscillations and shear movements always accompany the pressure oscillations, more specifically near the walls where both interact with the acoustic movement (inside the viscous and thermal boundary layers). The combination of all these oscillations and their interaction with solid boundaries produce a variety of effects. Although these effects as they occur in every day life are too small to be noticed, they need to be modelled carefully in a lot of applications and even they are able to produce powerful engines.
The first part of the presentation aims at presenting the fundamental phenomena involved in both the acoustic propagation in viscous/thermal-conducting fluids at rest and the interaction of the acoustic fields with walls inside the viscous and thermal boundary layers (mathematical formalisms will be relegated to further discussions, so they will not detract from developing intuition in the presentation).
In the second part of the presentation, three applications will be presented, each of them involving viscous and thermal boundary layer effects: - precise measurement of the Boltzmann constant using quasi-spherical resonator, involved in the redefinition of the international system of units, - acoustic gyrometer involving acoustic coupling in rotating cavities due to the inertial effects on the shear movement in the viscous boundary layer, - acoustic engines and acoustic refrigerators, involving respectively the generation of acoustic fields and conversely heat transfer using acoustic energy, both occurring inside the thermal boundary layer.

Number of words in abstract: 251
Keywords:

AFPAC2008/19
Acoustic Modelling in View of a Determination of the Boltzmann Constant within 1 ppm for the Redefinition of the Kelvin

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iMERA/Euromet Project 885 is co-ordinating European effort towards a new determination of the Boltzmann constant to within 1 ppm with the aim of redefining the unit of thermodynamic temperature. This project will enable the National Physical Laboratory to perform primary thermometry in the region of -40 °C (Hg) to 156 °C (In) with sub-millikelvin uncertainties by 2012.
The chosen technique relies on determining the speed of sound in a monatomic gas. Using the radial acoustic modes of a spherical resonator, consisting of a copper shell and filled with argon or helium, the speed of sound can be measured with great precision and from this measurement the Boltzmann constant can be inferred. This project draws on expertise in dimensional, density, microwave and acoustic measurements at the state-of-the art.
In order to gain further understanding of the experimental configuration a vibro-acoustic model has been developed using the finite element method. Initial calculations were carried out to ensure that predictions of the resonant frequency could be made with the required precision by comparing against an analytical model of a spherical shell filled with a gas. A more elaborate model better representing the experimental configuration was then developed. Thermo-viscous effects close to the fluid-structure boundary were accounted for using a linear acoustic formulation, from which a normal incidence admittance boundary condition was derived and imposed on the inner surface of the resonator. Acoustic pressure, particle velocity and temperature variation as a function of position may be obtained within the gas as a function of frequency. It is therefore possible to investigate how changes in the configuration affect the frequency of radial modes. It is hoped that this approach will shed a better understanding of the underlying complex physical phenomena occurring within the resonator and that an optimised design may be arrived at.

Number of words in abstract: 298
Keywords: Boltzmann constant - Finite element modelling - thermo-viscous effects - Linearised Navier-Stokes equation

AFPAC2008/3
FE modeling of the temperature rise due to the propagation of ultrasonic waves in viscoelastic materials and experimental validation

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The ultrasound stimulated thermography method is usually used to detect the temperature rise at a defect position. The temperature rise can be due to the friction between the edges of the defect and/or the plastic deformation around the defect. This paper presents another aspect of the method when the ultrasounds are propagating in a viscoelastic anisotropic material, such as polymers or fibers reinforced polymers. The attenuation of the waves produces a distributed temperature field. Therefore, even a defect that does not produce some heat, can be detected, since the ultrasonic field is modified. A FE model is used for computing the temperature field and for predicting the possibility for an infrared camera of detecting the temperature rise and its modification due to a defect. The model computes the stress and displacement fields associated to the propagation and the loss of energy. Then the heat equation is solved with this loss as a source of heating. An experiment is done with a sonotrode that excites a PVC plate. The ultrasonic displacement at the top of the plate is measured with a laser velocimeter and introduced in the model. Finally, the model result is compared to the image produced by the camera.

Number of words in abstract: 200
Keywords: Finite Elements - Ultrasonic guided waves - Thermography - Viscoelasticity

AFPAC2008/13
TSM Resonators Array For a Broadband Investigation of Complex Structures

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Bulk acoustic wave sensors such as thickness shear mode resonators (TSMR) can be used to investigate the viscoelasticity of liquid or gels. For new hybrid materials, the monitoring of the structure evolution during their elaboration is required to optimize their characteristics. This investigation needs a multi-scale study and a spatial monitoring. This work presents a new sensor made of a TSMR array. Our device consists of interconnected resonators made on separate substrates. The thickness of the different substrates has been chosen to get a wide frequency range to perform a multi-scale investigation with a high sensitivity. Our array is designed to avoid acoustic interference between TSM resonators. The impedance evolution of the TSMR array is used to extract simultaneously the local viscoelasticity at different frequencies. This device is particularly suitable to investigate inhomogeneous fluids and no miscible fluids.

Number of words in abstract: 138
Keywords:

AFPAC2008/25
Vibrational modes of a single 500 nm gold particle revealed by the picosecond ultrasonic technique

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Spatial confinement of noble metals leads to a discretization of the vibrational modes allowed. For instance, the fundamental mode (the so-called "breathing" mode) is associated to an isotropic and periodic expansion/contraction of the nanoparticle. Characteristics of these modes depend on the nature of the material, the size of the nanoparticle and its shape: we can thus imagine local acoustic sources with adaptable vibrational spectrum. This spectrum is also strongly influenced by the environment of the nanoparticle, which can then be considered as a local acoustic probe. However, a better understanding and control of these modes is needed in order to use nanoparticles as nanoscale opto-acoustic transducers.
Picosecond ultrasonic is a time-resolved technique well suited to study acoustic properties of nano-objects[1] and micro-objects:[2,3] a femtosecond optical pulse (the "pump") heats the lattice of the particle, through optical absorption, resulting in the excitation of vibrational modes. A second optical pulse (the "probe") reveals these modes through a periodic modulation of the optical properties of the particle.
In order to use nanoparticle as local transducers, a first step is to be able to experimentally study a single particle, which also present the advantage of avoiding any inhomogeneous broadening of the response.[4] We report here on the detection of radial acoustic modes of a single gold particle (about 500 nm diameter) through the periodic modification of its reflectivity. Eigenfrequencies extracted from experimental results are in good agreement with those determined by solving the wave equation in a spherical geometry and for purely radial modes.
[1] N. Del Fatti et al. J. Chem. Phys. 110, 11484 (1999)
[2] G. A. Antonelli et al. J. Appl. Phys. 91, 3261 (2002)
[3] C. Rossignol et al. Phys. Rev. Lett. 94, 166106 (2005)
[4] M. A. Van Dijk et al. Phys. Rev . Lett. 95, 267406 (2005)

Number of words in abstract: 299
Keywords: Picosecond ultrasonics - Nanoparticle

AFPAC2008/12
Transient Space-Time Surface Waves Characterization Using Gabor Analysis

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Laser ultrasonics allow the observation of transient surface waves along their propagation media and their interaction with encountered objects like cracks, holes, borders. In order to characterize and localize these transient aspects in the Space-Time-Wave number-Frequency domains, the 1D, 2D and 3D Gabor transforms are presented. The Gabor transform enables the identification of several properties of the local wavefronts such as their shape, wavelength, frequency, attenuation, group velocity and the full conversion sequence along propagation. The ability of local properties identification by Gabor transform is illustrated by two experimental studies: Lamb waves generated by an annular source on a circular quartz and Lamb wave interaction with a fluid droplet. In both cases, results obtained with Gabor transform enable ones to identity the observed local waves. From this knowledge efficient ray models are proposed and compared to results obtained by classical methods like high resolution signal processing, 3D Fourier Transforms and theoretical classical modal analysis.

Number of words in abstract: 154
Keywords:

AFPAC2008/24
Acoustic waves generated by a laser pulse in an optically absorptive isotropic cylinder

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A cylinder is an important issue for the acoustic wave propagation research. Theoretical studies may be found in many textbooks (see e.g. [1]). However, few experimental results [2] have been obtained essentially due to difficulties of coupling piezoelectric transducers with curved surfaces. Having emerged in the 80s, the laser ultrasonics technique with its non-contact generation and detection process overpasses these limitations and permits to obtain experimental waveforms for any curved geometry.
In this talk, laser generation and propagation of acoustic waves in an optically absorptive isotropic cylinder is studied. A laser pulse line focused at the surface is absorbed over the volume and thus creates a radially distributed source. Assuming an exponential law of optical absorption, taking convolution with the appropriate two-dimensional elastodynamics Green's function, and applying two inverse transforms enable to calculate the sought response.
Experiment is performed on a 5 mm diameter colored glass rod with a Nd:YAG laser delivering 5 ns pulses. A first experiment using a pump-probe technique on a tungsten fiber of 5 μm diameter is reported. A Ti:Sapphire laser pulses of 100 fs is used to excite the micrometric fiber. Change of reflectivity at the surface of the sample is used to probe acoustical arrivals. Good agreement is obtained with calculated waveforms for given optical absorptive properties, thus demonstrating that sound generation process is accurately taken into account. Interesting perpectives concerning NDE of micrometric fibers used in composite materials is expected.
[1] J.D.Achenbach, "Wave propagation in elastic solids",North-Holland, Amsterdam (1973)
[2] D.Royer, E.Dieulesaint, X.Jia, Y.Shui, "Optical generation and detection of surface acoustic waves on a sphere", Applied Physics Letters 52, 706-708 (1988)

Number of words in abstract: 272
Keywords:

AFPAC2008/29
Numerical and experimental results on sonic bandgaps in 1-D phononic crystals with periodically grafted symmetric stubs

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The wave propagation in periodic systems has received a great deal of attention during the last years. By analogy with the studies driven on photonic crystals, many works were conducted on phononic crystals. In this talk, the propagation of elastic waves through a one dimensional chain of beads with grafted stubs is experimentally as well as numerically investigated. The results obtained by both approaches are well correlated. First, only one symmetric stub is considered in the middle of the chain and it introduces a dip in the spectral response of the chain. The numerical analysis shows that this dip is due to the excitation of a stub mode that cancels the transmission from one extremity of the chain to the other. Then periodically grafted stubs are considered and, depending on the nature of the stubs as well as its periodicity, rejecting filters or selective filters are obtained, which frequencies can be adjusted. Therefore, it opens potential applications of these structures for filtering or demultiplexing.

Number of words in abstract: 164
Keywords: phononic crystal - bandgaps

Mercredi 10 (Wednesday, 10)

Invited talk:

08:30 – 09:00 **A. Dowling**
The "silent aircraft" initiative

09:00 – 09:20 **D. Parenthoine, L. Haumesser, F. Vander Meulen and L.-P. Tran-Huu-Hue**
Strong harmonic generation in a PZT / Aluminium rod resonator

09:20 – 09:40 **G. Memoli, P. Gélat, M. Hodnett and B. Zeqiri**
The importance of temperature control in the operation of high power ultrasound reactors

09:40 – 10:00 **A. Ndieguene, J. Carlier, S.-X. Wang, P. Campistron, D. Callens-Debavelaere and B. Nongaillard**
Using SU-8 photo resist for broadband mechanical matching at 1 GHz

10:00 – 10:30 *Tea – Coffee*

10:30 – 10:50 **Y. Pennec, B. Djafari-Rouhani, H. Larabi, J. Vasseur and A.-C. Hladky-Hennion**
Band gaps in a phononic crystal constituted by cylindrical dots on a homogeneous plate

10:50 – 11:10 **G. Haïat, S. Naili, Q. Grimal, M. Talmant, C. Desceliers and C. Soize**
Finite element model of the ultrasonic propagation in cortical bone: application to the axial transmission device

11:10 – 11:30 **A. McCredie, E. Stride and N. Saffari**
Quasi-static and dynamic elastography of depth-dependent cartilage behaviour

11:30 – 11:50 **G. Haïat, F. Padilla, M. Svrcekova, M. Chevalier, D. Pahr, P. Laugier and P. Zysset**
Relationship between the ultrasonic parameters and apparent modulus of human cancellous bone assessed by micro finite element analysis

AFPAC2008/35
The Silent Aircraft Initiative

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The Silent Aircraft Initiative was launched with the aim of developing a conceptual design for an aircraft, whose noise would be almost imperceptible outside the perimeter of an urban airport. The project has been carried out through collaboration between about 40 researchers at the University of Cambridge, MIT and a 'Knowledge Integration Community' which includes many different stakeholders, including industry, government and academia.
Avoiding some traditional aircraft noise sources requires a radical rethink about the configuration. An all-lifting design has many benefits, enabling a closer integration of airframe and engine than the traditional 'tube and wing'. Low-noise design includes taking advantage of shielding of engine noise by the airframe; low-noise engines with large, low speed jets; an order of magnitude increase in absorption by liners; and operations for low-noise informing the design. The emerging conceptual design, SAX40, is predicted to achieve a radical reduction in noise and to use 25% less fuel per passenger mile than the best of current aircraft.

Number of words in abstract: 161
Keywords:

AFPAC2008/11
Strong harmonic generation in a PZT/ Aluminium rod resonator

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In this work, the extentional vibration mode of a coupled PZT/ Aluminium rod resonator is studied experimentally. Geometrical characteristics of the piezoelectric PZT are its 27 mm length and its 4x4 mm^2 cross section area. The excitation voltage consists in sinusoidal bursts in the frequency range (20-50 kHz). Velocity measurements are performed at both ends of this system, using a laser probe. Strong harmonic distortions in the mechanical response (up to -20 dB with respect to the primary wave amplitude) have been observed. The corresponding input levels (20 V/cm) are far lower than those which are necessary to observe quadratic second harmonic generation in a free PZT resonator (100 V/cm) [1]. The strong non-linear effect can be explained as a super-harmonic resonance of the system due to a specific ratio between the eigen frequencies of the two parts of the resonator. Evolution of fundamental and harmonic responses are studied as a function of input levels. In addition, the transition from a quadratic regime of second harmonic generation to a strong non-linear one is discussed.
[1] D. Parenthoine, L. Haumesser, F. Vander Meulen, M. Lethiecq, L.-P. Tran-Huu-Hue. " Nonlinear constant evaluation in a piezoelectric rod from analysis of second harmonic generation " Accepted in IEEE Trans. Ultrason. Ferroelec. Freq. Contr

Number of words in abstract: 207
Keywords: Non-linear acoustics - Piezoelectricity - Modal analysis

AFPAC2008/4
The Importance of Temperature Control in the Operation of High Power Ultrasound Reactors

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Cavitation induced by high power ultrasound is used in a large number of industrial applications ranging from cleaning vessels to sonochemical reactors. Commercial reactors are usually designed to deliver a fixed amount of power at a fixed frequency regardless of external conditions and this goal is usually achieved by adjusting the voltage on the transducers. This solution, however, does not guarantee the same field geometry when temperature changes occur and, consequently, the level of cavitation activity and its spatial distribution may be modified.
The presentation describes a study of the significance of this effect for a 25 kHz sonochemical reactor, which is being developed as a reference facility for studying acoustic cavitation at NPL. Field measurements, acquired using a hydrophone in different locations inside the cavitation reactor, are compared with FEM models applied at different temperatures, showing that significant changes in the acoustic pressure distribution (and consequent cavitation activity) can result from relatively small temperature variations.
Modal analysis will be used in this work as a tool to explain the physical reasons behind this behaviour and the effects of a coarse temperature control will be assessed in terms of the improved stability of the acoustic pressure field.
This work also highlights some of the limitations of modal analysis for the design of more complex reactors and associated temperature control methods

Number of words in abstract: 220
Keywords: cavitation - ultrasound - mode analysis - thermal control

AFPAC2008/10
Using SU-8 photo resist for broadband mechanical matching at 1 GHz.

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Our goal is to integrate acoustic functions in BioMEMS from ZnO transducers deposited on silicon substrates and resonating around the 1 GHz frequency. Acoustic waves propagate through the silicon substrate and we need to maximize its transmission in water (the insertion losses at the Si / water interface are 6dB). The solution usually used is to adjust the impedance by two non-reflecting quarter wavelength layers made of glass and polymers (epoxy) having a proper acoustic impedance. In the context of integration, it is interesting to use photosensitive materials so as to achieve some patterns. The goal is to create composite materials based on mixed with nanoparticles having adequate impedances. These new materials are characterized with their acoustic velocity, impedance and attenuation. The nanocomposite layers are deposited on the substrate by spin coating to get a thickness of about 10 μm, in order to achieve the separation of acoustic echoes from the material (even if lamda/4 thickness is lower than 1μm). For this, we measure the parameter S11 which represents the ratio between the reflected acoustic wave and the incident acoustic wave at the interface silicon / nanocomposite. Then the bandwidth is obtained by plotting the insertion losses as a function of frequency for a given reflection coefficient between the silicon substrate and the photoresist. We have established the characteristics of some nanocomposites made of SU-8 and various concentrations of nanoparticles like TiO2, SrTiO3 or W . We have compared the mechanical matching efficiency of these different nanocomposites.

Number of words in abstract: 247
Keywords: mechanical matching - BioMEMS - SU-8 phot resit

AFPAC2008/30
Band gaps in a phononic crystal constituted by cylindrical dots on a homogeneous plate

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Using the Finite difference Time Domain method (FDTD), we investigate the existence of absolute band gaps associated with a phononic crystal of finite thickness constituted by a periodical array of cylindrical dots deposited on a thin plate of a homogeneous material. We demonstrate the existence of a low frequency gap in the band structure of the phononic crystal plate which means that the acoustic wavelengths in the constituent materials are much larger than the lattice period. The opening of the gap is discussed as a function of the geometrical parameters of the structure, in particular the thickness of the homogeneous plate and the height of the dots. We show that the gap persists even if we change the materials constituting the plate and the dots. Besides, the band structure can exhibit one or more higher gaps whose number increases with the height of the cylinders. Finally, we discuss the condition to realize waveguiding through a linear defect inside the phononic crystal dots.

Number of words in abstract: 162
Keywords: Phononic Crystal - Low frequency gap - plate

AFPAC2008/17
Finite element model of the ultrasonic propagation in cortical bone: application to the axial transmission device

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The axial transmission technique is used clinically for cortical bone assessment. However, the ultrasonic propagation in this multiscale transverse isotropic medium remains unclear, because of the heterogeneous nature of cortical bone. At the macroscopic scale, the distribution of porosity induces a gradient of material properties oriented in the radial direction. The aim of this work is to evaluate the effect of a spatial gradient of material properties on the ultrasonic response of a transverse isotropic bone structure. A 2D finite element time-domain method is developed to simulate transient wave propagation in a three-layer medium constituted of an inhomogeneous transverse isotropic solid layer sandwiched between two acoustic fluid layers and excited by an acoustic linear source located in one fluid layer delivering broadband ultrasonic pulses (1 MHz center frequency). The model couples the acoustic propagation in both fluid media with the elastodynamic response of the solid. A constant spatial gradient of material properties in the direction perpendicular to the layer is considered in the solid for two values of bone widths h corresponding to a relatively thick or thin bone (h=0.6 and 4 mm). For thin bone widths (0.6 mm), results are in agreement with the symmetric mode S0 of Lamb waves assuming a homogeneous material with spatially averaged material properties. For thick bone widths (4 mm), the results are in agreement with the propagation of a lateral wave. For thick bone width, our results allow the estimation of an equivalent penetration depth of the lateral wave in the case of a transverse isotropic inhomogeneous solid layer (0.6 and 0.95 mm for a gradient of C11 and mass density respectively). This study was supported by the Agence Nationale de la Recherche (Contract BoneChar n° BLAN06-2_144779).

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Quasi-static and dynamic elastography of depth-dependent cartilage behaviour

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Joint cartilage is an important load bearing structure in the body which has only limited ability for regeneration after damage. In order for tissue engineers to design functional constructs increased understanding of healthy tissue is required. Joint cartilage is a specialised structure of hyaline cartilage. Hyaline cartilages are poroviscoelastic solids containing fibril matrix reinforcements. Healthy joint cartilage is known to be layered and it is thought this layering is important for correct tissue function. However, the behaviour of each layer during static and dynamic loading is poorly characterised. Ultrasound elastography provides access to depth-dependent information in a sample during real-time loading protocols. A 15MHz focussed transducer was selected to provide details from the scatterers within a small fixed region in the cartilage. Quasi-static and dynamic loading protocols were applied to samples while ultrasonic signals before and during compression cycles were recorded. Received ultrasonic signals were processed to provide time shift profiles using a sum squared difference method and cross-correlation. Two different structures of hyaline cartilage have been tested ultrasonically and mechanically to determine the suitability of the method for monitoring layer differences under load.

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Relationship between the ultrasonic parameters and apparent modulus of human cancellous bone assessed by micro finite element analysis

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Quantitative ultrasound (QUS) has been shown to be useful to assess bone quality and to predict bone fracture risk. Characteristics of ultrasound transmission through cancellous bone are governed by bone material and structural properties. However, the translation of QUS results into bone strength remains elusive. The aim of this study is to investigate the relationship between broadband ultrasonic attenuation (BUA), speed of sound (SOS), and the apparent elastic modulus of cancellous bone (E), which is a surrogate marker for bone strength. An ancillary objective is to compare the ability of QUS variables and of bone quantity (BV/TV) alone to predict bone strength. Bone samples were prepared from human femur specimens and scanned with synchrotron radiation micro-computed tomography. Finite-difference time domain simulations of wave propagation were performed in three orthogonal directions of the 3-D microstructures of trabecular bone. BUA and SOS values were derived for each sample and each direction. In parallel, a voxel-based micro finite element linear analysis was employed to compute the apparent Young's modulus (E) of each sample and each direction of testing. In the antero-posterior direction, which is perpendicular to the main trabecular alignment, highly significant linear relationships were found between SOS and E, BUA and E, and BV/TV and E. The prediction of E was slightly improved with a multiple linear regression model combining SOS and BUA. Our results suggest that SOS has a significantly better predictive power of E compared to BUA. QUS perform better than BV/TV alone to predict the elastic modulus of cancellous bone. Since apparent modulus of cancellous bone was shown to be closely related to apparent strength, this study demonstrates the potentiality of QUS technique to assess fracture risk when the direction of testing is not parallel to the main trabecular alignment.

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