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Ultrasound in Environmental Protection - Some Recent Developments

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Environmental protection means different things to different people. It can refer to methods of preventing pollution – and this includes the massive field of green chemistry, low pollution fuels (including the use of biodiesel and fuel cells for vehicles) and emission control. But it can also mean the removal of existing pollution e.g. the decontamination of the atmosphere, the clean-up of soil and the purification of water (both chemical and biological). This presentation will address the second interpretation under the headings:

Air	Agglomeration of smokes and aerosols
Land	Removal of oil and PCB contamination
Water	Biological and chemical decontamination

In the last three years the major advances in ultrasonic technology have gone down two different pathways. There have seen major moves in therapeutic ultrasound including the use of focused ultrasound in cancer treatment and the manipulation of cells in an acoustic field to facilitate sonoporation. The latter is heading rapidly towards gene therapy and requires tiny carefully designed reactors with well-defined static fields operating in the MHz range. On the other hand there are groups who are scaling up sonochemical treatments to deal with large-scale systems involved in water and sewage treatment works and reservoirs. In between there are still legions of scientists working with conventional laboratory systems in attempts to open up new areas for the uses of ultrasound.

An investigation of the threshold pressure for inertial acoustic cavitation generated within a cylindrical sonochemical reactor operating at 25 kHz

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Acoustic cavitation is employed within many applications such as ultrasonic cleaning and materials processing. *Inertial* cavitation is commonly considered to be the phenomenon giving rise to bubble collapse events which are of sufficient violence to generate the physical and chemical effects required in these applications, such as erosion, free-radical formation, etc. The key factor governing whether acoustic cavitation occurs, and the severity of the subsequent violent collapse, is the acoustic pressure *at the site* of interest within the vessel or reaction chamber. Cavitation is commonly associated with a certain threshold pressure, below which inertial cavitation effectively does not occur. This paper investigates the magnitude of this threshold pressure, for a sonochemical reactor operating at 25 kHz.

This vessel is being developed as a test bed through which reference methods of cavitation monitoring and detection are being evaluated and established. It comprises a cylindrical reactor of internal diameter 318 mm, around whose inner surface are positioned thirty 25 kHz transducers disposed in three banks of 10. The overlap region of the acoustic fields generated by the individual transducers gives rise to a highly focused field with a strong pressure maximum along the central axis of the reactor. By varying the electrical power delivered to the transducers, a variety of acoustic conditions may be generated not only along the central axis, but also elsewhere within the test vessel.

The onset of acoustic cavitation has been investigated using underwater acoustic hydrophones in conjunction with special hollow cylindrical sensors which detect high-frequency acoustic emissions (megahertz and above) produced by the violent collapse of bubbles. In this presentation, results of the spatial distribution of acoustic pressure and cavitation activity generated within the vessel under various operating conditions are compared, and used to derive an estimate of the *acoustic cavitation threshold*. The implications of the findings of the study are discussed.

Towards a measure of inertial cavitation – The NPL Cavimeter

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Applications of high power ultrasound are found in a great many industrial sectors, from healthcare, through sonochemistry, to ultrasonic cleaning. The reproducible characterisation and eventual quantification of the primary driving process behind these applications, cavitation, has remained the subject of challenging study.

NPL has already developed an acoustic cavitation sensor to address this need. Passively detecting the acoustic emissions from oscillating and collapsing bubbles, the cylindrical sensor design includes an acoustically absorbing outer shield layer that provides the sensor with spatial resolution, and the 110 micron pvdf film used is able to acoustic signals present up to 10 MHz.

This paper describes the design, development and testing of bespoke instrumentation (the NPL Cavimeter) to analyse the signals produced by the cavitation sensor. The Cavimeter features simultaneous indicators of the direct acoustic field, subharmonic component, and of the broadband noise, which is generally regarded as a measure of inertial cavitation activity. It also describes the successful outcome of a subsequent trialling exercise, in which four Cavimeter and sensor systems were loaned to UK manufacturers and users to characterise high power ultrasound devices in the cleaning and sonoprocessing industries.

Investigation of sound fields in ultrasound cleaning baths and correlation with the erosion effect

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Despite the widespread use of ultrasound-supported cleaning in technology and manufacturing, general principles for its application and an efficient operation do not exist. Since the sound field is the cause and driving force of all processes, its measurement and characterization are the key to a better understanding and help in the selection of parameters for an economical operation of the devices. But sound field measurements in the appropriate frequency range from 20 kHz up to more than 1 MHz pose a number of problems, such as the interaction of too large sensor elements with the sound field and the risk of sensors being damaged by cavitation.

Two types of sensor systems, based on piezo-electrical hydrophones and optical fiber tips which fulfil the requirements on accuracy and withstand high-power ultrasound fields and cavitation, were investigated. In experiments with an externally controlled cleaning bath working at reproducible conditions, the spatial distribution of spectral components of the sound field, e.g. the amplitudes of the fundamentals (f0=45 kHz), the harmonics, the sub- and the ultra-harmonics as well as the noise power (NP) in a low (100 kHz to 200 kHz) and a high (1.00 MHz to 1.25 MHz) frequency band, was determined. In addition, these parameters were related to the cavitation effect by means of an image analysis procedure of aluminum foil which was exposed to the same sound field. Based on the image of the foil, the perforations as well as the indentions were analyzed and quantified with special image processing software. The results of the two dimensional correlation analysis reveal clear differences between the spectral parameters in relation to the erosion effect. The best correlation was always found with the fundamental frequency component.

Both sensor types are able to measure the sound field distribution in cleaning baths under real conditions and to determine the spots where the best cleaning effect can be expected. For a great number of applications, standard hydrophones are suitable instruments and optical fiber tips have shown to be of advantage for the operation in high-power fields or in limited space.

A Role for Ultra Precision Grinding in the Fabrication of High Frequency Piezoelectric Transducer

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High frequency ultrasonic transducers are in demand for high spatial resolution measurements in medical diagnostics and non-destructive testing (NDT). However, cost-effective fabrication of transducers with frequencies above 20 MHz is challenging because of the need for a thin layer of active material. Piezocomposites are the material of choice in high performance transducers at lower frequencies, but their thickness must be in the range 35 – 45 mm for a frequency of 50 MHz. Such thicknesses can be achieved by netshape processing of piezoceramic, but physical removal of material from a greater thickness than final thickness is imperative for piezocomposite material. The choice of an adequate material removal process is problematic as conventional grinding would be insufficiently precise and standard lapping/polishing would be too slow and therefore expensive.

In this paper, results are reported from an alternative process of ultra precision grinding of piezocomposite material. This was carried out on the novel Loadpoint PicoAce machine (Loadpoint, Swindon, UK) operating in the ductile mode and incorporating intra-process tool dressing. Unsupported layers of 1-3 piezocomposite material of thickness <<100 mm have been achieved with surface roughnesses commensurate with high frequency operation and little evidence of physical discontinuities between the ceramic and polymer phases under scanning electron microscopy. These results suggest that ultra precision grinding may play a significant role in the practical implementation of high frequency piezocomposites for ultrasonic transducers.

Patent Portfolio Development Strategies for Attracting Investors

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A comprehensive patent portfolio is often one of the most important foundations for building a company. Not only do broad patent rights protect the company's technology from potential competitors and infringers; they facilitate raising the capital required for the company's development and growth. Investors frequently look for early-stage companies or raw ideas that have commercial potential, provided that adequate patent rights have been or can be secured to protect the underlying business. Because patent rights can play a substantial role in the success of the business and consequently provide a substantial payoff to the investors, an attractive patent portfolio can increase the likelihood of investment.

Accordingly, from its infancy, a company seeking funding should consider strategically developing a patent portfolio. That is, the development of a company's patent portfolio requires strategies in order for it to protect the underlying business and to be attractive to investors. This presentation will discuss good intellectual property practices from the outset to safeguard the technology, and strategies for developing a patent portfolio which would not only protect a company's technology but also be attractive to prospective investors. The presentation will also examine and discuss the Technology Risk. This criterion enables investors to evaluate the proprietary aspects of the technology, including patent position and ownership; further development work to get to the first product; assess manufacturability; and assess the potential breadth of the technology's application.

A Modular 250 Kilowatt High Power through-feed Fluidsonic Processor using a concentrated 20 kHz ultrasonic field for chemical and biological applications.

Dr Frank F Rawson and Ms Sue Osborne, FFR Ultrasonics Ltd

Results generated over a 5 year period show ultrasonic processing at through-feed volumes of 12 m3 /hour on a 24 hour/7 day operation is both technically and commercially viable. The patented radial cell technology will be discussed covering several applications including sewage sludge, chemical reactions and fibre extraction.

Laser scanning Doppler vibrometer data will be presented together with finite element analysis data.

The FFR Fluidsonic Processor is modular, enabling power levels of 6 kw to 250 kw to be installed. A generically similar 2 kw laboratory batch processor enables process development from laboratory to pilot plant to full production plant using the same ultrasonic field.

Sonochemistry work can now be scaled up to industrial scale applications on a proven commercial basis.

iQ Series Ultrasonic Power Supply

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Dukane Corporation introduces a complete new line of digitally controlled ultrasonic power supplies for plastic welding. The iQ series has the fastest data update speed of any ultrasonic power supply available today.
Another unique feature is the "plug and play" technology. The mechanical design incorporates an externally accessible card rack, which allows for quick field modifications or upgrades to the system. The software recognizes the cards and adjusts the menu structure accordingly. The new user intuitive menu structure minimizes the learning curve.
The iQ series of power supplies has the smallest foot print in the industry based on true RMS watts per cubic inch. Dukane was the first to develop and patent Auto-trac frequency circuitry. The new iQ series offers digitally controlled Auto-trac along with other frequency control profiles.
The iQ series is available in all standard frequency and power ratings from 200 to 5000 watts. Inputs and outputs for system control and data acquisition is available in both serial and Ethernet protocols.

Finite element analysis of ultrasonic cutting in one direction

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Ultrasonic assisted cutting is one of the advanced and new machining techniques. This paper represents the finite element model of turning process assisted by ultrasonic vibration of cutting tool. This work has been implemented using MSC-MARC software by applying a frequency of 20KHz and an amplitude of 10 micron to the vibrating tool for machining Udimet500- and Al52S- based workpieces.

Ultrasonic vibration was applied in one and two directions and the stresses and forces acting on the tool and workpiece were obtained for orthogonal machining. A comparison was made between the stresses and their distribution along with the loads acting on the tool.

The above mentioned investigation was then extended to different tool geometries (for various rake and clearance angles). The evaluation of the stress distribution was done at isothermal conditions. The workpiece was considered to deform elasto-plastically.

Updated Lagrange analysis and adaptive remeshing were employed in order to analyze the process.

Advances in the development of power ultrasonic technologies based on the stepped plate transducers.

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As well known the stepped plate macrosonic transducers represent a novel contribution to the efficient generation of ultrasonic energy in fluids and more specifically in gases. During many years the Power Ultrasonics Group of the Institute of Acoustics (IA-CSIC) has been involved in the development of such transducers for industrial applications. At the same time, an electronic team of the Institute of Applied Physics (IFA-CSIC) has been also working in the development of the corresponding electronics for driving and controlling such specific power transducers. In this way, an industrial or semi-industrial development of such technology for its application to different processes has been carried out.

This presentation deals with the later advances in such development and with the stage of the industrial applications.

In the transducer development it is to be underlined the use of rectangular stepped-grooved plates for its suitability to fit specific practical problems. In addition, the design of the transducers and, in particular, of the plate profiles has been improved by finite element methods. As a consequence, a major versatility in the potential use and effects of the stepped- grooved plates has been reached.

In the electronics, the introduction of a new digital procedure for the frequency and power control has made the equipment more stable, keeping automatically the working conditions at the maximum efficiency even when operation starts.
The application of the technology to different processes is presently at industrial and/or at semi-industrial stage. The main processes to be mentioned are defoaming, drying, washing and extraction with supercritical fluids.

Ultrasonic defoaming is a process with a great potential in the food and pharmaceutical industries where the conventional chemical antifoam agents are presently forbidden. The new technology is already at industrial stage (International Patent PCT/ES2005/070113).

Ultrasonic drying is a process based on the vibrational removal of moisture from the interior of the food product. This process avoids heat application keeping the quality of the foodstuff. The new technology is at semi-industrial stage (US Patent 6233844B1, 2001).

Ultrasonic washing of fabric materials is a new process based on the production of cavitation in a thin layer of liquid. In this way the effect on the fabric is effective. The new technology is at semi-industrial stage (US Patent 6266836B1, 2001).
Ultrasonic extraction with supercritical fluids is a new process based on the application of high-intensity ultrasound to accelerate the extraction effect of supercritical CO_2. The new technology has shown to be efficient in a semi-industrial installation (International Patent PCT/ES03/00398)

Transducer and Acoustic Characterization Posters – 20 March 2007

A Systematic Design and Optimization Approach for Ultrasonic Transducer

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Recently, finite element method (FEM) has been utilized increasingly in design of ultrasonic transducers, especially the power transducers. According to the effectiveness of FEM in this issue, it is promsing if one can set up a design procedure to profit from its capabilities. In this research, a systematic design and optimization approach for ultrasonic transducers will be studied. After parametrical modeling in the first phase, the meshing approach and boundary condition will be studied. At this stage, the comparison of natural frequencies in two case of constrained and unconstrained node will be proposed as a new design approach. The resonance and anti-resonance frequencies will be extracted by modal anlaysis and then the harmonic analysis will be used to compute the power consumption of the transducer. Finally, a systematic design approach will be proposed and developed for booster and horn as the two main parts of the transducer.

Evaluation of Joint Losses in Langevin Style High Power Transducers

George Bromfield

The joints between the piezoelectric elements within a transducer drive stack represent an unwanted mechanical loss that can cause heat resulting in a non-linear unstable frequency / impedance characteristic. Historically, half-wave resonators configured as dumbbell transducers have been used for high power life testing of pre-stressed piezo stack assemblies. Experimental methods have evolved to more accurately measure the quiescent “in-air” power loss of this type of transducer. The end mass velocity can now be conveniently and accurately measured using a laser vibrometer. Power analyzers can now simultaneously display measurements of voltage, current, phase angle, fundamental frequency power and harmonic power.

In order to try and quantify and separate out the losses associated with the piezo element and the joint, 2 dumbbell transducers were made from the same batch of piezo. In one transducer the rings have been lapped down to half their initial thickness with each pair electrically connected in series. The performance of this transducer with 9 joints and 8 rings 1mm thick is benchmarked against the other transducer that has 5 joints and 4 rings that are 2mm thick. A proprietary stack assembly method, PiezoBond™, was used to reduce the joint losses to an absolute minimum and the level of bias stress was accurately controlled.

This presentation illustrates a technique whereby a computer model of the dumbbell transducer has been used to calculate the accumulated elemental power loss. Since the power loss within the transducer is predominately caused by the relatively low Qm piezo element and the adjacent joint a "best fit" iterative method has been used to quantify this combined value of Qm for both the 4 ring and 8 ring test transducers.

Microfabrication of Piezoelectric Composite Ultrasound Transducers (PC-MUT)

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High frequency ultrasound is needed for high resolution imaging applications in dermatology, ophthalmology, intravascular imaging, and laproscopy. A microfabrication technique was developed at TRS, for the first time, using photolithography based deep RIE micromachining process for high frequency piezoelectric composite ultrasound transducers (PC-MUT) with unprecedented bandwidth and sensitivity comparing with their PZT counterpart, p-MUT and CMUT as well. Conventional arrays operated below 20 MHz are constructed by dice-and-fill process to form composite structures. Alternative composite fabrication methods based on stacked plates or tape casting technology have shown promise in recent years for PZT composite transducers fabrication, but all these processes are not applicable to high frequency single crystal composite fabrication because of the process limitation in handling thin single crystal plate or film. On the other hand, single crystal piezoelectrics have considerably higher piezoelectric coefficients and electromechanical coupling factors than PZT ceramics and as a result they are being used to fabricate ultrasound transducers with unprecedented bandwidth and sensitivity. A new micromachining process is developed in this work to fabricate 1-3 PMN-PT crystal-polymer composite structures for ultrasound transducers operating at frequencies from >40 MHz, and bandwidths in excess of 80% with sensitivities even better than current ceramic transducers operated below 20 MHz.

Dry etching and wet etching micromachining processes have been studied and finally RIE etching is advanced because of its precise dimension control. Nickel and platinum are chosen for the etching mask, both Cl_2 and SF_6 based etching chemistries have been investigated and the etching rate about 12 micron/hour with almost vertical etching profiles have been achieved. The 1-3 composite transducer with kerf width of < 6 micron, beam width of 15 micron and beam height of 40 micron are designed and fabricated based on the developed RIE etching process followed by epoxy filling, lapping and electroding. The single crystal composite properties with central frequency of 40 MHz were tested showing effective coupling coefficients around 0.7, and the HF transducer pulse-echo test results will be reported by Dr. Jian Yuan from Boston Scientific in this symposium. This paper will presents more in detail on the microfabrication techniques for PC-MUT. The presented micromachined single crystal technology would be an unprecedented advance for high frequency ultrasound imaging and would lead to greatly improved diagnostic capability. This microfabrication technology could also be applied to other piezo MEMS devices.

The Characterization of the Cylindrical Therapeutic Transducers using Acoustic Holography

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In atrial fibrillation ablation therapy cylindrical ultrasound transducers are used to create circumferential lesions around the ostia of pulmonary veins. The core of this approach is to produce circumferentially uniform high intensity ultrasound field. Of particular interest is the identification of the radiating surface velocity hot spots as a result of the material imperfections, defects, solder contacts, presence of parasitic vibration modes. Acoustic holography offers a powerful tool for reconstructing the surface velocity from near and far field two-dimensional hydrophone pressure measurements (Williams, 1996, J. Acoust. Soc. Am. 99, 2022, Williams et al., 1987, J. Acoust. Soc. Am. 81, 389). We describe an investigation of alternative back-propagation technique for cylindrical transducers, that employs acoustic field calculations based on second Rayleigh integral and principle of time-reversal of the acoustic field in lossless media (Sapozhnikov et al., 2006, Acoust. Phys., 52, 324). Reconstructed surface velocity is used to identify transducer defects, calculate acoustic pressure at various distances from the transducer, and compare it with experimental observations.

Acoustic Field Characterization with Schlieren System

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The concept and design of Ultrashape's Schlieren system are presented. The system is dedicated for evaluation of Ultrashape's high-intensity ultrasound transducers in production as well as those under the development. Advantages and limitations of Schlieren imaging compared with other methods of acoustic field examination are discussed and new ways for system performance enhancing are proposed. Results of theoretical modeling are compared with actual measurements performed in the frequency range 0.2 – 1.0 MHz and are shown to be in good agreement.

Acoustical characterization of a cylindrical resonator for multi-bubble sonoluminescence experiments

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Liquid-filled cylindrical acoustic resonators stimulated with pulsed or steady-state neutron radiation can be used to generate intense bursts of multi-bubble cavitation and the associated phenomenon of sonoluminescence. It has been claimed that, with certain deuterated liquids, the conditions achieved in collapsing bubble clusters are sufficiently extreme for the production of secondary fusion neutrons [1] (so-called sonofusion). The fundamental tool needed for the study of this possible effect is a high *Q* resonant cavity capable of being locked onto a chosen mode of oscillation while being driven at high power levels. Such a cavity has been constructed in this work, on the basis of a published design [2] in which the wall of the cylindrical chamber is fabricated from borosilicate glass and the ends from anodised aluminium. A large PZT ring transducer bonded to the outer wall of the cylinder was used to produce ultrasound and the cavity was driven at frequencies in the vicinity of a compound radial-longitudinal mode of oscillation. A second PZT, mounted on the bottom surface of the cell, served as a hydrophone providing a feedback signal for cavity tuning.

The cell was filled with test liquids and the impedance matched at the desired operating frequency. The acoustical field has been measured along the axis of the cavity using a movable miniature hydrophone probe. Studies have been conducted using a range of drive power levels using two different test liquids: acetone and water. Resonator impedance, efficiency, tuning and *Q* factor will be discussed for the two cases. Strategies for maintaining cavity tuning at high-drive levels in the face of temperature variations and cavitation will be described.

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Time-domain HIFU field measurements by ruggedized hydrophone and reciprocity techniques

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INTRODUCTION - The growing use of high intensity focused ultrasound (HIFU) for therapy has led to a need to characterize HIFU-transducer fields. Acoustic fields do not scale linearly with intensity; nonlinearities appear at therapeutic intensities and contribute to the therapeutic effect. Therefore, measuring the fields at the intensities of the intended applications is critically important. Common thinfilm hydrophones can be damaged at high intensities. Recently, Onda Corp. (Sunnyvale CA USA) has introduced model HNA-0400 ruggedized needle hydrophone. Evaluations of this hydrophone have been limited to manufacturer whitepapers. Here we compare the time-domain field characterization ability of the HNA-0400 hydrophone to the reciprocity technique (based on the Helmholtz-Rayleigh acoustic reciprocity theorem).
METHODS - The acoustic field was produced by a Sonic Concepts (Bothell WA USA) annular-array, 5-element, spherical-cap, PZT therapy transducer having a 35-mm focal length, 33-mm aperture, and 14- mm diameter central hole. A single element was excited with a 2-cycle, 5.25-MHz excitation pulse to produce a peak acoustic power of approximately 100 W. The therapy transducer was attached to a threeaxis, linear-motion, servomotor controller, and the transducer was immersed in a 3-l Pyrex beaker filled with degassed water. The HNA-0400 hydrophone was affixed vertically at the bottom of the beaker. In the reciprocity technique, the hydrophone tip served as a passive reflector. The therapy transducer was connected to the receive channel of a pulser/receiver. The pulser/receiver output was acquired with an 8- bit digitizer with sampling frequencies of 250 MS/s to 1 GS/s. In the hydrophone technique, the hydrophone was connected directly o the digitizer. Scan planes were formed from sets of uniformly spaced, parallel scan lines; scan volumes were formed from sets of uniformly spaced, parallel scan planes. A characteristic (such as peak negative pressure) of each scan line was selected, reducing the volume to a single transverse or axial plane intersecting the acoustic focal region.
RESULTS - The hydrophone method provides considerably more spatial detail than the reciprocity method, revealing the beam's transverse side lobes, which are not visible in the reciprocity images. In addition, it exhibits a signal-to-noise ratio of 39 dB under the conditions studied, compared to the

reciprocity signal-to-noise ratio of 36 dB. We also note that field strength can be estimated directly with the hydrophone technique, whereas the reciprocity technique, without supplemental measurements, provides only relative values.

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Modal Interactions in Ultrasonic Cutting Devices

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http://www.mech.gla.ac.uk/Research/Dynamics/UIA07acmlmcposter.pdf

Modal interactions, and particularly combination resonances, are characteristic of ultrasonic devices driven at high power in a longitudinal mode. Such behaviour has been modelled previously for parametrically excited simple structures such as beams and bars, and it is possible to demonstrate that ultrasonic devices can exhibit dynamic responses that are qualitatively similar to theoretical models of autoparametric systems. In this study, modal interactions are measured, and the benefits of designing systems with a reduced number of modes are demonstrated.

Previous studies of multiple-blade ultrasonic cutting systems have reported and characterised the problems associated with modal interactions. Combination resonances are a common feature of the dynamic response of systems driven in longitudinal resonance. For ultrasonic devices, multiple tuned- component systems with complex geometries are particularly prone to stress failures due to such modal interactions. In order to design systems that can operate at a single driving frequency without significant energy leaks into non-tuned modes, care must be taken to avoid modal frequencies of the system that have special relationships with the driving frequency. This can be achieved if accurate finite element models of the device can be created and subsequent geometry modification strategies can be implemented to effect modal frequency shifts. This design approach is more straightforward for devices where there are few modes below the driving frequency. For devices with a high number of modes, remodelling to effect frequency shifts in a set of modes predicted to interact, is likely just to result in an alternative modal interaction. The most reliable solution is to reduce the number of modes that exist below the driving frequency, so that modal frequency shifting by small geometry modifications can be effective.

Modal interactions can occur if special relationships exist between one or more modal frequencies and the excitation frequency. The type of modal interactions that can occur depends on the nature of the excitation and on the system nonlinearity. An autoparametric system is one in which the forced response of the primary part of the system, possibly a single forced mode, acts as a parametric excitation on the secondary part, either as a principal parametric resonance involving one mode or a combination resonance involving multiple modes. The net effect is a two-way interaction between the two parts for which overall steady-states are possible. The effects of parametric excitation are such that large responses may be generated in a plane perpendicular to that of the excitation, provided that certain relationships exist between the excitation frequency and the frequency of the excited internal mode or modes. For ultrasonic devices, the modal frequency relationships most often measured in systems exhibiting modal interactions are: a modal frequency is approximately equal to half the tuned excitation frequency, called a principal parametric resonance where Ω/2 □ ω1; the sum of two modal frequencies is approximately equal to the tuned excitation frequency, called a combination resonance or three-mode interaction where Ω □ ω2 + ω3. Ω is the external excitation frequency, and ω1, ω2, ω3 are three internal modal frequencies.

Wheat straw modified ultrasound pulping process

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This research work in Hungary brings together all relevant knowledge about high-power ultrasound to develop the basis for new, affordable, environmentally and competitive pulping process. For years the application and value of high-power ultrasound in the pulp and paper industry has not been widely accepted or used. The already installed and integrated pulping processes have only particularly aim the usage of this new energy source, beside its low cost either. With our investigation, a modified pulping process aimed at using ultrasound power only and it has shown to offer access to fibers satisfactory. From the results of research experiences, it can help to consider and move toward pilot trials.

It the first step wheat straw (agricultural by-product) alkaline AQ was pulped and then it was treated by high-power ultrasound under different noble-gases (argon, krypton, xenon) compilation. In the second step wheat straw without alkaline pre-treatment was irradiated by high-power ultrasound under alkaline pH and different noble-gases. From the two different pulps beating degree, acid-insoluble lignin content, iodine sorption and tensile index properties have been examined and evaluated.

In this presentation we would like to explore the extent to which noble-gas combination with ultrasound may be more useable to reduce the lignin content and enhance fibrillation meanwhile and introduce an ultrasound assisted, modified alkaline pulping process.

Overall, the processes were found to offer lignin decreases over 75 % in two steps, fibrillation increases from 12 to 70 °SR within 20 min. ultrasound irradiation, tensile index increases 65% and iodine sorption from 100 to 145 mg iodine/g cell which shows that the accessible region increased.

For the sustainable development it is required to improve the existing techniques and/or devise alternate techniques and spread the new techniques widely resulting into improved social living standards without sacrificing our environment and life places. Use of high power ultrasound based processing in paper and pulp industry can result in significant improvement at the same time reducing the consumption of energy and chemicals.

Enhancement of Diffusion and Distribution of Sodium-Chloride in Pork Meat by Ultrasonic Method

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Curing is one of the most ancient meat preservation methods, which contributes positively to the technological and sensory characteristics of the meat. The curing technology is based on the addition of salt, which acts as a preserving agent and is also responsible for causing the physico-chemical and biochemical phenomena that contribute to the development of flavour. Common to all curing methods is that salt must diffuse through the meat matrix and in doing so the diffusion rate will depend on the local diffusion coefficient. High intensity ultrasound has been proposed to increase salt diffusion in meat through the cavitation phenomena. Cavitations occur readily at low frequency, but the cavitation intensity treshold increases with frequency. The objective of the present work was to investigate the effect of ultrasound intensity and treatment time on the brine distribution and on the meat texture. Pork loins (Longissimus dorsi) of same size and weight (7 cm, 350 g) were treated separately both in an industrial vacuum tumbler and by a high power ultrasound equipment (1117 kHz) for 1, 2, and 3 hours. Brine contained 20% sodium-chloride. Treatments were performed at 5 °C, applying 20 minutes breaks after every 40 minutes of treatment. Applied ultrasonic intensities were 2.6, 5.2 and 7.9 W cm-2. Texture analysis was performed by an Instron Series 4200 IEEE-488 Interface equipped with compression (d=57mm) and penetration (d=5mm) fittings. Diffusion of brine was evaluated by measuring the salt content in 6 different locations of the muscle samples by ion-selective electrode.
Results showed that ultrasonic treatment did not increase the diffused salt content of Longissimus dorsi samples compared to tumbled samples, however more uniform distribution of brine was observed. The concentration of diffused salt increased both with increased ultrasound intensity and with increased treatment time. Based on the result of texture analysis it can be concluded that ultrasonic treatment improved the tenderness of meat samples. In the case of ultrasound treated samples higher penetration force was recorded compared to samples treated in tumbler, meaning a good tendering effect. Moreover, more homogenous texture was achieved by applying ultrasound. The longer treatment time the more tenderness was achieved.

Ultrasonic Field Prediction of a 25 kHz cleaning vessel using the finite element method

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A reference cavitating vessel is being established at the National Physical Laboratory, as part of a technical work area whose objective is to investigate standardised methods for assessing the cleaning performance of ultrasound cleaning vessels. The vessel operates at a frequency of 25 kHz and comprises 30 peripheral transducers in an 'inward-looking' or focussed configuration.

In order to aid the characterisation of this vessel and provide confidence in measurements, a theoretical study of the acoustic pressure distribution generated within the water medium used within the vessel was carried out. A finite element (FE) model of the vessel complete with transducers was developed. The model was set up using the PAFEC (Program for Automatic Finite Element Calculations) FE software. Symmetry of the experimental configuration is exploited, hence significantly reducing run times. The piezoelectric properties of the transducers are accounted for, as well as the dynamics of the vessel walls and fluid/structure interactions. The model enables the ultrasonic pressure field to be predicted for a sinusoidal voltage input at the transducer electrodes, and allows for full electro-mechano-acoustical coupling.

Within this presentation, the results of the FE calculations are discussed in detail and compared with measurements carried out using underwater acoustics hydrophones. Key features of the measurements are reproduced in the FE results, although careful attention to material properties must be paid.

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The BBB represents both a safeguard against the penetration of physiologically harmful substances into the central nervous system (CNS), and a considerable hurdle to the delivery of therapeutic agents. Blood vessels in the brain differ from those in the rest of the body in that they prevent most drugs from passing into the surrounding tissue. While this is often beneficial, it can inhibit the range of therapies that can be employed to successfully treat diseases such as Alzheimer's and brain cancer.

BBB disruption with hypertonic solutions (typically mannitol) enhances CNS penetration of macromolecules, but at the cost of pronounced fluid shifts and lack of regional specificity. Ultrasound-mediated BBB disruption has been another approach explored. High intensity focused ultrasound (HIFU) has been demonstrated to open the BBB at energy levels that do not result in cellular injury, but a drawback is the long duration of opening induced. Recently an upregulating effect of LIPUS on cytokines and chemokines has been observed that might also occur in other tissues.

Accidental occurrence of MRI contrast agent extravasation in a patient after treatment with low-intensity ultrasound prompted us to investigate whether low-intensity pulsed ultrasound (LIPUS) could be used to safely and reversibly open the blood-brain barrier, allowing large molecules to pass through. In three pre-clinical rodent studies and an ongoing primate study, evidence has been collected that a localized, safe, and reversible opening of the BBB can be enabled by LIPUS exposure.

A technology allowing safe, targeted, reversible opening of the BBB would potentially revolutionize both the study and treatment of CNS disorders, including neurodegenerative conditions and brain malignancies that have proven resistant to conventional approaches.

PZT thick film for high frequency ultrasonic applications

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Within the field of high frequency ultrasound there has been a call for a new technology for fabrication of devices working at higher frequencies and suitable for production in large numbers at a low cost. The technology of screen printing is well suited for this since the manufacturing process is well known and easy to implement. The resulting thick film also exhibit excellent piezoelectric as well as acoustic properties which is favoured in medical imaging applications. However, screen printing PZT thick film structures is limited to flat substrates. In order to deposit thick film structures on topographic substrates a different approach is needed. Pad printing is well known as a means to print graphic illustrations or symbols on curved substrates such as tubes and spheres. In our work this technology has been adapted to produce focused PZT thick films on curved substrates. The PZT paste is originally optimised for use in screen printing but by tuning the rheological properties of the paste by changing the amount of organic vehicle and solvents, the paste can be used for pad printing as well. The pad printed thick films exhibit the same excellent properties as screen printed thick films and have been used as transducers in a medical imaging system giving high quality images of organic structures.

Bacterial Inactivation using Radial Ultrasonic Horns

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www.mech.gla.ac.uk/Research/Dynamics/UIALondon07mlucasPoster.pdf

This study investigates the design of a 20 kHz radial-mode ultrasonic horn with a tuned mounting system, for development as a flow-through device for bacterial inactivation. Currently, longitudinal-mode probe horns have been adapted for flowthrough bacterial inactivation but they rely on a very low flow rate and the configuration does not allow for an in-line inactivation process. The results show that a radial-mode ultrasonic horn is more effective at bacterial inactivation than the more conventional longitudinal-mode probe device. The primary cause of cell death is through cavitation caused by the pressure field created in the fluid by ultrasonic vibration of the device. To improve the design of the radial-mode horn, a model of the horn and fluid cavity is created that can be used at the design stage to create a device that has the best cavitational field for the inactivation of bacterial organisms. This is achieved using finite element analysis to calculate the pressure distribution in the fluid cavity for a device operating at 20 kHz. The results of the finite element study are validated against experiments using chemiluminescence supported by photographs of the cavitational field. The model is also used to calculate the pressure field for a longitudinal-mode probe device where the model can also be validated in a similar way. It is demonstrated that despite the simplifying assumptions which neglect the complex nature of fluids undergoing cavitation, good estimations of the pressure fields created by the two devices, and hence where cavitation is likely to occur within the fluid, are achieved. Finally, results of the inactivation rates of E.coli K12 using an ultrasonic probe and two radial mode horns (tuned to the R0 and R3 modes) are compared to demonstrate the effectiveness of the horn tuned to the R0 mode in creating a cavitation field concentrated at the centre of the fluid cavity, which provides the best inactivation rate.

Modeling the Heat Effect of Ultrasound in the Irradiated Tissues

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The temperature of the body tissues during ultrasound irradiation depend on the tissue and treatment properties. The newly developed computational model can determine the temperature changes in the skin-muscle-tumor-blood system between different tissue and treatment parameters. The model can calculate with the respiration (315-318K) and denaturing (e.g. HIFU) hyperthermia too. The basic parameters are the geometry, (m); specific heat, (J/gK); density, (g/cm3); heat conductivity, (J/msK); sound velocity (m/s); attenuation coefficient (Np/cm MHz) and the perfusion rate of blood in the different tissue layers (ml/gtissue/min). The effective treatment parameters are the emitted electric output, (J/s); the mechanical efficiency (%); the number (pieces); and the surface area of the transducers (m2); and the area (m2) and temperature (K) of the cooling surfaces. The model calculates many of intermediate data from these. Some of these is the sound path in the different tissues, (m); the blood quantity in the tissue layers, (m); the geometry of the irradiated tissue bodies, (m, cm2, cm3); the acoustic hardness, (Pa s/m); sound reflection and sound transmission occurring at the interfaces, (Np); heat exchanger wall thickness of the irradiated bodies, (m); heat dissipation and heat exchanger surface areas, (m2); flow rate of blood in the tissues located in the path of ultrasound, (ml/tissue mass in g/min); and the sound attenuation effect in the different tissues, (Np). The basic and intermediate data gives the generated heat (K/s) decreased by the heat energy transported (J/s) to the surrounding tissues by blood and heat conductivity, and the actual temperature (K) of the irradiated tissue. The algorithm contains the pre-cooling possibility of the tissues before and during the irradiation with a specific area and temperature cooling surfaces. The model considers that single rectangular transducers are focused to a target zone, which equal to the surface of one transducer.

The actually modeled situation is that the tumor must be reaching a 316K temperature; however the temperatures of other two layers must be under than 313K. The heat generation was examined in the function of thickness and perfusion rate of blood in the different tissue layers. During the solution, we varied the pieces and ultrasound power of transducers and the surface and temperature of the cooling surfaces.

The conclusion is that the aims were solvable between every situation. The future is that the model can handle the ray interferences and the angle of incidences.

Effect of ultrasonic cutting blade orientation on cutting temperature

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Ultrasonic bone cutting offers advantages compared with orthopaedic devices that rely on a reciprocating action including the elimination of swarf, improved cut quality and precision, and reduced reaction forces. The technology has become accepted as an alternative cutting procedure for use in surgical operations on soft tissue. Recent studies conducted on bovine bone and a bone substitute material have shown that the use of ultrasonic cutting blades is very effective and results in a precise and fast operation using relatively low forces. Previous work by the authors has highlighted the significance of frictional heating during ultrasonic cutting procedures, a phenomenon that can lead to material degradation and excessive surface burning. The work presented a method of reducing cutting temperature, due to both ultrasonic energy absorption and heat conduction, by controlling ultrasonic cutting parameters and a method of further reducing cutting temperature by including blade geometry modifications that reduce the Coulomb friction condition between the blade and the specimen. Such studies have been concerned with uni-axial cutting blade orientations and opportunities exist to enhance orthopaedic cutting by developing blades that can operate in more than one cutting plane.

This paper investigates the relationship between cutting parameters and temperature around the cut site for a synthetic bone material during guillotine and slicing mode cutting. Cellular necrosis has been documented to occur if a cutting temperature in excess of 55°C is experienced for 30 seconds or longer, although this varies between specimen batches due to quality factors such as age, health and location. Large temperature increases, which are of short duration, will therefore not necessarily cause thermal damage during cutting. The primary aim of the investigation is to eliminate thermal damage by optimising cutting parameters and to investigate the effect of blade orientation on cutting temperature. A range of grade 5 titanium alloy ultrasonic cutting blades, tuned at two different frequencies are used in the experiments. The effect of different cutting parameters such as blade tip vibration velocity, applied load, frequency and cutting speed are investigated in guillotine and slicing mode cutting. Cutting temperature is monitored at various locations remote from the cut site during both modes of cutting and the results demonstrate that optimal cutting parameters can be incorporated into the cutting blade design to reduce or eliminate thermal damage without using an additional blade cooling system. The study also highlights the possibility of combining mixed mode cutting orientations during surgical operations on bone.

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Epicardial HIFU for Treating Atrial Fibrillation

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Atrial Fibrillation, a type of irregular heartbeat, is a serious medical condition with implications ranging from fainting, physical discomfort, pain, stroke and even sudden death. Essentially, the electrical circuitry of the heart muscle becomes disrupted causing irregular beating or quivering of the cardiac muscles. An established method of treating this condition is by forming tissue-lesions which redirect the electrical circuits. The lesions themselves are electrically nonconductive and essentially block undesired electrical conduction paths.

We will describe a set of disposable FDA approved SJM HIFU products now on the market which utilize epicardial high intensity focused ultrasound (HIFU) to perform this function in an improved manner over non-HIFU approaches. Some generic benefits of HIFU for this application will be described including the ability to project heating energy below the surface. These HIFU disposables, each of which utilizes multiple integrated transducers, are easy to use and they reduce the surgical procedure time markedly from hours to minutes.

An overview of the transducers, cabling and console/GUI will also be given.

FUSBOTs: Image-guided Robotic Systems for FUS (Focused Ultrasound Surgery)

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Minimally invasive and non-invasive surgical techniques remained a prime research focus in bio-medical arena in the past over two decades due to their numerous advantages over conventional surgery methods. Remote ablation of deep-seated abnormalities by various modalities such as the use of focused high intensity ultrasound can provide completely non-invasive procedures if the energy in the beam is carefully targeted. Tissue ablation due to High Intensity Focused Ultrasound (HIFU), alternatively known as Focal Ultrasound Surgery (FUS), is primarily effected by conversion of mechanical energy of an ultrasound wave into heat energy at its focal point. A temperature range of 60-80°C is achieved and the thermal effect could lead to immediate coagulative necrosis within focal zone.

In this paper, the potential of mechatronic/robotic assistance in the operating room and system overview of various robotic systems, named FUSBOTs for non-invasive ablative procedures are described. The operation of the ablative/surgery system requires appropriate positioning of HIFU transducer(s) in a pre-arranged spatial configuration. For FUSBOTs, the robotic manipulator design and thus kinematics and dynamics of mechanical configuration are based on various specific applications. The common features include: the use of image guided, interactive and supervisory control by the surgeon. The dimensions and range of motions of our robotic systems correspond to human anthropomorphic data.

Local Control in Bone and Soft Tissue Malignances Treated by High Intensity Focused Ultrasound

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Material and Method: By using of Chungqing HIFU knife, 37 cases of bone and soft tissue malignances were treated in Shandong Tumor Hospital and Institute of China from May 2001 to May of 2004. Thirty-five out of 37 cases were diagnosed pathologically through needle aspiration, True-cut or operative biopsy. Two huge pelvic masses originates unknown. Classification is as follows.

Osteosarcoma 18; Chondrosarcoma 1; Bone metastasis 1; MFH of Bone 3; Fibrosarcoma 4; MFH 4; Liposarcoma 4; Others 2

Enneking staging of osteosarcoma: B 2 cases, 3A 3 cases, B 13 cases, 6 cases with lung metastasis.

JC HIFU, made by Chungqing medical ultrasound research Institute was used. Treatment time is varying from 4000 seconds to more than 25000 seconds and energy is varying from 80 to 160W.

Results Efficacy was evaluated by symptoms, AKP levels, tumor volume changes, histology necrosis, radiology and nuclear medicine demonstrations.

All the patients in whom HIFU treatment were performed have relief of symptom including function improving, pain relieving, and tumor size decreasing. The AKP level decreasing is observed in 15 cases of 18 osteosarcoma patients who underwent HIFU treatment, which usually happens one week after HIFU. MRI shows the signal change of blood supply stoppage and enhanced CT demonstrated intensity and dimension change of tumor area. ECT proved disappear or diminished hot area.

Transducer Control Algorithms

George Bromfield

The attributes of an ideal transducer control algorithm include an ability to precisely maintain a predetermined value of end effector velocity and frequency. Most practical ultrasonic transducer designs involve the screw thread attachment of a horn or waveguide. Therefore an ability to detect the loosening of the attachment during high power operation is also an advantage.

Velocity control: Exiting transducer control algorithms are unable to compensate for changes in the piezo properties that occur during operational use. These changes are complex and are related to age, temperature and pressure. Under high drive conditions the behavior of the transducer is nonlinear resulting in a drop in resonant frequency and a distorted impedance characteristic. A simple method of velocity control is presented whereby a correction factor is derived from the non-motional impedance/phase characteristic.

Frequency control: Transducer control algorithms typically select an operational frequency that is between the motional series resonance frequency and the anti-resonance frequency. The relative merits of current control at frequencies close to resonance and voltage control at frequencies close to anti-resonance will be discussed.

Loose tip detection: This is typically achieved by measuring changes in impedance associated with the presence of secondary resonances and a shift in the resonance frequency. An alternate detection method is based on measurements of phase angle between the applied voltage and current at frequencies below and above the resonance frequency.

The Physical Effects of Bubbles and Cavitation in High Intensity Focused Ultrasound Therapy

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The application of ultrasound to tissue at therapeutic levels can, in some cases, result in bubble formation. These bubbles can promote mechanical disruption, accelerate tissue heating, and contribute to the formation of irregularly shaped lesions. The relevant mechanical and thermal effects depend critically on several factors, such as temporal peak and temporal average acoustic intensity, the duration of cw insonation, the duration and duty cycle of pulse insonation, the presence of cavitation nuclei, tissue temperature, and the tissue acoustic, rheological, and thermal properties. We will present a brief primer on the relevant bubble dynamics followed by a summary description of what physical effects matter, when and why. Implications for HIFU treatment monitoring through the active and passive bubble detection are discussed. [Work supported by the Dept. of the Army (award No. DAMD17-02-2-0014) and the Center for Subsurface Sensing and Imaging Systems (NSF ERC Award No. EEC-9986821).]

Quantitative ultrasound techniques using axial transmission to assess bone fragility

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Quantitative ultrasound is a growing diagnostic modality for its ability to assess skeletal status and predict fracture risk. The generic term "axial transmission technique" indicates a measurement configuration in which an ultrasonic probe (consisting of a set of transmitters and receivers) are placed on the skin to measure the velocity of a wave that propagates along the cortical bone layer parallel to its long axis. Interestingly, several wave types can propagate depending on the ratio of the cortical thickness to the wavelength. Several axial transmission devices have been developed based on substantial different approaches. One type of axial transmission technique uses high frequency ultrasound (e.g., 1 MHz) to generate a wave that propagates along and just below the surface of the bone. The so-called longitudinal lateral wave, that propagates at the compression bulk velocity, is of special interest for *in vivo* ultrasound of cortical bone because it arrives prior to all other contributions and therefore, can be easily determined from time-of-flight measurements of the signals received at different positions parallel to the interface. Furthermore, it has been shown to reflect both the cortical porosity and the mineralization, two bone factors that influence bone strength. In other approaches, low frequency transmission (50- 350 kHz) is used to excite and measure guided waves propagating in the bone at relatively low velocities. These waves arrive, in general, after the first-arriving signal. In general, several modes propagate, but the fundamental antisymmetrical guided wave mode A_0 (plate mode in a simple plate theory) or the fundamental flexural F(1,1) mode (in a 3D cylindrical geometry) tends to dominate the received signal and its velocity is measured. This mode is potentially interesting due to its strong dependence on cortical thickness and specific signal processing techniques have been developed to extract and characterize this propagation mode. Based on finite-difference time domain simulation, an inversion scheme has been developed to inverse the data and estimate the cortical thickness. Potential applications for the axial transmission include the assessment of bone fragility in several bone pathologies that affect bone strength and monitoring of bone healing.

Applications of Ultrasound Radiation Force

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Radiation force produced by momentum transfer into materials from traveling ultrasound waves can be used to physically displace tissue. Measurements of the resulting displacement can be used to estimate intrinsic mechanical properties of the tissue such as shear storage and loss moduli. Ultrasound can be used to place force distributions deep in the tissue and to measure the resulting displacement response to the force. The result is remote measurement of tissue properties. Some tissues are isotropic and remote force methods can determine mechanical moduli over a suitable frequency range. Other tissues are anistotropic, but homogeneous, such as muscle. In this case the force application and subsequent measurements must be related through a suitable model to the anisotropic material properties. Some tissues have structure such as vessels. Judicious choice of vibration modes and resulting motions can greatly aid in solving the very complex motion for the related material properties in such complex structures. Using remote application of force and measurement of resulting motion we have measured the complex shear modulus in 1) isotropic tissue such as liver, 2) anisotropic tissue such as muscle, and 3) in structures such as vessels. The goal of this program is to relate the measured fundamental properties to onset and extent of disease.

Effect of ultrasound microbubble contrast agent on rabbit liver VX2 tumor with high intensity focused ultrasound therapy

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Objective To study the effect of ultrasound microbubble contrast agent dosage on VX2 liver tumor in rabbit treated by high intensity focused ultrasound(HIFU).
Methods Forty-five rabbits borne VX2 tumors were randomly averagely assigned into three groups. Group A received purely irradiation. Group B and Group C both received enhanced HIFU therapy, the different laid in the dosage of ultrasound microbubble contrast agent, group B was 0.03ml/kg and group c was 0.05ml/kg. Four hours later since stopping therapy, all rabbits were slaughtered for morphological, pathological and electron microscopy examination. All tumors were stained by Triphenyl Tetrazolium Chloride (TTC) for measurement sizes of coagulation necrosis in the target regions. The duration of exposure was considered, too. **Results** Ultrasound microbubble contrast agent could enhance HIFU to treat liver tumor(P<0.05), and HIFU therapy efficiency raised with the increased of dosage of ultrasound microbubble contrast agent(P<0.05). **Conclusion** It was feasible to enhance HIFU therapy liver tumor with ultrasound microbubble contrast agent, but not blindly increase the dosage of ultrasound microbubble contrast agent to ensure the safety in clinical HIFU therapy.

36 kHz Ultrasonic Surgical Horns For Endoscopic-Nasal Approaches to Brain Tumors

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Ultrasonic aspirators are used in neurosurgery for removal of tumors in the brain, where a transducer and horn with a central hole fragment and suction tissue. An extended length horn is discussed, which supports the fullest extent of brain surgery in endoscopic-nasal approaches. A bone-tip is discussed for removing bone encountered accessing deeper regions. Representative clinical cadaveric sections and surgery are exhibited. Attaining resonant frequency, predicting displacements, and monitoring stress distribution and errant motion are afforded with FEA (Finite Element Analysis) for emerging complex-contoured horns, complementing one-dimensional mathematical models. An FEA method utilizing constraints and a base acceleration excitation of the transducer is compared to a full model method with no artificial constraints and a damped forcing function. Agreement between measured horn displacement and FEA results for the full model of the transducer, connecting body, and horn are within 2.5 µm (1.8% error) for both the extended length horn and a baseline device, and 7.6 µm (6% error) for the asymmetric geometry of the bone-tip. Nominal von Mises stresses due to vibration are maintained below 254 MPa, or less than 1/3 the yield strength of the titanium alloy.

Measurement of acoustic power measurement to 300 W

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The total ultrasound output power of a HIFU system is one of the most important quantities during clinical treatment. However, the very high intensities in HIFU fields can easily damage a radiation force balance target, and the relationship between power and radiation force is sensitive to changes in focal distance.

A new fluid-filled radiation force balance target has been built specifically for use in HIFU fields up to 300 W or more. It enables us to extend our range of measurement services and offer traceable power measurements up to at least 300 W with typical uncertainties of ±6%.

In addition, a new technique has been developed which uses the same type of target but does not depend on the measurement of radiation force. This is based on measuring the thermal expansion of the fluid within the target. It may be more appropriate for very wide aperture fields or for systems of unusual geometry, such as hemispherical or sparse arrays.

The principles have been described previously. In this presentation, additional validation results will be given (including use with a horizontally firing transducer) and measurements of clinical extracorporeal and transrectal HIFU systems up to 300W will be presented.