ACOUSTIC RADIATION FORCE IMAGING OF BRACHYTHERAPY SEEDS

F. Mitri, P. Trompette, and J.Y. Chapelon
National Institute of Health and Medical Research, INSERM U556, Therapeutic Ultrasound Research Laboratory, Lyon, FRANCE
mitri@ieee.org

Abstract

We have initially reported the use of object's resonance frequencies to increase signal-to-noise ratio (SNR) and have better contrast in images. In this work, vibro-acoustography technique based on the radiation force of ultrasound was used to detect metal seeds embedded in agar gel phantom for two different angles of incidence. It is shown that by setting the low-frequency excitation force at the fundamental resonance frequency of the seed, the quality factor (i.e. SNR) is highly increased, providing a better way for its detection. A modal analysis was performed using the finite element method (FEM) to determine the vibration characteristics (resonance frequencies and mode shapes) of the seeds, in order to be used as the low-frequency excitation force. As expected, the resulting vibro-acoustography images have shown remarkable contrast in comparison to images obtained at non-resonance frequencies for both angles of incidence.

Introduction

The use of brachytherapy to treat patients with early-stage prostate cancer has increased significantly over the past several years. The treatment procedure involves implantation of many small radioactive metal sources, called seeds, in the prostate under transrectal ultrasound guidance [1]. In this technique, it is desirable to insert an optimal distribution of seeds which requires precise information about their locations. However, at the present time, transrectal ultrasound alone cannot yield complete information because ultrasound beams are reflected specularly from the metallic seeds and back-scattered wave motion cannot reach the ultrasound probe, unless incidence happens to be normal.

In this work, vibro-acoustography technique [2], based on acoustic radiation force, is used in a fundamentally new way [3] to identify brachytherapy metal seeds by using their fundamental resonance mode excitation. In this paper, we present vibro-acoustography images of two seeds implanted in agar gel phantom, showing the very high contrast in comparison to those obtained at non-resonance frequencies.

Method

Vibro-acoustography uses mechanical response of an object to local cyclic radiation force. The force is a result of a complex pressure field produced by amplitude modulated focused ultrasound beam. The feature of this method is that high spatial resolution can be obtained by applying the cyclical force to a confined point in space (i.e. focus) using two focused ultrasound beams at slightly differing frequencies. Object vibrations produce emission of low-frequency sound field in the surrounding medium that can be detected by a hydrophone. The acoustic emission field is expressed as [2]:

$$\Phi(\Delta f) = C\, d_r\, H(\Delta f)\, Q(\Delta f) \qquad (1)$$

where C is a constant proportional to the intensity of the primary ultrasound beams, $H(\Delta f)$ represents the transfer function of the propagation medium and receiver, which is assumed to be fixed and known, and $Q(\Delta f)$ is a complex function representing the mechanical frequency response of the object at the selected point. Maximal values of $\Phi(\Delta f)$ are obtained at optimal values of $Q(\Delta f)$, i.e. the resonances of the object under test. Hence, by using $Q(\Delta f)$'s resonances for low-frequency radiation force excitation, optimal spatial distribution of $\Phi(\Delta f)$ can be obtained and used to construct the images.

Equipment

A spherically focused transducer divided into two annular array elements was used, producing the two beams at slightly differing high frequencies. The annular transducer has a diameter of 40 mm with a focal distance of 35 mm and a natural resonance frequency of 2.20 MHz. Driving signals for the elements were obtained from two RF-amplifiers (KMP Electronics) that were modulated by two function generators (HM 8131-2 Hameg) both controlled by a pulse generator (8112 A HP). The transducer was mounted on a 3-D positioning system (Micro-contrôle) and immersed in a tank of degassed water. The low-frequency signal was registered using a hydrophone (SQ 03 Sensor) preamplified, band-pass filtered (AF 420 Multimetrics) in the 10 to 80 kHz range and recorded by digital oscilloscope (2340 A Tektronix). The data was then transferred via an IEEE-488 communication BUS to a PC controlling the positioning system.

Experimental procedure

The method was tested on an agar gel phantom in which two brass seeds of the same diameter (1 mm) with different lengths (10 mm and 7.5 mm respectively) were implanted and located about 5 mm deep from its flat surface. A modal analysis was performed using the finite element method (FEM) [4] to determine the vibration characteristics (resonance frequencies and mode shapes) of the seeds. In the experiments, the excitation vibration frequencies were determined from the finite element simulations. In a first process, the incident ultrasound beams were perpendicular to the seeds axis and focused at 5 mm in depth from the gel surface. The scanning process was performed by raster scanning the transducer over the gel phantom. The images covered an area of 14 mm by 12 mm, scanned at 0.2 mm/pixel. In a next stage, the incident ultrasound beams were parallel to the seeds axis and the images covered an area of 6 mm by 10 mm, scanned at the same step.

Results

The frequency used for imaging corresponds to the resonance frequency of the longest seed calculated *a priori* using the modal analysis. The fundamental resonance frequency corresponding to a bending vibrational mode is 33.940 kHz. Figure 1 and Figure 2 show the vibro-acoustic images at the fundamental resonance frequency when the primary ultrasound beams were perpendicular and parallel to the axis of the seeds, respectively.

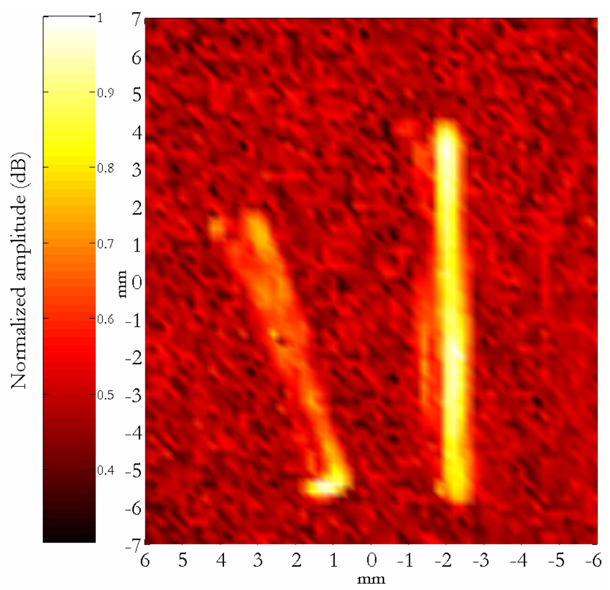

Figure 1: Vibro-acoustography image at 34 kHz; the fundamental resonance frequency of the longest (right-angle incidence)

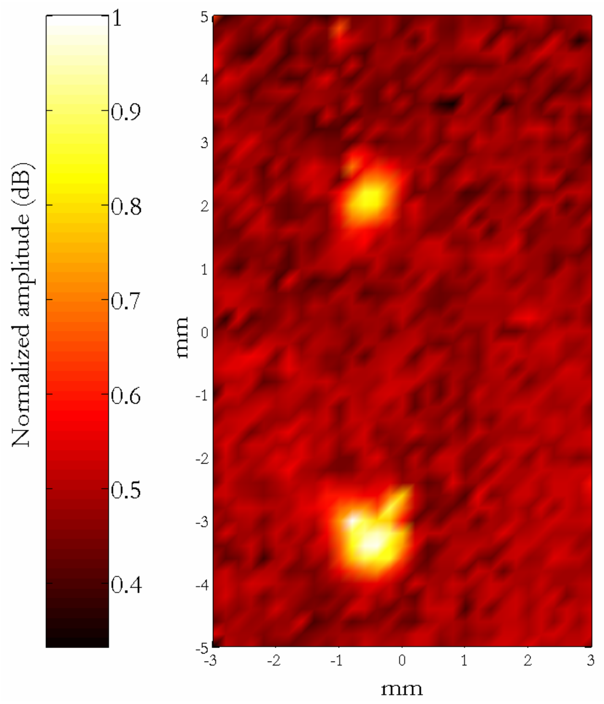

Figure 2: Vibro-acoustography image at 34 kHz; the fundamental resonance frequency of the longest (zero-angle incidence)

Conclusion

The resulting vibro-acoustic images demonstrate that this method is very powerful in detecting brachytherapy seeds independently of their positions relatively to the incident field, providing very high contrast in images in comparison to those obtained at non-resonance frequency. Further development of vibro-acoustography in monitoring brachytherapy may lead to a novel imaging tool for medical applications.

Acknowledgements

This work was supported by Grant No. 01-2-93-0314 of an RNTS project from the French Ministry of Economy, Finance and Industry.

References

[1] H.H. Holm, N. Juul, J.F. Pedersen, H. Hansen and I. Stroyer, "Transperineal 125-iodine seed implantation in prostatic cancer guided by transrectal ultrasonography," Journal of Urology, vol. 130, pp. 283-286, 1983.

[2] M. Fatemi and J.F. Greenleaf, "Ultrasound stimulated vibro-acoustic spectrography," Science, vol. 280, pp. 82-85, 1998.

[3] F. Mitri, P. Trompette and J.Y. Chapelon, "Detection of object resonances by vibro-acoustography and numerical vibrational mode identification" (Journal of the Acoustical Society of America 2003 – in press)

[4] Ansys Inc.