Determination of nonlinearities produced by strong focused beams.

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Introduction

The ultrasonic microscope techniques are used in material investigations as well as in medical and biological applications. For instance, in living cells in culture the values of acoustic impedances and attenuation coefficients in the cell periphery can be determined using SAM images. The new interesting field is high frequency ultrasonography - the technique operating at high Megahertz frequency and with focused beams. This technique is successfully used for detection and diagnosis of a skin and eye diseases. The visualisation of living tissues or living cells at the microscopic resolution provides a foundation for many medical and biological applications. In all these applications the possible temperature increase should be avoided to eliminate its destructive influence on the cells and tissues.

In the present paper we would like to show by means of numerical and experimental methods the effects of high non-linearity occurring at the ultrasonic microscopy and to present some potential dangers for biological applications caused there by temperature increases.

Propagation of acoustic waves in ultrasonic microscopy is a complex problem due to high pressure values obtained in the focus and distortions of a pulse shape caused by energy transformation from fundamental frequency to higher harmonics. Nonlinear effects produced by strong focused beams with half angle apertures exceeding 16 deg. cannot be described by simplified theories based on the paraxial approximation. Also diffraction effects and high absorption of the applied liquids should be considered. Therefore in calculations a numerical model developed by J. Wójcik was applied [1]. An ultrasonic scanning microscope operating at 34 MHz [2] was applied in experimental part. To obtain a high nonlinearity of the microscope even at relatively small input power an acoustic beam was strongly focused by a spherical glass lens with a half angle aperture of 50^0.

Temperature increase in the focus was estimated numerically basing on calculated pressure amplitudes of harmonics and a procedure developed by Wojcik [3].

The results present actual state and further possibilities of the applied numerical method for the detail investigations of nonlinearities in the ultrasonic focusing devices.

Experimental assessment of nonlinearities generated by SAM

A 100 MHz PVDF probe was constructed (an active probe diameter - 1mm) and applied for measurements of signals transmitted by SAM. The acoustic pulses of four periods duration at the center frequency of 32 MHz were generated by SAM transmitter and focused by the glass, spherical microscope lens (focal length - 3mm, aperture half-angle – 50 deg). The lens cavity was situated in the transition zone of the near and the far field of the $LiNbO_3$ transducer assuring a smooth, Gaussian distribution of acoustic pressure on the lens surface.

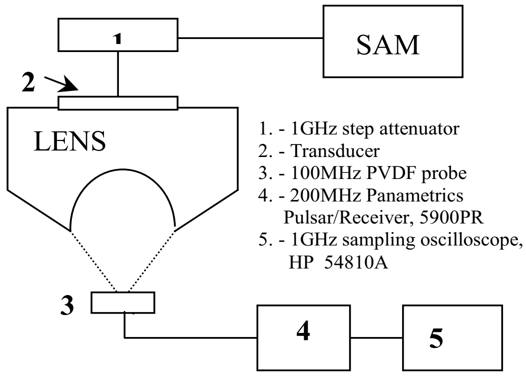

Fig. 1. The measurement system

The probe was placed in the focus or in the vicinity of the focus. The wide band amplifier (Panametric 5900PR) amplified the signals detected by the probe. Then, the signals were sampled and stored by the digital oscilloscope (HP 54810A). The signal amplitude spectra were calculated (Mathcad 2001 procedures) and compensated for the frequency characteristic of the probe. The probe characteristic (Fig.2) was determined by recording the probe response for a short, 2ns long electric pulse.

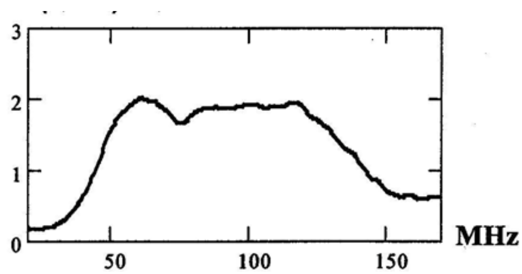

Fig.2 Frequency characteristic of the probe. Horizontal scale in MHz

Numerical calculations

For numerical determination of the pressure distributions a procedure based on Fourier series was applied. A plane boundary pulse was transformed by a concave spherical lens to a focused ultrasonic beam. The basis and details of this procedure were described in a previous paper by Wójcik. It was based on the nonlinear propagation procedure of Christofer and Parker [4]. In the glass which was directly coupled with the transducer linear numerical methods were used based on typical formulae valid for solid media with longitudinal and transverse wave speeds of 5900 m/s and 3600 m/s respectively and neglected absorption.

For a focused ultrasonic pulse propagating in water a nonlinear numerical procedure was necessary due to nonlinear properties of water and to very high pressure concentration. Also absorption effects were taken into account

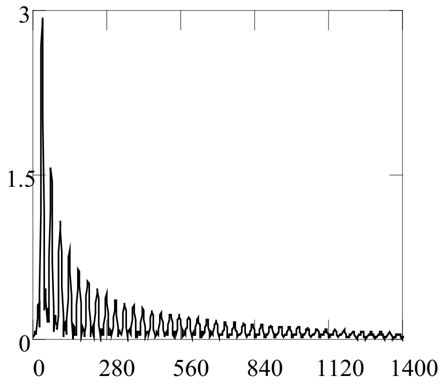

Fig. 3 The computed spectrum in focus (scale in MHz).

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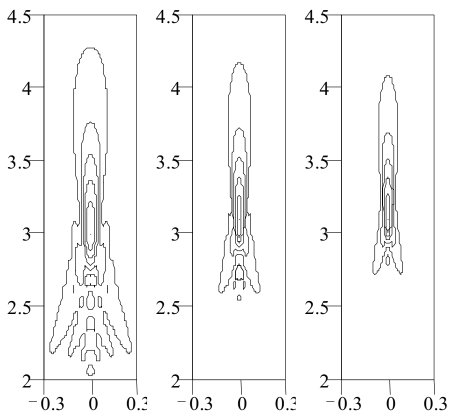

Fig. 4 Constant pressure contours (step 0.2) computed for the first 3 harmonics (all scales in mm).

COMPUTATIONS VERSUS EXPERIMENT

Computations were performed for various pulse pressure amplitudes causing nonlinear propagation. The pressure of 1 MPa at the axis of the input of the spherical lens found to match the numerical spectrum with the experimental one. The numerical results had to be averaged over the surface of the probe to be compared with experimental results. For averaging, the computed transverse pressure distributions in the beam were used. The averaged spectra are shown in Fig. 5 and the normalised amplitudes for the first 5 harmonics are summarised in Tab.1.

The computed spectra were in a good agreement with experiments up to the 5-th harmonic. The computed spectrum (Fig. 2) shows in focus a very high number of harmonics up to 1400 MHz. This result cannot be directly used in the experimental microscope due to the limited receiving band and unknown signal to noise ratio.

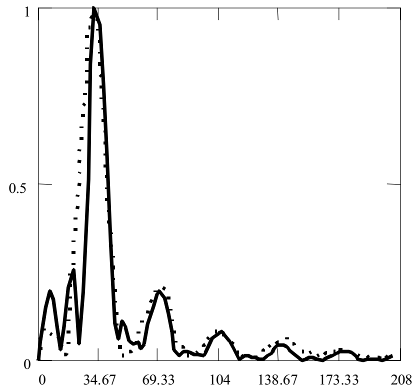

Fig.4. The experimental spectrum (dotted) and computed one (solid), averaged over the probe surface. Horizontal scale in MHz.

Nr of harmonic	1	2	3	4	5
calculated amplitudes	**1**	**0.19**	**0.8**	**0.4**	**0.025**
measured amplitudes	**1**	**0.20**	**0.8**	**0.6**	**0.03**

Table 1. Numerical and experimental pressure amplitudes of first 5 harmonics (after normalization).

The temperature increase depends on many factors such as the local intensity, its duration time, repetition frequency, and kind of the tissue, its attenuation and on the nonlinar parameter B/A. The calculated temperature increase in focus of our microscope in water, for repetition frequency of 20KHz and other parameters as mentioned above was equal to 0.7^{o}C. This value was obtained for relatively low voltage amplitude of 15V exiting the transducer. In the focus a considerable part of transducer input energy is converted into higher harmonics. According to saturation curve, a further increase of input pulse amplitude only slightly changes amplitude of a fundamental harmonic. The receiving transducer has a limited bandwidth and usually only fundamental pulse harmonic is detected. Thus an amount of energy in focus and induced heat generation does not correspond to the received signal amplitude.

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REFERENCES

1. Wójcik J. Basis of numerical procedure. Ultrasound in Med. and Biol.25, 290-292,1999.
2. Litniewski J., An acoustic microscope for microflaw inspection and subsurface imaging. Archives of Acoustics, vol. 26, no 1, 2001
3. Wojcik J., Filipczynski L., Kujawska T. Temperature elevations computed for three layers and four layer obstetrical tissue models in nonlionear and linear propagation cases. Ultrasound in Med. and Biol.25, 259-267, 1999
4. Christopher P and Parker K. New approaches to nonlinear diffractive field propagation, J.Acoust.Soc.Am. 90, 488-400, 1991