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Investigation of spatial distribution of sound field parameters in ultrasound cleaning baths under the influence of cavitation

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Abstract

Ultrasound cleaning baths fitting the full range from micromechanical components up to large machine parts, are regularly used in industry and in the lab. Despite the large number of applications, generally approved principles and objective criteria for parameter settings which allow an efficient operation are non-existent. The empirical selections of the running parameters often impede an optimization in terms of produce and reproducibility.

One proposal for an objective description of the processes is the characterization of the sound field in the cleaning bath, which causes cavities, and subsequently, the cleaning process. Sound field measurements in the appropriate frequency range from 20 kHz up to more then 1 MHz incorporate a number of problems, such as large sensors disturbing the sound field, a lack of accuracy and the risk of being destroyed by cavitation bubbles.

Measurement systems based on optical fiber tips and piezo-electrical hydrophones will be presented, which fulfil the accuracy requirements and withstand ultrasound fields with high power and cavitation. The spatial distribution of sound field parameters such as positive and negative peak pressure, amplitudes of fundamentals, harmonics and sub-harmonics as well as the energy density and spectral density in several frequency ranges are determined in experiments.

Finally, the determined field parameters are related to the cavitation effects by means of photometric analysis of perforated aluminium foil. Perforations as well as intentions are analyzed and quantified from scanner images of the exposed foil samples using special image processing software.

The experiments indicate clear differences in the structure of the sound fields and the spectral properties between the several types of cleaning baths, transducer arrangements and excitations.

Keywords: Ultrasound cleaning; Cavitation; Ultrasound erosion; Sound field characterization

1. Introduction

Ultrasound in the frequency range from 20 to 200 kHz is applied in a various ways in technology, medicine and research for the cleaning of various-sized parts or for increasing the exploitation of chemical reactions. Despite the widespread use of ultrasound-supported cleaning and sonochemistry, general principles for application and optimized operation are not present. Instead, processes are controlled empirically with parameters fitting only the special setup and application [1].

This unsatisfactory circumstance is caused by the extreme diversity of different technical tasks, the strong dependence of the processes on numerous parameters and the complicated nature of the cavitation process inside the fluid. A special challenge is the description of the sound field inside the medium and the interaction with the bubble clouds [2]. As the sound field is the cause and the driving force of all processes, its measurement and characterization is the key to a better understanding and support of decisions in the sense of an economical operation of the devices.

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This paper describes first results of the challenging task, to prove if sound field parameters (e.g. pressure amplitude of the fundamental frequency, sub-, ultra- or second harmonics) are suitable for the assessment of the cleaning effect (e.g.), and which of them provide objective criteria for the controlling and optimization of the processes.

Sound field measurements using optical and piezo-electrical sensors and the extraction of spectral parameters are described in Section 2. An improved analysis of the erosion of aluminium foil for quantification of the cleaning effect is presented in Section 3 and finally a typical result of the correlation between erosion and acoustic parameters is reported in Section 4.

2. Sound field measurements

2.1. Scanning system and piezo-electrical sensor measurements

A three-axis scanner (Micro-Controle TI 78), controlled via GPIB-bus, was used for the positioning of the sensors in the active volume of the ultrasound cleaning bath (Elma TI-H-5 equipped with two transducers, working frequencies 24 kHz and 45 kHz, acoustic peak power ≈200 W). The bath temperature was monitored with a Pt100 sensor attached to a Digital Multimeter (PREMA 5017) and also controlled via GPIB-bus. After pre-amplification, the hydrophone signals (B&K 8103/∅ 9.0 mm, Reson TC 4038/∅ 4.0 mm, LC-05/∅ 2.5 mm) were digitized by a Digital Storage Oscilloscope (Tektronix TDS 3032B) in single shot mode and subsequently saved on the PC hard drive (Fig. 1). The data recording was performed automatically and controlled via PC by a MATLAB program. All features like scan planes, step wide and number of single shots were adjusted in the user interface and monitored during the whole measurement.

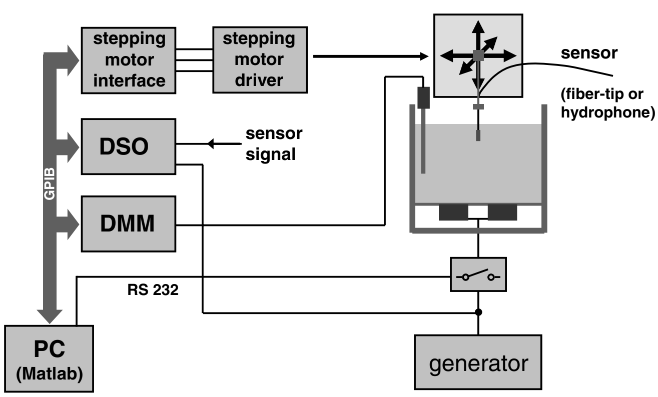

Fig. 1. Bock schema of the measurement system.

During the long-lasting scanning procedures it was necessary to take care of the stabilization of measurement conditions and relevant parameters: (i) use of an external function generator (Kontron 8551) and power amplifier (TAmp TA-500) to ensure stable excitation of the transducers, (ii) switching the field off in time intervals needed to reach the next scan positions to avoid further heating of the bath fluid, (iii) application of a cooling coil and thermostat (Lauda RE104) for temperature control and (iv) connection of an external water reservoir for the equilibration of the fluid level in the cleaning bath and compensation of water loss due to vaporization.

All measurements were made with distilled (de-ionized) water, either degassed or saturated. The oxygen content was determined in pre- and post-scanning procedures. The water level about the transducer surface, which corresponds to the bottom of the cleaning bath, was fixed at 128 mm for all measurements. So the total bath volume was about four litres.

Fig. 2 shows the pressure amplitude mappings of the fundamental frequency component of two scans performed in a plane parallel to the transducer surfaces for two different power settings. Clearly distinguishable are the circular shapes of the two transducers mounted on the bottom of the cleaning bath and the differences in the pressure amplitude.

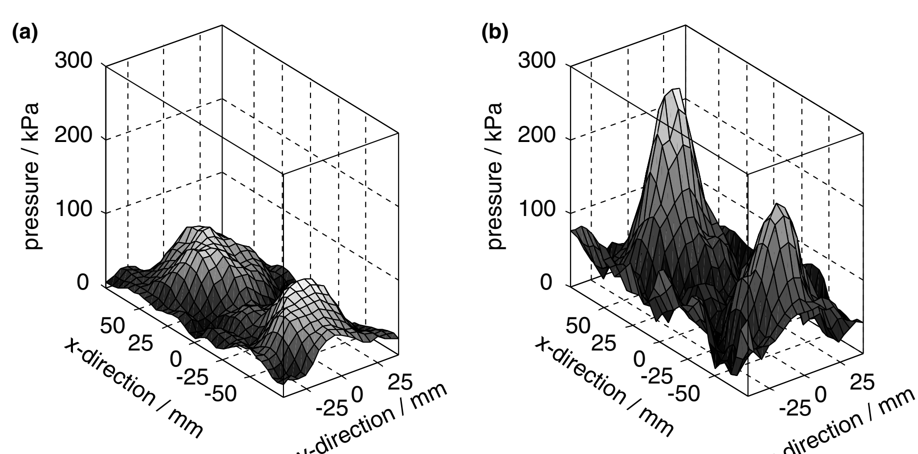

Fig. 2. Mapping of sound pressure (fundamental frequency component) parallel to the bottom of the bath (*xy*-plane) with 16.5 mm distance from transducer surface; (a) power 30%, (b) power 90%.