ASSESSMENT OF THE HIGH-POWER ULTRASOUND POINT SOURCE FOR THE MINIMALLY INVASIVE SURGERY

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Abstract

Research programmes in the field of high power ultrasound applications in neurosurgery, has been pointed to the possibility to apply high-power ultrasonic point sources for minimally invasive neurosurgery. Earlier experiences with noncontact applications of high energy ultrasound have induced the idea of ultrasonic energy transfer through an elastic wire waveguide. The scope of this work is to present the results of theoretical and experimental research in the field of generation and propagation of high-power ultrasound as well as of its application in minimally invasive neurosurgery. Theoretical part covers methods for calculation and modelling of optimised ultrasonic transducers giving a basis for design of a high-power ultrasonic point source for minimally invasive surgery. Generation and transmission of ultrasonic waves from the ultrasonic transducer, through the mechanical concentrator to the endoscopic tool and the ability for adaptation to different surgical applications have been described. By means of the conducted analysis, terms of transmission and transformation of the acoustic energy from the ultrasonic transducer to the endoscopic tool have been determined. In the analysis of the mechanical concentrators, with the help of finite elements method modelling, parametric optimisation of the concentrator shape and length has been conducted. In the experimental part, methods for verification of the theoretical results have been presented. This includes methods for validation the performance of the 1,6 mm titanium wire as an endoscopic tool and experimental methods for assessment of electric and acoustic characteristics of the high-power ultrasonic point source. The emitted acoustic power, sound pressure distribution in the free field (vertical and horizontal plane) and the efficiency coefficient of the ultrasonic probe have been determined experimentally by measurements in an anechoic hydroacoustical tank. The results of this research present a stimulus for application of high-power ultrasound in the minimally invasive surgery, while the experimental results indicates the need for metrological supervision of this and similar surgical equipment.

Introduction

During interdisciplinary collaboration in scientific-research programmes in Republic of Croatia, implementation of new operative procedures for treatment of neural tissues with a high-power ultrasonic point source has been initiated. The whole procedure and method could not been verified with the existing measurement equipment, so a fully functional prototype has been designed and constructed. The device named NECUP-2 (Neurosurgical Endoscopic Contact Ultrasonic Probe, Ver. 2) consists of an ultrasonic generator, piezoelectric transducer, mechanical concentrator and an endoscopic tool made from titanium wire with diameter of 1,6 mm.

Figure 1 : Neurosurgical Endoscopic Contact Ultrasonic Probe, Ver. 2 – NECUP-2

Purpose of the investigation

The purpose of this investigation was to solve some questions following from application of the high-power ultrasonic point source in minimally invasive surgery. The main targets of this study can be expressed as follows:

- Set-up a theoretical model of the ultrasonic transducer that enables realisation of the high-power ultrasonic point source, as an optimal technical solution in the minimally invasive surgery.
- Set-up a theoretical model for description of the ultrasonic energy transfer from the ultrasonic transducer, across the mechanical concentrator to the distal end of the endoscopic tool that can be matched to the specific surgical procedure.
- Set-up a theoretical model for description of endoscopic tool vibration and experimental verification of results.
- Implement realistic and credible experimental methods for assessment of electroacoustic parameters of the high-power ultrasonic point source in surgery. Basic acoustic model of the low-frequency contact surgical system had to be verified by measurement.

Modelling the NECUP-2

a) Piezoelectric transducer

The ultrasonic transducer is modelled as a single-side loaded piezoelectric sandwiched transducer by means of the Mason's model.

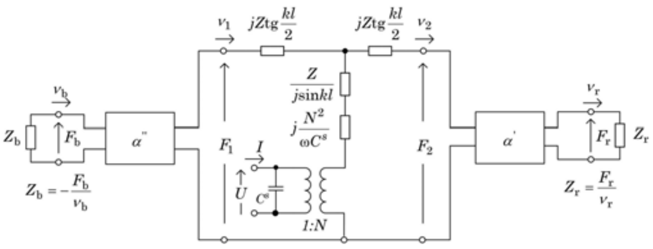


Figure 2 : Mason's model of the single side loaded piezoelectric sandwiched transducer for the NECUP-2

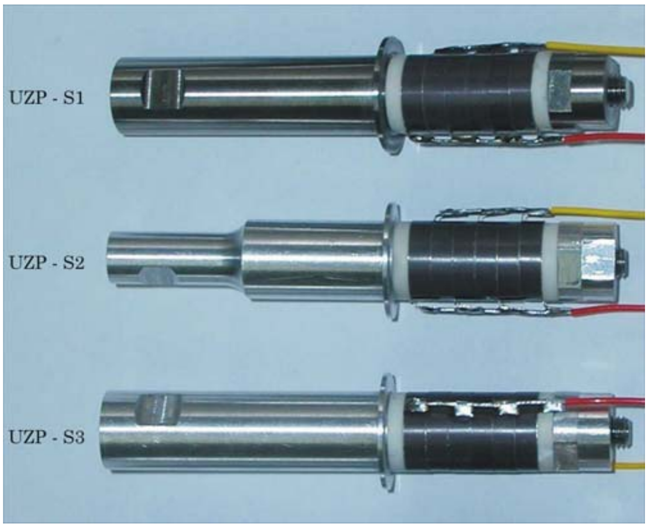


Figure 3 : Ultrasonic transducers used for this study

b) Optimisation of the mechanical concentrator

The optimisation of the shape, displacement and strain has been performed by means of FEM. As a compromise between desired high displacement, low strain and production costs, the stepped concentrator with a transition radius of r = 94 mm has been chosen.

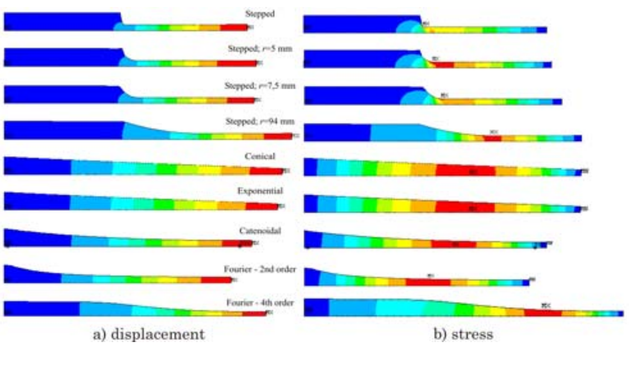


Figure 4 : FEM analysis of mechanical concentrators

c) Substitution diagram of the NECUP-2

In the general substitution diagram, the mechanical concentrator and the endoscopic tool are modelled as T-fourpoles:

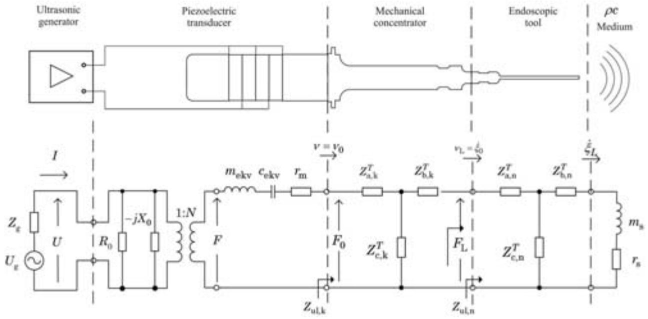
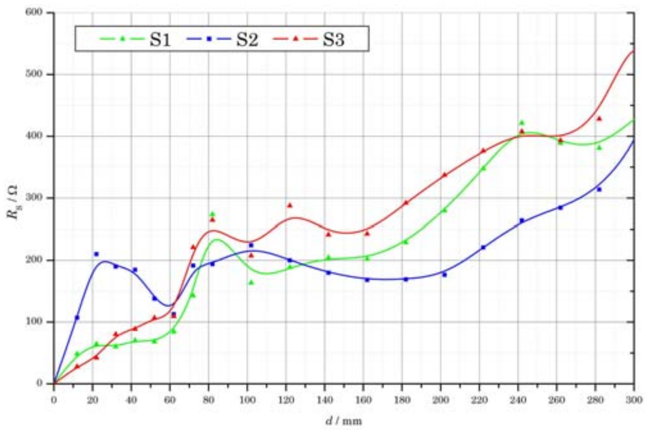
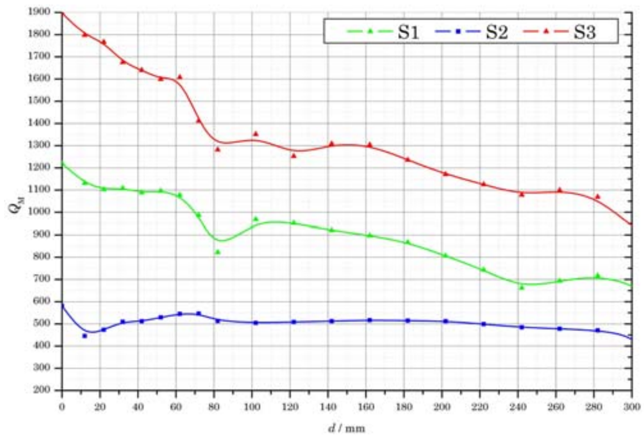


Figure 5 : A general substitute schema of NECUP-2

Electroacoustics measurement





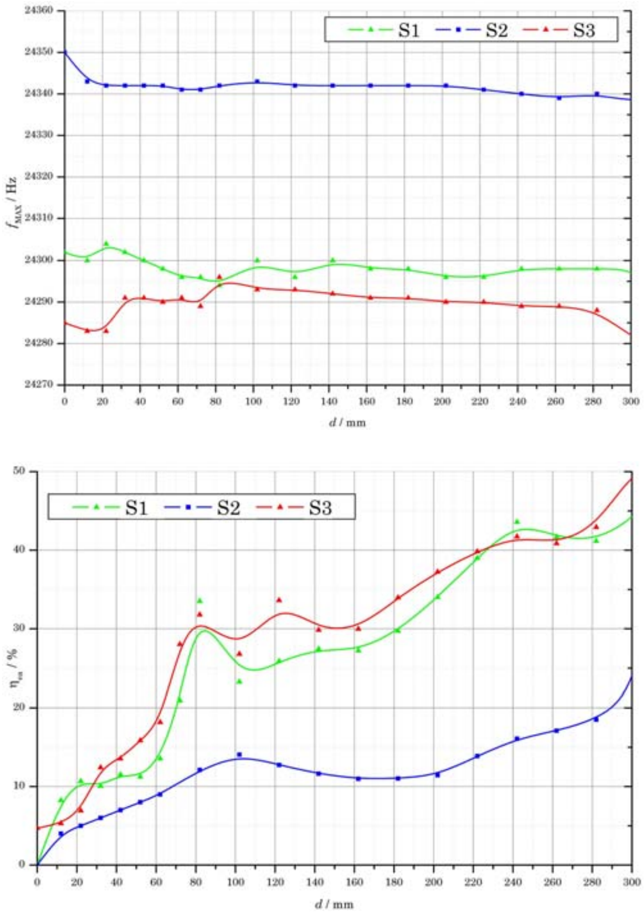


Figure 6 : Dependence of radiation resistance R_S, mechanical quality factor Q_M , frequency f_{MAX} and electroacoustic efficiency η_{ea} on the immersion depth of the probe

Conclusion

According to the acoustic theory it is obvious that contact ultrasonic surgical devices correspond to high-power ultrasonic point sources, so in the theoretical calculations they can be replaced with an acoustic model of the "pulsating sphere". The emitted acoustic power of such sources will not depend on shape of the distal end of the probe, but on the amplitude of the source strength. In the far field, the radiation resistance of such sources is proportional to the emitting area of the sound source, and does not depend on frequency, but corresponds to the radiation resistance of the plane wave. Measurement of ultrasonic surgical systems according to valid IEC standards will not provide a full picture on important characteristics of this system, so by means of a number of measurements in the anechoic tank with the NECUP-2 probe, equipped with an endoscopic tool of 293 mm in length, the characterization area of this system could be widened (calculated radiation resistance, mechanical quality factor, f_{MAX} and electroacoustic efficiency η_{ea}). The measurements have completely confirmed theoretical expectations of the radiation resistance dependence on the sound source area, i.e. an equality to the radiation resistance of the plane wave in the far sound field. According to the expectations and the theoretical model, the mechanical quality factor decreases with increase of the loading (immersion depth of the probe tip). In a similar way the emitted acoustic power depends on the acoustic source area, so with a small emitting area of the sound source it is reasonably to expect a smaller electroacoustic efficiency, which could be experimentally confirmed.

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