Experimental analysis of a high-intensity focused ultrasound power transfer system

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Abstract. To achieve efficient wireless acoustic power transfer, high-intensity focused ultrasound (HIFU) aims at the reduction of spreading losses experienced by current methods. HIFU concentrates the acoustic energy at the focus where a disk is placed. Experiments are performed to understand the influence of nonlinear wave propagation observed at high excitation levels of a focused ultrasonic power transfer system operating under spatially resonant conditions. Analysis of the experimental observations show that the efficiency of energy transfer is reduced as acoustic nonlinear effects become significant. Furthermore, the maximum voltage output position shifts away from the focal point of the transducer. This study is relevant to the development of novel efficient ultrasonic power transfer devices when using focused sources.

Introduction

Ultrasonic power transfer (UPT) has emerged as a promising technology to wirelessly power devices [1]. A UPT system consists of a piezoelectric transducer that converts the input electrical power to vibration-induced acoustic waves. These waves induce vibrations in a piezoelectric receiver to generate electric power. However, the spreading losses from planar and spherical acoustic sources is a key limitation in implementing the UPT technology [1]. This study combines high intensity focused ultrasound (HIFU) with UPT to increase the efficiency of the HIFU-UPT system. This is expected as HIFU source concentrates the energy over a small spatially localized focal spot where a receiver can be placed to receive maximum acoustic power. When considering an HIFU-UPT system, wave distortion is complex and pronounced due to combined nonlinearity and diffraction effects, especially in the focal region [2]. Additionally, reflections from the HIFU and receiver surfaces form standing waves. This study investigates the dynamics impacting the maximum voltage output position (MVOP) of the receiver under nonlinear spatially resonant acoustic conditions in an HIFU-UPT system.

Results and discussion

Figure 1 shows the root mean square (RMS) of the harvested voltage by the receiver at different positions along the axial axis of the transducer for relatively low, medium and high excitation levels. It is observed that at relatively low excitation levels, the MVOP is the focal point, z = 0, as expected. As the source excitation level is increased to relatively medium and high levels, the MVOP shifts towards the HIFU source before stopping at z = -10 and the ratio of the output to the input voltage decreases. These trends indicate that acoustic nonlinear and saturation effects are significant at medium and high excitation levels, respectively. The reduction in the ratio of output to input voltages and the shift in the MVOP contradict the expectation that maximum acoustic energy can be realized at the focal point for all excitation levels. To understand this behavior, the influence of fundamental component of the excitation acoustic spectrum on the disk is analyzed. This is because only the frequency of the fundamental component of the acoustic field coincides with one of the structural modes of the disk at 0.5 MHz and contributes to majority of the voltage response [3]. The rate of increase in the amplitude of the fundamental component of the pressure field decreases with increase in input excitation and at positions closer to focal point, due to increase in nonlinear effects [2]. In addition, the diffraction effects increase the width of the main lobe at positions away from the focus [2]. These variations cause the effective acoustic force on the disk to be larger at z = -10 than at the focal point. This explains the increase of effective force and consequent voltage response of the disk at positions away from focus along with the shift in MVOP, with increase in excitation amplitude, Fig. 1.

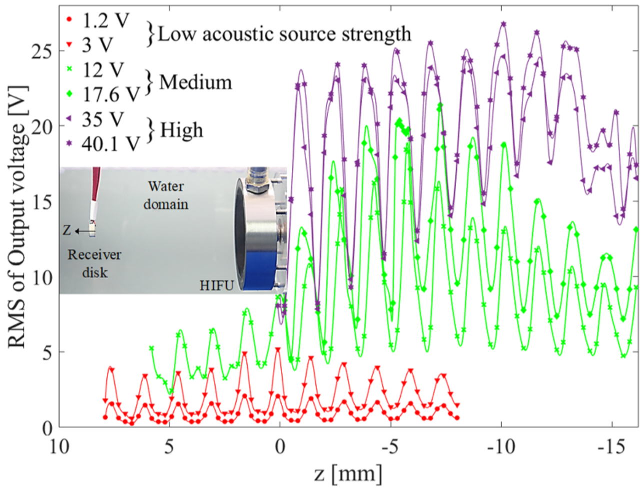

Figure 1: Output voltage along the axial axis, z, for different levels of input HIFU voltage. The different colors denote variations in the pressure field from linear to weakly linear to saturation as the excitation is increased from low to medium to high amplitudes, respectively. The inset shows the experimental setup of a piezoelectric disk used to harvest voltage from the HIFU source.

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References

[1] Awal, M. R., Jusoh, M., Sabapathy, T., Kamarudin, M. R., & Rahim, R. A. (2016). *IJAP*, 2016

[2] Hamilton, M. F., & Blackstock, D. T. (Eds.). (1998). *San Diego: Academic press.*

[3] Bhargava, A., Meesala, V. C., Hajj, M. R., & Shahab, S. (2020) *arXiv preprint* arXiv:2006.12691.