Numerical and Experimental Study of The Standing Wave, Near Field and Low Frequency Acoustic Levitation System

A THESIS

Submitted by

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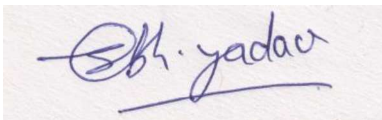

Place: IIT Mandi Saurabh Yadav

Date: 24/09/2021

DECLARATION

I hereby declare that the entire work embodied in this Thesis is the result of investigations carried out by me in the **School of Engineering**, Indian Institute of Technology Mandi, under the supervision of **Dr. Arpan Gupta**, and that it has not been submitted elsewhere for any degree or diploma. In keeping with the general practice, due acknowledgements have been made wherever the work described is based on finding of other investigators.

Place: IIT Mandi

Date: 24/09/2021

Signature:

Name: Saurabh Yadav

CERTIFICATE

I hereby certify that the thesis entitled **"Numerical and experimental study of the standing wave, near field and low frequency acoustic levitation system"** submitted by Mr. Saurabh Yadav, a Research Scholar in School of Engineering, Indian Institute of Technology Mandi, for the award of **DOCTOR OF PHILOSOPHY**, is a record of an original research work carried out by him under my supervision and guidance. The thesis has fulfilled all the requirements as per the regulations of the institute. The results embodied in this thesis have not been submitted to any other university or Institute for the award of any degree or diploma.

Signature:

Name of Guide: Dr. Arpan Gupta

Date:

ABSTRACT

Handling of small components and highly reactive materials is quite challenging and requires special attention. Acoustic levitation is an interesting technique which can levitate the particles/objects of different shape of the different materials freely in the air. Due to the ability of handling the materials without any physical contact, this technique is widely used in the containerless processing of the materials. In this work, one specific method of acoustic levitation, called standing wave acoustic levitation, is discussed. In standing wave acoustic levitation system, an ultrasonic transducer-reflector arrangement is used to develop the standing wave in a region. Small components/materials can be suspended freely near the pressure nodes. The frequency of the excitation of the transducer is in the ultrasonic range (40.305 kHz for this study). The numerical simulation and experimental validation to levitate seven polystyrene particles weighing 0.15 mg each are shown. Further, another low-cost standing wave acoustic levitation system is developed. Along with being inexpensive, the new acoustic levitation system is also very simple to operate.

To provide the motion to the freely levitating object without any physical contact is a key challenge. This is accomplished by generating moving standing wave using two ultrasonic tweezer setup by varying phase of one of these tweezers. The lateral movement of levitating particles in a single axis acoustic levitation system is demonstrated experimentally and numerically. It is found that the single particle, as well as the multiple particles (three particles of average weight of 0.15 mg each), can be moved simultaneously without any physical contact. Further, a mechanical design with five transducers having revolute joints is demonstrated numerically to create a focal point and hence levitate objects. By providing rotation to these transducers, two standing waves are created which are moved to merge two pressure nodes and hence mix the two freely levitating liquid droplets.

The resonance phenomenon is the key for the standing wave acoustic levitation system. To obtain the right air gap/distance between the driver and the reflector surfaces for the levitation system's resonance condition is significantly important. Various computational techniques such as finite difference and finite element method are used to obtain the right distance between driver and reflector. An experimental setup is also developed to validate

the numerical results. In another study, dependence of the resonance condition on the size of the levitating particle as well as the position of the particle between the driver and the reflector has also been studied. Further, finite element approach is also used to study the variation of acoustic pressure at pressure antinode with respect to the size of the reflector. The optimum diameter of the reflector is calculated for maximizing the levitating force for three resonance modes.

The total radiation force on a spherical levitating object, which is placed between a single axis acoustic levitator, is obtained using finite element simulation. Variation in the total radiation force on the spherical levitating object with respect to the position of the object between the driver and the reflector is studied in resonance as well as non-resonance condition. Simulation results are verified with experimental results available in the literature. Further, a parametric study has been performed on the radius of curvature of driver and reflector. Three different cases have been considered - 1. Curved driver surface with flat reflector surface 2. Curved reflector surface with flat driver surface 3. Both driver and reflector having curved surfaces. It is observed that the case with both driver and reflector surfaces being curved results in maximum radiation force on the spherical levitating object. Total radiation forces for all three cases (with optimum value of radius of curvature) as well as the flat surfaced driver-reflector arrangement are compared.

While levitating the object freely in the medium, the translational and the rotational stability of the levitating object are significantly important, particularly for the near-field acoustic levitation phenomenon. For the stability study, a numerical model is developed and validated with the experimental study presented in the literature. It is found that the levitating object can be levitated stably at the displacement antinodes of the flexural mode vibrations of the driver plate.

Lastly, the acoustic levitation of spherical object using low frequency sound wave is studied. An experimental setup is prepared. The resonance frequency corresponding to the first resonance condition is calculated using finite element method. The experimental setup is excited at the calculated resonance frequency and the levitation of the spherical object (table tennis ball weighing 2.7 g) is demonstrated.

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