771. Ultrasonic systems for liquid pulverizer

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Abstract. Analyzing known liquid pulverizers which are driven by piezoelectric transducers we obtain that almost all of them are using longitudinal vibrating mode. So we decide to create a dual-effect system which will act as a pump and sprayer.

Using FEM analysis the proposed model was analyzed and it is natural longitudinal frequency was found. Modeling results (frequency, displacement) were compared with real parameters of working transducer and they were nearly the same. The main study object was to find how fluid moves through a capillary under ultrasonic vibrations. The experimental results are populated below.

Keywords: ultrasonic, piezoelectric, mechanics, cavitations.

Introduction

The possibility of spraying liquids using ultrasonic fluctuations has a large appliance field, such as spraying of drugs, wet cleaning, air conditioning, accelerating chemical reactions, spraying fuel, molten chemicals for the manufacture fine powders, etc. [1], [2].

Quickly developing nano-technology also may find some application of such system for spraying nano particles, to make a smooth thin layer, etc. [3].

Because of all things mentioned above it is clear that such a system can find it is application in scientific research area and also in civil everyday living.

Principle of ultrasonic spraying

Ultrasonic spraying is based on ripping particles by means of cavitation, since small liquid particles have small mass they can fly away from the source. So to make liquid spray we need to generate a standing wave in elastic body (liquid). Depending on liquid thickness above the transducer it is more power needed to create required amplitude to rip some particles from the man liquid mass and push it into air.

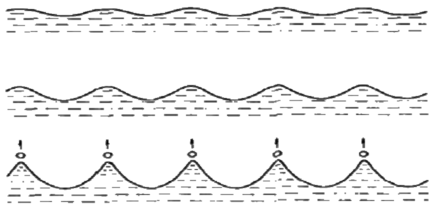


Fig. 1. The separation of droplets from the waves crests

As soon as cavitations threshold, has been reached surface particles starts to separate and form a small droplets (Fig. 1.) [2], the average size of aerosol droplets depends on actuators driven frequency [1]:

$$D = a \cdot \lambda_k \quad (1)$$

where a - is a proportionality factor, that depends on the liquids viscosity; λ_k - the length of the capillary waves, which is equal to:

$$\lambda_k = \sqrt[3]{\frac{8\pi\sigma}{\rho f^2}}, \qquad (2)$$

where σ - coefficient of liquids surface tension; ρ - liquids density; f - frequency of ultrasonic fluctuations.

From (2) formula follows, that in order to reduce the size of sprayed particles, it is necessary to increase the frequency. Depending on frequency particle size may vary from 3 µm to 80 µm with respective frequencies of 10 MHz to 20 kHz.

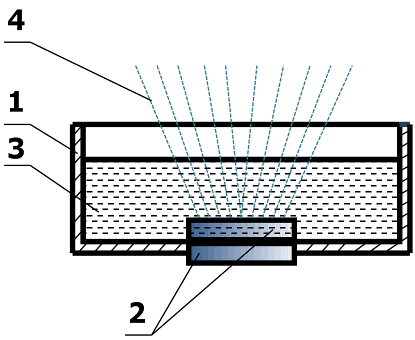
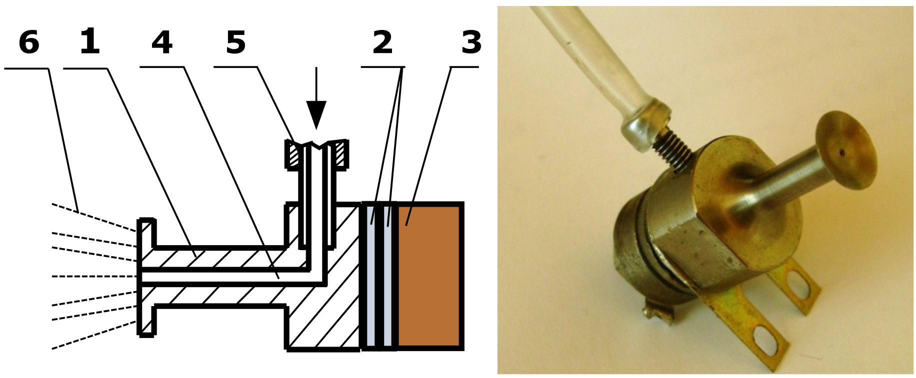


Fig. 2. High-frequency ultrasonic dispersion: 1 - tank, 2 - piezoelements, 3 - liquid, 4 - sprayed liquid



a) b)

Fig. 3. Schematics (a) and real view (b) of sprayer:
1 - transducer, 2 - piezoelement, 3 - counterweight, 4 -flow channel, 5 - inlet port, 6 - sprayed liquid

Most simple sprayer can be made of tank and two piezoelectric discs polarized by thickness. By applying resonance frequency voltage on electrodes liquid can be sprayed from the surface as shown on (Fig. 2).

Mostly, to spray liquid a so called Langiven pack is used. In Langevin pack a piezoelectric rings are used instead of discs. The whole system consists of transducer, piezoelectric rings, and counterweight which are bolted tightly together. Thus the mechanical displacement significantly increases on the transducers end. Because of enormous amplitude difference a Langevin pack with a transducer is used in such systems and much more other systems where mechanical amplification is needed (Fig. 3).

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As literature [4], says the minimum displacement needed to spray liquid from surface is 15 µm. Therefore used transducer to amplify mechanical displacement and make it enough for spraying. However, that reduces the spraying area and productivity.

Ultrasonic sprayers working in closed space

In some cases, liquids need to be sprayed closed space. We studying two types of ultrasonic sprayers, which are used not only for spraying liquids, but also delivers liquid to spraying zone.

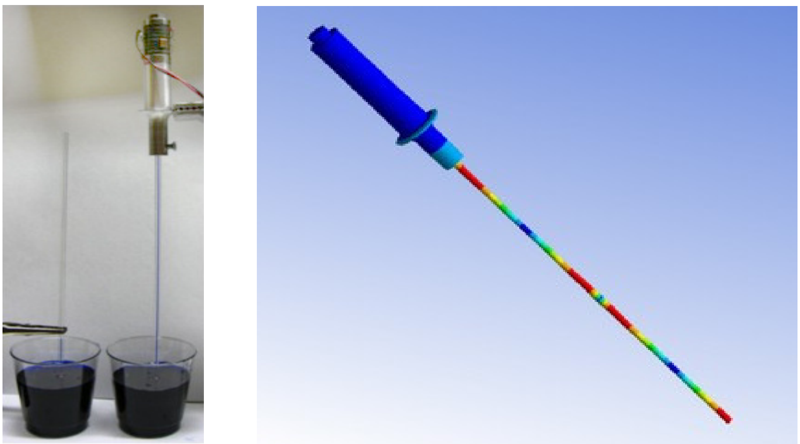
The first type – sprayer–pump, pumping is based on ultrasonic capillary effect, when liquid is forced to raises up in a capillary tube by cavitation created pressure. By the end of the tube it is sprayed. We call such ultrasonic system, a system with a static capillary.

The second type – is inhaler where capillary is appears in-between vibrating system and input element. Such capillary constantly changes it is size (dynamic capillary).

We have previously proposed ultrasonic spraying systems, working in closed space [5]. Also there are some open sprayers – inhalers, full researches on this type of sprayers was not made.

Ultrasonic capillary effect

Transportation – liquid pumping based on the ultrasonic capillary effect [6]. A number of tests were made using capillary tubes. Longitudinal and transverse vibrations were applied on a glass capillary however liquid pumping was notified using longitudinal vibrations. The glass tube was used with a most effective inner diameter according to [6] (0.4 mm.) external diameter was (3 mm).



a) b)

Fig. 4. Colored water raises up in a capillary tube under longitudinal vibrations (a) and a model of the same system made using FEM method (b)

The glass tube was glued to ultrasonic transducer. Tube length was adjusted to fit the transducers created fluctuations so at the end of the tube we have maximum amplitude (Fig. 4b).

Fig. 4b shows the modeling result of proposed transducer with a glass capillary. Transducer is made of aluminum alloy D16T. It uses ring type piezo elements with such geometry D - 12.7, d – 5.5, h-2 mm, type – PI-181. Natural frequency is 62 kHz, burdened with glass capillary 61 kHz.

Fig. 5 shows, relation between capillary inner diameter and maximum liquid raise inside it with constant power. Four different liquids were tested, almost all have the same values, thus we can say that rising level depends mostly on inner capillary inner diameter.

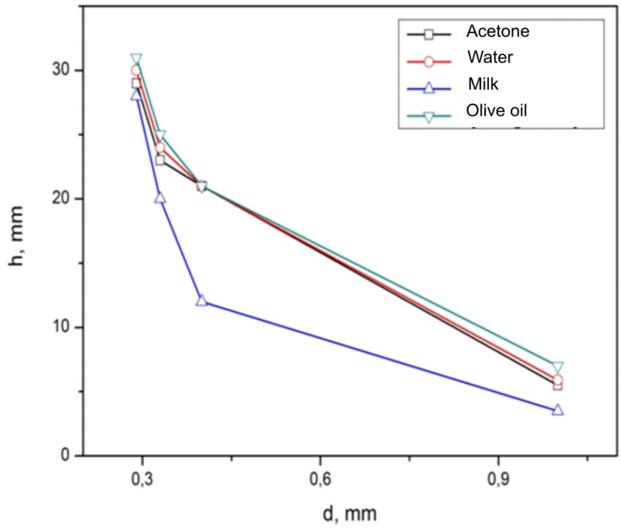


Fig. 5. Liquid rise, level dependence on capillary diameter

During tests with transverse vibrations the level of raised liquid was the same as without vibrations. Such a result allows us to propose that enormous amplitudes created at the end of capillary tube are needed to create cavitation and as a result liquid raises in a capillary tube.

Sprayer with a static capillary

Researching ultrasonic capillary effect a few tests were made with a static capillary. Such a system is shown on Fig. 6 – ultrasonic sprayer.

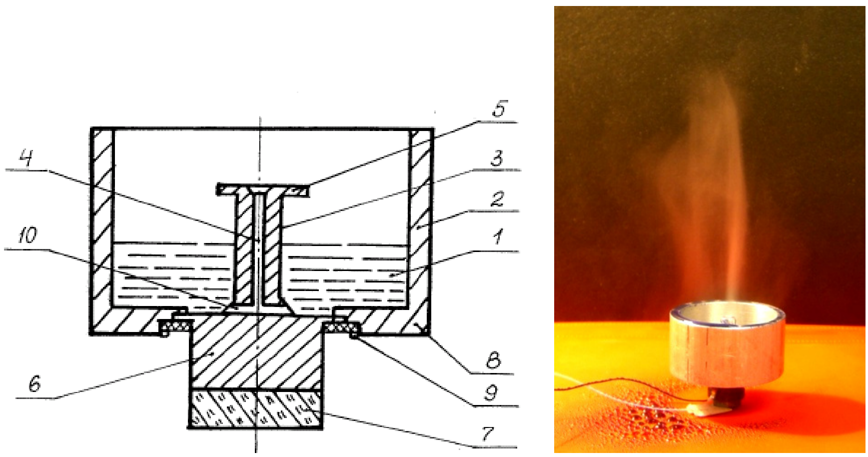


Fig. 6. Half size view schematics and a picture of real working device: 1 - liquid, 2 - vessel, 4, 10 - capillary, 5 - spraying surface, 6 - actuator, 7 - piezoelement, 8 - vessel with liquid, 9 - fastening

Sprayer consists of transducer (6), with drilled capillary holes (4, 10) in it. Through the hole (10) the liquid enters to vertical capillary hole 4, which, under the influence of ultrasonic vibrations, rises on the spraying surface (5). This piezoelectric system is working at resonance frequency on the firs mode of longitudinal vibrations. The spraying intensity depends on voltage applied to piezo elements.

It should be noted, that liquid at the spraying surface acts as a load to vibrating system forcing it is resonance frequency to low, and impedance is rising up (Fig. 7).

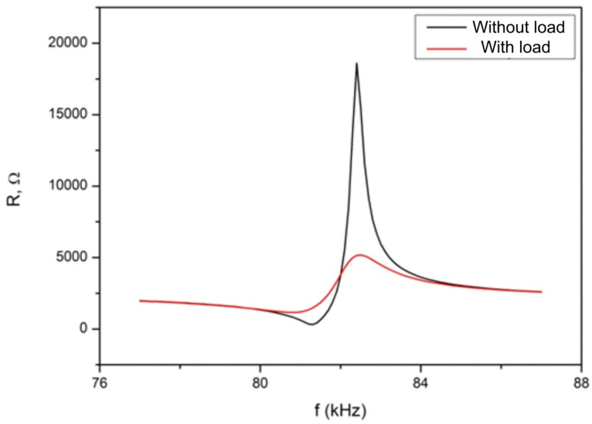
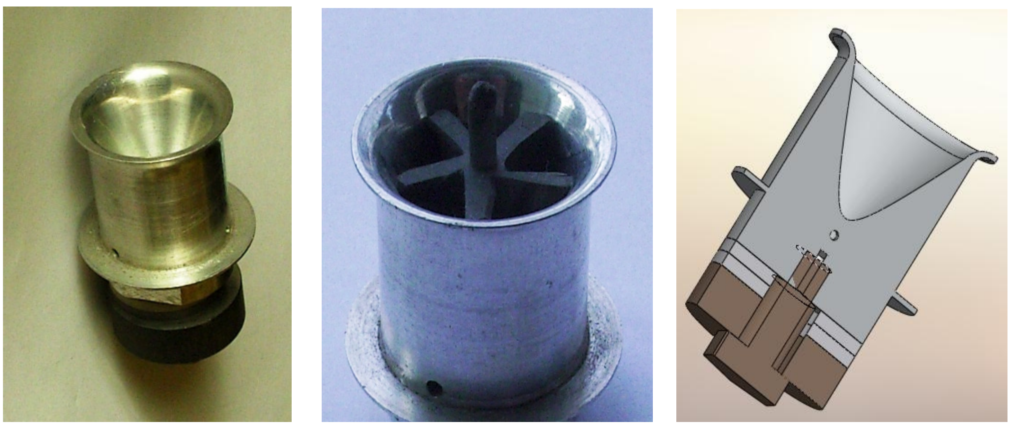


Fig. 7. Impedance-frequency characteristics of piezoelectric actuator

Sprayer with a dynamic capillary

Actuators with dynamic capillary are less influenced by the liquid. The capillary is constantly varying as input rotor moves at the transducer. The capillary accidently appears in-between transducer inner wall and rotor. The maximum amplitude of the transducer at it is end liquid moves to it through a capillary and eventually sprayed when reaching the top (Fig. 8).

The actuator is half-wave length, material D16T, the vibration is produced by two piezoelectric rings with size of 18×9×2mm, type – PI 181. Rotor for dynamic capillary is made from polyurethane.



a) b) c)

Fig. 8. Piezoelectric actuator with dynamic capillary:
a – general view, b – actuator with polyurethane rotor, c – cross-section view

By applying voltage to actuator it is starts to vibrate, the rotor spins and forms a capillary between its self and actuators walls. Using this capillary combined with fluctuations liquid is raising up and appears at the top end. The maximum amplitude at top end prays the liquid into air.

Fig. 9 shows the photo of proposed device with actuators top view and vessel for liquid. Fig. 10 shows actuators model made using FEM – natural fluctuations.

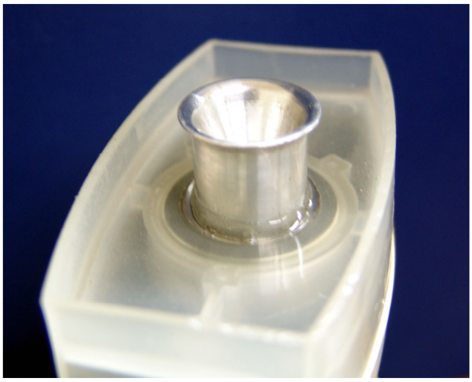


Fig. 9. General view – actuator built into the vessel

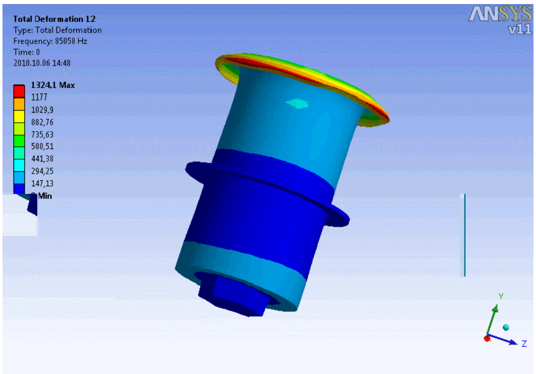


Fig. 10. Natural fluctuations of actuator. FEM model

Displacement measurement on the top end of actuator was made using laser vibrometer OFV-5000.

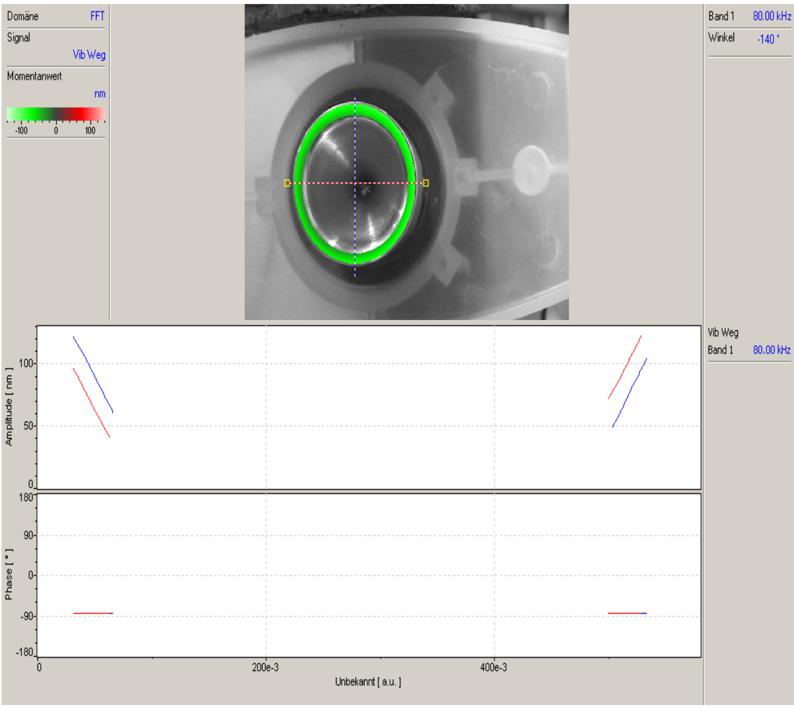


Fig. 11. Displacement distribution on the actuators top surface

As shown on Fig. 11 the green ring on the end of transducer represents maximum fluctuations. When liquid appears on this ring or near, it is sprayed off.

Conclusions

1. As technology develops fast enough it is necessary to proceed performing such tests seeking to invent new ultrasonic spraying systems.
2. The important thing mentioned in this paper is that only longitudinal (high amplitude) fluctuations are causing forces to the liquid to move through a capillary tube.
3. Offered ultrasonic systems with static and dynamic capillary were successfully realized in sprayers working in a closed space.

Acknowledgements

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