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TUBULAR ULTRASONIC TRANSDUCER: MUST WIH AXIAL EXCITATION VERSUS CONVENTIONAL WITH RADIAL EXCITATION

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Abstract. This paper presents comparison between two excitation solutions for tubular ultrasonic transducer. The axial excitation is widespread in conventional ultrasonic transducer. The radial excitation is proposed in order to have an uniform acoustic energy all along the tube. This excitation approach is also proposed to allow the modularity by adding several tubes.

1 INTRODUCTION

Ultrasonic transducers are commonly used for transmitting mechanical energy to several kinds of media: fluid, polymers. . . . in order to impact its properties.

Ultrasonic transducers are usually used for converting electrical energy to mechanical vibration. The Langevin solution is widely used for this conversion. This solution is based on two different masses at the ends of active material (typically piezoelectric material). Both masses are mechanically connected by a screw in order to preload and ensure the compression of the piezoelectric material during the vibration. The weight of both masses is different in order to favour the vibration in one direction. In order to increase the emitting surface, the ultrasonic transducers are connected to a large surface structure with adapted impedance in order to fit with the frequency resonance of the ultrasonic transducer. The most common cases are flat surfaces or tubular surface. For the flat surface, several ultrasonic transducers are required and the number of transducers is directly linked to the active power. The technological limitation for the tubular solution is the tube length. Tubes are convenient for some coating application if width is limited to typically less than 1 m. A new need addressed in H2020 PROTECT Eu project is to coat large textiles width using sonochemistry [http://protect-h2020.eu/]. For such a need, it is required to produce a uniform acoustic energy all along the textile widths. Similar acoustic uniformity requirements are also meet in ultrasonic unclogging of cylindrical filters.

In order to overcome this technological limitation, several research activities have been performed. The wasted vibration issued from the Langevin ultrasonic transducer is recovered by connecting two tubes in both sides of the ultrasonic transducer [1]. The proposed solution is called wing type ultrasonic transducer. This architecture enables to increase the emitting surface through two tubes. Nevertheless, a non-vibration area remains at the piezoelectric stack location which means a non-uniform treatment all along the tube. So, another architecture is proposed [2] by the by using two ultrasonic transducers at the two ends of the tube. This option enables to increase the length of the tube by 25 to 30 %. In the same way, the length of the tube is limited at 2 to 2.5 m. For longer tube, the attenuation of the vibration occurs in the middle of the tube. Such a solution is called a push-pull, ultrasonic transducer. This solution allows for increasing the length of the tube. Nevertheless, the modular approach seems more suitable for a longer tube. The modular approach is proposed [3] using the ultrasonic transducer connected in axial excitation. In this case, the diameter of the tube is higher compared to the diameter of the ultrasonic transducer. This approach allows connecting several tubes in serial from the mechanical point of view. So the ultrasonic transducer is located in the hollowed part of the previous tube. The entire tube is constituted by several tubes connected together by a welding process at the external diameters of the tube. In this case, the vibration is uniform all along the tube. This architecture allows having a longer tube with less dissipation of the vibration at the tube level. However, the ratio between the axial displacement of the ultrasonic transducer and the radial displacement at the tube lever is not favourable due to the difference between the diameter of the ultrasonic transducer and the diameter of the tube. Instead of using the ultrasonic transducer in the axial vibration, the approach of [4] is to use the strain generated in the radial direction of the ultrasonic transducer and transmitted to the tube through the internal diameter. This architecture is proposed to allow to pass the fluid (or the media) to treat inside the tube (instead of outside).

The approach proposed in this paper is to use a radial excitation in order to install the ultrasonic transducer within the tube. This configuration named MUST standing for Modular UltraSonic Transducer and patented by CTEC [5] is preferred in the perspective of providing a uniform acoustic energy along the transducer. It also offers a good potential for using the ultrasonic transducer in a modular approach, by stacking them to get a length of several meters.

2 CONVENTIONAL AXTIAL EXCITATION

Tubular ultrasonic transducers are based on ultrasonic transducer (for the mechanical vibration generation) connected to one end of the tube. The second end of the tube is connected to an heavy mass (see Figure 1). The ultrasonic transducer is based typically on Langevin transducer. The aim of the tube is to increase the emitting surface through its external surface which is immersed in the media to treat.

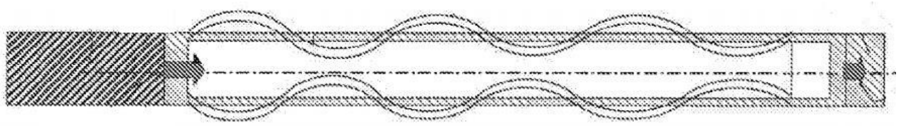


Figure 1: Tubular ultrasonic transducer approach

2.1 The transducer solution

The Langevin transducer which is typically made up of rear mass, head mass (emitter) and active material (stack of piezoelectric material) is depicted in Figure 2. The screw is used to preload the stack of the all the components constituting the ultrasonic transducer. In this way, the screw ensures that all the components stay connected during the vibration of the ultrasonic transducer.

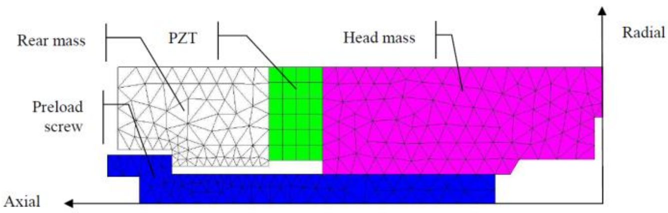


Figure 2: Typical Langevin, ultrasonic transducer (axisymmetric view)

The resonance frequency of such a system depends on the dimension and the material properties of the ultrasonic transducer components. The simplified formulation depicting this relation is given by the formulation given hereafter.

$$\text{wavelength } (\lambda) = \frac{1}{f} \times \sqrt{\frac{E}{\rho}} \qquad (1)$$

With:

E: Young modulus [N/mm²]

ρ : Density of the material [Kg/m^3]

f : Considered frequency [Hz]

Finite Element Method gives a more accurate prediction. The shape and the mapping of the axial and radial displacement are given the pictures below (Figure 3).

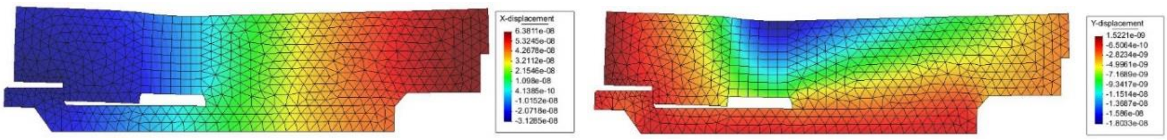


Figure 3: The axial and the radial displacement on the ultrasonic transducer

The displacement is considered in free-free consideration. The resonance frequency of the transducer is about 24.3 kHz with a coupling coefficient of 24 % at this frequency. The displacement depicted is given for 1 volt supply. The density of the rear mass is chosen in such a way to favour the emitting energy in the head mass side. The displacement of the transducer in the axial and radial all along the transducer is given in the curves below.

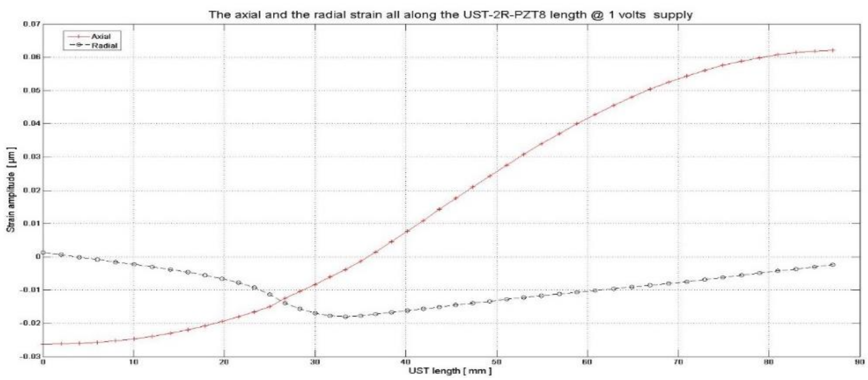


Figure 4: The axial and the radial displacement on the UST

In order to increase the emitting surface, the ultrasonic transducer is connected to the tube. The design of the tube is done in order to fit with the resonance frequency of the ultrasonic transducer. In such a configuration, the system is called ‘Tubular ultrasonic transducer’. This design is based on the previous equation above (equation 1).

2.2 The resonator behaviour

The assembly of the tube on the ultrasonic transducer is described below (Figure 5). The tubular part is designed in order to allow the maximum radial displacement while being compliant with the material fatigue.

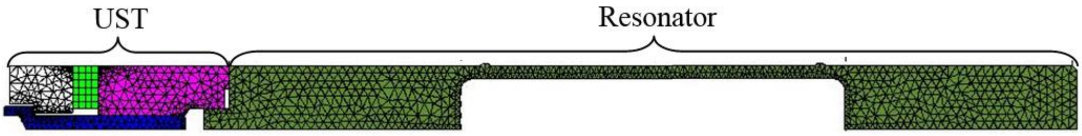


Figure 5: Tubular ultrasonic transducer with simple excitation

The analyses of the Eigen shape of the tube show two different shapes of deformation. The cylindrical shape corresponds to the increase of the tube diameter at a given position (Figure 6). The black lines correspond to the initial diameter of the tube, the red lines to the maximum position of the tube and the green line to the minimum position of the tube. For the elliptic shape, the diameter of the tube increases in one direction and decreases in the other direction at the given position (Figure 7). In the same approach, the black lines correspond to the initial diameter of the tube, the red lines to the maximum position of the tube and the green line to the minimum position of the tube.

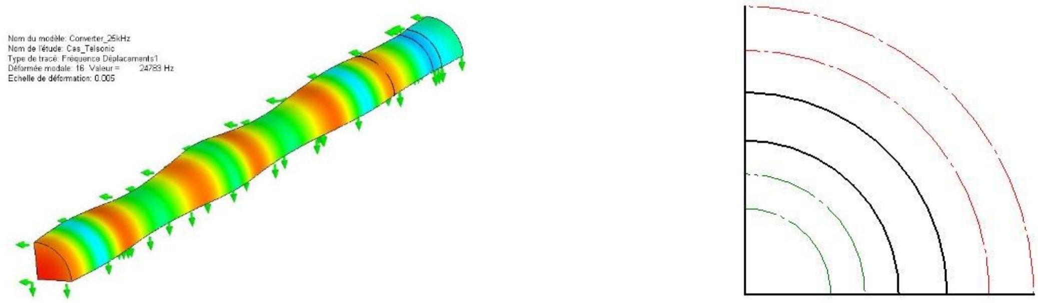


Figure 6: Tubular with the cylindrical deformation

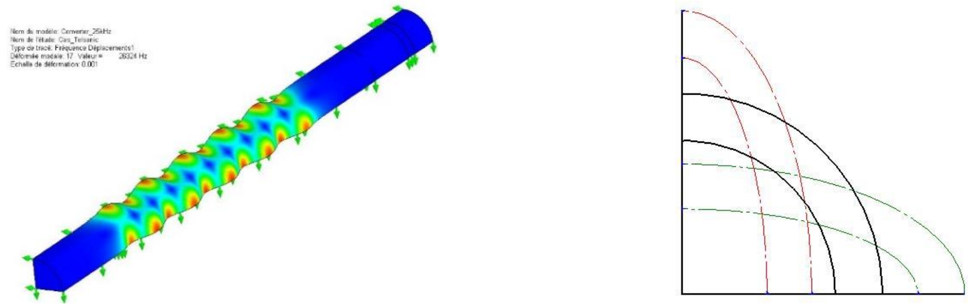


Figure 7: Tubular with the elliptic deformation

The cylindrical deformation of the tube occurs at 24.1 kHz 500 mm length of the hollowed part of the tube. The radial and the axial displacements all along the tube are given by Figure 8. The radial displacement at the hollowed part is lower by 50 % compare to the axial displacement.

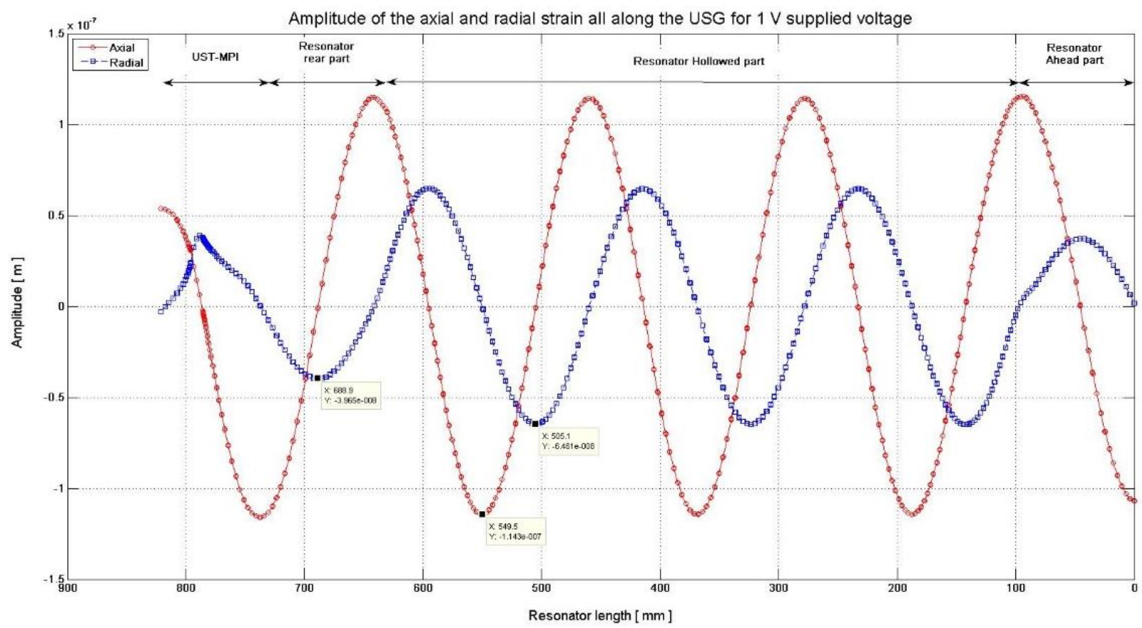


Figure 8: Tubular with the elliptic deformation

The impact of the vibration issued by the tube on the fluid has been studied. The mapping of the pressure generated by the transducer on the fluid (water in this case) is given below (Figure 9). The pressure is non-uniform all along the tube. The pressure is higher in the closer part of the tube to the generator and the pressure is attenuated at the farther part of the tube. This attenuation is due to the damping effect of the fluid. The maximum pressure is about 778 Pascal.

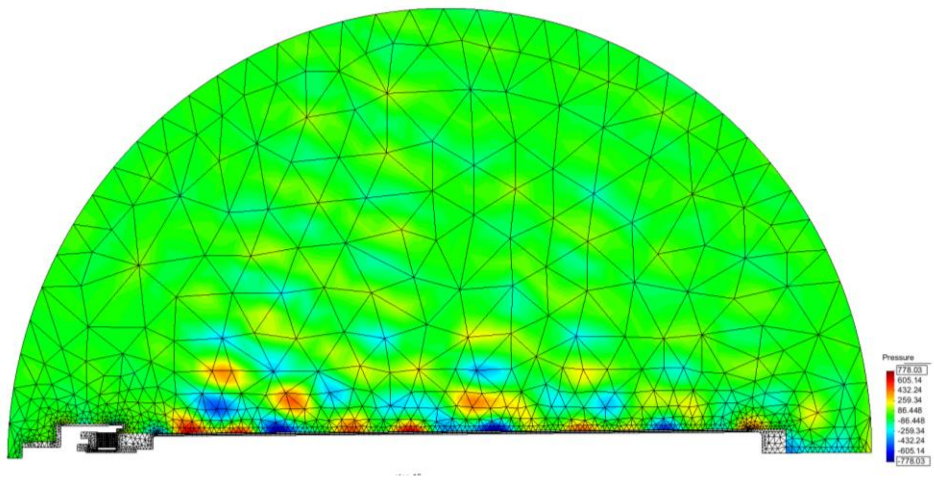


Figure 9: The generated pressure in the fluid (water) by the tubular ultrasonic transducer.

3 MUST WITH RADIAL EXCITATION

3.1 The transducer solution

For the MUST, the radial excitation ultrasonic transducer has been developed by Cedrat Technologies (Figure 10). The approach of this transducer is to install the head mass between both stacks of piezoelectric material and both rear masses on the other side of both piezoelectric stacks. Finally, a bolt connects the both rear masses. The activation piezoelectric material will compress the head mass of the ultrasonic transducer this will increase the diameter of the head mass.

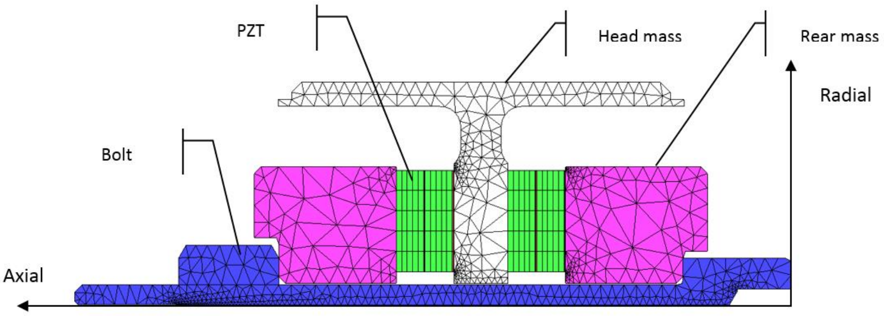


Figure 10: The ultrasonic transducer for radial excitation configuration (axisymmetric view)

The shape of the deformation of the radial excitation ultrasonic transducer is given below (Figure 11). The frequency resonance of the ultrasonic transducer is equal to 25.7 kHz with a coupling coefficient of 44.5 %. The displacement in the radial and axial displacement all along is also compared. The displacement in the radial direction is lower by 41 % compares to the axial direction. In the case of a hollowed preload screw, the amplification ratio decrease to 38 %.

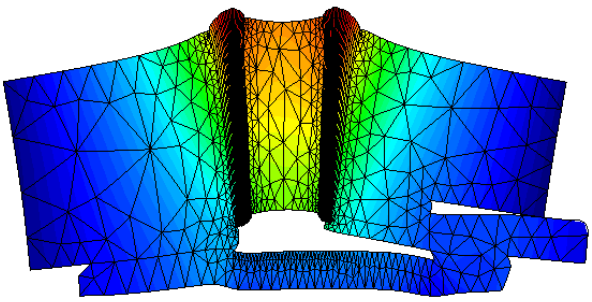


Figure 11: The ultrasonic transducer for radial excitation configuration

In the same way, the ultrasonic transducer is connected to the tube in order to increase the emitting surface of the transducer. The attachment isn't done with the same approach compare to the axial excitation solution.

3.2 The resonator behaviour

The mechanical connection between the ultrasonic transducer and the tube is obtained directly due to the shape of the monolithic part of the head mass (Figure 12).

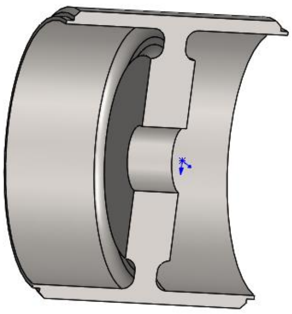


Figure 12: The head mass geometry for axial excitation configuration.

Once the ultrasonic transducer assembled (piezoelectric stack, rear mass and bolt) to the head mass, both tubular ends are connected mechanically to tubes.

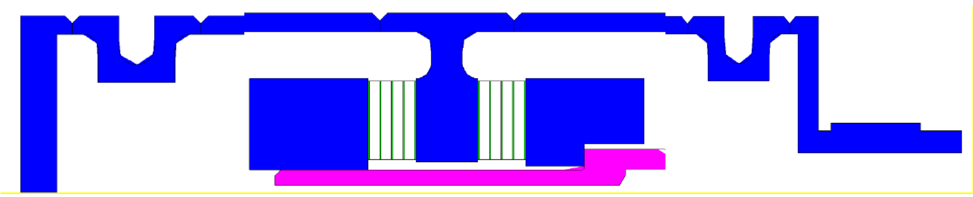


Figure 13: Tubular ultrasonic with the radial excitation

The frequency resonance of the ultrasonic transducer installed in the tube is equal to 25.0 kHz. The shape of deformation at the tube level corresponds to the cylindrical one (Figure 14). At both ends of the transducer, the geometry of the tube is changed in order to avoid the propagation of the vibration issued from the tube to the structure of the tank.

The wiring of both piezoelectric stacks comes out of the tube from the same side. (right side - Figure 13). The cable located in the left side goes through the hollowed preloading from the left to the right side of the tube.

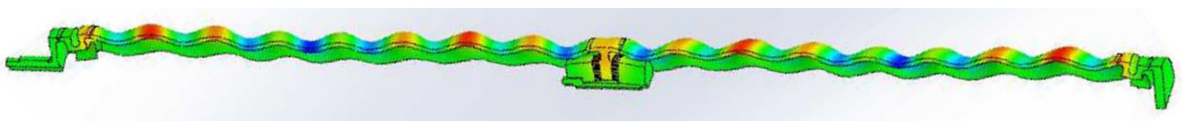


Figure 14: The tube deformation on the MUST transducer

The impact of the vibration issued by the tube on the fluid has been studied. The mapping of the pressure on the fluid (water in this case) is given below (Figure 15, to compare with figure 9). The pressure is uniform all along the tube, which is the main advantage of this transducer technology. The maximum pressure is about 6195 Pascal. The pressure level is obtained at the same level of voltage as for ultrasonic transducer in axial excitation configuration.

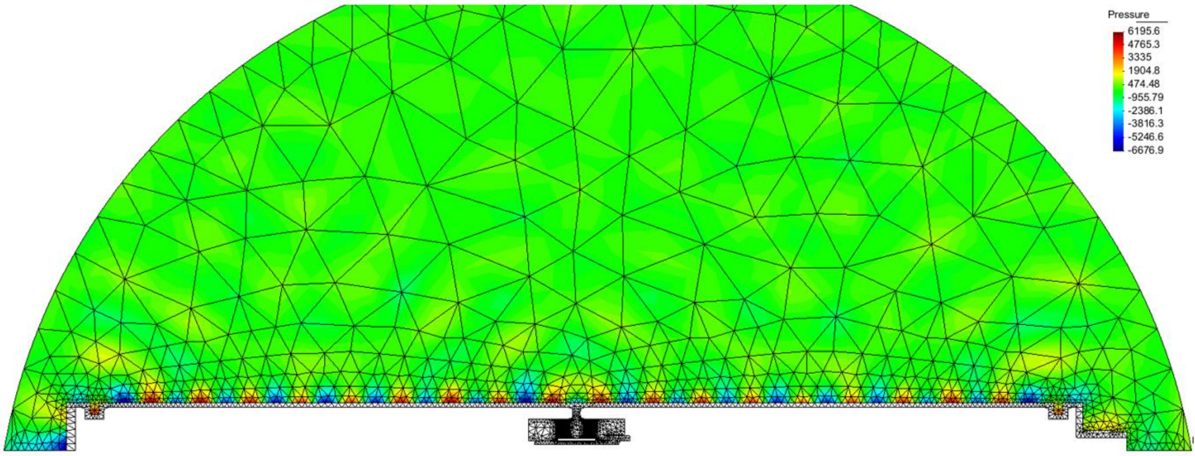


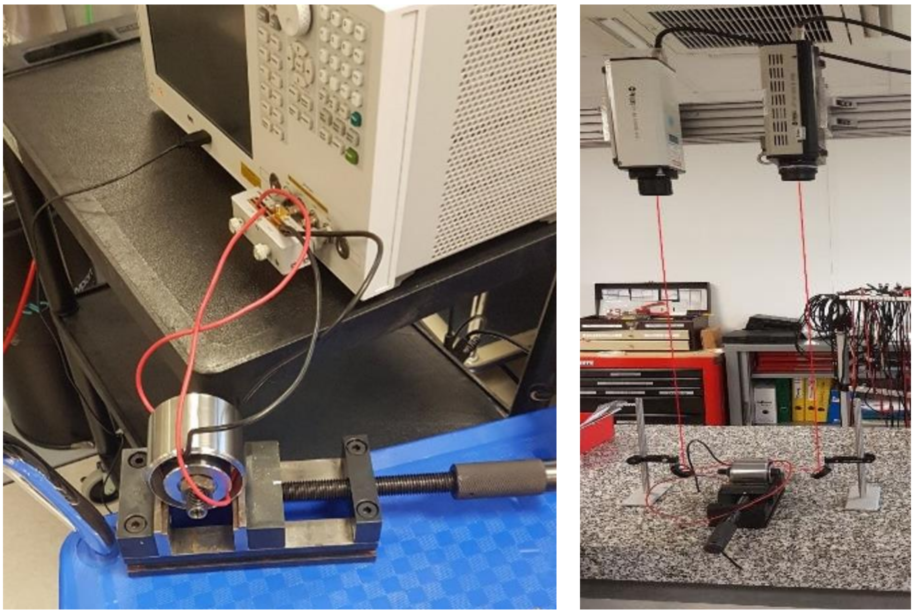
Figure 15: The generated pressure in the fluid (water) by MUST ultrasonic transducer

4 PROTOTYPING

An ultrasonic transducer with radial excitation prototype (Figure 16) has been manufactured in order to evaluate and compare the simulation and the experimental results. The stack of piezoelectric material and rear mass have been assembled.

Figure 16: The ultrasonic transducer for radial excitation assembly

A preliminary measurement has been performed in order to evaluate and compare the results to the simulation. The test has been done in two steps, the first one to measure the resonance frequency of the system (Figure 17 - a) and the second to measure the amplitude of displacement generated at the ultrasonic transducer level (Figure 17 – b).



(a) (b)

Figure 17: The ultrasonic transducer for radial excitation on test bench

The preliminary measurement one the prototype for the first test a variation of the frequency resonance from 25.7 kHz (simulation) to 22.1 kHz (measurement). The first analysis of such a variation of frequency could be generated due to the boundary condition which is not the same between the simulation and the test bench. For the second test, the displacement ratio as measured is about 45 % between the axial and the radial direction (for both cases of screws). The simulation shows a ratio of 41 % for standard screws and 38 for the hollowed screws. In the case of the standard screw, the coupling coefficient is about 37 % and 22 % in the case of the hollowed screw.

Two tubular ultrasonic transducers, one with axial and one with radial excitation approach have been manufactured (Figure 18) in order to evaluate their performances and to compare between both solutions. Further measurement and experimentation are planned in the near future. This test will include the performance measurement on immersed and also connected several MUST in order to increase the length of the tube (so the emitting surface) without losing vibration at the ends of the tube.

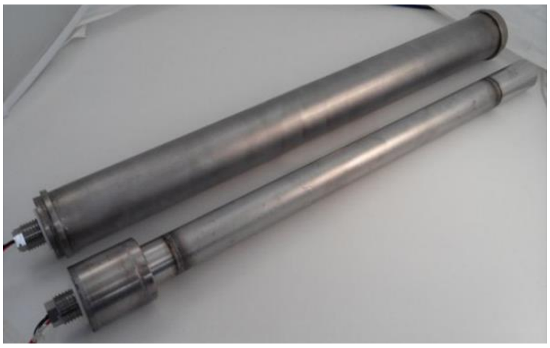


Figure 18: The MUST and conventional ultrasonic tube transducer

5 CONCLUSIONS

The comparison study between the axial and the radial excitation on the tubular ultrasonic transducers has been done in this paper. The radial excitation approach has been studied in order to improve the capability of such a solution for getting a homogeneous acoustic energy generation and higher tube length by staking. This has lead to a new Modular Ultra Sonic Transducer (MUST). Based on FEM simulation, its results show a higher coupling coefficient for the radial excitation with the same amplification ratio than conventional tube transducer using axial excitation. The pressure generated by the MUST is uniform all along the tube as wanted.

The experimental campaign is still in progress in order to have deeper information about the performance of MUST solution especial in the immersed configuration.

This activity takes parts on H2020 PROTECT project (GA 720851) targeting the textile sono-chemical treatment to get anti-bacteriologic property.

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