Program Digest, 2019 IEEE International Ultrasonics Symposium (IUS)
Glasgow, Scotland, October 6-9, 2019

Development of Hydrostatic Annular Ultrasounds Transducers for Intravascular Sonoelastographic Shear Velocity Imaging

1st Hamid R. Chabok
dept. of Industrial and Systems Engineering
The University of Southern California
Los Angeles, USA
chabok@usc.edu

2nd Abolfazl Akbari
dept. of Mechanical Engineering
Babol Noshirvani University of Technology
Mazandaran, Iran
abolfazlakbari19@yahoo.com

3rd K. Kirk Shung
dept. of Biomedical Engineering
The University of Southern California
Los Angeles, USA
kkshung@usc.edu

***Abstract*— The design, fabrication, and testing of hydrostatic annular ultrasounds transducers for intravascular sonoelastographic shear velocity for imaging is presented. By using dual element piezo rings with through-blood acoustic shear waves propagation, the miniaturized hydrostatic annular ultrasound transducer was developed. The annular array was designed and fabricated using two sets of different thickness piezo-rings embedded in steel rings with fine grooves of 250 µm wide separated by a 1 mm polymer spacers, and a light backing layer of Epo-Tek 301(Epoxy Tech., Inc., Billerica, MA). Epoxy was used for backing layers, and a flexible circuit was used for interconnecting the annuli with 75 Ohm coaxial cables. One array was tested, and the results were found to be in reasonable agreement with the numerical simulation. The highest measured total acoustic pressure for pulse-echo response and the maximum displacement of PZT rings in radial direction around 19.5 MHz for this transducer was 24 kPa and 8 nm, respectively.**

Keywords—Blood Vessel Sonoelastography, Intravascular Imaging, Shear wave, Ultrasounds Transducers

I. Introduction

In our previous related work, a first-of-a-kind acoustic communication (modem) system [1] to transfer data through the fluid in the pipeline by an acoustic annular radial-mode transducer for industrial applications was developed that is shown in Fig. 1. Moreover, an experimental test set up was planned and performed. Therefore, acoustic transverse waves propagation has been used to send and receive a signal through the fluid in the pipeline [2]. In a medical extension of our previous study, a novel method of acoustic wave generation to develop an intravascular imaging with the shear wave elastography of the blood vessel walls is investigated which the schematic of this study is shown in Fig. 2.

Conventional acoustic radiation force imaging uses compressional wave and requires additional vibration source. In these methods, speed of wave does not vary significantly for biological tissues compared with the variation of the shear wave velocity in the same tissues. Shear-wave sonoelasticity imaging which is targeted at imaging the shear modulus of tissue has a wide dynamic range that can be exploited. From the physics point of view, elastography quantitatively aims to image the

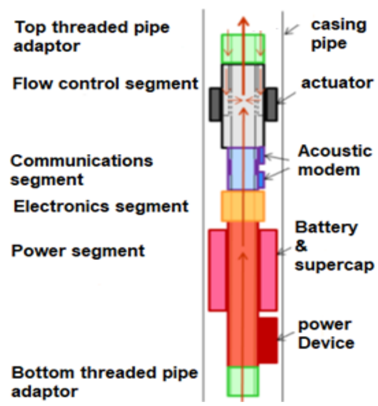

Fig. 1. *Schematic of an annular transducer consisting of liquid filled chamber for acoustic communication*

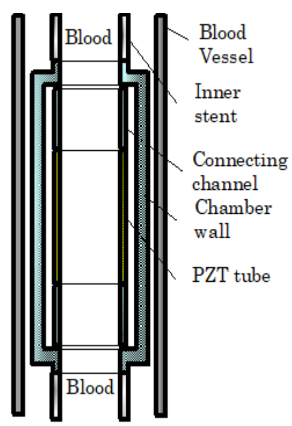

Fig. 2. *Schematic of a hydrostatic annular transducer consisting of blood filled chamber for elastography in artery*

Young's E modulus, the physical parameter corresponding to the stiffness. Vascular imaging plays a central role in the assessment of blood vessels and can be used to diagnose diseases related to abnormal blood flow. Different contrast mechanisms have been explored for non-invasive portable imaging of tissue vasculature [3,4].

The motivation for this project is to develop a flexible fabrication procedure for non-invasive intravascular sonoelastography imaging. Our goal at this stage is to design a novel stent-like arrays transducer that can map elasticity of the vessel walls with this novel stent-like transducer.

II. Methods

A. Novelties

This intravascular stent-like imaging and elastography system presents a number of novelties in one device; such as: (1) instead of longitudinal waves this design is using transverse wave, which can provide elastography of the blood vessel walls, (2) low frequency transverse acoustic waves enable signal to travel more inside the blood vessel and transmit data and receive image echoed from the vessel wall by the second transducer, (3) attenuation of the received signal by the second annular stent transducer can map and measure blood viscosity.

What is more, radial mode of the special piezo-rings as a part of innovation is employed. This means shear waves dominantly propagates in the media, and the transducer does not block the blood flow.

The modeled properties [5] of the 1-3 composite are listed in Table 1. The properties other components used in the array design are listed in Table 2. These properties were used in a numerical simulation of a single element with results shown in Fig. 4, Fig. 6 and Fig. 7.

B. Fabrication

The brief fabrication procedure is as follows:

First, the piezo-ceramic ring shape in radial mode piezoelectricity with PZT-5A material was built using the interdigital bonding technique [6], lapped and sputtered with Cr/Au on both sides.

TABLE 1. Calculated 1-3 composite material properties

Property	TRS200HD + Epo-Tek 301
Piezo Vol.[%]	57
ρ [kg/m3]	4998
$\varepsilon_{33}^{s}/\ \varepsilon_0$	527
κ_t	0.6
v_l [m/s]	4223
Z [MRayl]	21.1

TABLE 2. Annular array design components

Component	Value
Matching layer thickness (Epo-Tek 301, 3.05 MRayl)	16 µm
Composite thickness	44 µm
Copper (on the flexible circuit) thickness (41.61 MRayl)	1 µm
Flexible circuit thickness (Polyimide, 3.11 MRayl)	25 µm
Backing Layer (Epo-Tek 301)	2 mm

Backing and matching layers were then cast and lapped to the desired thicknesses. Then, the 75-ohm coaxial cables (150-0352-9NN, Tyco/Precision Interconnect, Portland, OR) were soldered to the flexible circuit. The backing layer was bonded to the flex circuit. The annular array pieces of transducer were then bonded to the flex-circuit. An additional Cr/Au electrode was sputtered to connect the ground side of the array to the flex-circuit. Finally, the matching layer was bonded to the array as a final step before testing. Epo-Tek 301 was the epoxy used for all bonding steps [7].

The significant parts of the designed transducer are listed as below:

Shear Wave Ultrasound Transducer Array:

- Main elements: four different thickness piezo-rings embedded in steel rings and each part separated by 1mm polymer.
- Stainless Steel rings have slots with 250 µm width essential for providing hydrostatic pressure.
- Number of electrodes: four annuli electrodes with 75 Ohm coaxial cables.

Composition:

- Piezo-ceramic: PZT-5A fine grain (TRS200HD, TRS Tech., State College, PA)
- Backing: Epoxy: Epo-Tek 301 (Epoxy Technologies, Billerica, MA)

III. Results

In this section, some essential features that will affect the efficiency of the transducer are examined. The frequency domain of generated and propagated acoustic waves from the designed transducer is shown in Fig. 4, Fig. 6 and Fig. 7.

Radial displacement of transducer is one of the most influential aspects of the designed device as it shows in Fig. 3. The measured radial displacement of transducer is shown in Fig. 4. The first noticeable displacement happened at 12.5 MHz and the second one at 19.5 MHz; However, no significant displacement was shown after 27 MHz.

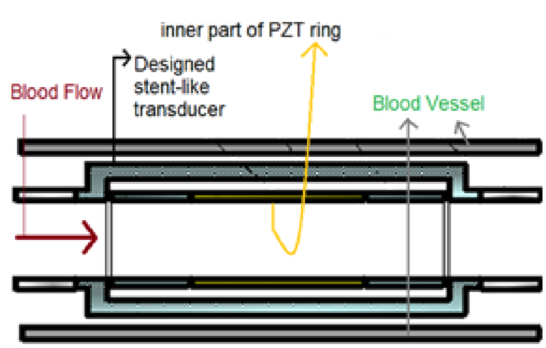

Fig 3. *Inner part of PZT ring*

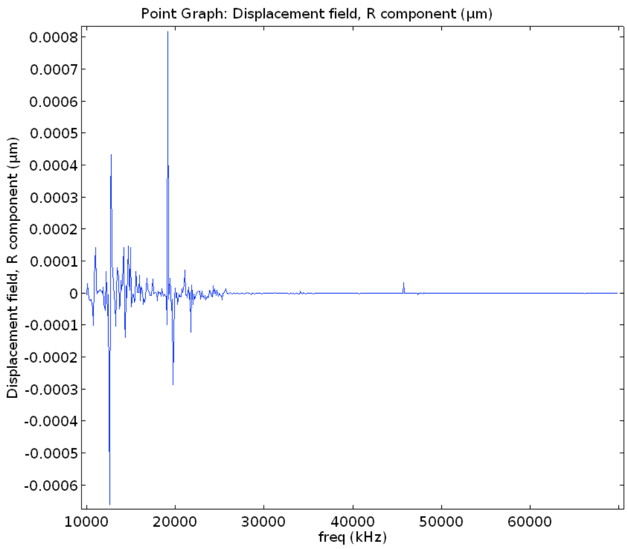

Fig 4. *Measured Radial Displacement of inner part of Transducer VS Frequency Range*

The other critical feature that relates to the design of the transducer, is the value of generated acoustic pressure at the middle of the blood vessel as it depicted in Fig. 5. The highest value of total acoustic pressure was recorded at 19.5 MHz which was around 24 kPa, and the value gradually drops into zero after 27 MHz as it is shown in Fig. 6.

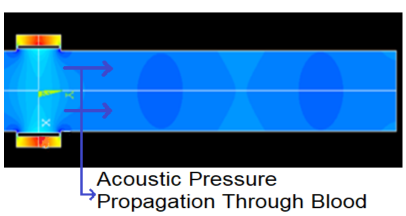

Fig 5. *Acoustic Pressure Propagation*

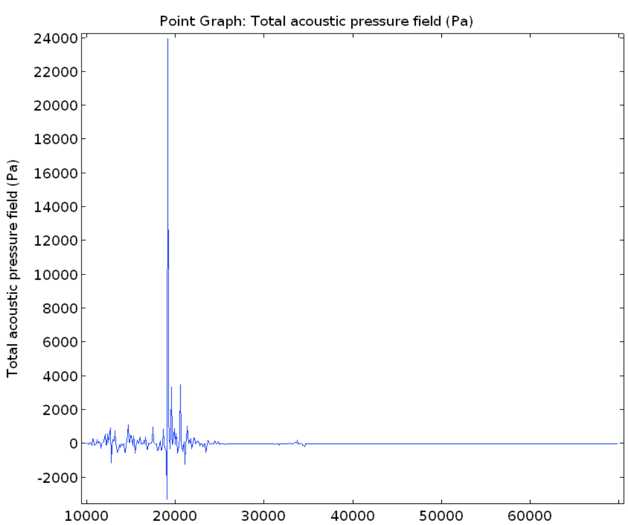

Fig 6. *Measured Total Acoustic Pressure at middle of Blood Vessel VS Frequency Range*

Regarding the value of Von Misses stress of inside of PZT rings at different frequencies, Fig. 7 shows some significant values. First peak happened at 12.5 MHz and others at 19.5 MHz, 48 MHz and 69 MHz and the values of Von Misses stress were 4.6*10^5 (N/m^2), 2*10^5 (N/m^2), 1.8*10^5 (N/m^2) and 2. *10^5 (N/m^2), respectively.

IV. Discussion and Conclusion

We believe that we have developed a flexible fabrication procedure for non-invasive intravascular sonoelastography shear velocity imaging annular arrays. The annuli have been tested and compared with the FEM software results and computer models showing that they are in reasonable agreement considering the discrepancy between the modeled and measured composite properties. Concerning validating experiments, we evaluated two phantoms of various stiffness. Shear velocities were calculated using time-of-flight methods. Next-generation stent-like arrays will be focused on designing a lightweight 1-3 composite and flex-circuit for higher sensitivity and frame rate.

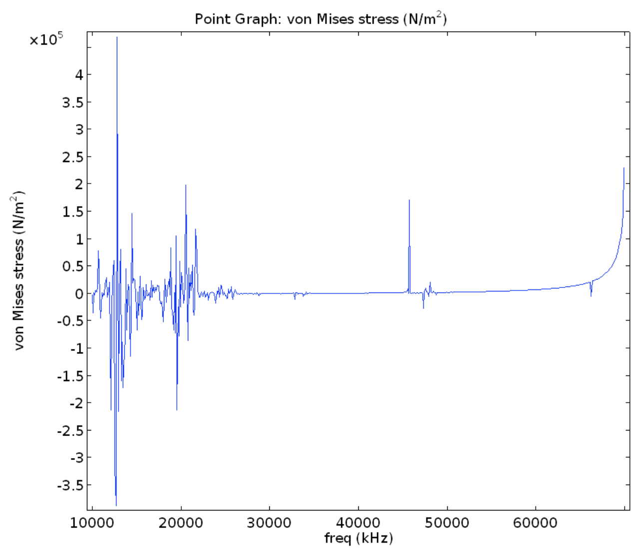

Fig 7. *Von Misses Stress at inner surface of PZT ring VS Frequency Range*

Acknowledgment

Authors wish to thank Dr. K. Kirk Shung for his insights and access to ultrasound transducer resources at USC.

References

[1] X. Bao, H. Chabok, H. Lee, M. Badescu, S. Sherrit and Y. Bar-Cohen, "An annular transducer consisting of liquid-filled chamber for acoustic communication in downhole oil pipe," NTR Docket No.49859, Submitted on Apr. 30, 2015 Provisional Patent Application was filed by Caltech CIT-7183-P on May 2015.

[2] H.Chabok, A.Akbari, A.Fathi, "An Annular Transducer Utilizing a Suspended Chamber for Sonic Signal Transmission in Oil Pipe," unpublished.

[3] J. L Gennisson, T. Deffieux, M. Fink, & M. Tanter, "Ultrasound elastography: principles and techniques. Diagnostic and interventional imaging", 94(5), 487-495, 2013.

[4] Sarvazyan, A. P., Urban, M. W., & Greenleaf, J. F. "Acoustic waves in medical imaging and diagnostics. Ultrasound in medicine & biology, 39(7), 1133-1146, 2013.

[5] W. A. Smith, B. Auld, Modeling 1-3 Composite Piezoelectrics: Thickness-Mode Oscillations, IEEE Trans. Ultrason., Ferroelect., Freq. Contr., Vol. 38, 1990, pp. 40-4.

[6] R. Liu, K.A. Harasiewicz, and F.S. Foster, "Interdigital pair bonding for high frequency (20–50 MHz) ultrasonic composite transducers," IEEE Trans. Ultrason., Ferroelect., Freq. Contr., vol. 48, no. 1, 2001, pp. 299–306.

[7] H. Chabok, J. Cannata, H. Kim, J. A Williams, J. Park, and K. Shung, "A high-frequency annular-array transducer using an interdigital bonded 1-3 composite,'' IEEE transactions on ultrasonics, ferroelectrics, and frequency control, 58(1), 2011.