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Proceedings of Symposium on Ultrasonic Electronics, Vol. 34 (2013) pp. 237-238
20-22 November, 2013

Simulation and Verification Experiment of Radiation Sound Pressure Waveform from Finite Aperture Piezoelectric Transducer

放射音圧波形シミュレーションとその検証実験

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1. Introduction

Wave form shape from a finite aperture piezoelectric transducer used in non-destructive testing and medical ultrasound is improtant. Because it affects to signal noise ratio. Transducer and pulser designers pay attention to the wave form shape. In this report we show basic thiroy, pictures captured by photo elastic phenomenon and hydrophone of generating wave form by finiteaperture piezolelctic transducer.

2. Theory of wave form from transducer

We apply control theory considering the waveform of the emitted sound from the finite aperture piezoelectric element. As knowing the wave form response by a step-funciton shape applied potential, we know the wave form by any shape applied potential. Fig.1 LEFT shows a applied step-function potential. Poezoelectric element is almost same as a capacitor which stores energy by distortion. In ideal, the current flow into a capacitor by step-function potential is a niddle shape. But in actual, a pulser and the element have internal resitance. Therefore current is similar as doted line. The distortion of the

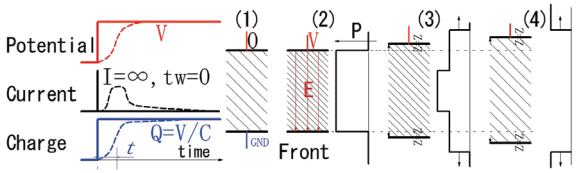

Fig.1 LEFT: Applied potential, Current and Charge, **RIGHT**: Sound from element

element is palarell to the charge on electrodes of the element shown as bellow. The charge dulation is not so long. For example, a 0.5MHz 40mm diameter element have 1nF…5nF capacitor. Pulser output impecance is less than 20 ohm and pulser satulation current is larger than 10A. The Dulation is smaller than 100ns. This is enough smaller time than element period. In micro, grain size of element is about 1um. The element is almost homogeneous. In shot time after applied step-funciton potential, internal electric field is satulated and homogeneous pressure was generated in whole element. In this perio, each part of the element dose not move, because of Neton's fitst law(Fig.1(2)). Pressure propagate both derection(Fig.1(3)). This is proved by wave fomula with constant pressure as initila condition. According to pressure poropagation to outside, the bothe side surfaces of the element move. When the acoustic impecdance of element and the outside are same, rectangle shpe pressure wave propagte(Fig.1(4)).

3. Simulation

Based on the above logic, a simulated wave form from element is shown Fig.2. We disregard the satulation property and rise time of pulser, but use internal resistor R_0. The element capacitor changed by internal pressure conditon. But in sumilation capacitor is constant as C_0.

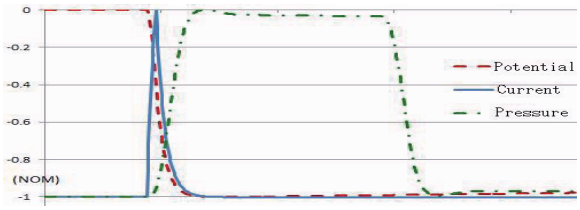

Fig.2 Simulation in ideal condition of applied potential, current and generated pressure wave form.

Applied potential and current changes according to time constant to R_0*C_0 shown as Fig.2. Both slopes of output pressure is little bit larger than the time cnstant R_0*C_0.

4. Measured waveform by pressure sensor

We made a special transducer which have a thick backing material mady by same ceramic material as the element. Measured potential, current and pressure wave as Fig.3. We used high frequency wide band transducer 20MHz 3mm diameter as pressure sensor. It was worked with high impedance(100Mohm) input amplifire. The amplifire works as same as a charge amplifier. We used a long duration spike pulser as a step function pulser. The output pressure wave form in Fig.3 is very close to Fig.2. Diffrences from Fig.2 are;

1) current is satulated by FET characeristic(about 30A)
2) Falling slope of potential is not time constant curve,

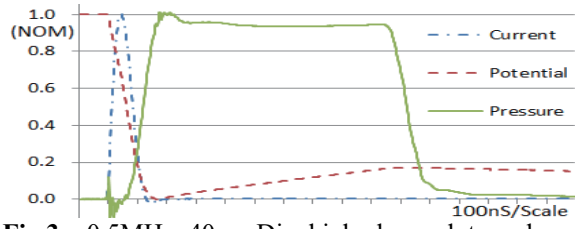

Fig.3 0.5MHz 40mmDia high damped transducer and exciting by spike pulser through 20mm borosilicate glass

but almost linear. This is cased by current satulation.
3) We can observe a kick back potential form element. This is triangle shape. The spike puser is disconnected from a transducer after charge finished. The load of element is high impedance. We can see potential as receiving mode of piezoelectric element.

5. Measured by Photo Elastic Phenomenon

Fig.4 is a block diagram of Ultrasonic Visualization System (UVS) including Ultrasonic Laser Profiler and measured samples. This system is using photo-elastic phenomenon. Observe about 40x30mm or smaller area at glance. Observed intensity by CCD with Gamma 1 is

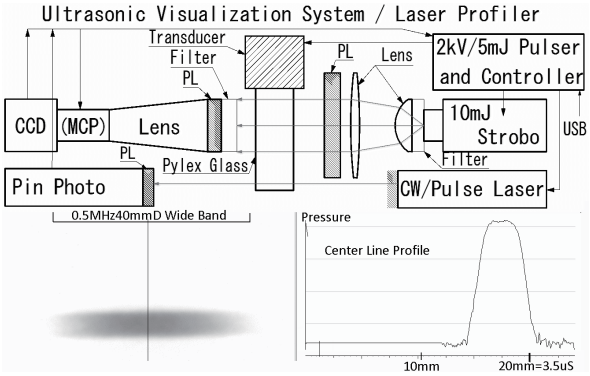

Fig.4 Ultrasonic Visualization System (UVS)

proportional to the square of the stress. Sound pressure is the square root of intensity. The system has a distortions of a lens system (one example center is bright and dark ambient). This system uses photo elastic phenomenon; but, at the same time light ray also deflects by stress. The glass without stress and only atmospheric pressure surrounding it. Commercial transducers are designed basically start with positive sound pressure by applying negative voltage. In above condition we observe nearly rectangular pressure waveform with the same special transducer.

6. Layers effect

Transducer made by many layers; piezoelectric crystal, electrode, protect layer and glue. These make distortion of wave form. We observe such signal on Screen of oscilloscope or Flaw detector.

We made simulation software of multi-layer reflection and combined to the simulation software stated above. Fig.5 LEFT shows the result. The width of each step are same period of round trip layer thickness. We use several thickness of PVC sheet and observed through pressure wave with same transducer mentioned above. The result

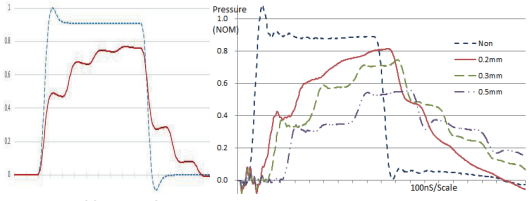

Fig.5 Effect of Layers

is shown Fig.5 RIGHT Simulation and experiment are similar (red lines). When we use thinner PCV we can observe just smooth integration curve for rectangular pressure wave form. We can see rather large overshoot on pressure wave form of Fig.5 RIGHT. This is ringing of lead inductance and element capacitor.

7. Difference by Pulser type

There are many type of pulser to excite piezoelectric element; spike, square, burst pulser etc. Spike pulser is almost same as step-function pulser when the duration is enough long. The square and burst pulses are just super

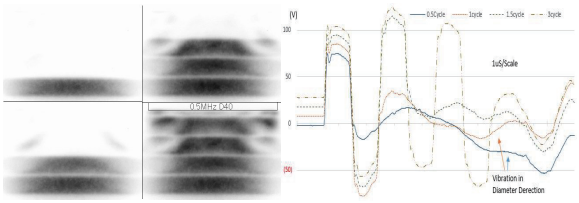

Fig.6 Step,Squre,Burst pulser LEFT; by UVS RIGHT by pressure sensor

composition of positive and negative step-function pulser. Fig.6 shows wave form of sound by different cycle excitation captured by UVS and measured by pressure sensor. A half cycle excitation or step-function generate half pressure wave. A cycle excitation or square pulser make positive and negative rectangular pressure wave. Be care, one atmosphere make brightness change between negative and positive pressure.

We observe very low frequency wave in curve measured by the pressure sensor. This is wave propagate diameter direction of piezoelectric element. The wave strength is depending on piezoelectric material itself, backing material, electric pole thickness, protect layer material and thickness and/or surrounded material of the elements. These arrangement is a knowhow of transducer maker.

We observe non-flatness of pressure on Fig.6 LEFT. These are Beam Edge Diffusion waves which generated by each beam pressure slope on the both sides. This strength is caused by also similar combination mentioned above.

8. Conclusion

Basically piezoelectric element generate rectangular shape pressure wave ideally and trapezoideum shape actually. The slope of trapezoideum is similar to C_0*R_0 time constant. Layers make big distortion of wave form. Square or burst exciting is just super composition of step-function exciting.

Reference

[1] Y.Udagawa: *Introduction to Ultrasonic Wave Technique – Transducer, Pulser, Receiver and Device-*, Nikkan Kogyo Shimbun Ltd, Tokyo (2010)

[2] Y.Udagawa and Guy Reim: Wave Propagation Simulation in Coarse Grain (attenuative) Materials」 IUS October 2012