An acoustic imaging system using impulse ultrasound

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A novel ultrasonic imaging system using impulse ultrasound is described. The properties of transient sound field of a concave transducer were examined in the experiments. Imaging was done based on findings of the transient field using a printed electronic circuit board, DIP type IC as a solid sample and pork meat including muscle and fat as a soft tissue sample. As the results of impulse ultrasound imaging, a spatial resolution of 0.3 mm were revealed and the speckle-free image which differ from the usual pulse imaging can be obtained. Moreover, imaging of the inner parts as well as the surface of the object can be made by adjusting the focal point to a appropriate position.

Keywords: Focused impulse ultrasound, Transient sound field, Direct wave, Edge wave, Impulse imaging, Spatial resolution

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1. INTRODUCTION

The measurement of acoustic properties is one of the most important means to determine the nature of a material and has recently been used as a tool for evaluating the performance of materials and devices. Acoustic imaging is another means of investigating materials, devices, soft tissues and other objects, utilizing the difference in their acoustic impedance. In this case, a shorter ultrasonic pulse including impulse ultrasound improves the time resolution and the focused ultrasound enhances the spatial resolution of the image.

We earlier observed the sound field in transient radiation from various types of transducers using the "time transition pattern"^{1,2)} method.

In this paper, the principle and procedure of the focused impulse ultrasound imaging system are described based on knowledge of the acoustic transient field.

Brief properties of the focused ultrasound field will initially be described, then the impulse ultrasound image of the printed circuit board, DIP type IC for logic operation, and pork meat are samples

demonstrating the effectiveness of the system.

2. PRINCIPLE OF IMAGING USING IMPULSIVE ULTRASOUND

2.1 Sound Field in Transient Radiation from a Concave Transducer

The sound field in transient radiation from a baffled concave transducer was observed using the "time transition pattern" method,²⁾ and was found to consist of two components as indicated in Fig. 1: one is the direct wave (DW) radiated from the surface of the transducer, and the other is the edge wave (EW) emitted from the edge of the transducer. Since both direct and edge waves converges at the focal point, a sound wave with higher time- and spatial resolution is obtained. Polarity of sound pressure of the two waves is reversed before and behind the focal point,³⁾ so that polarity of both sound, *i.e.*, plus and minus, exists as a doublet-like impulse at the focus.^{2,4)} An acoustic image with both higher time resolution and spatial resolution can be obtained by placing the object at the focal plane.

Fig. 1 Acoustic field in transient radiation from a concave transducer. DW and EW represent the direct wave and edge wave, respectively. Inside the region enclosed by the dotted line, sound pressure polarity of both DW and EW are reversed before and behind the focal point.

2.2 Apparatus and Method of Imaging

Figure 2 is a schematic block diagram of the imaging system using impulse ultrasound. A PZT ceramic spherical type transducer was used which had a radius of curvature of 24 mm and an aperture angle of 78 degrees. The center frequency of the transducer used was 2 MHz. An ultrahard plaster for the precise modeling of a tooth was used as the backing material. A step voltage of 20~50 volts was applied to the transducer, then an impulse ultrasound wave was radiated in the medium, water in this case, and was reflected by the object placed on the focal plane. The reflected wave from the object was received by the same transducer and was fed to the amplifier to adjust the signal to an appropriate level for the brightness modulation. The signal from the focal point was extracted by a gate circuit

and then fed to the Z-axis of the CRT display as a brightness modulation signal. The object to be imaged was installed on a three dimensional stage (not shown in Fig. 1) which was able to move on the focal plane. Position of the object was detected by two potentiometers as the voltage signal and fed to the X and Y axes of the CRT display. The received signal was thus indicated as the brightness modulated spot on the CRT display with the information of the position of the object. The impulse ultrasound image can be obtained by recording the locus of the light spot on the photographic film while scanning the object in the focal plane using the computer controlled stepping motors for X and Y directions.

2.3 Sound Field Characteristics of the Transducer

Figure 3 shows the waveform at the focal point of the transducer observed in water by a miniature hydrophone made of PVDF piezoelectric film and with a diameter of 1 mm. Doublet-like impulse ultrasound is observed followed by a few ringing of the transducer.

As the methods for improving the inadequate impulse ultrasound, heavy backing, low Q transducer such as PVDF transducer, and the alternative driving method, like a active damping method,⁵⁾ which compensates the frequency properties of transducer should be adopted.

Figure 4 (a) and (b), respectively, show the axial and lateral sound pressure profiles obtained by scanning a small steel ball (0.8 mm diameter) around the focal point. From these profiles, the half width of axial and lateral pressure are 0.8 mm and 0.4 mm, respectively. Thus the spatial resolution of the system better than 0.4 mm is expected. This value

Fig. 2 Schematic block diagram of the imaging system using impulse ultrasound.

Fig. 3 Sound pressure profiles of the concave transducer used. (a) Axial and (b) lateral profile.

is one half of the wavelength in continuous ultrasound at 2 MHz, so that the image having a higher spatial resolution can be expected.

Figure 5 shows the acoustic transient field pattern of the transducer using the time transition pattern. The sound field is very simple and both direct wave and edge waves are focused at the focal point. It is clear from Figs. 3~5 that an impulse ultrasound

having a higher time- and spatial resolution is obtained at the focal point, so that an ultrasonic image peculiar to impulse ultrasound can be acquired. In the imaging, only one polarity of the doublet-like impulses was selected to get the brightness modulation signal. Samples of the image obtained by the present system are demonstrated in the next section.

3. SAMPLE OF IMAGES

Figure 6 (a) is the photograph of the printed electronic circuit board on whose surface was deposited copper film of $80\text{ }\mu\text{m}$ thick. The substrate was made of glass epoxy resin and had holes of $1\text{ mm}\phi$ to fix the device and the letters of "WV 231." Figure 6 (b) shows the acoustic image obtained by the present method; the holes and letters are imaged and the difference of the reflectivity of sound, namely, acoustic impedance of the substrate with and without the copper film are clearly pictured.

Figure 7 is the image of a 14 pin dual in-line type integrated circuit (DIP type IC). The inner wiring pattern molded by ceramic resin can be imaged. Since width and space of the wires of this IC were 0.4 mm and 0.3 mm , respectively, the spatial resolution visible from this image is $0.3\sim 0.4\text{ mm}$. These values are less than the diffraction limit of the wavelength at 2 MHz ultrasound and these are special merit of the impulse ultrasound imaging.

Fig. 4 Waveform of the sound pressure wave at the focal point observed by the miniature PVDF hydrophone.

Fig. 5 Time transition pattern of the concave transducer. Focal point is indicated by the arrow.

Fig. 6 (a) Photograph of the printed electronic circuit board and (b) acoustic imaging by impulse ultrasound.

Fig. 7 Impulse imaging of the dual in-line type integrated circuit.

(a)

(b)

Fig. 8 Photograph of pork meat (a) and its acoustic image (b).

The inner as well as the surface of the object can be probed by adjusting the sound focus inserted into the inner part of the object.

Figure 8 (a) is a photograph of pork meat in which the muscle and fatty parts are mixed together, and Fig. 8 (b) is its impulse ultrasonic image. The fatty parts are brightly shown and the muscle part is dark, allowing conclusion that the impedance ratio of the fatty tissues to that of water is higher than that of muscle. As the pork meat had no flat faces, the gate width used to extract the reflected signal from the object at the focus should be adjusted more wider ($\approx 2 \mu s$) than that of solid samples.

In the imaging system, scanning interval between each line was $0.1 \sim 0.3$ mm, and the time required to

obtain the image was 2~3 min.

4. DISCUSSION

A method and system of ultrasonic imaging using impulse ultrasound has been described. Focused impulse ultrasound with higher time- and spatial resolution can be obtained by the transient exciting of a concave transducer. These are advanced remarkably by improving the transmitting and receiving method of the system. In the impulse ultrasound field, the pressure polarity of the direct wave is reversed before and behind the focal point as indicated in Fig. 1, that is, the phase of sound is reversed. The polarity of the edge wave, however, seemed to be reversed on the axis of the transducer, so that a doublet-like impulse existed at the focal point. To correlate the sound pressure level to the intensity of the light spot on the display, only one of the impulse wave polarities was used. Impulse imaging has no interference between the incident and reflected wave allowing a speckle-free image which differs from the usual AC pulse image. The inner part as well as the surface of the object can be imaged by setting the focal point at an appropriate position. Using these features, the acoustic properties of materials, devices, soft tissues and *etc.* can be characterized, so that our system will become a powerful tool in the field of the material science, manufacturing and ultrasonic diagnosis. Moreover, an extraction of new information of the material can be expected by the common use of our system and the usual pulse imaging system.

5. CONCLUSION

The principle and the process of the impulse ultrasonic imaging system were described. Initially, the properties of the transient sound field of a concave transducer were determined by the experi-

ments. Then, image samples for the electronic printed circuit board, DIP type IC and pork meat were demonstrated to confirm the performance of the system. The results showed that a spatial resolution of 0.3 mm with a speckle-free image was attained.

We hope to improve this system so that it will expand to a quantitative evaluating one to cultivate a new field in material science.

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