SCANNING ACOUSTIC MICROSCOPE WITH TRANSDUCER SWING ALONG BEAM AXIS

N. Chubachi, T. Sannomiya, J. Kushibiki,
K. Horii, H. Maehara, and H. Okazaki

Faculty of Engineering
Tohoku University
Sendai, Japan

Abstract

A transducer swing mechanism is introduced to accomplish a new scanning acoustic microscope system in the interference mode, which is applied to the quantitative measurement of acoustic velocities in thin materials. In this system, the distance between a pair of aligned focusing transducers along the beam axis is varied periodically, as the specimen is synchronously scanned in the X direction. Measurements of acoustic velocities are performed with this system for two kinds of polymer films, polyester and PVF_2 films, and a dog's cardiac infarcted tissue at a frequency of 150 MHz.

1. Introduction

The quantitative measurement of the acoustic properties of materials in microscopic scale is very important in the fields of polymer science, biological science, medical ultrasonics, nondestructive evaluation, etc.. An acoustic microscope is perhaps an only tool which is available for these purposes. Recently, a scanning laser acoustic microscope (SLAM) has been operated in the interference mode to detect the acoustic velocities in small area of the specimen, and the quantitative measurements of the acoustic velocities in biological tissues have been demonstrated by Goss et al. [1],[2]. In the scanning acoustic microscope (SAM) system [3], the combination system of plane-wave and focusing-wave transducers has been also developed to accomplish the interference mode operation by tilting the plane-wave transducer, so that the acoustic velocity distributions can be measured in the similar way [4],[5]. In the acoustic microscope system, a coherent plane-wave illumination is not always accepted favorably due to the following problems: (i) the uniform plane wave cannot easily generated, (ii) the effect of diffraction influences on the received signals much more than the confocal SAM system, (iii) the radiation power of the transmitted transducer cannot be effectively used.

In this paper, we describe a mechanism, newly introduced into a conventional scanning acoustic microscope, which vibrates the focusing transducer along the beam axis to vary periodically the distance between a pair of aligned focusing transducers. This mechanism and its operation are applicable to both the transmission mode and reflection mode. If used in the transmission mode, an interference microscope of a new type becomes available without the plane-wave illumination. The construction and the performance of the new SAM for interference-mode operation in a frequency range around 150 MHz are described. Experiments are performed with this SAM at 150 MHz to measure acoustic velocities for two kinds of polymer films, a polyester film and a PVF_2 film, and a dog's cardiac infarcted tissue.

2. Operation Principle

Figure 1 shows the configuration of acoustical parts in the new interference microscope. A pair of focusing transducers are confocally aligned along the beam axis and a specimen is placed around the focal plane in a coupling liquid. To produce the interferogram in this system, the distance between a transmitting and receiving transducers is varied periodically, and the specimen is syncronously scanned in the X direction. The output signal of the receiving transducer is electrically mixed with the reference signal and then interferogram can be shown on the CRT display by using the conventional electronic techniques, as the specimen is slowly displaced in the Y direction.
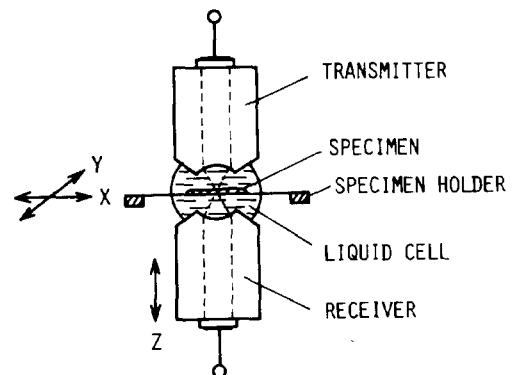

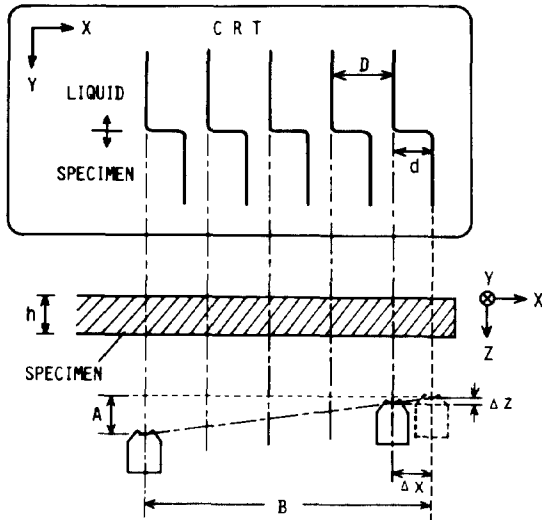Fig. 1. Basic configuration of the new interference microscope.

Fig. 2. Schematic diagram showing the relative
positions of the receiving transducer to the
specimen and their relation to the inter-
ference pattern displayed on CRT.

Figure 2 schematically depicts the relative
positions of the receiving transducer to the speci-
men and their relation in the interference pattern
displayed on the CRT.   The spacing of the fringe
lines depends on the acoustic velocity of the
coupling liquid, the acoustic frequency and the
ratio B/A, where A is the Z-vibrating width and B
is the X-scanning width.   When the specimen is
placed on a propagation path of an acoustic beam,
the fringe lines will shift to the right or left
depending on the acoustic velocity of the specimen.
The fringe lines in Fig.2 show the shift toward
right for the specimen with a velocity higher than
that of coupling liquid.

The spacing of the fringe lines D is given as
follows:

$$D=(B/A)\lambda_l=(B/A)\cdot(v_l/f),\qquad(1)$$

where λ_l and v_l are the acoustic wavelength and the
acoustic velocity, respectively, in the coupling
liquid, and f is the acoustic frequency.

The fringe shift d depends on the thickness h
of a specimen, the ratio B/A and the acoustic
velocity ratio v_l/v_s, where v_s is the acoustic
velocity in the specimen.   That is, d is given by
follows:

$$d=h(B/A)\cdot(1-v_l/v_s),\qquad(2)$$

From the equations (1) and (2), the acoustic velocity
v_s in the specimen is,

$$v_s=v_l/(1-d\lambda_l/Dh)=v_l/(1-N\lambda_l/h),\qquad(3)$$

where N is the normalized lateral fringe shift that
is defined as the ratio of the fringe shift d and
the fringe spacing D.   Therefore, if the acoustic
velocity of the coupling liquid and the thickness
of specimen are known and the fringe shift is
measured on the CRT as explained in Fig.2, the
acoustic velocity in the specimen v_s can be calcula-
ted by the equation (3).

3. Construction and Performance of the System

Figure 3 shows the block diagram of our system
of interference microscope.   In the system, the
differentiator is a newly introduced electrical
circuit for differentiating the video signals to
obtain the clear fringe lines that make the measure-
ment of the fringe shift easy.   The phase detector
is composed of a limiter amplifier and a double
balanced mixer, and the accuracy of phase detector
is measured to be better than 1 %, when the input
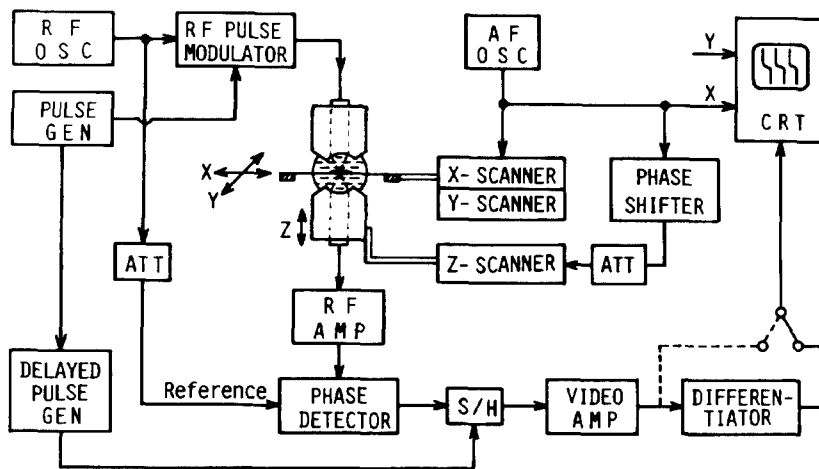dynamic range is kept within 30 dB.

Fig. 3. Block diagram of
the new acoustic
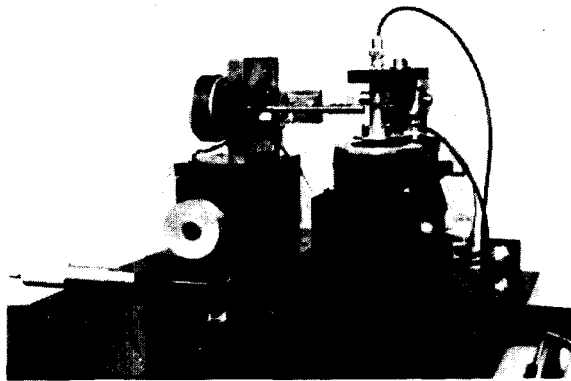interference micro-
scope system.

Fig. 4. Photograph of the mechanical part of the
system.

Figure 4 is a photograph of the mechanical
part of the system. A loudspeaker is employed to
scan the specimen in the X direction, and a commer-
cially obtained vibrator is employed to vibrate the
receiving transducer in the Z direction at a fre-
quency of 50 Hz, where the displacement of the
vibrator is detected by an accelerometer. The
driving signals for them are supplied in common from
an AF oscillator, and the phase of the Z-vibrating
signal is adjusted by the variable phase shifter,
to vibrate the receiving transducer syncronously in
the Z direction as the specimen is scanned in the
X direction. The spacing of interference fringe
lines can be varied by changing the vibrating width
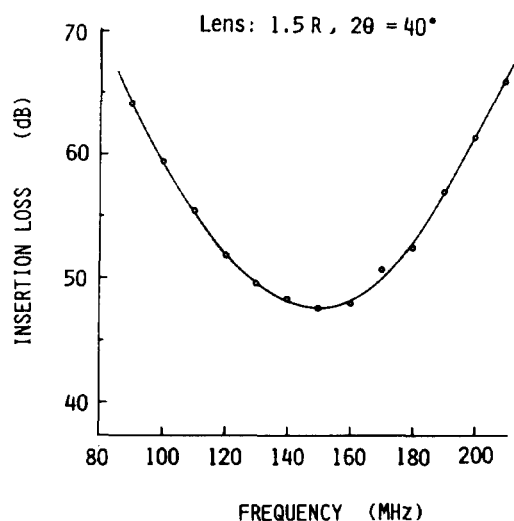in the Z direction.

Fig. 5. Frequency response of insertion loss at the
confocal arrangement (including the loss of
water ; about 15 dB at 150 MHz).

The focusing transducers employ ZnO pizoelec-
tric films formed on the flat end of acoustic sap-
phire lenses, of which the diameter is 1 mm and the
center frequency is about 150 MHz, and SiO_2 films
with the thickness of 9.96 μm are deposited onto the
concave surface of the lenses as an acoustic anti-
reflection coating (AARC) [6]. The radius of cur-
vature of the lens is 1.5 mm and the half aperture
angle of $\Theta=20°$ is determined to be smaller than that
of the conventional SAM system, so that the longer
depth of focus can be obtained. This could be pos-
sible to get a wide swing range in the Z direction.

Figure 5 shows a frequency response of the
insertion loss between the sending and receiving
transducers including the loss of water as a
coupling liquid, when both the transducers are
arranged confocally. The minimum insertion loss of
47 dB is obtained around 150 MHz. To examine the
allowable swing range in the Z direction, the output
signal of the receiving transducer is measured while
one of two transducers is relatively moved off along
the beam axis from the confocally arranged position
at a frequency of 150 MHz. In Fig.6, the variation
of the output signal is plotted with respect to the
Z axis. The -3 dB width of the curve is observed
to be 350 μm along the Z axis. So, our system can
take at least the swing range of 350 μm for the
vibration of the receiving transducer to obtain the
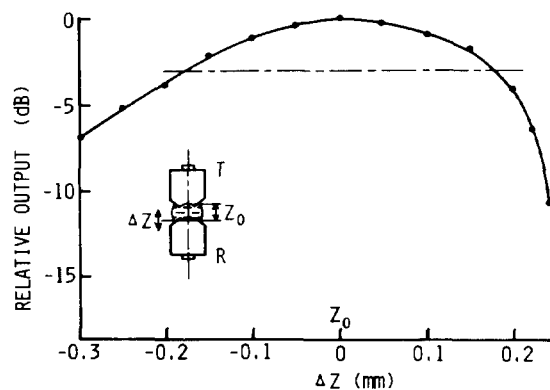clear interference patterns.

Fig. 6. Variation of receiving output with respect
to Z axis, when the receiving transducer
was moved from the confocally arranged
position at 150 MHz,

Next, we have observed the received output
signal when a stainless steel wire of 35 μm in
diameter has been scanned in the X direction on the
focal plane in water, in order to examine an influ-
ence to the acoustic wave diffraction. The varia-
tion of the output voltage along the X axis is shown
in Fig.7 (a). This is compared to that obtained in
the combination system of plane-wave and focusing-
wave transducers shown in Fig.7 (b). It can be
easily seen that the diffraction effect is almost
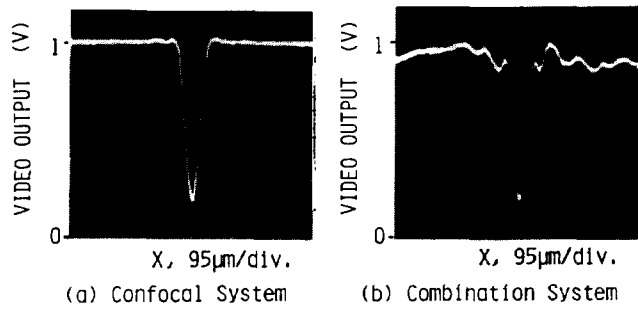removed in the case of confocal system.

(a) Confocal System   (b) Combination System

Fig. 7. Variation of receiving output voltage along
X axis, when a stainless steel wire of 35 μm
in diameter has been scanned in the X direc-
tion on the focal plane in water (a), and
that obtained by the combination system of
plane-wave and focusing-wave transducers
for comparison (b).

4. Experiments and Discussion

Various experiments for acoustic velocity
measurements have been performed with some polymer
films and biological tissues at a frequency of 150
MHz in water as a coupling liquid.

The interferograms observed for two kinds of
polymer films are shown in Fig.8. They show the
interferograms observed with a polyester film of
38 μm in thickness at the temperature of 24 °C in
(a) and with a polyvinylidene fluoride (PVF$_2$) film
of 30 μm in thickness at the temperature of 26 °C
in (b), respectively. The fringe lines shift
toward right in both figures at the water-specimen
boundary, since the specimens have velocities higher
than the velocity of water. The average acoustic
velocity of the polyester film is calculated to be
2310 m/s and that of PVF$_2$ film is calculated to be
2280 m/s by using Eq.(3) as the normalized fringe
shifts N being 1.35 and 1.03, respectively. In the
calculation, the data of velocity of the coupling
water reported by Greenspan et al. in Ref.7 are used.

As an example of biological tissue, an
interferogram observed at the temperature of 23 °C
with a dog's cardiac infarcted tissue of 50 μm in
average thickness is shown in Fig.9 (a) and its
optical image is shown in Fig.9 (b). The specimen
has been fixed by formalin at first, embeded by
paraffin to slice and the experiment is carried
out after removing the paraffin completely. The
average fringe shift observed at the boundary
between water and the tissue is measured to be 0.56
although the fringe shift is slightly meandered
depending on the tissue structure. So, the average
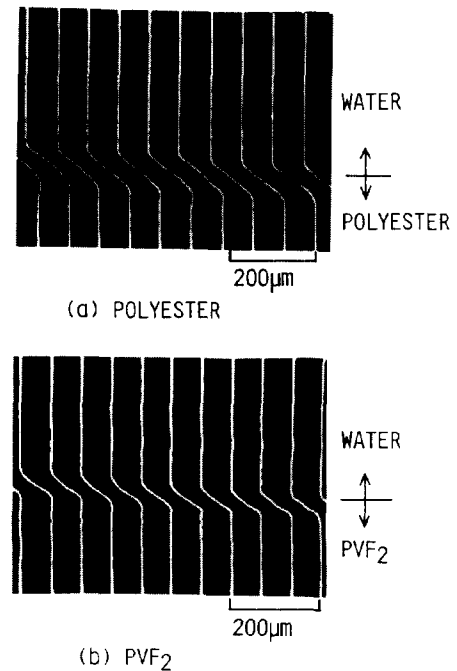velocity is determined to be 1680 m/s.

(a) POLYESTER

(b) PVF$_2$

Fig. 8. Acoustic interferograms obtained at 150 MHz
for polyester film of 38 μm thickness at
24 °C (a) and PVF$_2$ film of 30 μm thickness
at 26 °C (b).

(a) INTERFEROGRAM

(b) OPTICAL IMAGE
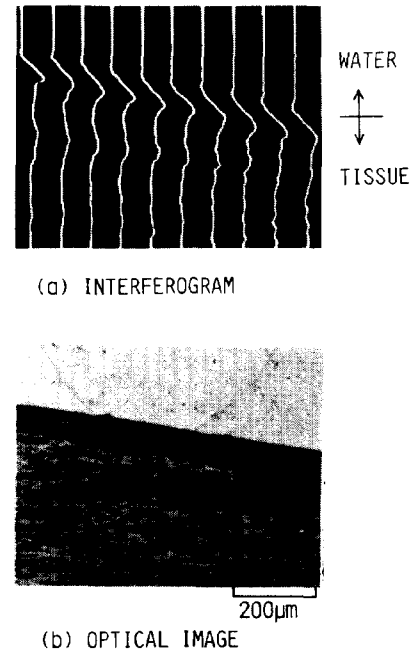
Fig. 9. Acoustic interferogram obtained at 150 MHz
for dog's cardiac infarcted tissue of
50 μm thickness at 23 °C (a) and its optical
image (b).

5. Conclusions

A new acoustic interference microscope has been proposed in this paper to measure acoustic velocities of thin materials quantitatively, in which one of the aligned focusing transducer is vibrated periodically along the beam axis. The construction and the performance of the SAM have been described. It has been shown that diffraction effects observed in the combination system of plane and focusing transducers were preferably eliminated by using the focusing transducer system, presented here. Experiments of velocity measurement have been further demonstrated with specimens such as polymer films and a biological tissue at a frequency of 150 MHz. This interference microscope system composed of focusing transducers is expected to be used widely as a very useful tool for tissue characterization, material characterization and nondestructive evaluation, because the system can be easily constructed by a slight modification of the conventional SAM system.

Acknowledgement

References

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