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Simulation of Scattering Acoustic Field in Rod and Identify of Ultrasonic Flaw Detecting Signal

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Abstract

A method of acoustic field simulating was proposed, in this paper, the authors simulated the scattering acoustic field generated by impulsive line source in a glass rod, and compared the results with the dynamic photoelastic experiments, explained the forming mechanism of the scattering wave (e.g. the boundary wave) of ultrasonic flaw detection in rod. Based on this, the serial echo signal of the flaw detection in rod by single transducer was identified, and a signal processing method was suggested. According to these, using single transducer, testing one time, lots of mechanical property could be analyzed.

Key words: simulation, scattering acoustic field, flaw detection, rod

1. Introduction

Rod is one of the most basic shapes of both raw material and industrial products, accordingly, study about the evaluation of mechanical properties and defect testing of a rod using ultrasonic is very significant. Lots of work had been done about the rod defect testing, but only a little portion of the signal received from the rod could be identified and used[1][2]. It is because that the pulse acoustic field in a rod is not very clearly to us, this paper means to improve this. Based on the numerical simulation and dynamic photoelstic experiment, the authors researched on the transient acoustic field and wave in an optic glass rod, analyzed the mechanism of the ultrasonic transmition in a rod, and then identified the signal received by the emitting transducer. Using the identified signal, the authors calculated the velocity of longitudinal wave, transverse wave and rayleigh wave in the rod, also did the elastic modulus of the rod.

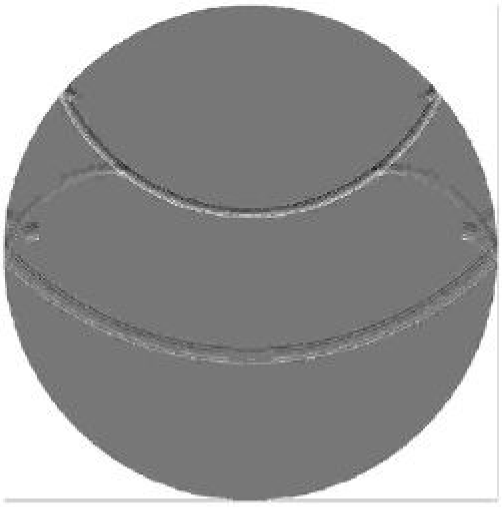
2. Numerical simulation of the acoustic field in rod and photoelastic experiment

While simulating the acoustic field, dealing with the medium that acoustic parameter and bound condition is already knew, the medium can be treated as a signal translating system. The input of it is emitting signal of the transducer, and the output is the acoustic field as a function of time and space. Then, the simulation of the acoustic field can be divided to two steps: first, got the impulse response of the system; second, do the time convolution with the impulse response and the input signal, and get the real acoustic field. Got the impulse response of the system using snell law and Huygens principle, i.e. the acoustic field of the emitting source is terminated at the scattering point, and the scattering point continued as a sub-source, the energy and direction of the sub-source are decided by snell law, and the entire acoustic field is all the source‘s field (emitting source and sub-source) adding together. Figure 1 is the comparison of the numerical simulation result and the dynamic photoelastic photo, in figure 1(b), R indicated to the rayleigh wave, T is the transverse wave, L is the longitudinal wave, and L-T is the reflected transverse wave from the longitudinal wave on the cylinder boundary.

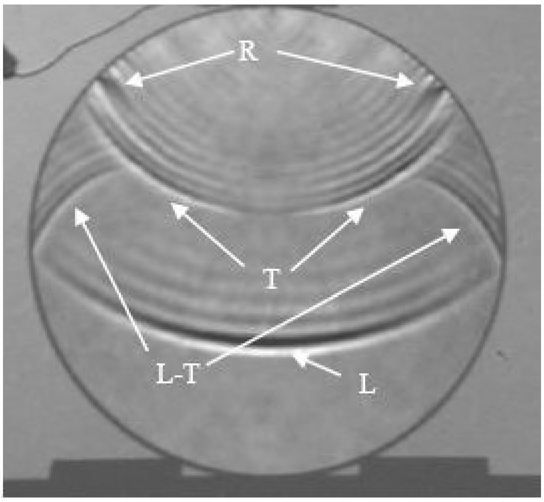
As showed in figure1, the result of the numerical simulation accorded well with the photoelastic photo, so we could explain the forming mechanism of the acoustic field as the addition of emitting source acoustic filed and the sub-source acoustic field.

3. Identification of ultrasonic echo signal of the defect testing in rod

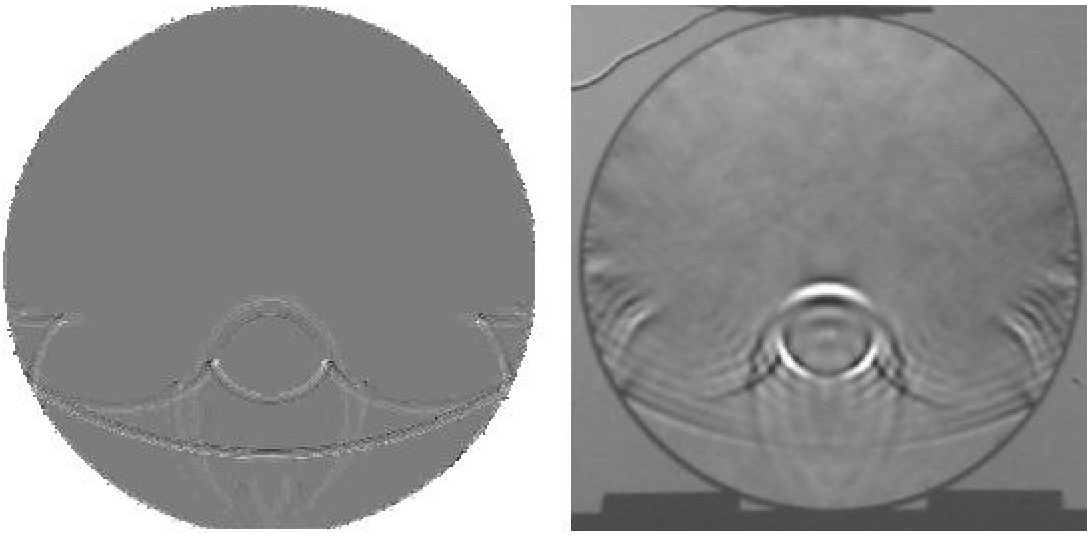
The rod in figure 1(b), its diameter is $80mm$, thickness is $40mm$. A longitudinal wave transducer is used in photoelastic experiment and flaw detecting, which frequency is $1.8MHz$, diameter is $20mm$. Figure 2 shows the signal received by that transducer in period from $0\mu s$ to $100\mu s$, in the figure, using number to index the wave packets that are going to be identified. We will identify the signal with the help of the photoelastic experiment and numerical simulation.



（a） numerical simulation result(t=10 μs)



(b)dynamic photoelastic photo(t=10 μs)



（c） numerical simulation result(t=19.6 μs) (d)dynamic photoelastic photo(t=19.6 μs)

Figure 1. comparison of numerical simulation and photoelastic photo

3.1 First bottom echo

Easy to know, in the figure 2, the wave packet 1 is the first bottom echo of the longitudinal wave, its transmitting distance and flight time can be expressed as formula (1):

$$\frac{4R}{C_l}+\tau=t_1=27.32 \tag{1}$$

And, R is the radii of the rod, unit is mm; C_l is the velocity of longitudinal in the rod, unit is $mm/\mu s$, τ is the delay of the system, unit is μs, t_1 is the first zero point of the wave packet 1, unit is μs。

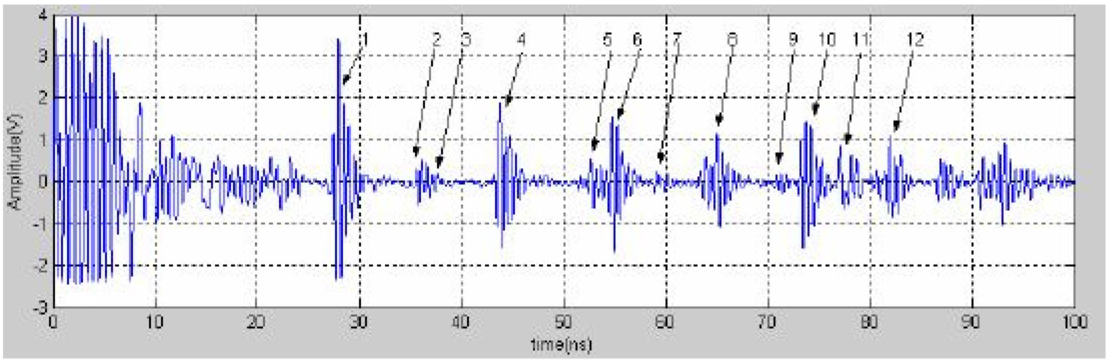


Figure 2. receiving signal and wave packet index

3.2 Equilateral triangle of the ultrasonic transmitting path:

In figure 2, the wave packet 2, its first zero point is $t_2=35.44\mu s$, the forming mechanism of it is shown in figure 3(a). The three arrows composing the equilateral triangle indicates the transmitting path of the longitudinal wave that came into being the wave packet 2. I.e. emitted from point A; at point B reflected to a longitudinal wave that transmitted along the horizontal line (in figure 3(a), Lt indicates the wave front of the reflect wave); then at point C, reflected to be a longitudinal wave transmitting in a symmetrical path with the emitting wave, and received by the transducer at t_2.

Similarly, in the photoelastic experiment we can observe the equilateral triangle transverse wave that transmits in the same path. It is show in figure3 (b), Tt indicates the wave front of the equilateral triangle transverse wave, that was going to return to the transducer. In figure 2, the equilateral triangle transverse wave corresponds to the wave packet 7, its first zero point is $t_7 = 58.99\mu s$. Because using a longitudinal wave transducer, the amplitude of wave packet 7 is smaller.

Dealing with the wave packet 2 and the wave packet 7 the same as the wave packet 1:

$$\frac{3\sqrt{3}R}{C_l} + \tau = t_2 = 35.44 \qquad (2)$$

$$\frac{3\sqrt{3}R}{C_t} + \tau = t_7 = 58.99 \qquad (7)$$

C_t is the velocity of transverse wave in the rod.

Comparing with the photoelastic experiment, we can obtain that in figure 2 the wave packet 3 is the transverse wave which is reflected by the emitting longitudinal wave on the bottom. For it is mixed with wave packet 2, we can’t get its first zero point, but still register it as convention:

$$\frac{2R}{C_t} + \frac{2R}{C_l} + \tau = t_3 \qquad (3)$$

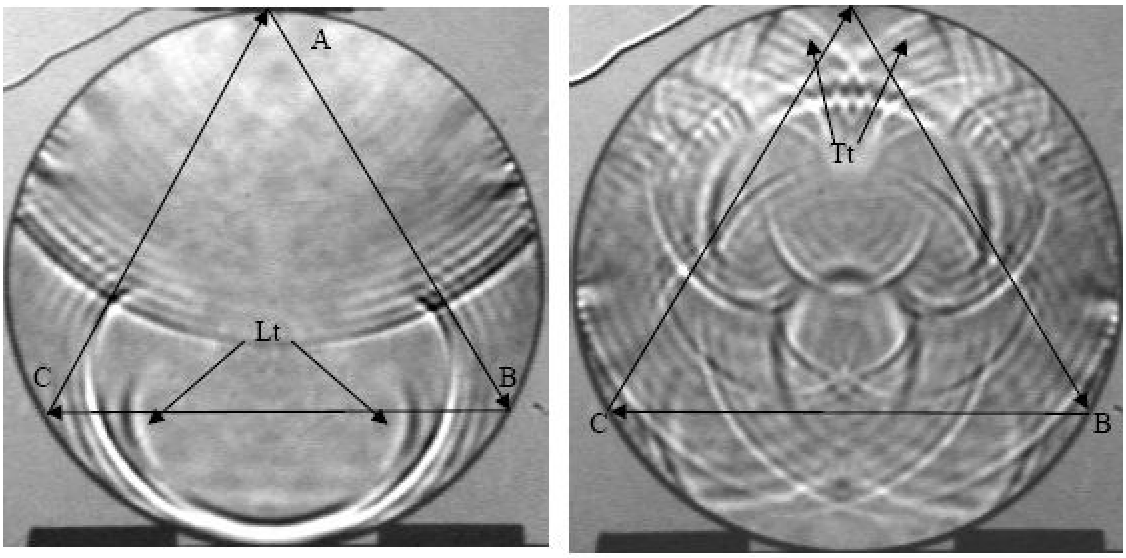
t_3 Is the first zero point of wave packet 3.

3.3 Isoceles triangle of the ultrasonic transmitting path:

In figure 2, the first zero point of the wave packet 4 is $t_4 = 43.62\mu s$, its transmitting path is shown in figure 4(a), AB: transmits with the velocity of longitudinal wave; BC: transmits with the velocity of transverse wave; CA: transmits with the velocity of longitudinal wave, and CA=AB. All the wave front that transmit in this three paths, no matter the entire path is AB->BC->CA, or BC->CA->AB or other else, the signal of them would be received by the transducer at time t_4. In figure 4 (a), $L-T$ indicates the wave front of the transverse wave reflected from the longitudinal wave.

Similarly, the transverse wave has a similar transmit path, shown in figure 4(b), $T-L$ indicates the wave front of the longitudinal wave reflected from the transverse wave.

The corresponding wave packet in figure2 is wave packet 5, its first zero point is $t_5 = 51.54\mu s$, because in this path, the transducer can receive some longitudinal wave, the amplitude of the wave packet 5 is bigger.



(a)longitudinal wave equilateral triangle (t=14.1 μs)

(b) transverse wave equilateral triangle (t=56.2 μs)

Figure 3 . the formation and receiving of equilateral triangle wave

According to the snell law, the wave packet 4 can be registered as:

$$\frac{4R\cos\theta_l}{C_l} + \frac{2R\sin(2\theta_l)}{C_t} + \tau = t_4 = 43.62, \qquad \frac{\sin\theta_l}{C_l} = \frac{\cos(2\theta_l)}{C_t} \tag{4}$$

θ_l is the longitudinal wave’s incident angle.

And the Isoceles triangle transverse wave is the same:

$$\frac{4R\cos\theta_t}{C_t} + \frac{2R\sin(2\theta_t)}{C_l} + \tau = t_5 = 51.54 \qquad \frac{\sin\theta_t}{C_t} = \frac{\cos(2\theta_t)}{C_l} \tag{5}$$

θ_t is the transverse wave’s incident angle.

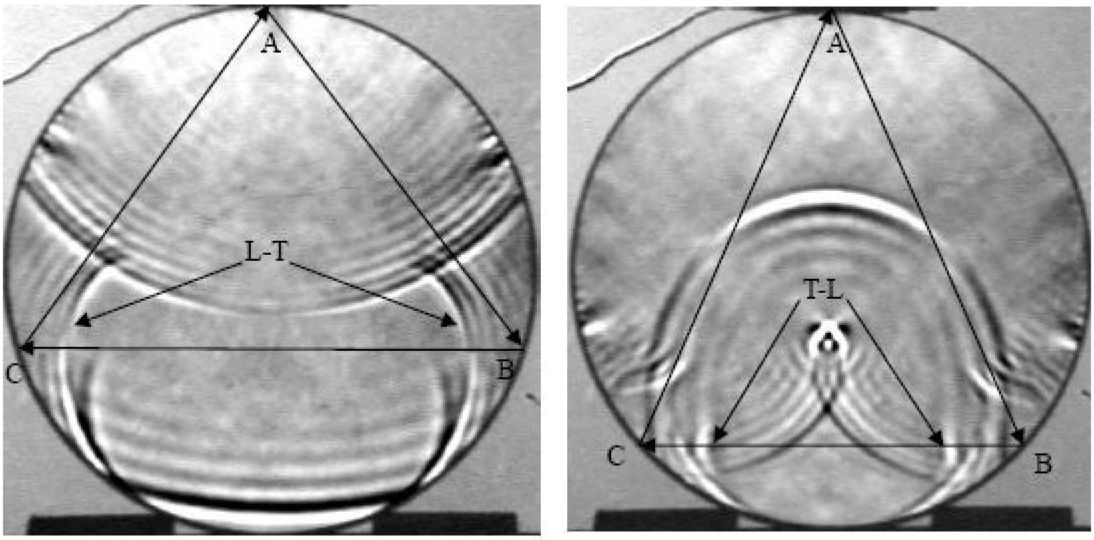
3.4 Others

The wave packet 6 in figure 2 is the second bottom echo longitudinal wave of the emitting longitudinal wave, its first zero points can’t be accurately measured for it’s compound with the wave packet 5, still register it as:

$$\frac{8R}{C_l} + \tau = t_6 \tag{6}$$

In figure 2 the wave packet 7 is identified before. The wave packet 8 is more complex, it included some bottom echo wave compounded with longitudinal wave and transverse wave, and a longitudinal wave with star-shape path, and a transverse wave with equilateral pentagon path, for all the wave signal mixed together, can't get accurate first zero time, it's not registered. The wave packet 9 is twice flight time of the longitudinal equilateral triangle wave, so registered as:

$$\frac{6\sqrt{3}R}{C_l} + \tau = t_9 = 70.72 \qquad (9)$$



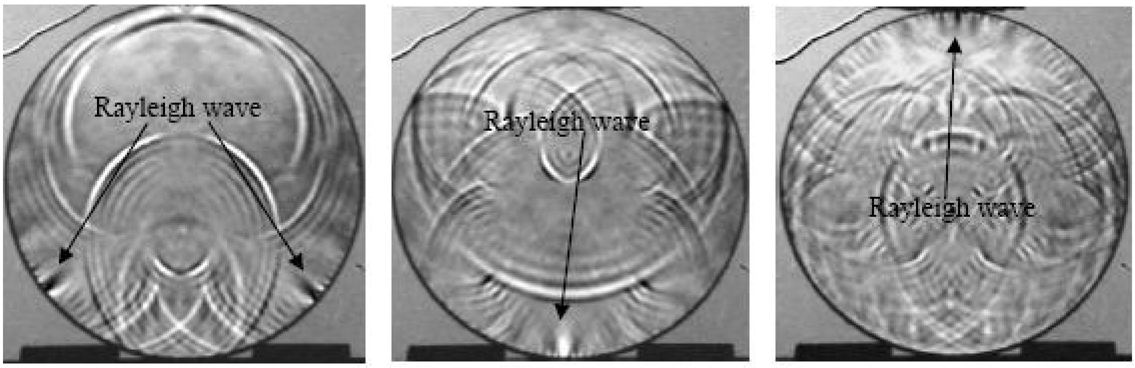
(a) longitudinal wave isoceles triangle

(t=13.1 μs)

(b) transverse wave isoceles triangle

(t=22.2 μs)

Figure 4. the formation and receiving of isoceles triangle wave



(a) not converge

(b) converged at the bottom

(c)converge at the transducer

Figure 5. photoelastic photo: the transmitting of rayleigh wave

The wave packet 10 and 12 are also compound wave packets, so they are not registered. The wave packet 11 is the rayleigh wave transmitted around the cylinder surface, it is useful in evaluating the surface quality, the first zero time of it is $t_{11} = 76.82$, registered as:

$$\frac{2\pi R}{C_R} + \tau = t_{11} = 76.82 \qquad (11)$$

C_R is the velocity of the rayleigh wave，figure 5 shows the transmitting of the rayleigh wave.

The signal in figure2 is from optic glass rod, the position of the wave packets at the time axis is determined by the ratio between the velocity of longitudinal wave and transverse waver. In different material, that may be different, but if we can get some wave packets' first zero point, using the formula (1)(2)(3)(4)(5)(6)(7)(9)(11) , the corresponding velocity can be measured. Accordingly, for different material, creating the signal models like the signal shown in figure 2, it is helpful for the ultrasonic NDE of the rods.

4 Experiments and elastic modulus calculation

In homogeneous material, the elastic modulus can be calculated using these formulas [3]:

The shear modulus: $G = \rho C_t^{\,2}$; The Young's modulus: $E = \rho C_t^{\,2}\dfrac{3C_l^2 - 4C_t^2}{C_l^2 - C_t^2}$;

The bulk modulus: $K = \rho C_l^{\,2} - \dfrac{4}{3}\rho C_t^2$; The poisson's ratio: $\sigma = \dfrac{1}{2}\dfrac{C_l^{\,2} - 2C_t^2}{C_l^{\,2} - C_t^2}$.

ρ is the density of the material. The experiment results are shown in figure 6, table1 and table 2.

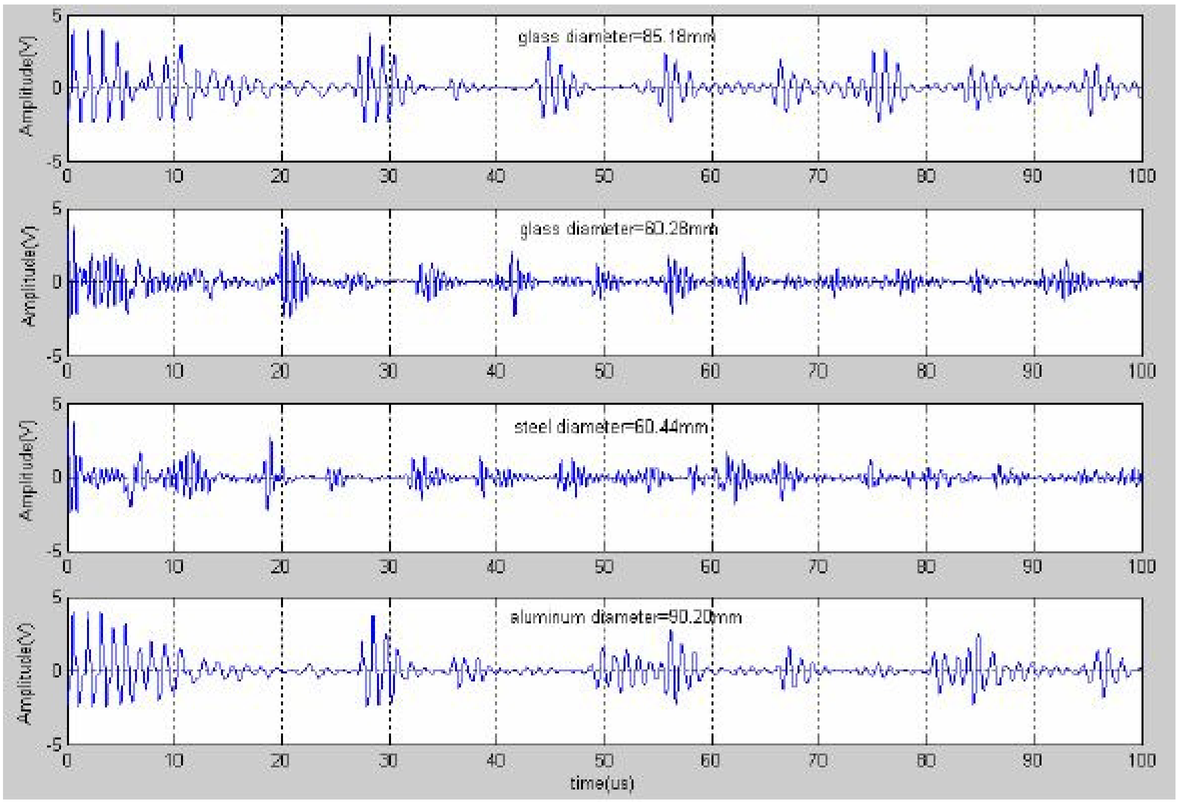


Figure 6. receiving signal in the experiments

Table1 experiment data (in the table “/” means can’t get accurate first zero point.)

material	Diameter (mm)	t_1 (μs)	t_2 (μs)	t_3 (μs)	t_4 (μs)	t_5 (μs)	t_6 (μs)	t_7 (μs)	t_9 (μs)	t_{11} (μs)
Glass1	80.18	27.32	35.44	/	43.62	55.48	/	58.99	70.72	76.82
Glass2	60.28	20.01	25.91	/	32.74	39.83	41.23	45.32	/	60.23
Steel	60.44	18.82	24.12	/	32.09	40.01	38.30	/	/	57.76
Aluminum	90.20	28.33	36.82	42.50	49.56	66.92	55.93	/	73.16	95.57

Table 2 calculation of velocity an elastic modulus

material	diameter (mm)	C_l (m/s)	C_t (m/s)	C_R (m/s)	τ (μs)	ρ (g/cm^3)	G $(10^{10} N/m^2)$	E $(10^{10} N/m^2)$
Glass1	80.18	5905	3531	3286	0.16	2.423	3.021	7.381
Glass2	60.28	5681	3366	3082	-1.21	2.423	2.745	6.751
Steel	60.44	6205	3384	3250	-0.66	7.905	9.052	23.33
Aluminum	90.20	6406	3225	2965	0.84	2.800	2.912	7.748

5 Conclusions

Using numerical simulation and dynamic photoelstic experiment, the authors explained the forming mechanism of the pulse acoustic field in rods; and created signal models and velocity calculating formulas for rods, in the situation that uses single longitudinal wave transducer. Then the velocity of different type ultrasonic wave and the elastic modulus of different materials were measured, so using only one transducer, the mechanical property of rods could be analyzed completely.

Reference:

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[2] ML-T-9047G Titanium and Titanium Alloy Bars (Rolled or Forged) and Reforging Stock, Aircraft Quality

[3] Chen Yifang, Zhang Jiajun. A Research on Testing Elastic Moduli of Workpiece Materials. Proceedings

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