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INFLUENCE OF THE ELECTICAL PARAMETERS ON THE ULTRASONIC PROBE IMPEDANCE AND THE REFLECTED PULSES

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Basing on the modified Mason's equivalent circuit of an ultrasonic transmitting-receiving probe [3], [4] the influence of compensating inductances, a coaxial cable, wire conductors and parallel resistance on the probe immitance and the reflected pulses is discussed.

The influence of the wire conductors connecting a transducer with a coil or a coaxial connector for large diameters (i.e. 20 mm) and high frequencies (i.e. 10 MHz) on the probe immitance should be taken into account.

The influence of the coaxial cable on the probe immitance and the reflected pulses depends on the electrical impedance of a probe.

The compensating circuit containing three inductances — two in series and one parallel is discussed.

The influence of the parallel resistance on the reflected pulse is shown and compared with the influence of transducer backing.

It was shown that the length of transmitting burst should be chosen depending on the frequency band-width of the probe.

1. Introduction

The design principles of transducers with matching layers was described in the previous paper [5]. In this work the influence of electrical parameters: compensating inductances, a coaxial cable, wire conectors, a parallel resistance and input impedances of a transmitter and a receiver on the reflected pulse is discussed.

Calculations are carried out, modified Mason's model described in [4] being assumed (Fig. 1). Because in this paper only the PZT ceramic transducers are discussed, the mechanical and dielectrical losses can be neglected. All quantities are **relative** (dimensionless).

- frequency $x = \Pi f / f_m$,
- mechanical impedance of the investigated medium $R_b = R_B / R_p$,
- mechanical impedances of the matching layers $R_{01} = R_1 / R_p$,
  $R_{02} = R_2 / R_p$,

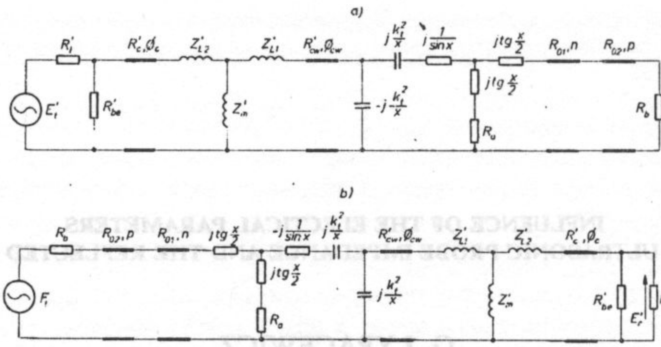


Fig. 1. Equivalent circuit of the transmitting (a) and receiving (b) probe circuit (parameters described in the paper).

- electrical impedance of the transmitter $R_t' = R_t / Z_E$,
- electrical impedance of the receiver $R_r' = R_r / Z_E$,
- characteristic resistances of the cables:

$$R_c' = R_c / Z_E \text{ (coaxial cable)},$$
$$R_{cw}' = R_{cw} / Z_E \text{ (wire connectors)},$$

- impedance of the parallel resistance $R_{be}' = R_{be} / Z_E$,
- reactance of the inductances $Z_m' = k_t^2\, x / \Pi^2 m^2$ (parallel)

$$Z_{L1}' = k_t^2\, x\, L_1^2 / \Pi^2$$
$$Z_{L2}' = k_t^2\, x\, L_2^2 / \Pi^2 \text{ (in series)},$$

- thickness of the matching layers $n = d_{01} / \lambda_{e01}$,

$$p = d_{02} / \lambda_{e02},$$

- length of the cables $\Phi_{cw} = l_{cw} / \lambda_{el}$,

$$\Phi_c = l_c / \lambda_{el}$$

- voltage of the transmitter output $E_t' = E_t / N$,
- amplitude of the pulse reflected from an ideal reflector

$$E_r' = E_r / E_t,$$

- mechanical force in the investigated medium F_t,
- transmitting-receiving transfer function H (assuming the pulse reflection from the ideal reflector).

Here:

$Z_E = 1/\mathrm{Real}\,[Y_p(f_e)]$ — the electrical probe impedance.

$N^2 = 2k^2 f_m C_0 R_p$ — turns ratio of the electromechanical transformer E_t — voltage of the transmitter (on the electrical side of the electromechanical transformer), f_m — mechanical resonance frequency, f_e — electrical resonance frequency (for f_e the imaginary part of mechanical impedance of a loaded transducer is equal to 0 [4]), A — transducer area, $R_p = A\rho_p c_p$, $R_B = A\rho_b c_b$, $R_A = A\rho_a c_a$, $R_{01} = A\rho_{01} c_{01}$, $R_{02} = A\rho_{02} c_{02}$ — mechanical impedances of the transducer, investigated medium, back loading and two matching layers, respectively, λ_{e01}, λ_{e02} — acoustic wavelengths in the matching layers, d_{01}, d_{02} — thickness of the matching layers, C_0 — clamped capacitance of the transducer, m, L_1, L_2 — parameters of inductances:

parallel and in series, k_t — electromechanical coupling coefficient for the thickness vibration, $Y_p(f_e)$ — electrical admittance of the probe (without inductances and cables), R_{cw}, R_c — characteristic resistances of the wire connectors and the coaxial cable, R_{be} — parallel resistance, λ_{emcw}, λ_{emc} — electromagnetic wavelenghts in the wire connectors and in the coaxial cable, l_{cw}, l_c — length of the wire connectors and the coaxial cable.

As one can see all quantities describing the probe are dimensionless — the frequency is related to mechanical resonance frequency, the mechanical impedances are related to the transducer mechanical impedance, the electrical impedances are related to the electrical impedance of the probe for the electrical resonance frequency (calculated for the probe without cables and inductances), the thicknesses of matching layers are related to the acoustical wavelength, the lengths of cables are related to the electromagnetic wavelength and the reflected pulse amplitude is related to the transsmitting pulse amplitude.

2. Coaxial cable, wire connectors

For the ultrasonic medical diagnosis transducers of 3 – 50 mm diameter operating at 2 – 20 MHz are used. The probe impedance (defined as $Z_E = 1/\text{Real}[Y_p(f_e)]$ depends on the transducer dimensions (the thickness and the diameter), on the piezoelectric material parameters (see Table 1), on the acoustic load of the transducer (an investigated medium, a back loading, matching layers) (Figs. 2, 3) and on the compensating circuit (see Sec. 3).

Table 1.

Piezoelectric material	Density $\times 10^3 kg/m^3$	Acoustic impedance $\times 10^6 kg/m^2s$	Relative dielectric constant ε_r	Electromech. coupling coefficient k_t
quartz	2.65	15.1	4.6	0.09
PZT 5A	7.75	33.7	830	0.49
$BaTiO_3$	5.7	31.2	1260	0.38
$LiNbO_3$	4.65	34.2	30	0.49

Ultrasonic probes for the medical diagnostic application are made usually of the PZT material. As it is shown in Fig. 3, electrical impedances of the probe of a large diameter and a high frequency are equal to single ohms. In these cases, although the cable length is much smaller than the electromagnetic wavelength the influence of the cable on the impedance and transfer function of transmitting-receiving circuit is great, and therefore the cable should be taken into account and be treated as a long line.

Let us consider the influence of the cable, at different ratios of the cable characteristic resistance to the probe electrical impedance Z_E, on the probe admit-

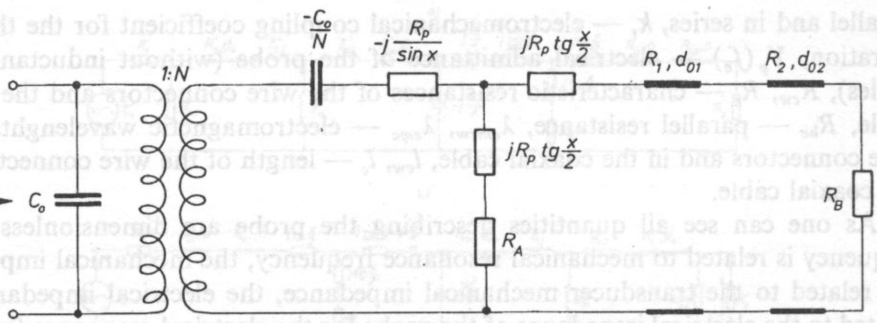


Fig. 2 Equivalent circuit of a transducer loaded acoustically throught matching layers with an investigated medium impedance $R_B = A\rho_b c_b$ and with a back load $R_A = A\rho_a c_a$.

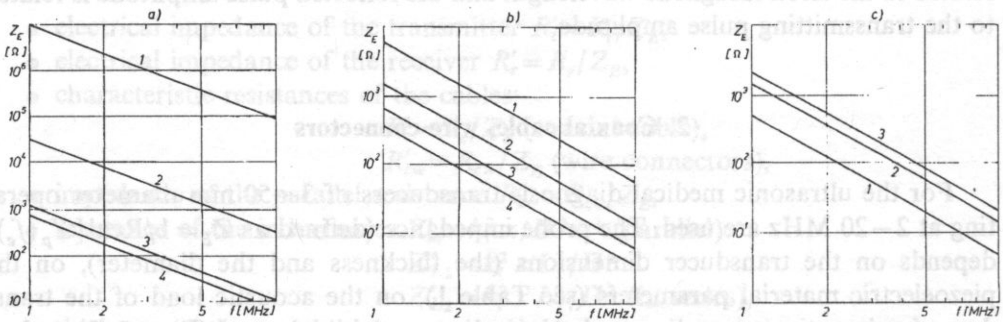


Fig. 3 Electric impedances Z_E of piezoelectric transducers calculated according to a circuit in Fig. 2 in the frequency function $\rho_b c_b = 1.5\ 10^6$ kg/m²s, $\rho_a c_a = 3.2\ 10^6$ kg/m⁶s, a transducer piezoelectric material — PZT 5A (excluding 3a), a transducer diameter equal to 10 mm (excluding 3b), one matching layer — $d_{01} = \lambda_{e01}/4$, $\rho_{01}c_{01}$ (and $\rho_{02}c_{02}$ — in Fig. 3c) calculated according DeSilets formula
a — different piezoelectric materials: 1 — quartz, 2 — $LiNbO_3$, 3 — $BaTiO_3$, 4 — PZT 5A
b — different transducer diameters: 1 — 5 mm, 2 — 10 mm, 3 — 15 mm, 4 — 20 mm
c — a different number of layers: 1 — without a layer, 2 — one layer, 3 — two layers

tance characteristics and on the reflected pulses. To neglect the influence of other probe parameters, the length of the cable, the PZT material, one matching layer calculated according DeSilets [7], the back loading, the parallel inductance compensating a clamped capacitance C_0, are assumed to be the same.

In Fig. 4 the influence of the length of short ($\Phi_c = 0.02$ or 0.05) cables matched to the probe impedance ($R_c' = 1$) on the circuit parameters is shown. As one can see, changes of admittances, transfer functions and reflected pulses in comparison with the values for a probe without a cable can be neglected, although for a longer cable ($\Phi_c = 0.05$ corresponds, for example, to a 3 m cable for 5 MHz or 1.5 MHz for 10 MHz) the changes of the admittance and the transfer function are noticeable.

If the probe impedance is large (i.e. $R_c' = 0.05$) the cable can be treated as a capacitance and should be compensated by a parallel inductance larger than for a probe without a cable (Fig. 5). Comparing the results for such a compensated

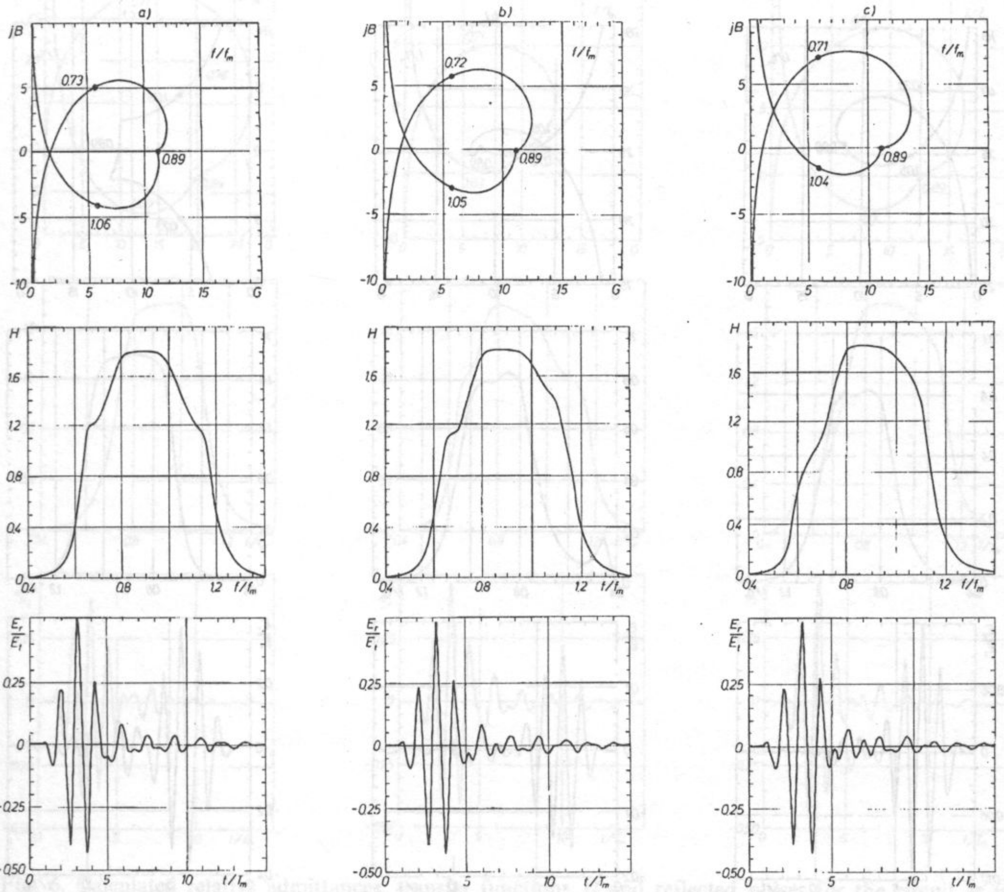


Fig. 4. Calculated relative admittances for PZT transducers radiated into water ($k_t = 0.5$, $R_b = 0.044$) through a matching layer ($R_{01} = 0.125$, $n = 0.25$), without a back load ($R_a = 0$), with a parallel inductance ($m = 0.865$), their transfer functions H and reflected pulses ($R'_t = 0.01$, $R'_r = 10$, a transmitting pulse is a half-period of sine of 0.89 frequency)

a — without a cable

with cables matched to the probe impedance ($R'_c = 1$) of a different length: b — $\Phi_c = 0.02$, $c = \Phi_c = 0.05$.

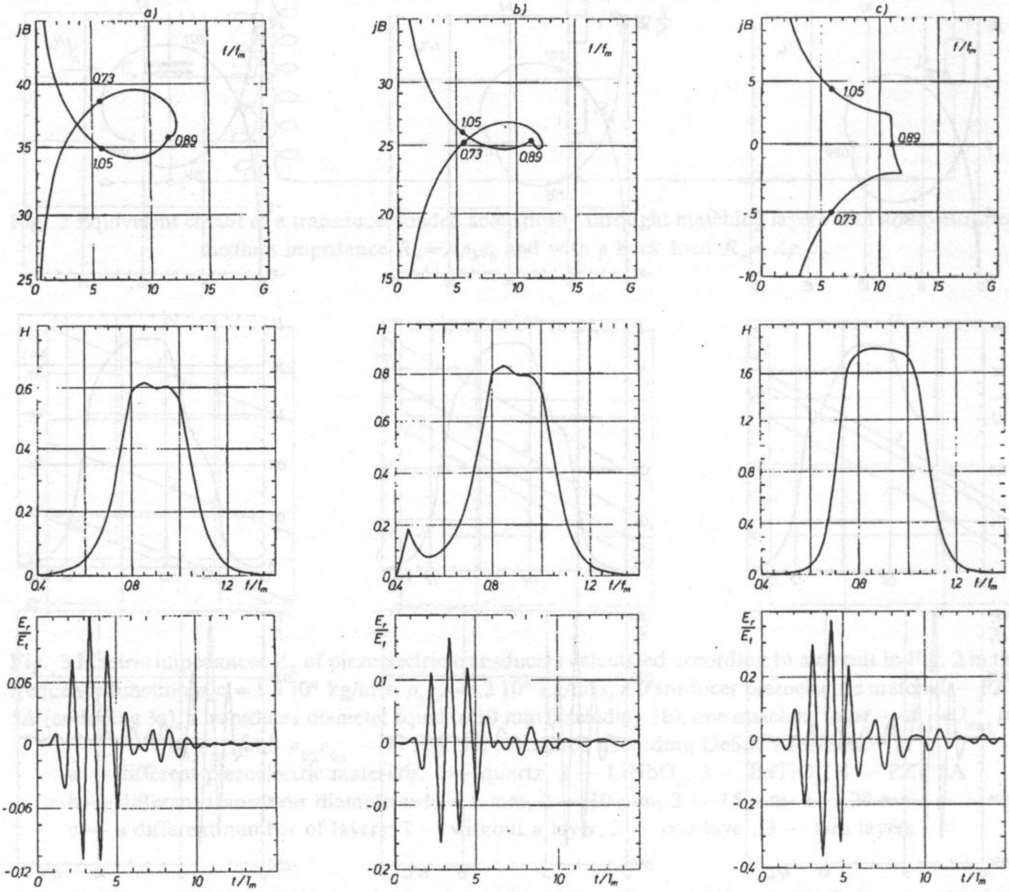


Fig. 5. Calculated relative admittances, transfer functions H and reflected pulses for the circuit as in Fig. 4, with a cable of a characteristic resistance less than a probe impedance ($\Phi_c = 0.02$, $R'_c = 0.05$) with different parallel inductances: a $-$ $m = 0$ (without a coil), $b - m = 0.865$, $c - m = 1.59$.

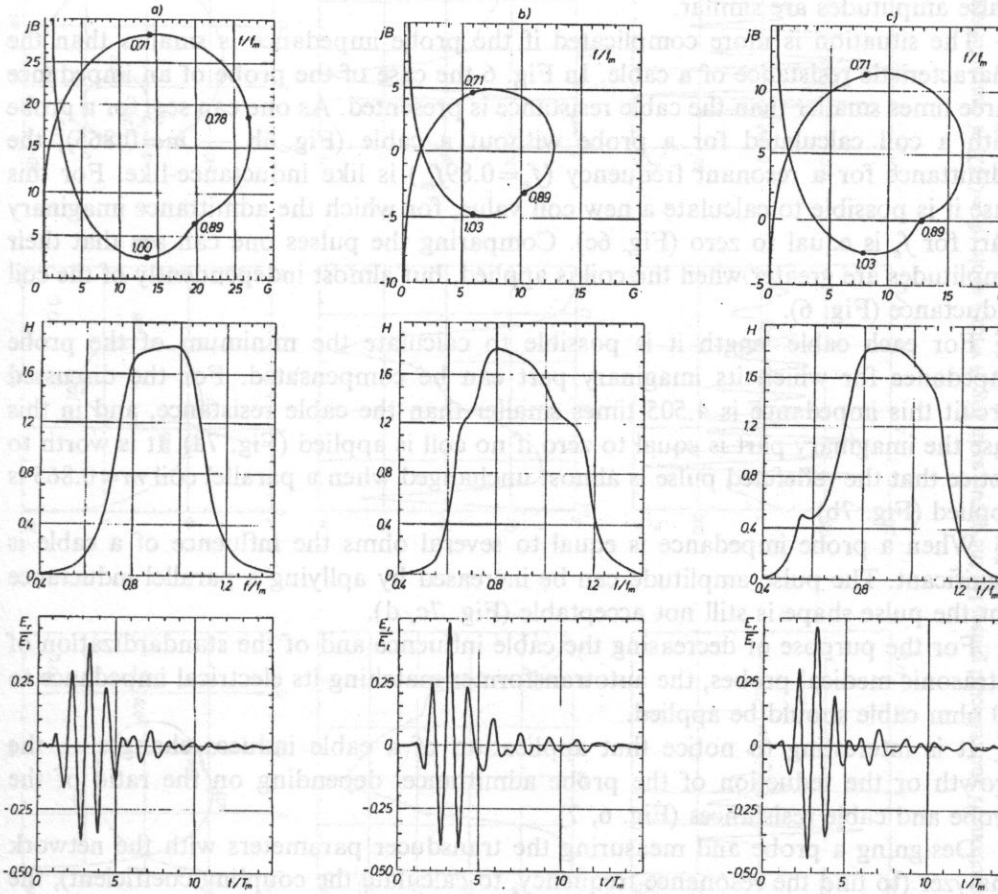


Fig. 6. Calculated relative admittances, transfer functions H and reflected pulses for the circuit as in Fig. 4, with a cable of a characteristic resistance greater than a probe impedance ($\Phi_c = 0.02$, $R'_c = 3$) with different parallel inductances: a $-$ $m = 0$ (without a coil), b $-$ $m = 0.865$, c $-$ $m = 0.689$.

probe with the results for a probe without any cable (Figs. 5c and 4a), one can see noticeable differences in admittances, transfer functions and pulse shapes, but the pulse amplitudes are similar.

The situation is more complicated if the probe impedance is smaller than the characteristic resistance of a cable. In Fig. 6 the case of the probe of an impedance three times smaller than the cable resistance is presented. As one can see, for a probe with a coil calculated for a probe without a cable (Fig. 6b — $m=0.865$), the admittance for a resonant frequency ($f_e=0.89f_m$) is like inductance-like. For this case it is possible to calculate a new coil value, for which the admittance imaginary part for f_e is equal to zero (Fig. 6c). Comparing the pulses one can see that their amplitudes are greater when the coil is applied, but almost independently of the coil inductance (Fig. 6).

For each cable length it is possible to calculate the minimum of the probe impedance for which its imaginary part can be compensated. For the discussed circuit this impedance is 4.505 times smaller than the cable resistance, and in this case the imaginary part is equal to zero if no coil is applied (Fig. 7a). It is worth to notice that the reflefcted pulse is almost unchanged when a parallel coil $m=0.865$ is applied (Fig. 7b).

When a probe impedance is equal to several ohms the influence of a cable is significant. The pulse amplitude can be increased by apllying a parallel inductance but the pulse shape is still not acceptable (Fig. 7c, d).

For the purpose of decreasing the cable influence and of the standardization of ultrasonic medical probes, the autotransformer matching its electrical impedance to 50 ohm cable should be applied.

It is interesting to notice that application of a cable induces changes — the growth or the reduction of the probe admittance, depending on the ratio of the probe and cable resistances (Fig. 6, 7).

Designing a probe and measuring the transducer parameters with the network analyzer (to find the resonance frequency, to calculate the coupling coefficient), the influence of the wire connectors on the probe parameters should be taken into account. Although the connectors are very short they should be treated as a long line of the characteristic impedance equal to 300 ohms. This influence is of course dependent on the probe impedance which is a function of the transducer loading (a back load, matching layers, investigated medium). In Figs. 8a the calculated admittances of the PZT transducer of 20 mm dia, 10 MHz, loaded symmetrically with a perspex (applied usually to measure the transducr parameters) are shown. The electrical resonance and quadrant frequencies are remarkably changed when connectors are used. It means that on the basis of admittance measurements of low ohm (large diameters, high frequencies) transducers finding the electrical resonance frequency and coupling coefficient k_t [1], [6] is imposible.

In Fig. 8b the admittances of the same transducer with one matching layer (used, for instance, for the eye examinations) with and without wire connectors are shown. The changes of admittance due to the connectors are different than for the probe

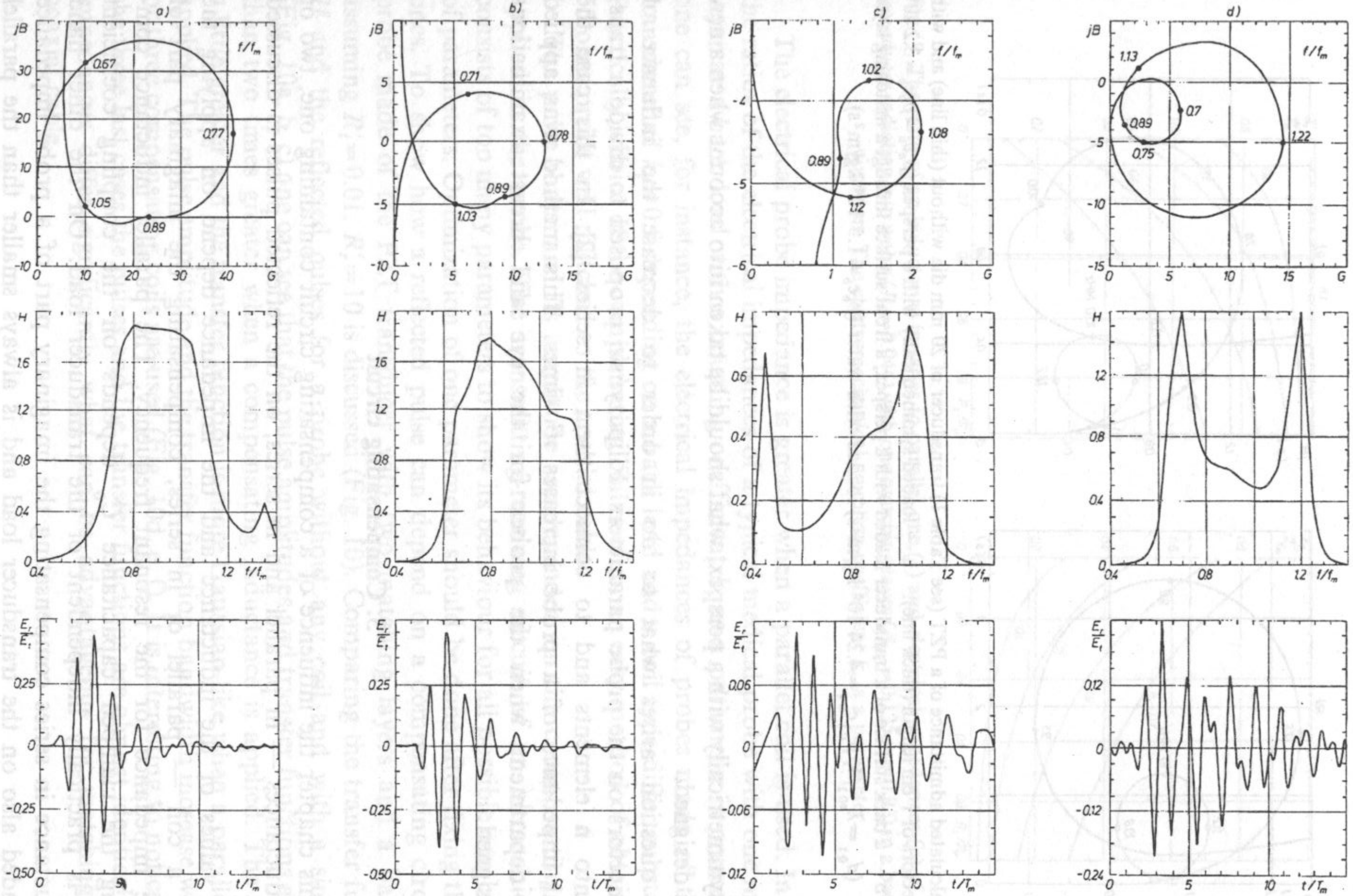


Fig. 7. Calculated relative admittances, transfer functions H and reflected pulses for the circuit as in Fig. 4 with a cable ($\Phi_c=0.02$) of characteristic resistance much greater than a probe impedance, without and with a parallel inductances: a – $R'_c=4.505, m=0$ b – $R'_c=4.505, m=0.865$, c – $R'_c=25, m=0$ d – $R'_c=25, m=0.865$.

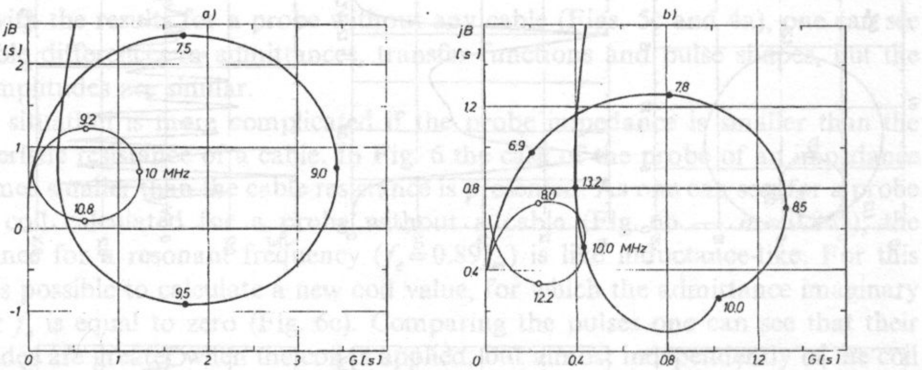


Fig. 8. Calculated admittance of a PZT (see Table 1) transducer of 20 mm dia without (thin line) and with wire connectors of 1 cm length (thick line): a — loaded symmetrically with a perspex ($\rho_a c_a = \rho_b c_b = 3.2\ 10^6$ kg/m²s) b — a back surface of a transducer loaded with a perspex, a front surface througt a matching layer ($d_{01} = \lambda_{e01}/4$, $\rho_{01} c_{01} = 4.24\ 10^6$ kg/m²s) loaded with water ($\rho_b c_b = 1.5\ 10^6$ kg/m²s).

loaded symmetrically with a perspex, what should be taken into account when a new probe is designed.

The question arises what to do in order to decrease the influence of the connectors on the probe parameters. Filipczyński proposed to divide a transducer into **n** elements and to connect them in series [2]. In this case the electrical impedance of a probe increases n^2 times. This method was applied in our department when the probes for the eye and breast examinations were designed.

3. Compensating circuit

In this chapter the influence of a compensating circuit containing one, two or three inductances — in parallel and in series, on the reflected pulses is discussed (Fig. 1).

The values of the inductance and the impedance depend on applying the type of a coil — parallel or in series, compensating the imaginary part of a probe impedance for the resonant frequency. The parallel inductance compensating the clamped capacitance C_0 depends on the coupling coefficient k_t, but is practically independent of the transducer load. On the other hand the inductance in series compensating the imaginary part of a probe impedance is depended also on the transducer load and is always smaller than the parallel one (Fig. 9a).

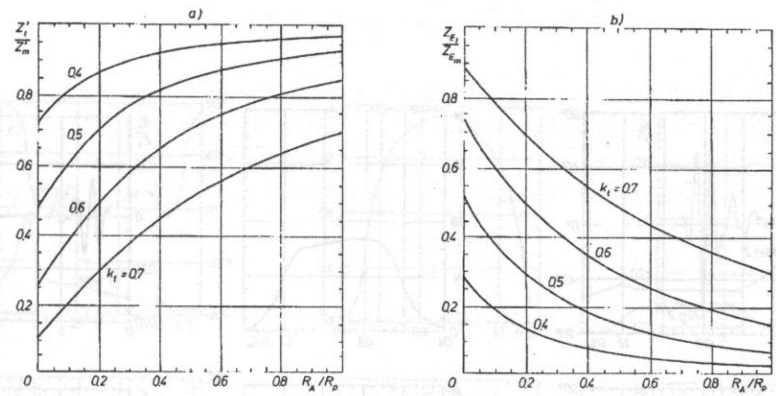
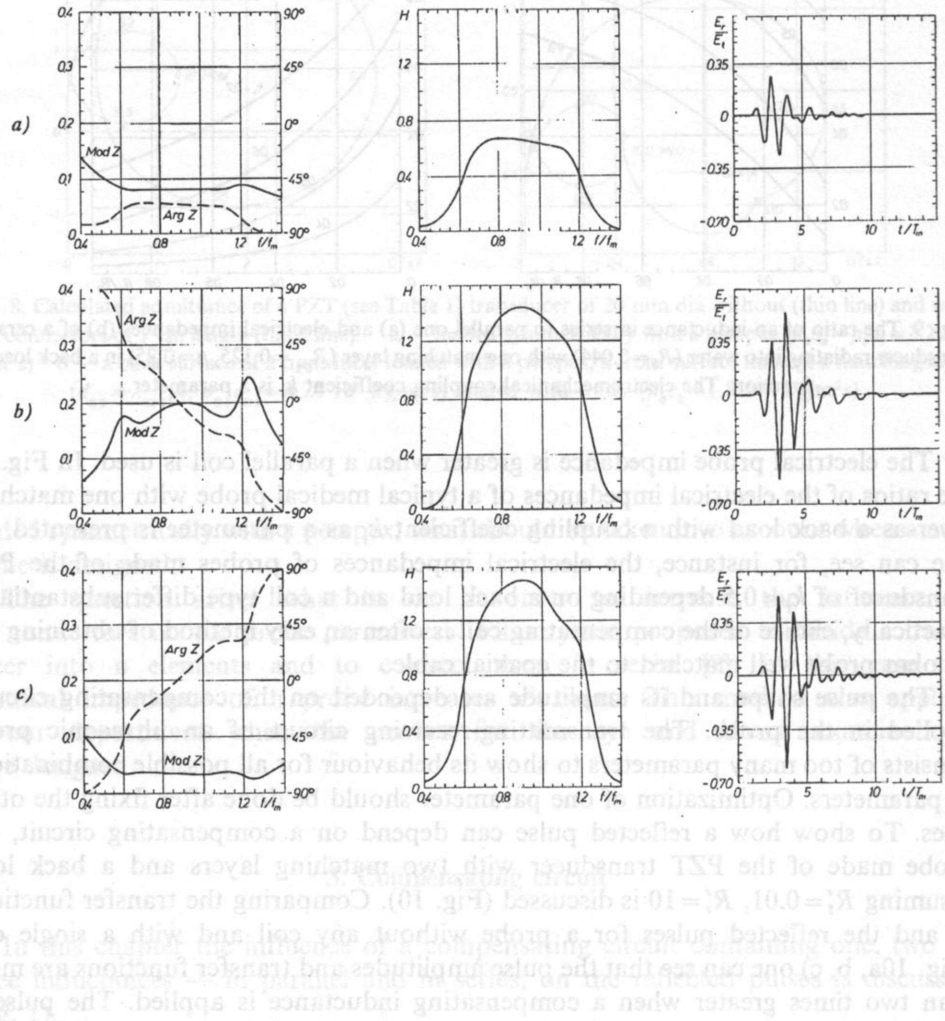


Fig. 9. The ratio of an inductance in series to parallel one (a) and electrical impedances (b) of a ceramic transducer radiating into water ($R_b = 0.044$) with one matching layer ($R_{01} = 0.125$, $n = 0.25$) in a back load R_a function. The electromechanical coupling coefficient k_t is a parameter.

The electrical probe impedance is greater when a parallel coil is used. In Fig. 9b the ratios of the electrical impedances of a typical medical probe with one matching layer as a back load with a coupling coefficient k_t as a parameter is presented. As one can see, for instance, the electrical impedances of probes made of the PZT transducer of $k_t = 0.5$ depending on a back load and a coil type differ substantially. Practically, choice of the compensating coil is often an easy method of obtaining the 50 ohm probe well matched to the coaxial cable.

The pulse shape and its amplitude are depended on the compensating circuits applied in the probe. The transmitting-receiving circuit of an ultrasonic probe consists of too many parameters to show its behaviour for all possible combinations of parameters. Optimization of one parameter should be done after fixing the other ones. To show how a reflected pulse can depend on a compensating circuit, the probe made of the PZT transducer with two matching layers and a back load assuming $R_t' = 0.01$, $R_r' = 10$ is discussed (Fig. 10). Comparing the transfer functions H and the reflected pulses for a probe without any coil and with a single one (Fig. 10a, b, c) one can see that the pulse amplitudes and transfer functions are more than two times greater when a compensating inductance is applied. The pulse is a little greater and the transfer function is more Gaussian-like when a parallel coil is applied. The pulse amplitude and the transfer function bandwidth increase when two or three compensating coils are used (Fig. 10d, e, f). It is interesting to notice that in the three last cases the pulses and the transfer functions are almost identical but the impedances differ significantly what can be advantageous for matching to the coaxial cable.



a)
b)
c)
Mod Z
Arg Z
H
E_r/E_i
f/f_m
t/T_m

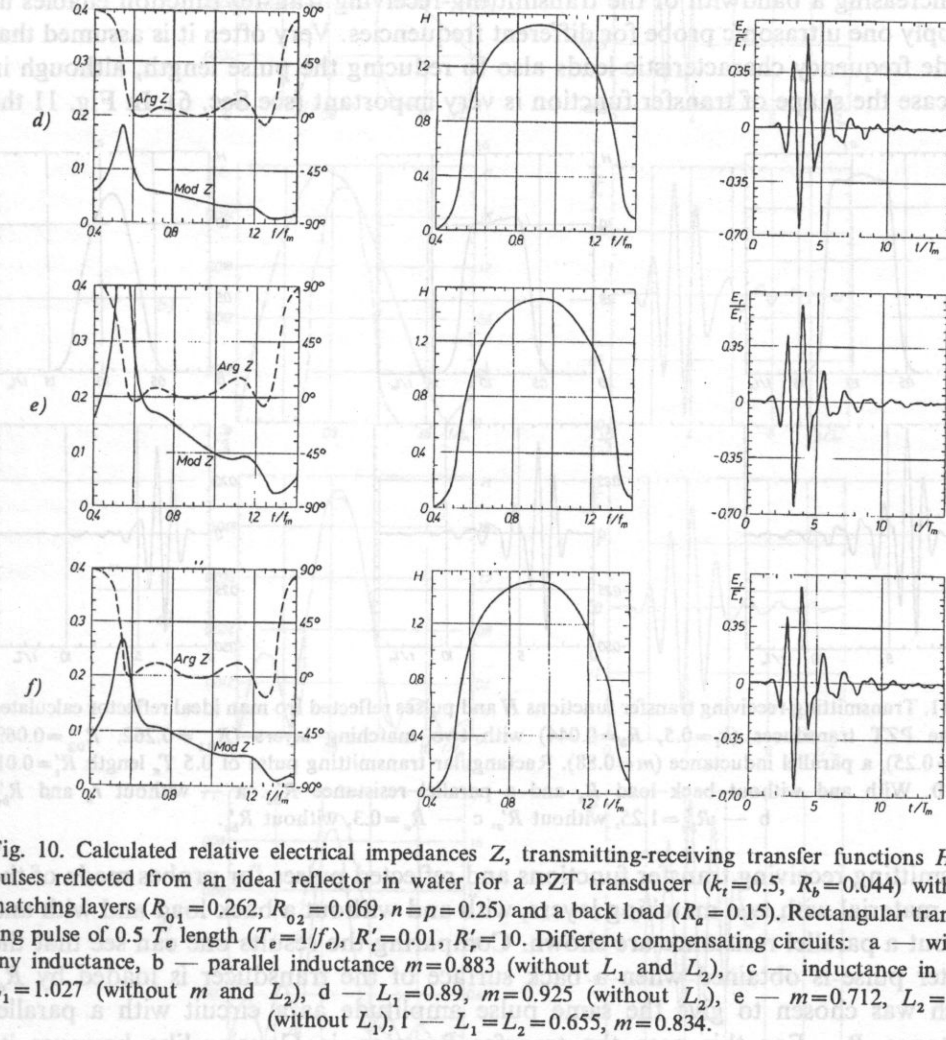


Fig. 10. Calculated relative electrical impedances Z, transmitting-receiving transfer functions H and pulses reflected from an ideal reflector in water for a PZT transducer ($k_t=0.5$, $R_b=0.044$) with two matching layers ($R_{01}=0.262$, $R_{02}=0.069$, $n=p=0.25$) and a back load ($R_a=0.15$). Rectangular transmitting pulse of 0.5 T_e length ($T_e=1/f_e$), $R'_t=0.01$, $R'_r=10$. Different compensating circuits: a — without any inductance, b — parallel inductance $m=0.883$ (without L_1 and L_2), c — inductance in series $L_1=1.027$ (without m and L_2), d — $L_1=0.89$, $m=0.925$ (without L_2), e — $m=0.712$, $L_2=1.154$ (without L_1), f — $L_1=L_2=0.655$, $m=0.834$.

4. Parallel resistance, back loading

Increasing a bandwith of the transmitting-receiving transfer function enables us to apply one ultrasonic probe for different frequencies. Very often it is assumed that a wide frequency characteristic leads also to reducing the pulse length, although in this case the shape of transfer function is very important (see Sec. 6). In Fig. 11 the

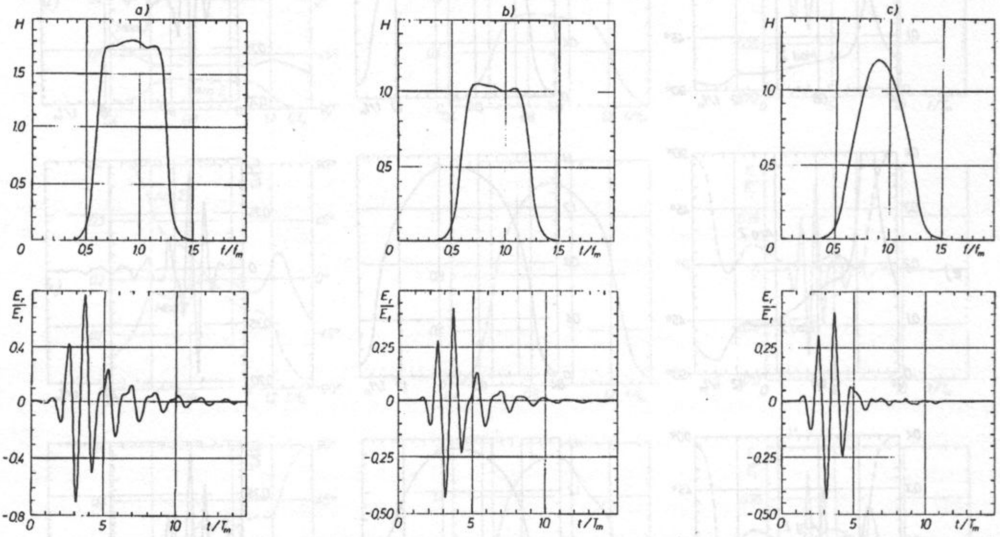


Fig. 11. Transmitting-receiving transfer functions H and pulses reflected fro man ideal reflector calculated for the PZT transducer ($k_t=0.5$, $R_b=0.044$) with two matching layers ($R_{01}=0.262$, $R_{02}=0.069$, $n=p=0.25$), a parallel inductance ($m=0.88$). Ractangular transmitting pulse of 0.5 T_e length $R'_t=0.01$, $R'_r=10$. With and without back load R_a and a parallel resistance R'_{be}. a — without r_a and R'_{be}, b — $R'_{be}=1.25$, without R'_a, c — $R_a=0.3$, without R'_{be}.

transmitting-receiving transfer functions and reflected pulses for probes made of the PZT material with two matching layers, with and without a back load and with and without a parallel resistance are shown. Comparing the results one can see that the shorter pulse is obtained when a back surface of the transducer is loaded by R_a, which was chosen to give the same pulse amplitude as a circuit with a parallel resistance R_{be}. For this case the transfer function is Gausian-like however its bandwidth is even narrower. It means that for shortening of the pulse the better way is to load a back surface of the transducer than to apply a parallel resistance.

5. Transmmiting pulse

The reflected pulse depends not only on the transmitting one, but also on the probe bandwidth. Therefore the length of the transmitting pulse should be chosen after taking into consideration the probe characteristics. In this section, as an

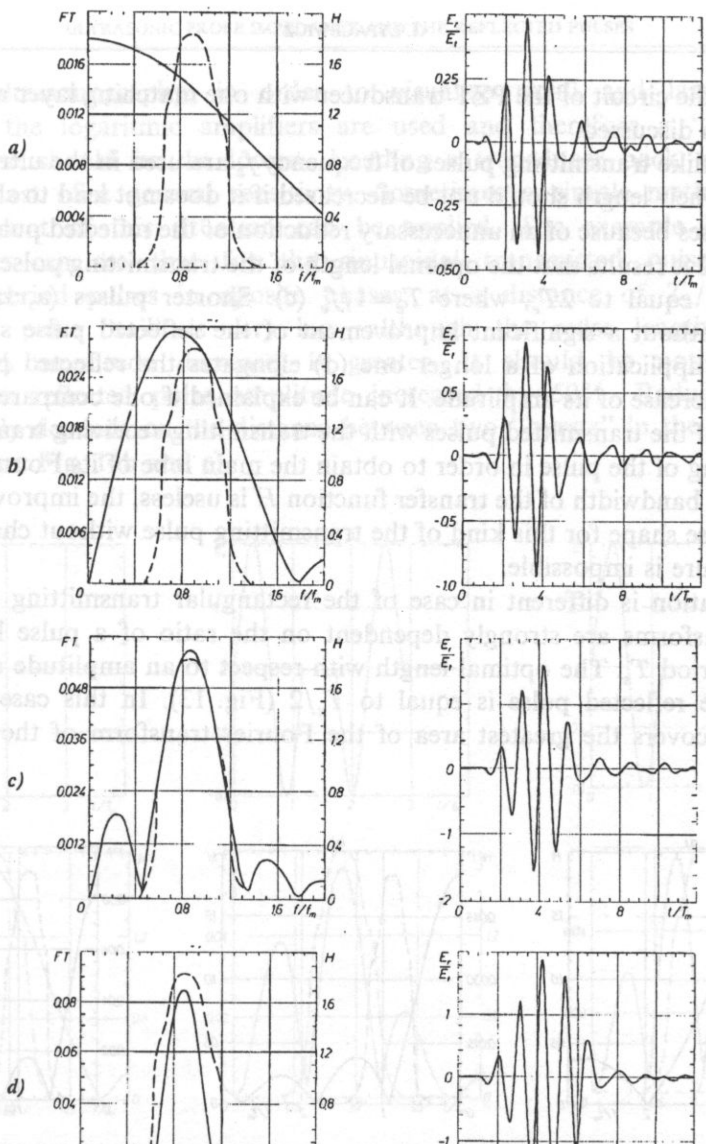


Fig. 12. Fourier transforms FT of burst transmitting pulses of a frequency f_e (compared with transmitting-receiving transfer function H — dashed line) and reflected pulses calculated for a PZT transducer ($k_t=0.5$, $R_b=0.044$) with one matching layer ($R_{01}=0.125$, $n=0.25$), without backing ($R_a=0$), with a parallel inductance ($m=0.887$). Different burst lengths, $R_t'=0.01$, $R_r'=10$: a — $T_e/2$, b — $1T_e$, c — $2T_e$, d — $3T_e$, where $T_e=1/f_e$.

illustration, the circuit of the PZT transducer with one matching layer and a parallel inductance is discussed.

The burstlike transmitting pulses of frequency f_e are used in the ultrasonography very often. Their length should not be decreased if it does not lead to shortening the reflected pulses because of an unnecessary reduction of the reflected pulse amplutide. From Fig. 12 it results that the optimal length of the transmitting pulse for this kind of probes is equal to $2T_e$, where $T_e=1/f_e$ (c). Shorter pulses (a, b) reduce the amplitude without a significant improvement of the reflected pulse shape; on the other hand, application of a longer one (d) elongates the reflected pulse without significant increase of its amplitude. It can be explained if one compares the Fourier transforms of the transmitted pulses with the transmiting-receiving transfer function H. Shortening of the pulse in order to obtain the main lobe of its Fourier transform wider than a bandwidth of the transfer function H is useless, the improvement of the reflected pulse shape for this kind of the transmitting pulse without changing of the probe structure is impossible.

The situation is different in case of the rectangular transmitting pulses. Their Fourier transforms are strongly dependent on the ratio of a pulse length to the vibration period T_e. The optimal length with respect to an amplitude as well as the shape of the reflected pulse is equal to $T_e/2$ (Fig. 13). In this case the transfer function H covers the greatest area of the Fourier transform of the transmitting pulse.

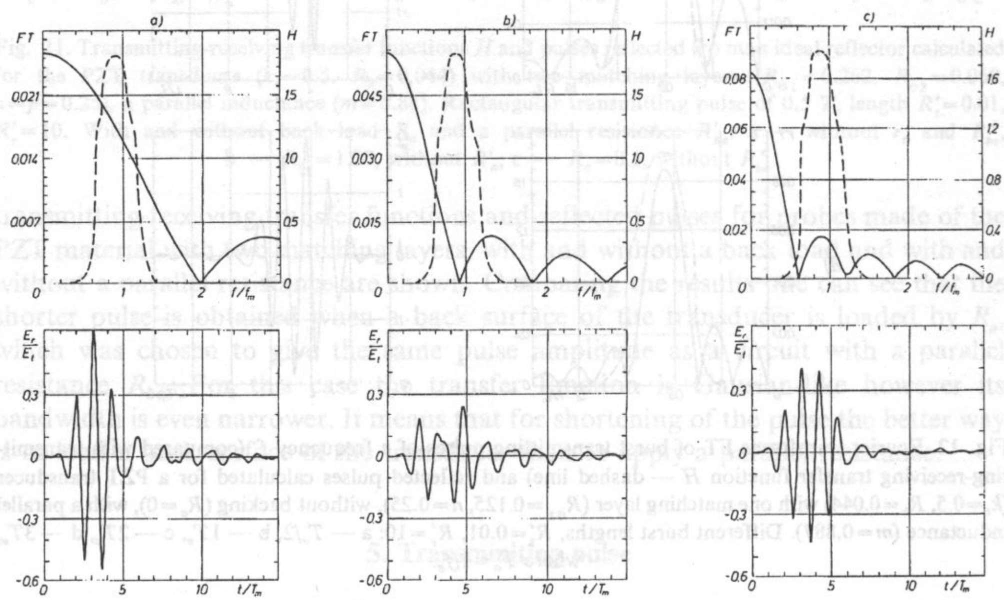


Fig. 13. Fourier transforms FT of rectangular transmitting pulses (compared with transfer function H — dashed line) and reflected pulses calculated for the transducer like in Fig. 12. A different transmitting pulse lengths: a — $0.5T_e$, b — $1T_e$, c — $1.5T_e$.

In the ultrasonography, in order to visualize small and large echos in one picture the logaritmic amplifiers are used and therefore a "tail" of the reflected pulse should be the lowest. Loading a transducer back surface helps but at the cost of a general sensitivity. Sometimes a simple method enabling an improvement of this situation can be applied. The example is shown in Fig. 14. One can see that for the sinusoidal transmitted pulse containing two single period pulses in oposite phases, at a distance of $T_e/2$ (Fig. 14b) the reflected pulse "tail" is very low, although the pulse length (calculated for the 10% amplitude decrease) is greater. It should be noticed that in that case the reflected pulse amplitude increased by 50%. Reduction of the "tail" strongly depends on the distance between two "bursts" in the transmitting pulse (compare Fig. 14b and c).

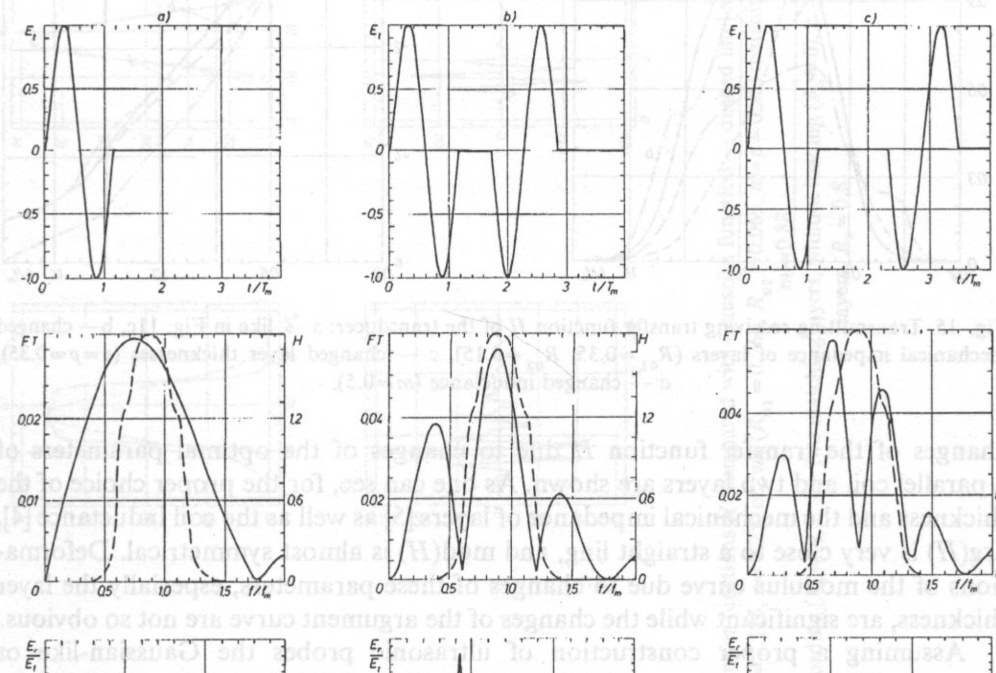


Fig. 14. Transmitting pulses (consisting of bursts of frequency f_e in oposite phases), their Fourier transforms FT (compared with transfer function H — dashed line) and reflected pulses calculated for the transducer like in Fig. 12. A different distance d_b between bursts: a — a single burst, b — $d_b = T_e/2$, c — $d_b = T_e$.

6. Influence of the transmitting-receiving transfer functions on reflected pulses

In general, the authors describing the ultrasonic probe behaviour do not discuss the influence of the shape and the argument of the transfer function H on the reflected pulses. This problem requires a special study, nevertheless some aspects of this question important from the designing point of view is presented. In Fig. 15 the

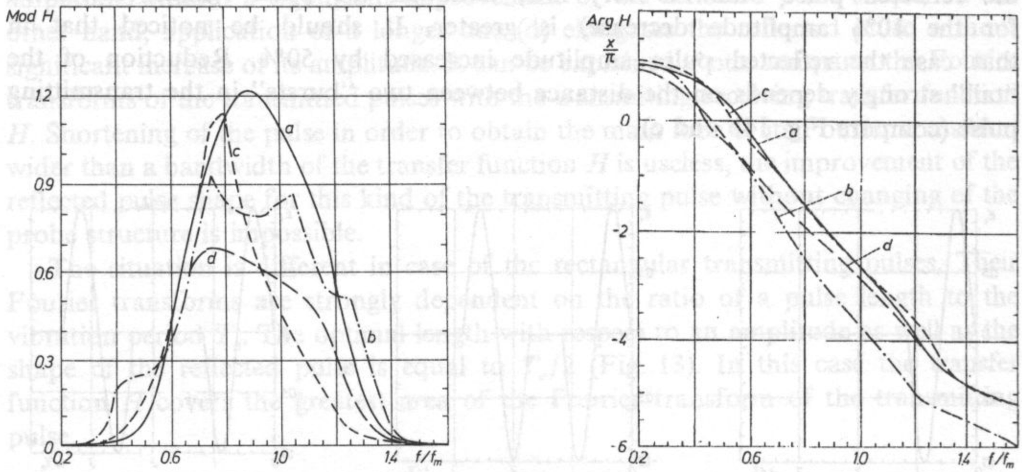


Fig. 15. Transmitting-receiving transfer function H of the transducer: a — like in Fig. 11c, b— changed mechanical impedance of layers ($R_{01}=0.35$, $R_{02}=0.15$), c — changed layer thicknesses ($n=p=0.35$), d — changed inductance ($m=0.5$).

changes of the transfer function H due to changes of the optimal parameters of a parallel coil and two layers are shown. As one can see, for the proper choice of the thickness and the mechanical impedance of layers [5] as well as the coil inductance [4], arg(H) is very close to a straight ling, and mod(H) is almost symmetrical. Deformations of the modulus curve due to changes of these parameters, especially the layer thickness, are significant while the changes of the argument curve are not so obvious.

Assuming a proper construction of ultrasonic probes the Gaussian-like or trapezium-like shape of the transfer function modulus (Figs 4—8, 10 and 11) and the linear argument (Fig. 15) can be approached.

The construction of the ultrasonic probe should depend on its destination. Application of two matching layers leads to widening of the frequency band (Fig. 16a, b), but the transfer function H becomes more trapezium-like and the reflected pulse "tail" becomes longer than for one matching layer. To shorten the reflected pulse, the back loading can be applied, but making it greater than the opitmal value worsens the pulse shape (Fig. 16c, d). As one can see in Fig. 16, the optimal pulse shape is obtained when transfer function H is close to the Gaussian one.

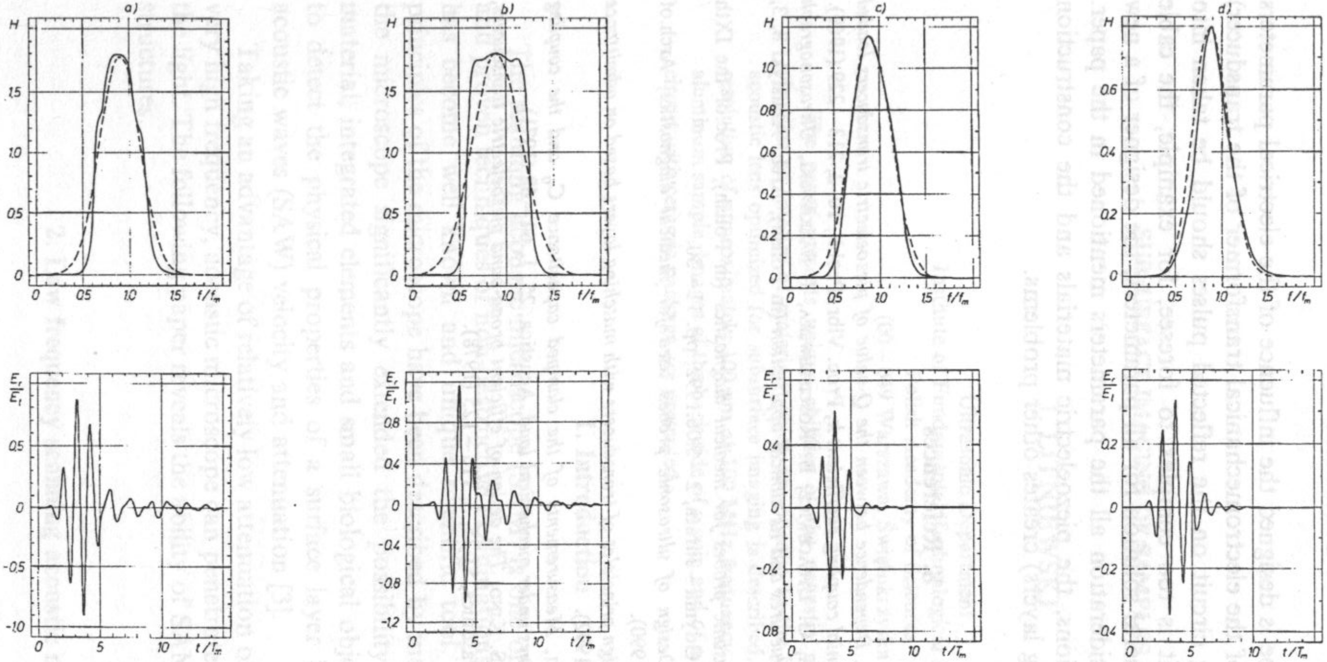


Fig. 16. Transmitting-receiving transfer functions H (compared with Gaussian function — dashed line) and reflected pulses calculated for the PZT transducer ($k_t=0.5$, $R_b=0.044$) with one ($R_{01}=0.125$, $n=0.25$) or two ($R_{01}=0.262$, $R_{02}=0.069$, $n=p=0.25$) matching layers for a different back load. Parallel inductance $m=0.88$

a — one matching layer, without loading ($R_a=0$), b — two matching layers, without loading ($R_a=0$), c — two matching layers, $R_a=0.35$, d — two matching layers, $R_a=0.8$.

7. Conclusions

When the ultrasonic probe is designed the influence of the electrical parameters (lying on the electrical side of the electromechanical transformer of the transducer) of the transmitting-receiving circuit on the reflected pulses should be taken into account. Because this circuit is too complex to foresee, for example, the cable influence and to find the general solution for all parameters, the designer of a new probe should take into consideration all the parameters mentioned in the paper. Each change of the dimensions, the piezoelectric materials and the construction possibilities (i.e. the matching layers) creates other problems.

8. References

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