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# ANALYSIS OF BROAD-BAND PIEZOELECTRIC SANDWICH TRANSDUCER WITH PERFORATED STRUCTURE

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## 1. Introduction

Pre-stressed piezoelectric sandwich transducers are used widely as sonic source for many low frequency ultrasonic applications, notably in the fields of macrosonics sand sonar. For certain applications a broader bandwidth is necessary. The sandwich transducer with perforated structure developed by us is formed by drilling holes longitudinally in the radiating head, and has been shown experimentally to possess a bandwidth approximately double that of a conventional nonperforated transducer, while its electroacoustic efficiency remains almost undeteriorated [1].

In this paper a theoretical model for the broadband structure is proposed. The frequency characteristics of the input electrical admittance of the transducer and the input mechanical impedance of the radiating head loaded by water, are calculated both as functions of the relative cross-section $\alpha$ of the bored part and the relative depth of the holes $\beta$ of the radiating head. Some theoretical results are compared with measured ones, the two fairly well agree.

## 2. Theoretical consideration

A sandwich transducer with perforated structure is shown in Fig. 1a. It is composed of a backing block (1); two piezoelectric ceramics (2), (4); an electrode (3); a radiating head with perforated structure (5), (6) and a thin cover plate (7). These sections are connected mechanically in series. A bolt for pre-stressing is ignored. Parts (5), (6) and (7) are considered to form a mechanical "transformer section". The backing block and the radiating head are electrically connected, and a constant voltage $E$ is applied between the electrode and the backing block, so that the two ceramic discs are connected electrically in parallel. The transducer is loaded to the right. By making the usual

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* Work done while at Institute of Physics.

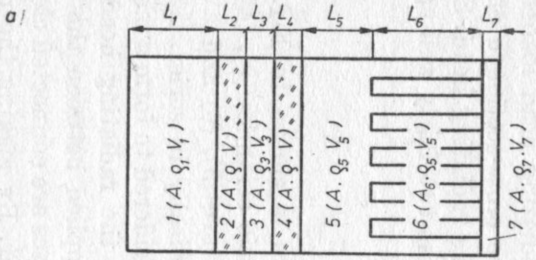

Fig. 1a. Transducer with perforated structure

1 — backing block; 5, 6 — radiating head; 2, 4 — ceramics; 7 — cover plate; 3 — electrode

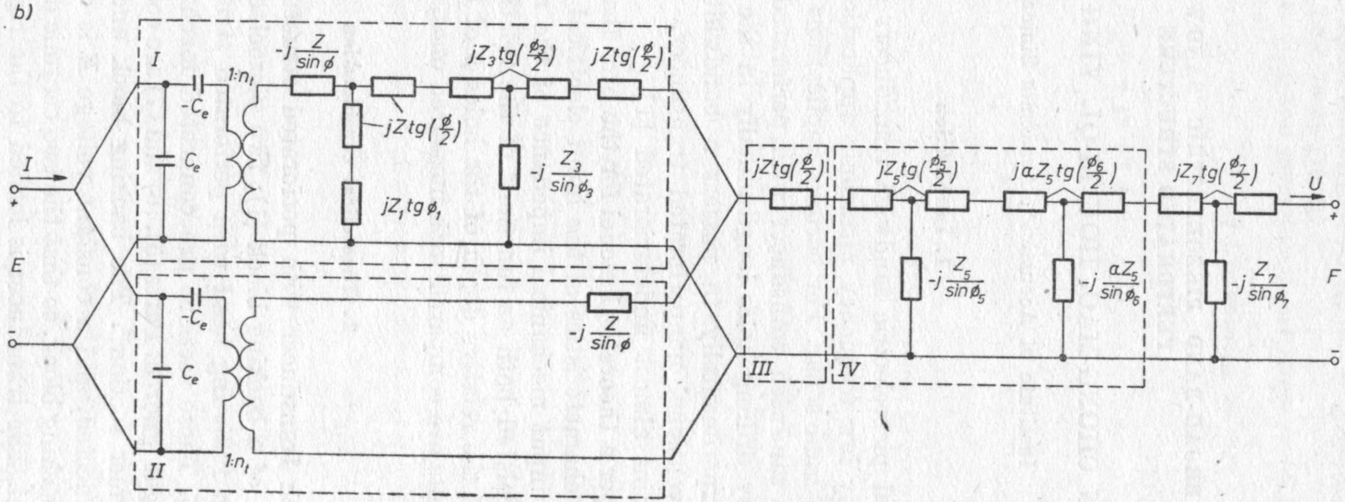

Fig. 1b. Equivalent electro-mechanical network of the transducer

one-dimensional approximation and neglecting the mechanical and dielectric losses, the equivalent electromechanical network of the transducer is given in Fig. 1*b*. In this model of analysis, the radiating section with perforated structure is treated as two cascade acoustic transmission lines of different cross-section $A$ and $A_6$, $A_6$ being $A$ minus the total area bored out. It is represented in Fig. 1*b* by two cascade $T$ – networks in the dash line block IV.

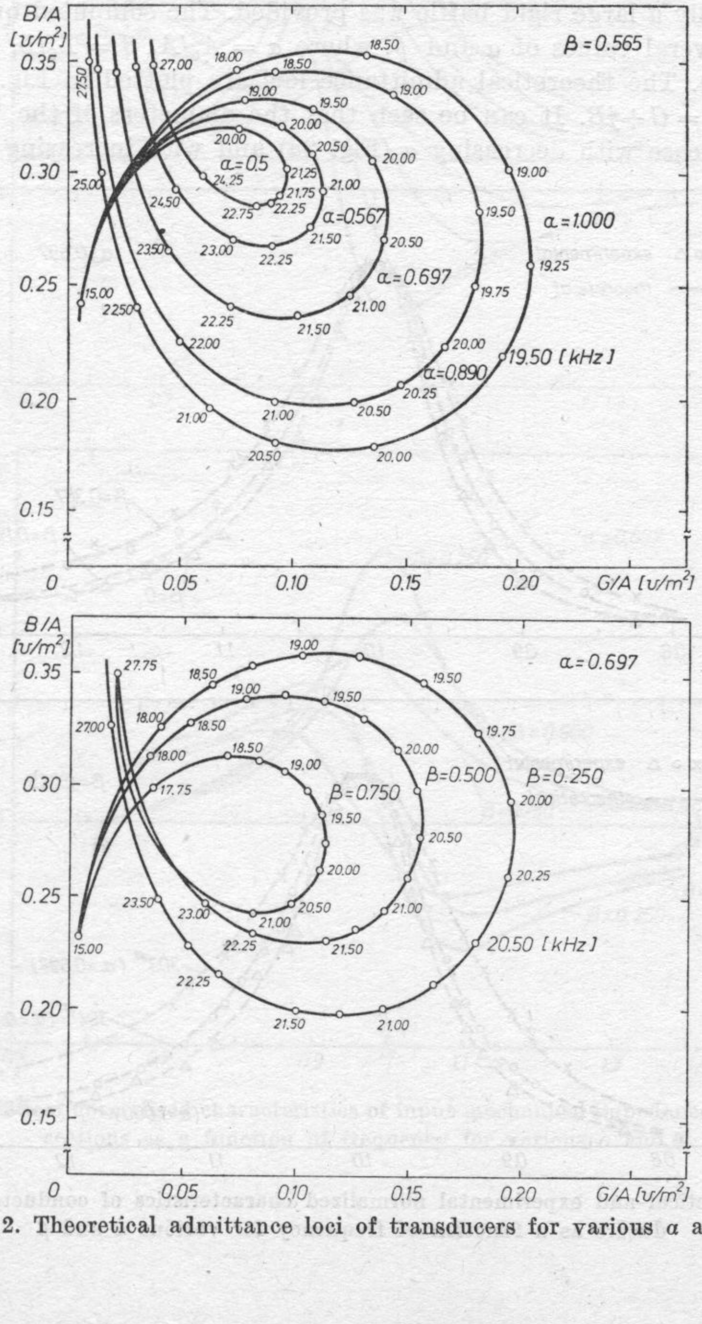

Fig. 2. Theoretical admittance loci of transducers for various $\alpha$ and $\beta$

## 3. Results and discussion

A computer program was effected to calculate from the network in Fig. 1*b* the electrical admittance at the electrical terminal of the transducer and the mechanical impedance looking into the "transformer section". These two quantities are related to the acoustical bandwidth of the transducer. The radiating face is supposed to be rigid and set in an infinite rigid baffle in water; experimentally a large rigid baffle was provided. The computed quantities are given for several values of $\alpha$ and $\beta$, where $\alpha = A_6/A$, $\beta = L_6/L$, $L = L_5+L_6$ (see Fig. 1*a*). The theoretical admittance loci are plotted in Fig. 2*a* and 2*b*, in which $Y = G+jB$. It can be seen that the diameters of the "admittance circles" decrease with decreasing $\alpha$ (Fig. 2*a*) and with increasing $\beta$ (Fig. 2*b*),

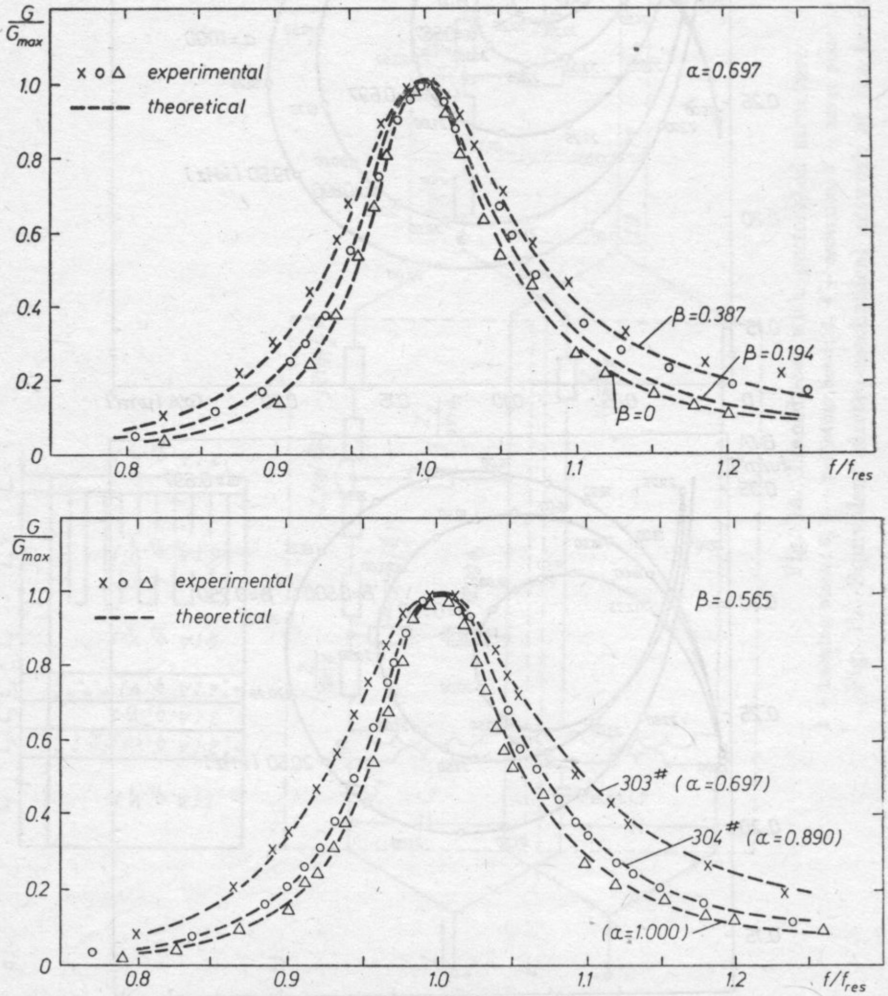

Fig. 3. Theoretical and experimental normalized characteristics of conductance of transducers as a function of frequency for various $\alpha$ and $\beta$

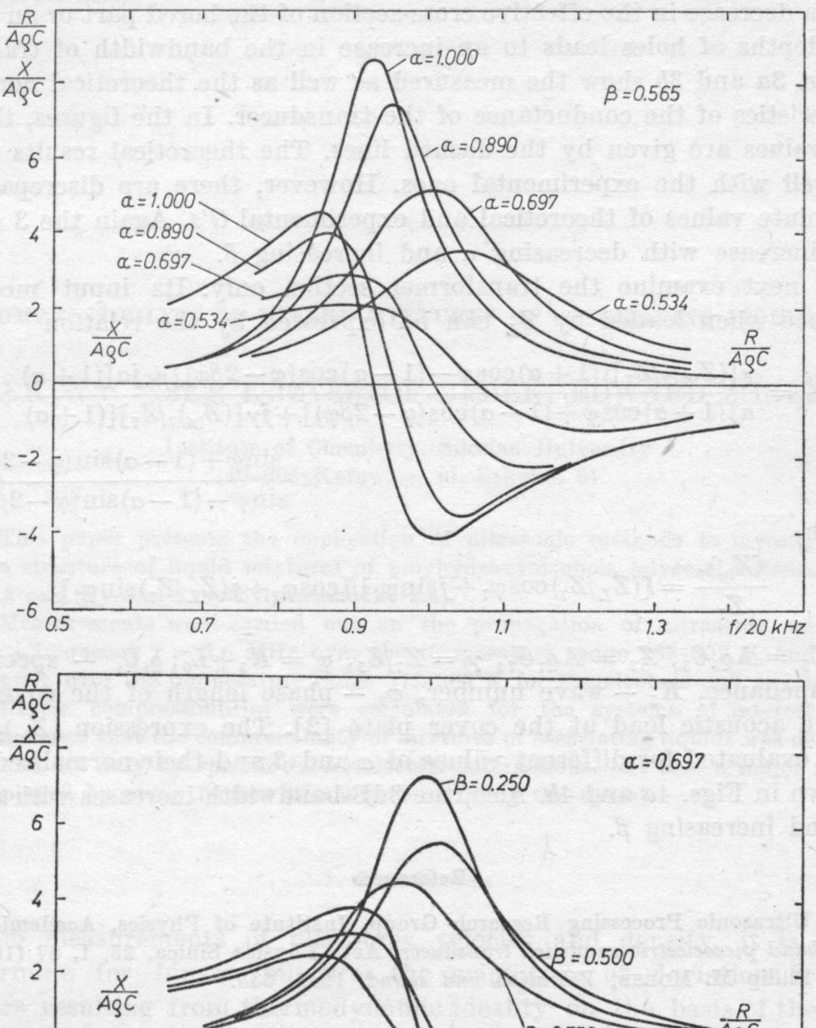

**Fig. 4.** Theoretical normalized characteristics of input mechanical impedance of transformer sections as a function of frequency for various $\alpha$ and $\beta$.

that is, a decrease in the effective cross-section of the bored part or an increase in the depths of holes leads to an increase in the bandwidth of transducer.

Figs. *3a* and *3b* show the measured as well as the theoretical normalized characteristics of the conductance of the transducer. In the figures, the theoretical values are given by the dashed lines. The theoretical results seem to agree well with the experimental ones. However, there are discrepancies in the absolute values of theoretical and experimental $G$'s. Again the 3 dB-banwidths increase with decreasing $\alpha$ and increasing $\beta$.

We next examine the transformer section only. Its input mechanical impedance when loaded by $Z_L$ can be expressed by the relation

$$\frac{(Z_{\text{in}})_5}{Z_5} = \frac{\gamma[(Z_{\text{in}})_7/Z_7][(1+\alpha)\cos\varphi-(1-\alpha)\cos(\varphi-2\beta\varphi)]+j\alpha[(1+\alpha)}{\alpha[(1+\alpha)\cos\varphi+(1-\alpha)\cos(\varphi-2\beta\varphi)]+j\gamma[(Z_{\text{in}})_7/Z_7][(1+\alpha)}\times$$

$$\times\frac{\sin\varphi+(1-\alpha)\sin(\varphi-2\beta\varphi)}{\sin\varphi-(1-\alpha)\sin(\varphi-2\beta\varphi)]},$$

in which,

$$\frac{(Z_{\text{in}})_7}{Z_7} = [(Z_L/Z_7)\cos\varphi_7+j\sin\varphi_7]/[\cos\varphi_7+j(Z_L/Z_7)\sin\varphi_7],$$

where $Z_5 = A\varrho_5C_5$, $Z_7 = A\varrho_7C_7$, $\gamma = Z_7/Z_5$, $\varphi = K_5+L_6$; $\varrho_iC_i$ – specific acoustic impedance, $K_5$ – wave number, $\varphi_7$ – phase length of the cover plate, $Z_L$ – the acoustic load at the cover plate [2]. The expression $(Z_{\text{in}})_5 = R+$ $+jX$ is evaluated for different values of $\alpha$ and $\beta$ and their normalized values are shown in Figs. *4a* and *4b*. Also, the 3dB-bandwidth increases with decreasing $\alpha$ and increasing $\beta$.

## References

[1] Ultrasonic Processing Research Group, Institute of Physics, Academia Sinica, *A broad band piezoelectric sandwich transducer*, Acta Physica Sinica, **25**, 1, 87 (1976).

[2] Philip M. MORSE, *Vibration and sound*, 1948, 333.

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