Al-Co-Fe ALLOYS FOR ULTRASONIC APPLICATIONS

Z. Kaczkowski

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Z. Kaczkowski

Polish Academy of Sciences Institute of Physics, Al. Lotników 32/46, 02-668 Warszawa, Poland

Résumé - Les alliages fer-aluminium-cobalt contenant de 12 à 14% de Al et de 1 à 3% de Co sont utilisés comme noyaux des transducteurs à ultra-sons de forte puissance dans la gamme des fréquences de 22 à 84 kHz.

Abstract - The iron-aluminium-cobalt alloys containing from 12 to 14 wt % Al and from 1 to 3 wt % Co are used for the core material of the high power ultrasonic transducers in the frequency range from 22 to 84 kHz.

I - INTRODUCTION

Saturation induction of Al-Fe-Co alloys containing from 12 to 14 wt% Al and to 3 wt % Co is not far removed from that of simple binary Al-Fe alloys having the same aluminium contents /1/ and it can change from 1.0 to 1.4 T. Addition of few per cent of the other elements can improve piezomagnetic properties of these Al-Co-Fe alloys /2/. Their saturation magnetostriction is greater than 40 x 10^{-6} and Curie temperature higher than 770 K. Due to the high resistivity (about 1 $\mu\Omega m$) the sheets of Alcofers may be thicker than those of nickel (ρ = 0.07 $\mu\Omega m$) in transducers working at the same frequency or may by used at higher frequencies (practically up to 100 kHz). The magnetic bias field for obtaining maximum magnetomechanical coupling coefficient is lower than that for the Alfers and much lower that that for the nickel. The magnetomechanical coupling coefficient of these alloys may be 50 % higher than that of the Alfers and 100 % higher than that of the nickel.

II - PIEZOMAGNETIC PROPERTIES

The maximum values of magnetomechanical coupling coefficient k and stress sensitivity coefficient d and other piezomagnetic properties /3/ of Alcofers depend on the state of structural order.
The annealing temperatures providing the maximum values of k and d coefficients (from 1000 to 1300°C) are somewhat higher than these for the ordered structure (about 900° C) /3,7/. Maximum values of k, fields H_{km} and annealing temperatures T providing the k_m, permeabilities at this fields μ_{km} and maximum stress sensitivity coefficient d_m for different chemical contents and sheet thickness are given in Table 1 /3-7/. The best piezomagnetic properties are for the partially ordered structure and are associated with zero magnetocrystalline anisotropy constants. By the adding of 1 to 2 % Co to 12-14 % Al-Fe alloys the piezomagnetic properties are improved, e.g. magnetomechanical coupling coefficient k is increased from 0.2 to 0.4 or more /3/. The mechanical quality factor is changing from 10 for very low polarizations to 1200 at 4 kA/m. For this reason the optimum bias would

Table 1. Maximum values of magnetomechanical coupling coefficient (k_m) and stress sensitivity coefficient (d_m), annealing temperatures (T) and magnetic fields providing k_m and d_m, (H_{km}) and reversible permeability for k_m (μ'_{km}) of Alcofer sheets with different thickness (t) /3-7/

Sample %Al	Sample %Co	t [mm]	T [°C]	k_m [-]	H_{km} [A/m]	d_m [nWb/N]	μ'_{km} [-]
12	1	0.25	1000	0.37	100	21.5	322
12	2	0.2	1000	0.32	100	24.2	570
		0.3	1000	0.45	65	28.2	320
13	1	0.3	1000	0.27	100	14.8	269
13	2	0.2	1300	0.37	100	28.6	554
		0.25	1300	0.32	200	18.1	283
14	1	0.2	1300	0.31	200	17.8	248

be higher than 500 A/m. The maximum of k and d_m and minimum of E_H occur at fields associated with domain rotations and non-180° wall displacements. These materials especially those containing 12% Al and 1 or 2 % Co are suitable for applications such as high power ultrasonic transducer cores.

III - ALCOFER TRANSDUCERS

The window transducer has the advantage of the forming a closed magnetic circuit. The result is nearly uniform excitation of the entire length of each leg (column) and reduction of leakage flux to a low value. In this case the calculations of resonance frequency from the total length only, e.g. $f_H = (1/2\ l)(E_H/\rho)^{1/2}$, will not always be a good approximation. The author /8/ proposed the following approximate formula for narrow columns window transducers:

$$f_r = \frac{f_H}{\sqrt{1 + \frac{2fh}{el} + \frac{2f^2}{el}\left(\frac{1}{2} - \frac{\pi}{8}\right)}} , \qquad /1/$$

where E_H is modulus of elasticity at constant field, ρ - density and l and e are the length and the thickness of column and h and f are the height and width of arm (Fig. 1-3). Transducers were made from

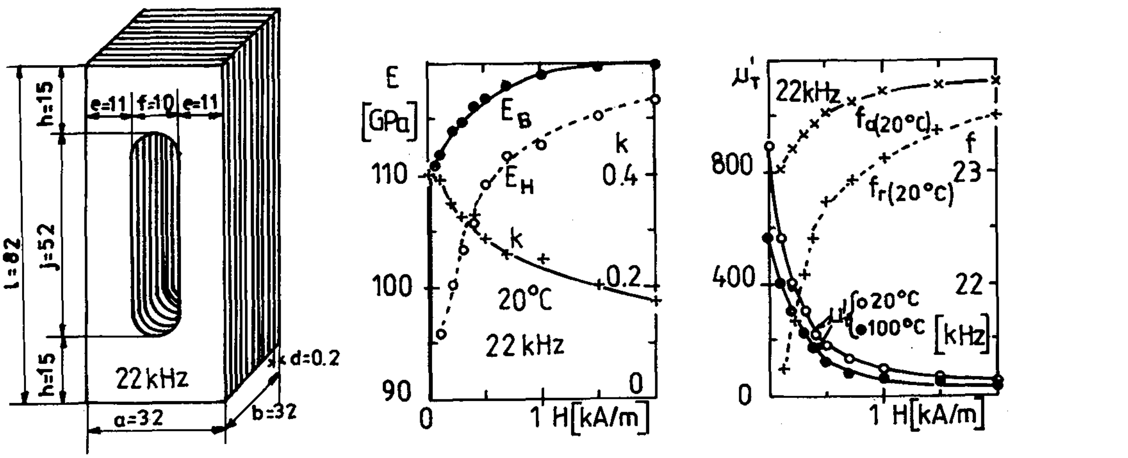

Fig. 1 -Dimensions, magnetomechanical coupling coefficient k, moduli of elasticity at constant magnetic field H and at constant induction B, resonance f_r and antiresonance f_a frequencies and relative values of dynamical permeability μT for 20 and 100° C of the free vibrating 22 kHz Alcofer transducer.

Al-Co-Fe alloy containing 12 wt % Al and 2 wt % Co /5/. Laminations have thickness equal 0.2 mm which after cutting were annealed at

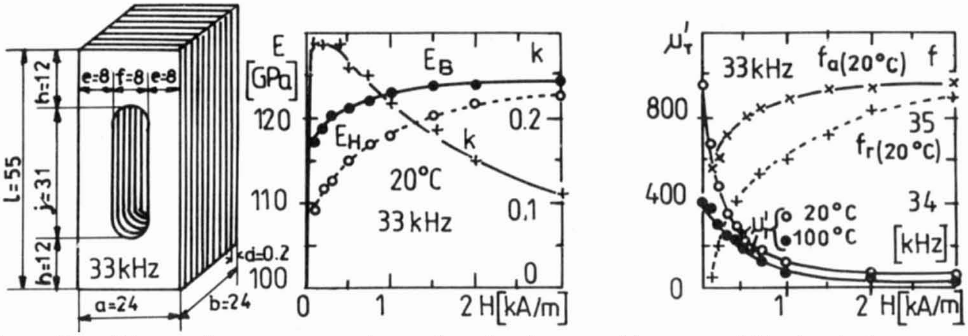

Fig. 2 - Dimensions, magnetomechanical coupling coefficient k, moduli of elasticity at constant magnetic field H and at constant induction B, resonance f_r and antiresonance f_a frequencies and relative values of dynamical permeability μ'_T for 20 and 100° C of the free vibrating 33 kHz Alcofer transducer

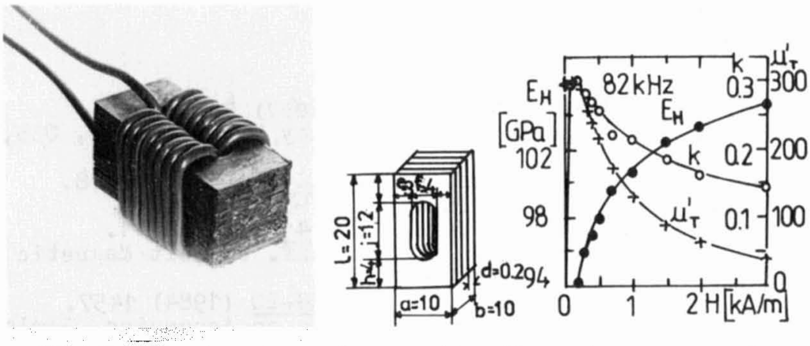

Fig. 3 - 82 kHz Alcofer transducer, its dimensions, magnetomechanical coupling coefficient k modulus of elasticity E_H and permeability μ'_T versus magnetic bias H

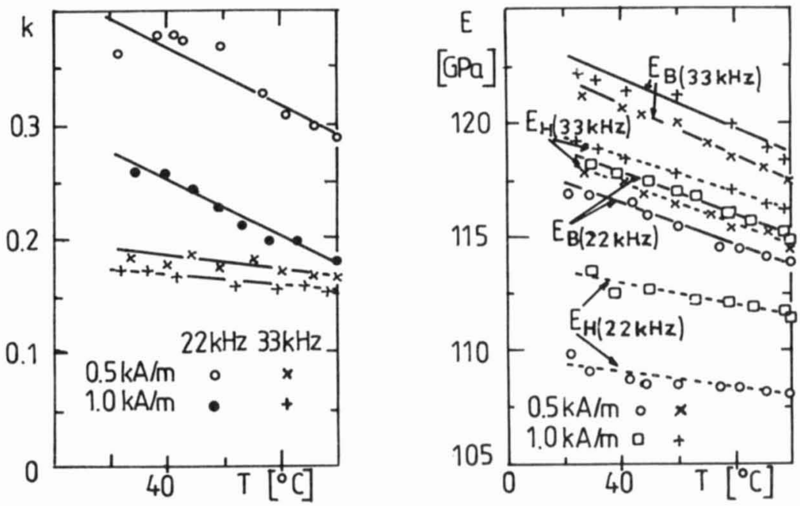

Fig. 4 - The temperature dependence of magnetomechanical coupling coefficient k and of the moduli of elasticity E_H and E_B for 22 and 33 kHz ultrasonic Alcofer transducers

1000°C for 2 hours in H_2 /8,9/. Their magnetomechanical coupling coefficient k moduli of elasticity, resonance frequency and permeability are presented in Fig. 1-3.
The temperature dependence of the magnetomechanical coupling coefficient and the moduli of elasticity for 22 and 33 kHz transducers in Fig. 4 is presented. Generally, the changes of the piezomagnetic properties in the temperature range from 20 to 100°C did not exceed 30%. The frequency changes with the magnetic bias - connected with ΔE effect - are not greater than a few kilohertz. Their impedance is similar to that presented for Alfer transducers, or for Alcofers in the other papers, e.g. /3/.

IV - FINAL REMARKS

Maximum values of magnetomechanical coupling coefficient were higher than 0.3 but optimum bias field was varying with temperature. Due to the high resistivity the Alcofer laminations may be thicker than those of nickel or may be used at higher frequencies up to 100 kHz with higher efficiency as that of nickel transducers for 20 kHz. Alcofer transducers may be used for high power ultrasonic applications under heavy conditions.

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