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A Design and Characteristics for Mode-Coupling $LiNbO_3$ Ultrasonic Motor Depended on Length to Width Ratio of the Stator Vibrator

モード結合型 $LiNbO_3$ 単結晶モータ振動子の長さ-幅寸法比の異なる設計と特性

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1. Introduction

The elastic compliances s^E_{i5} of X-rotated Y-plate $LiNbO_3$ have non-zero values and provide a mode coupling effect for in-plane longitudinal and flexural modes when the plate is additionally rotated in the *y*'-axis as shown in **Fig. 1**. We have proposed a single phase driven ultrasonic motor using a rectangular plate vibrator with coupling modes from the longitudinal 1st (L_1) and flexural 2nd (F_2) modes.[1-2] The degenerate or strongly coupling of L_1-F_2 modes is obtained in proper ratios for the length *L* to width *W* of the plate, and the ratios *W*/*L* for the degenerate are around 0.26 and 0.6.[3] Recently, a L_1-F_2 modes degenerated type USM using a PZT plate with *W*/*L*=0.63 is proposed.[4]

For the mode-coupling LN vibrator, we found that the coupling was obtained in widely ranges around *W*/*L*=0.8; in this paper, we mentioned analytical vibration characteristics and experimental results of motors by the difference in typical *W*/*L*.

2. FEM analysis results

Analytical results using ANSYS(R11) of the vibration characteristics for X135°-, Y'14°-rotated rectangular Y-plate as functions of *W*/*L* are shown in **Fig. 2**. These characteristics change steeply in primary coupling condition around *W*/*L*=0.26; that is, these are easily influenced by a dimensional error.

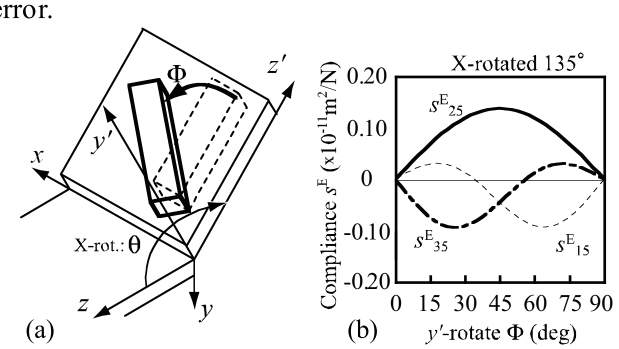

Fig.1 Cut angle definition(a), and elastic compliances as functions of the 2nd rotation angle Φ (b).

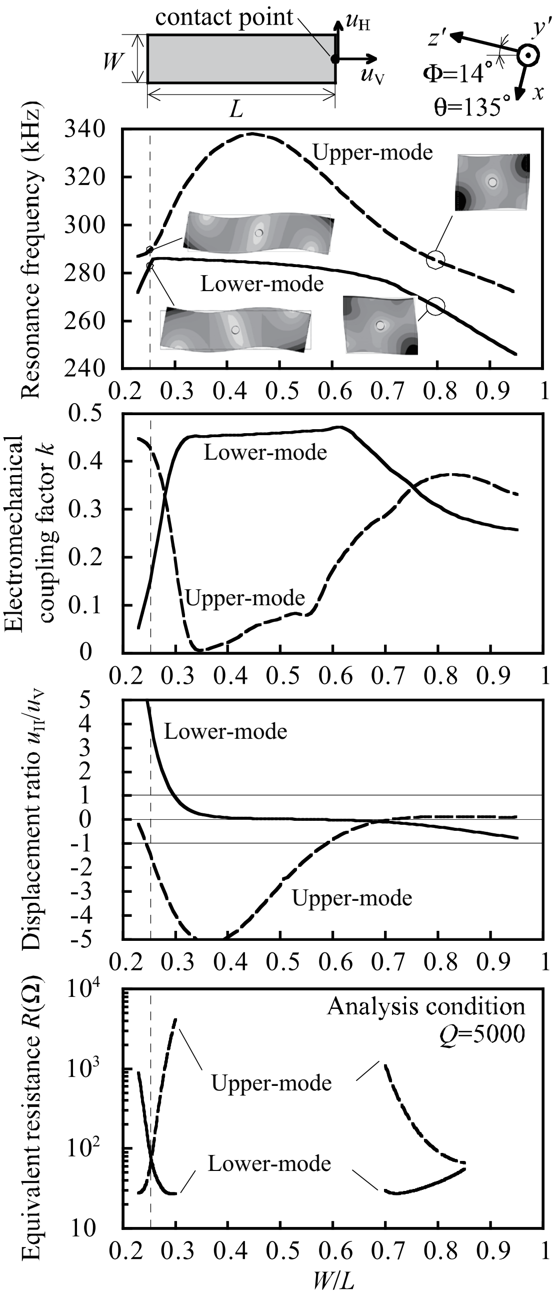

Fig.2 Analytical results for the dependency on *W*/*L*.

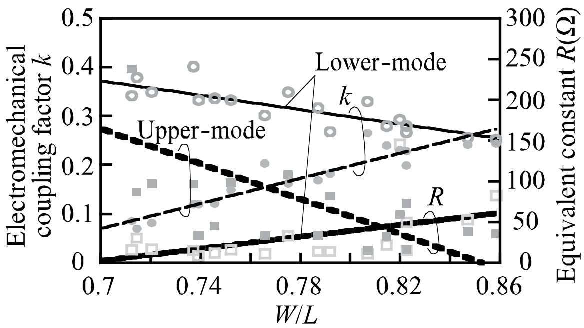

Fig.3 Experimental results of the coupling factors and equivalent resistances for the dependency on W/L.

Secondly effective coupling is observed in broad range around W/L=0.8. In the secondly coupling range, the displacement ratios and other characteristics change softly, and the differences of electromechanical coupling factor k between the upper and lower modes are relatively small. Additionally, the large distance of resonant frequencies between the upper and lower modes helps to easily select the aiming mode.

3. Experimental results

Figure 3 shows the experimental results as functions of W/L when the width is constant of 2.55mm and the length is ground. The values of k and R of the both modes come close each other around W/L=0.83, although we see some amount of different from the analyzed one because the samples are small and are affected by grinding and fixing errors.

The construction of stator vibrator for motor evaluation is shown in **Fig. 4**. The center points of top and bottom surfaces are glued with conductive epoxy to fix and feed electric power. On the contact surface to the stator shaft, a zirconia ball of 0.5mm in diameter is attached with inorganic adhesive for antiwear and point contact. **Table I** shows equivalent circuit constants of the trial stator vibrators of Sample-A (W/L=0.255) and Sample-B (W/L=0.822) for the upper and lower modes. The results as functions of the preload force shown in **Fig. 5** are the maximum revolution speeds of the shaft without mechanical load while the driving frequency is swept down.

The volume of Sample-A is almost 3 times larger than of Sample-B; thus, the quality factor which is affected by fixing structure and the revolution speed of Sample-B are totally smaller than of Sample-A. However, we can find that the motor using Sample-B rotates with gradual change in broad range of preload, but it is afraid of an affection of the low quality factor.

The optimum conditions to equalize the rotation characteristics in both directions will be future problem.

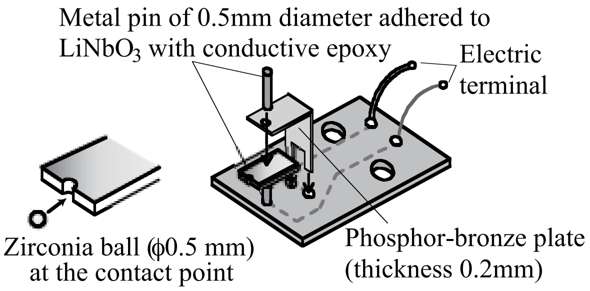

Fig.4 Construction of the stator vibrator for experiment.

Table I Equivalent circuit constants of the stators.

	Sample-A		Sample-B	
Dimensions	W/L=0.255 (2.55×0.5×10)		W/L=0.822 (2.55×0.5×3.10)	
Mode	Lower	Upper	Lower	Upper
Q	1125	612	220.9	146.5
f_0(kHz)	281.17	286.40	841.51	888.25
R(Ω)	335.6	348.8	121.4	784.8
L(mH)	213.6	118.6	5.1	20.6
C(pF)	1.50	2.60	7.05	1.56
Cd(pF)	30.2	30.3	100.6	96.2
kvn(%)	11.6	40.9	25.6	12.6

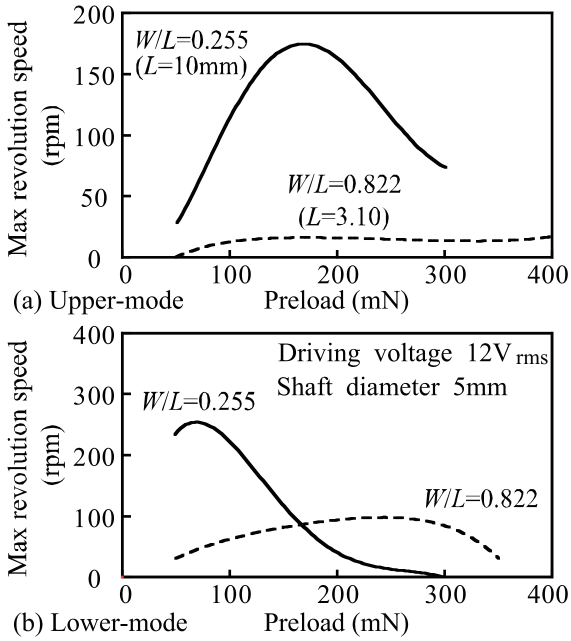

Fig.5 Maximum revolution speed vs. preload force.

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