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Analysis of the Backlash in an Ultrasonic Transducer for Volumetric Imaging

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1. Introduction

In medical ultrasonic diagnosis, volumetric imaging can be achieved with either a 2D array transducer or mechanical wobbling of a 1D array transducer. 2D array transducer, in general, still remains at a research stage due to its complicated structure, high cost and reliability problems [1, 2]. However, mechanical wobbling of a 1D array has several advantages over the 2D array such as a simple structure, low cost, and ease of volumetric image rendering with multiple 2D images. Hence, the mechanical wobbling transducer is seeing more and more applications in medical diagnosis fields.

The operation of an ultrasonic wobbling transducer depends on the motion of a motor in conjunction with a motor controller. The array motion in the wobbling transducer should satisfy several specifications to achieve clear volume images. Backlash is one of the important factors of the specifications that determine the reliability of transducer. The backlash means the error between the driving angle of a motor and the driven angle of the array. If there is big backlash, the images from the transducer will distort in time because the position of the ultrasonic array will vary in time even if the motor controls the array to maintain a constant position. The purpose of this study is to analyze the backlash mechanism of a wobbling transducer in order to improve the reliability of the transducer. For this purpose, an equation about the backlash is derived and analyzed. The backlash equation includes the effects of assembly tolerance of mechanical components, fabrication tolerance of the transducer and possible failures of various mechanical parts. For verification of the validity of the derivation, several test models of a wobbling transducer were fabricated and their test results were compared with calculation results from the backlash equation.

2. The Driving Mechanism

The wobbling transducer consists of a motor, a frame, an arm, an arm holder, a link and a 1D array. This driving mechanism can transmit power from the motor to the array by 3-steps.

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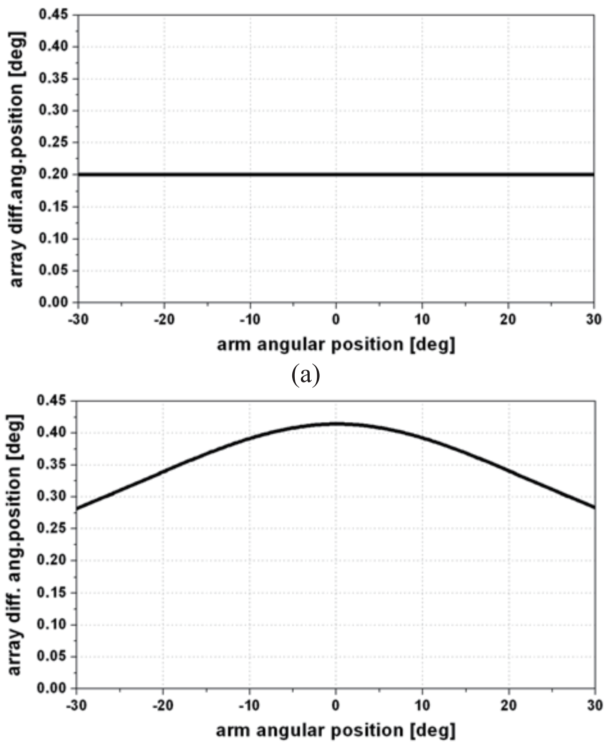
The rotator power of the motor makes a to-and-from circular motion of the arm through an arm holder. The motion of the arm makes the to-and-from rotational motion of the array through a link [2]. The driving angle of the array with the rotational angle of the motor is

$$\Phi = \tan^{-1}(r \tan\Theta / d)\,, \qquad (1)$$

where Θ is the rotational angle of the motor. Φ is the rotational angle of the array, r is the distance between a motor axis and the arm shaft, and d is the distance between the array shaft and the array pivot axis. If $r = d$, the driving mechanism has a linear motion profile. **Fig. 1** Shows the rotational angle of the array in relation to the rotational angle of the arm when the motion profile is either linear or nonlinear. If the driving mechanism has a nonlinear motion profile, the imaging quality of the array will be much poorer because array velocity is different at each wobbling angle.



(b)

Fig. 1 (a) linear motion profile (b) nonlinear motion profile.

3. Backlash Analysis

The cause of the backlash can be described by the structure of the mechanism and the relationship between mechanical components of the transducer. The cause of the backlash is divided into two types: the constant backlash by the inherent tolerance of components, and the changing backlash by the abrasion of components with the increase of a wobbling number. In a theoretical analysis, the backlash by the abrasion of components was neglected. When α is the error in the rotational angle, considering a change of r, the backlash is

$$\Phi_r = \tan^{-1}(r_c \tan\Theta / d), \qquad (2)$$

$$\beta_r = \Phi_r - \Phi, \qquad (3)$$

where Φ_r is the rotational angle of the array including the change of r, r_d is changed r, and β_r is the backlash by the change of r. Considering a change of d, the backlash is

$$\Phi_d = \tan^{-1}(r \tan\Theta / d_c), \qquad (4)$$

$$\beta_d = \Phi_d - \Phi, \qquad (5)$$

where Φ_d is the rotational angle of the array including the change of d, d_d is changed d, and β_λ is the backlash by the change of d. Considering a change of α, the backlash is

$$\Phi_\alpha = \tan^{-1}(r \tan\Theta / d) \pm 2\alpha, \qquad (6)$$

$$\beta_\alpha = \Phi_\alpha - \Phi, \qquad (7)$$

where Φ_α is the rotational angle of the array including the change of α, and β_α is backlash by the change of α. From Eqs. (2)-(7), the backlash by the tolerance could be calculated and it was about 0.33 degree. Most of the backlash was caused by the tolerance of a cam follower and axial play of the motor. Each of them has about 63.1 % and 31.9 % of the total backlash. For the backlash analysis of test models, a flow chart was drawn in **Fig. 2** which considered not only the variation of the backlash but also the trend of the backlash.

4. Measurement of Backlash

For the backlash measurement, several wobbling models were fabricated. The cause of the backlash was analyzed using the flow chart in Fig. 2. Measured backlash was at maximum about 0.5 degree while calculated backlash was about 0.33 degree. The difference was considered to be due to the assembly tolerance of components, fabrication tolerance and measurement error.

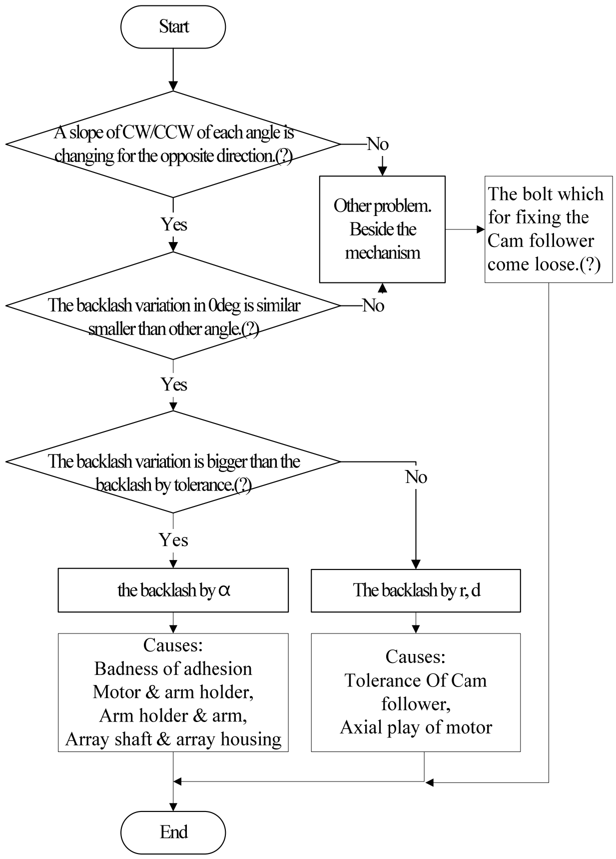


Fig. 2 Flow chart for the backlash analysis.

5. Conclusions

To develop an accurate and reliable diving mechanism of an ultrasonic wobbling transducer for volumetric imaging, the backlash was analyzed theoretically and its diagnosis scheme was presented as a flow chart. Following the scheme in the flow chart, the cause of the backlash in test models could be identified, which thus verified the validity of the diagnosis scheme. The scheme can be utilized to realize a more reliable wobbling mechanism of 3D ultrasonic transducers.

References

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