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A Study for Generating Elastic Shear Waves Having High Directivity Based on FEM Simulations

指向性の高い横波弾性波生成の有限要素法に基づく検討

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1. Background

Recently, elastic share waves have been used for various medical ultrasound imaging, e.g. the spinal cord and the heart. Especially, share waves are used for the latest real-time elastography systems as an important diagnostic criterion [1][2]. Generally, when we supply stress in tissue along a certain direction, arising share waves spread like a cone around the stress direction [3]. This phenomenon is unfavorable for fine imaging.

2. Aims

In order to properly send elastic share waves to the ROI, we study a method for generating elastic share waves with high forward directivity. We examine that excitation of stress distributions with even function and odd function. Generally, by supplying stress along a certain direction on two-dimensional surface, a stress distribution with even function is formed on it. On the other hand, by generating odd functioned .stress distribution causes the superposition of the arising two stress patterns having mutually inverse phases, and hence it is expected that the shear waves with high directivity are generated.

3. Methods

Using the input stresses with the spatial distributions in **Fig. 1** and with the temporal distributions in **Fig. 2**, we examined the directivity of the generated share waves using the PZFlex, which is a standard FEM cord for analysis of ultrasound propagation. In the simulations, we stretched the spatial gap g [m], which is a no stress portion and is placed on the center of the input stress distribution, and varied the time duration of the input stress pulse T [s]. In the analysis, we use the scalar potential φ and the vector potential $\mathbf{A}$=［A_1, A_2, A_3］. Particle velocity vector, i.e. temporal derivative of displacement can be formulated as follows:

$$\dot{\mathbf{U}} = \mathrm{grad}\phi + \mathrm{rot}\mathbf{A} .$$

Since φ corresponds to the longitudinal wave and the $\mathbf{A}$ corresponds to the share wave, we can compute the quantity of the share wave by evaluating the rotation of $\mathbf{U}$ obtained using the PZFlex because of $\mathrm{rot}(\mathrm{grad}\phi) = \dot{0}$. The propagation material was modeled as a living soft tissue shown in **Fig. 3**, and the parameters are adjusted as follow: The density is 1000 kg/m^2, the velocity of a longitudinal wave is 1500 m/s and the velocity of share wave is 1 m/s, width is 400 mm, height is 200 mm, and aperture width is 30 mm.

4. Results

Figure 4 indicates the quantity of the generated share waves for various g, and **Fig. 5** indicates the intensity of the share waves. Additionally, **Fig. 6** indicates the quantity of the generated share waves for various T, and **Fig. 7** indicates the intensity of the share waves. From these results, as g is decreased, the directivity becomes high, and as g is increased, the intensity becomes high. And as T is increased, the directivity becomes high and the intensity become low.

5. Conclusion

From the above results, we know that for small g and long T, the intensity of those are low, the superposition holds properly and the high directivity is actualized. In the future, we are going to expand these two-dimensional results into the three-dimensional problem including two-dimensional excitation system.

References

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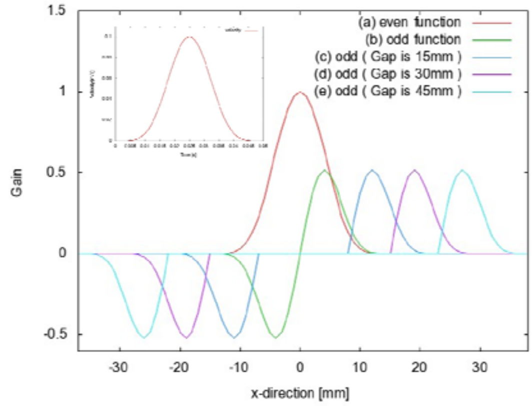

Fig 1. Spatial stress distributions with various Gap.

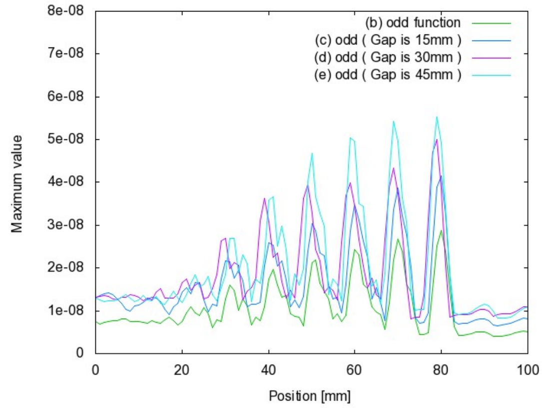

Fig 5. Intensity of the share waves for various Gap.

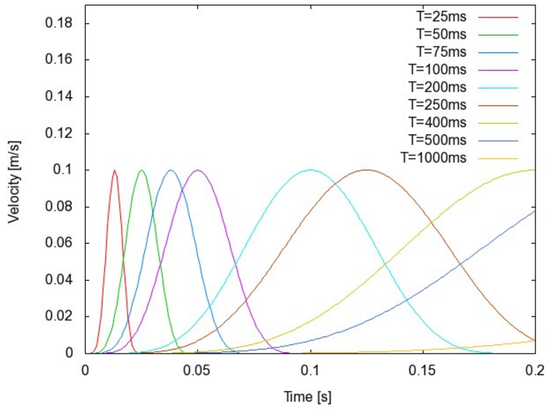

Fig 2. Temporal stress distributions with various *T*.

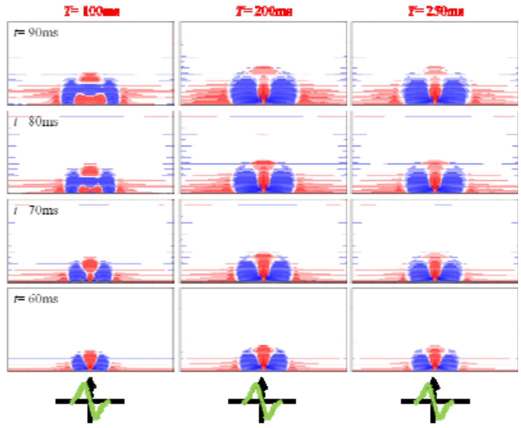

Fig 6. Generating process of share wave for various *T*.(t=60~90ms)

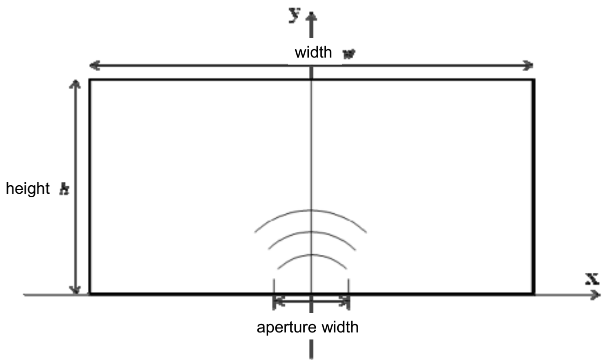

Fig 3. Two-dimensional simulation model of living soft tissue.

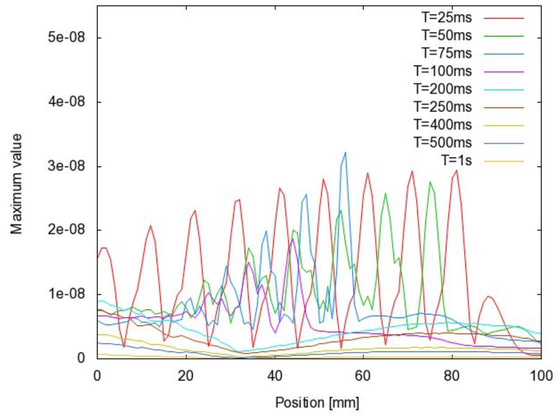

Fig 7. Intensity of the share waves for various *T*.

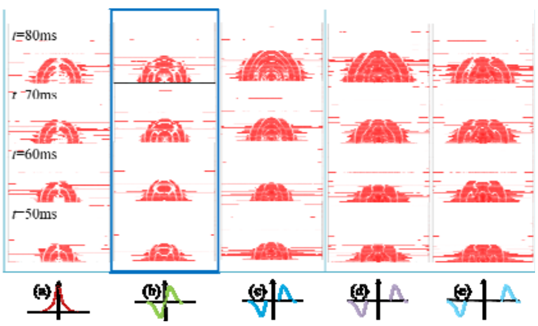

Fig 4. Generated share wave patterns for various Gap (t=50～80ms).