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Application of Guided Acoustic Waves for Inversion Calculation of Material Properties in Bones

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1. Abstract

Osteoporosis is a widespread and growing clinical problem with the global aging population increases. Therefore. this paper reports for the first time on inverse estimation of several bone properties from guided-wave measurements in bi-layered bone samples.

This study is focused in establish the quality of the bone material properties measured platform, to achieve the goal of quantitative assessment of material properties. The method is based on three steps: the modeling with bi-layer bones phantoms with guided wave on reduction of bone mass, then a laser ultrasound technique is used to measure the experiment data, finally, combined with theoretical dispersion relation and experimental dispersion relation, using global optimization of particle swarm algorithm to inverse estimation of several bone properties.

2. Theoretical Medol

The theoretical model is based on Partial Wave Expansion Method (PWE) [2], The guide wave propagation system is give as composition of many partial wave equation, using superposition method and assuming the boundary conditions, such as Fig. 1. The dispersion relation can be obtained according to the derivation in Fig. 2.

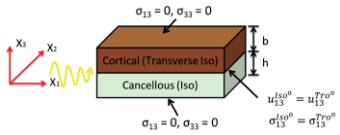

Fig. 1 Guided Waves propagating in bi-layered model

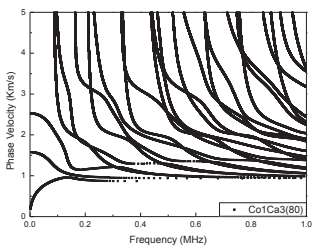

Fig. 2 Theoretical dispersion relations

3. Experimental Measurements

3.1 Samples

In this study, the material of all samples is bi-layered bone phantom(Sawbones, Vashon Island, Washington USA). The total of nine are plate. Specimen is composition of different cortical bone thickness and Cancellous bone density. The Cortical bone is given as transverse isotropic, and the Cancellous bone is given as isotropic.

3.2 Experimental Setup

The measurement configuration is depicted on Fig. 3. The emitter is used by Laser to scan along the length with a straight beam, The receiver is used by longitudinal transducer. This technique in which is called laser ultrasound technique.

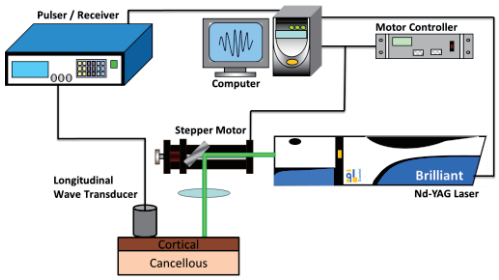

Fig. 3 Experimental configuration

3.2 Signal Processing

The multichannel time series are transformed in the (phase velocity C, frequency F) plane. One cycle of measurements consists of the sequential excitation of laser multiple emitters and yields time series signals. First, the time series are Fourier transformed with respect to time and then converting formula in Fig. 4. Measured dispersion compared with theoretical dispersion in Fig. 5.

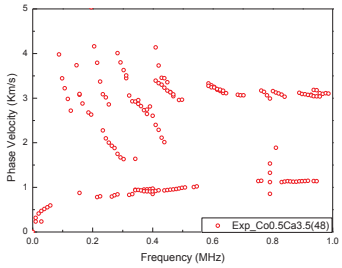

Fig. 4 Measured dispersion relations

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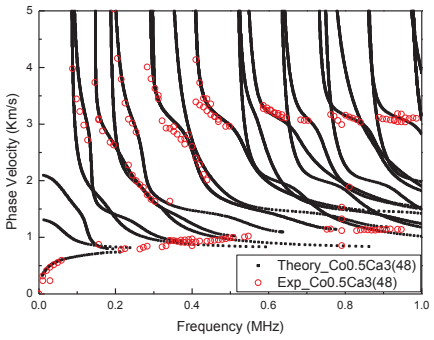

Fig. 5 Theoretical dispersion compared with measurement

4. Inversion technique

The Architecture of Inversion technique is depicted on Fig. 6. Reconstruction of density and thickness is carried out by minimizing the error function ε defined as the square differences between experimental dispersion curve and Theoretical dispersion curve. The optimization is used by Particle swarm optimization method.

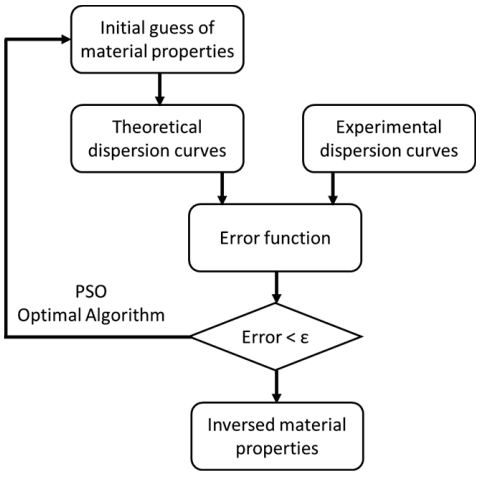

Fig. 6 Architecture of Inversion technique

5. Result

First, results on all plates are presented. The inversed dispersion results is obtained for the one of all plates in Fig. 7. In Table I, the estimated thickness is compared to the reference thickness. An optical microscope measurements vary typically within 0.02 mm in the area of measurements. Note that the variability of the estimated thickness is also at most 0.12 mm. The relative error on thickness was lower than 15%, the estimated density is compared to the reference density. The reference density is provided by the Sawbones company. Note that the variability of the estimated thickness is also at most 0.01 mm. The relative error on thickness was lower than 3%.

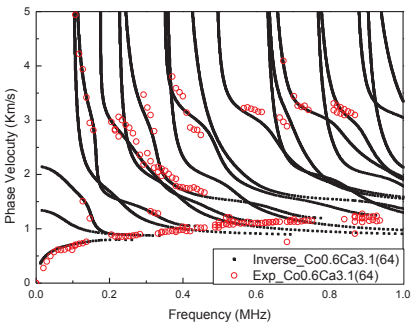

Fig. 7 Dispersion of bone phantoms inversed results

Table I. Three variables inversed results

Sample	Cortical			Cancellous					
	Thickness (mm)		Error	Thickness (mm)		Error	Density (g/cm³)		Error
	Ref.	Inv.		Ref.	Inv.		Ref.	Inv.	
Co0.6Ca3.1(64)	0.6	0.520	13%	3.1	3.062	1.4%	0.64	0.648	1.2%
Co1.3Ca3.4(48)	1.3	1.384	6%	3.4	3.339	1.8%	0.48	0.489	1.9%
Co1.6Ca3.2(80)	1.6	1.472	8%	3.2	3.229	0.9%	0.80	0.807	0.8%

6. Conclusions

- An inversion procedure is developed based on partial wave analysis (PWA) accounting for bi-layered bone structure consisted of transverse isotropic cortical bone and cancellous bone with various porosity.
- With the currently developed inversion procedure together with measurement of dispersions, simultaneous prediction of material properties is made possible for : Cortical thickness, Cancellous density, Cancellous thickness.
- Accuracy for the current inversion parameters are: Cancellous density : 3% ↓ (0.01 g/cm3), Cortical thickness : 15% ↓ (0.08 ~ 0.12 mm).

References

1. Petor Moilansn, "Ultrasonic guided waves in bone," IEEE Ultras. Freq. Conte., 55(6), pp.1277-1286, 2008.
2. Chih-Yen Chen, Che-Hua Yang, "Application of Guided Acoustic Waves for Modeling of Bone Properties," National Taipei Univ. of Technology, 2013.