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Application of wavelet transforms to mode visualization by laser speckle interferometry

振動モード可視化システムへのウェーブレット変換の導入

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1. Introduction

Piezoelectric resonators, in particular quartz resonators, are widely used in electronic devices such as mobile phones. The finite element method (FEM) is usually used for designing them, and measuring the vibration mode shapes experimentally is very important. The reliability of the design is ensured by comparing the calculated and experimental results. A number of methods for plotting the mode shapes of piezoelectric resonators have been developed [1-3].

Previously, methods for visualizing the mode shapes at a high speed used a combination of surface interferometry of scattered light, that is, speckle and image processing [4-8]. The change in intensity corresponds to the displacement of vibration. The speckle images on the quartz plate are captured with a CCD camera placed over the plate to obtain vibration distribution through image processing.

We introduced the noise reduction mechanism using wavelet transforms to the mode visualization system and evaluated its effectiveness.

2. Laser speckle interferometry

A diagram of the system to measure vibration distribution is shown in Figure 1. The speckle is generated by irradiating the device under test (DUT) surface with a collimated laser beam. Adjusting the angle of laser incident, and in-plane and out-of-plane vibration can be measured individually. The resonance frequency is measured by a network analyzer and DUT is driven by a signal generator. Obtaining two speckle patterns in vibrating from a CCD camera and calculating them using the differential or correlation filter, the vibration distribution can be obtained [9-10].

The laser used in the measurement, collimated by a collimating lens, generates a visible-wavelength beam; the optical wavelength is 655 nm, and the CCD camera has a 16-bit brightness resolution [11].

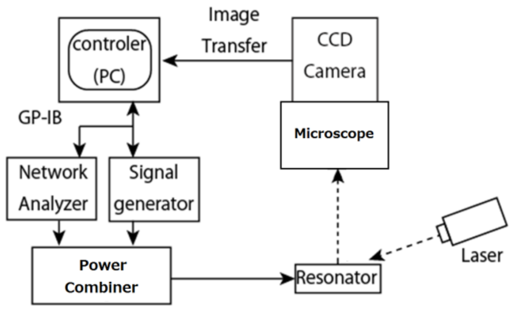


Fig. 1. Block diagram of measurement system

3. Wavelet transforms

With respect to the laser speckle method, the brightness difference from the measurement environment is reflected as the noise of the vibration distribution image according to its principle. The fact causes the decrease of measurement sensitivity, making it difficult to measure the vibration distribution. For this reason, we introduced a noise reduction mechanism using wavelet transforms to the measurement system. Wavelet transforms is a frequency analysis technique used in large fields of engineering such as signal processing [12-13].

The image data is given as two-dimensional discrete data $f(m,n)$ which is regarded as the scaling coefficient of level 0 $s_{m,n}^{(0)}$ [14]. First, discrete wavelet transforms in the horizontal axis is calculated, then discrete wavelet transforms to the coefficient in the vertical axis is done. By discrete wavelet transforms to the scaling coefficient of level j $s_{m,n}^{(j)}$, $s_{m,n}^{(j)}$ is unfolded to the following four components.

$$s_{m,n}^{(j+1)} = \sum_{l}\sum_{k} \overline{p_{k-2m}}\,\overline{p_{l-2n}} s_{k,l}^{(j)}$$

$$w_{m,n}^{(j+1,h)} = \sum_{l}\sum_{k} \overline{p_{k-2m}}\,\overline{q_{l-2n}} s_{k,l}^{(j)}$$

$$w_{m,n}^{(j+1,v)} = \sum_{l}\sum_{k} \overline{q_{k-2m}}\,\overline{p_{l-2n}} s_{k,l}^{(j)}$$

$$w_{m,n}^{(j+1,d)} = \sum_l \sum_k \overline{q_{k-2m}}\,\overline{q_{l-2n}} s_{k,l}^{(j)},$$

where $w_{m,n}^{(j+1)}$ is the wavelet unfolded coefficient and p_k and q_k are the constants given by the series of Daubechies. Of these unfolded components, only $s_{m,n}^{(j+1)}$ is unfolded to four components until level J.

The formal characteristic of the signal generally enables to be reproduced using a few unfolded coefficients, then the unfolded coefficients smaller than the threshold are replaced 0 as noise components. As a result, the signal is reconstituted by the following expressions.

$$\begin{aligned} s_{m,n}^{(j)} = \sum_k \sum_l \Big[& p_{m-2k} p_{n-2l} s_{k,l}^{(j+1)} \\ & + p_{m-2k} q_{n-2l} w_{k,l}^{(j+1,h)} \\ & + q_{m-2k} p_{n-2l} w_{k,l}^{(j+1,v)} \\ & + q_{m-2k} q_{n-2l} w_{k,l}^{(j+1,d)} \Big] \end{aligned}$$

4. Results

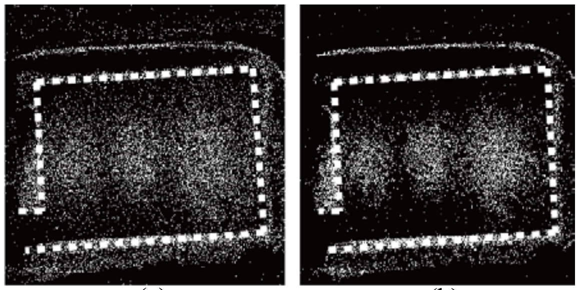
To evaluate the effect of the noise reduction mechanism using wavelet transforms, we compared the results using the differential filter and the noise reduction mechanism. The object used for the experiment was the 9.8 MHz SMD 3225-type AT-cut quartz resonator. We measured its third inharmonic mode (f=10.979 MHz). The output power of signal generator is 0 dBm.

Figure 2 shows the results using (a) the differential filter and (b) the noise reduction mechanism. Three vibration regions are confirmed in both results. The noise components exist around the vibration regions in Fig. 2 (a). On the other hand, visibility is improved by using the noise reduction mechanism in Fig. 2 (b).

5. Conclusions

We introduced the noise reduction mechanism using wavelet transforms to the mode visualization system , and improved the visibility.

For optimizing the mechanism using wavelet transforms, further discussion, such as the method of setting the threshold, is necessary.



(a) (b)

Fig. 2. Experimental results for inharmonic mode of the rectangular AT-cut resonator by (a) differential filter and (b) wavelet transforms. Dashed curves represent the shape of the electrode.

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