Viscoelasticity Measuring Method by FBG Equipped Stirrer for Blood Tumors Dissolution

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Abstract: About a removal operation of blood tumors in the brain using the suction pipe performed at medical operation, there is a problem that the blood tumor cannot be sucked because of its viscoelasticity. We have developed self-sensing actuator which reduces operation time by measuring viscoelasticity of the blood tumor and performing the medical treatment at the same time. On the other hand, the viscoelasticity characteristic has not been completely clarified yet since it is difficult to measure the viscoelasticity of a blood tumor in the living body. In the preceding study, a device to stir blood tumors during medical treatment has not been developed yet. In this study, a Fiber Bragg Grating strain sensor was installed to the stirring device for blood tumors dissolution and viscoelasticity of the blood tumor was measured and evaluated.

Key-Words: *Fiber Bragg Grating (FBG), Viscoelasticity, Sensor, Actuator, Medical Device*

1. Introduction

Endoscopic surgery using suction pipe is one of the current methods for removing blood tumor in the brain. In this operation, opening a small hole of about 1.5[cm] in the bone of skull and observing with a nerve endoscope. Since the influence on the scalp and brain can be reduced and the operating time can be shortened, the usage rate of the nerve endoscope is rapidly increasing. However, the blood tumor has a high viscosity in general, some cases not be enough aspiration. Therefore, if viscoelasticity measurement can be performed while stirring inside the suction pipe as shown in Figure1, which could not be suctioned can be more effectively dissolved and it is considered to be possible to sucked. From previous studies, stirring devices for blood tumor removal has be developed and its effects has been confirmed. In this research, we aim to develop a device that can measure hardness and viscoelasticity of blood tumor while stirring.

2. Viscoelasticity measurement device and measuring system

2.1 Viscoelasticity measurement device

A diagram of the viscoelasticity measuring device is shown in Figure 2. A brass plate having a length 50[mm], a width 3[mm] and a thickness 0.5[mm] was bonded to the mechanism of the displacement magnifying. In addition, a laminated piezoelectric element mounted on the mechanism of the displacement magnifying for vibrating the beam. As a sensor for measuring the strain change of the vibrating beam, an

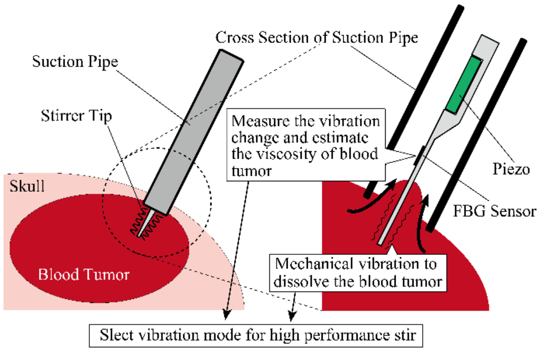

Figure 1 Schematic image of blood tumor removing operation.

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FBG sensor was attached to the position of 15[mm] from the base of the beam. The reference Bragg wavelength of the FBG sensor is 1565[nm].

2.2 Measuring system

A schematic diagram of measuring system and a photograph of experiment image are shown in Figure 3 and 4. Infrared rays having a wavelength of 1500 to 1650[nm] are irradiated from the light source. FBG sensing technologies are investigated in recent years because of their attractive characteristics such as immunity of electro-magnetic interference and compact size [1-3]. The irradiated infrared light passes through the optical fiber, the circulator, and reaches the FBG sensor affixed to the beam. FBG sensor is a sensor of the optical fiber type that changes the wavelength of reflected light depending to the strain. The infrared light reflected from the FBG sensor passes through the circulator and enters the WDM filter. The WDM filter has the transition region to the luminance changes in proportion to the change in the wavelength of the transmitted light [2-3]. The transmitted infrared ray through WDM filter is incident on the photodetector (PD), and a voltage proportional to the light quantity is outputted. Strain measurement system using WDM filter, it is possible to realize a high speed strain measuring at up to hundreds kHz sampling [4-6].

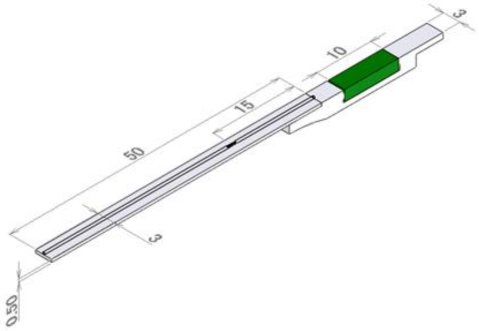

Figure 2 Viscoelasticity measurement device.

2.3 Principle of Viscoelasticity measurement

In this study, Lissajous projection method was used as a method of viscoelasticity measurement. The Lissajous figure for viscoelasticity measurement is plotted the stress-strain curve in general. In this research, we attempt the viscoelasticity measurement by plotting replace input voltage with stress and replace PD sensor output voltage with strain. Then influence of viscosity can be observed by the phase difference between the output voltage of the PD and the input voltage. In the viscoelasticity evaluation according to a general Lissajous figure, the viscoelasticity is evaluated by loss elastic modulus G_1, storage modulus G_2, and phase difference δ between stress and strain. And the following relational expression holds.

$$\frac{G_1}{G_2} = \frac{\sigma_0 / \varepsilon_{\max}}{\sigma / \varepsilon_{\max}} = \tan\delta \qquad (1)$$

where, ε_{max} is maximum strain, σ is stress at maximum strain, and σ_0 is stress at no strain. V is input voltage to piezoelectric element at the time of the maximum output voltage of PD.

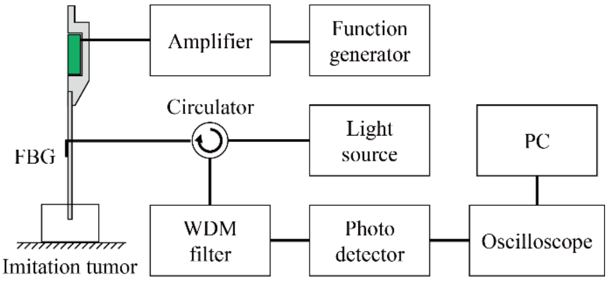

Figure 3 Schematic of strain measuring system of vibrating stirrer.

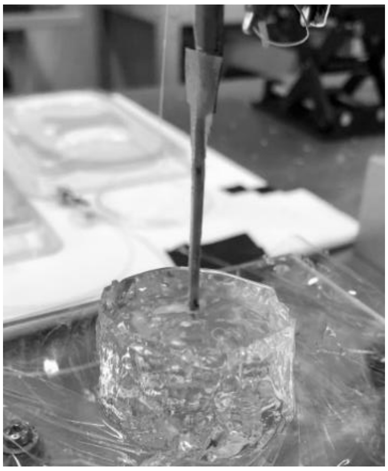

Figure 4 Photo of viscoelasticity measurement experiment.

The V_0 is input voltage at the time of the no voltage of PD. L_{max} is maximum output voltage of PD, and δ is phase difference between the output voltage and input voltage. The output voltage L of the PD is related to the strain ε of the beam and the input voltage V is related to the stress σ, and then the following equation (2) is defined.

$$\frac{G_{p1}}{G_{p2}} = \frac{V_0 / L_{\max}}{V / L_{\max}} = \tan\delta \qquad (2)$$

where G_{p1} represents the ratio of loss energy and represents stickiness of the object. G_{P2} is an incremental component of the internal energy in the object and represents the hardness of the object.

3. Viscoelasticity measurement experiment

As the imitated hematoma, a gelatin jelly with a height of 23 [mm] and a diameter of 40 [mm] was used as the object to be measured. Measurement objects with different hardness were prepared by changing the concentration of gelatin. Gelatin concentrations of 1%, 1.5% and 2% were used for the following experiments. Experiments were conducted by using sinusoidal wave as the input waveform, setting the input frequency to 110[Hz], the input voltage to 90[V], and offset the voltage in the positive direction. The resonance frequency of the device is 140[Hz]. The driving frequency for measurement should be separated from resonance frequency because not affected by phase shift due to the resonance. The beam was stabbed on the top of the gelatin and vibrated. The insert depth x from the top of the gelatin surface was changed to 2.5, 5, 7.5[mm] respectively as shown in Figure 4. The experiment was done once in each conditions. Figure 5, 6, and 7 show the results of the Lissajous diagrams respectively. From the figures, the Lissajous diagrams become smaller with increasing concentration of gelatin over the whole insertion depth. Since the gelatin concentration is related to the viscoelastic, this results suggests that it is possible to discriminate the viscoelastic property.

The δ, G_{p1} and G_{p2} are calculated from the equation (2) and shown in Table 1-3. From the table, the viscosity and elasticity were increased with the increasing the concentration of gelatin. This fact corresponds to the general tendency of gelatin jelly viscosity and elasticity. However, results were changed depending on the inserting depth x, this fact suggests that such as need control the insertion depth in the measuring state.

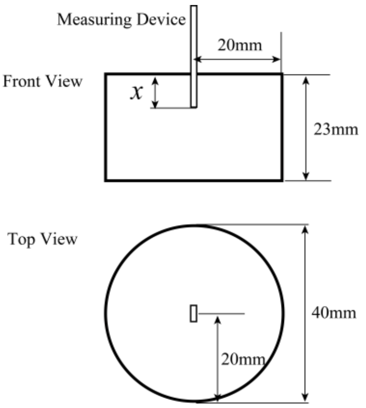

Figure 4 Setup of measuring experiment.

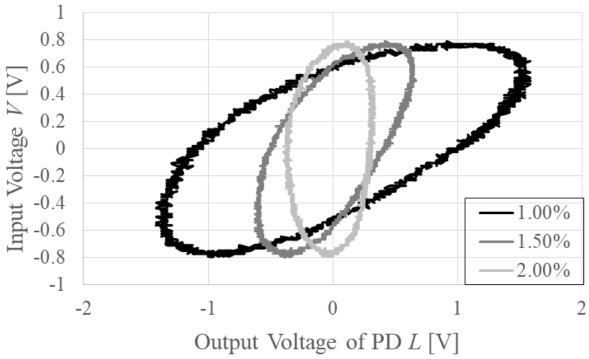

Figure 5 Lissajous figure for calculate the viscoelastic value of jerry in insert depth x =2.5mm.

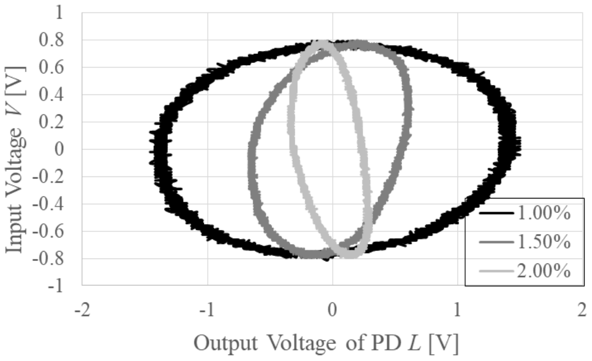

Figure 6 Lissajous figure for calculate the viscoelastic value of jerry in insert depth x =5.0mm.

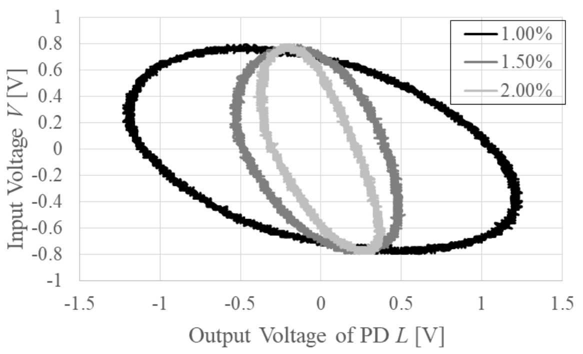

Figure 7 Lissajous figure for calculate the viscoelastic value of jerry in insert depth x =7.5mm.

Table 1 Result in x = 2.5[mm].

Density	G_{p1}	G_{p2}	δ[deg]
1.0[%]	0.40	0.38	46.9
1.5[%]	0.97	0.97	45.0
2.0[%]	2.92	2.67	47.5

Table 2 Result in x = 5.0[mm].

Density	G_{p1}	G_{p2}	δ[deg]
1.0[%]	0.51	0.06	83.4
1.5[%]	1.17	0.83	54.8
2.0[%]	2.75	2.83	44.2

Table 3 Result in x = 7.5[mm].

Density	G_{p1}	G_{p2}	δ[deg]
1.0[%]	0.54	0.44	51.1
1.5[%]	1.29	1.21	46.9
2.0[%]	1.50	2.22	38.5

4. Conclusion

We measured the viscoelasticity of gelatin jelly by the Lissajous figure of the input voltage on the vertical axis and the output voltage on the horizontal axis, using a system that can measure the high-speed strain using the WDM filter and the photodetector. We distinguished between viscosity and elasticity from the relationship between input voltage and output voltage.

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