Measurement System for Mechatronic Property of Biological Electrolyte Solution with Micro-Vibrating Electrode

Takayuki Sekiyama, Shigehiro Hashimoto, Yusuke Morita, Tomohiro Sahara, Yuta Morioka, Teruyuki Yamanari, Kenichi Yamasaki, Hideo Kondo, Aki Nakajima

Biomedical Engineering, Dept. of Electronics, Information, and Communication Engineering, Osaka Institute of Technology, Osaka, 535-8585, Japan
hasimoto@elc.oit.ac.jp

and

Hajime Otani, Hiroji Imamura

Dept. of Thoracic and Cardiovascular Surgery, Kansai Medical University Moriguchi, Japan

ABSTRACT

A new methodology to measure mechatronic property of biological electrolyte solution has been proposed, and measurement system has been designed with a micro-vibrating electrode. The signal was picked up with the designed system as a function of viscosity of the sodium chloride aqueous solution including dextran. The output signal depends on viscosity at higher frequency (>100 Hz), and on frequency at higher viscosity (>0.01 Pa s). The experimental data show that the designed system is effective to measure mechatronic property of biological electrolytes.

Keywords: Bio-measurement, Mechatronic property, Biological electrolyte solution, Micro-vibrating electrode, Viscosity, Frequency

1. INTRODUCTION

A biological body includes various electrolytes. Some studies tried to analyze the structure of organs with measurement of local electric impedance [1-6]. To avoid the change of structure by movement of ions with a direct current, an alternating current is applied to measure electric impedance of electrolyte solutions. In the previous study, a new methodology to measure local electric impedance has been proposed, and measurement system has been designed with a micro-vibrating electrode [7,8]. In the present study, a new methodology to measure mechatronic property of biological electrolyte solution has been proposed, and measurement system has been designed with a micro-vibrating electrode.

2. METHODS

Measurement of local electric impedance

The impedance between two electrodes soaked in an electrolyte solution varies with the distance between them. When the distance oscillates sinusoidally with a mechanically vibrating electrode, the impedance oscillates, too. The oscillation corresponds to the variation of impedance of the local space, where the electrode is vibrating (Fig. 1). The amplified variation was analyzed with spectrum and the amplitude at the corresponding frequency was measured. The equations to calculate local impedance from the output signal are described in the previous study [7].

Fig. 1: One electrode is fixed at point A and the other electrode is vibrating between B and C.

Electrode

The electrode was made of a glass micro-capillary filled with a potassium chloride aqueous solution (3 mol/L). A platinum wire was inserted in the center of the capillary. The diameter of the tip of the capillary is 0.04 mm. One of the electrodes was vibrated with a piezoelectric actuator (Fig. 2).

Measurement system

The measurement system consists of an oscillator, an amplifier, a spectrum analyzer, a phase-contrast optical microscope, a charge-coupled device camera, a recorder, and a monitor.

Electrolyte solution

The manufactured system was applied to measure electrolytes solution. The saline solution was substituted for biological electrolyte solution. The sodium chloride aqueous solution of 0.9 percent concentration was modified with dextran (<35 percent) to make variation in viscosity (0.001-0.6 Pa s).

To evaluate the effect of viscosity independently of impedance of electrolyte solution, two kinds of solution were prepared. One is solution with dextran: viscosity of 0.28 Pa s and sodium chloride concentration of 3 percent. The other is sodium chloride aqueous solution, which has same impedance as the dextran solution with stationary electrodes.

The performance has been tested at 25 degrees centigrade.

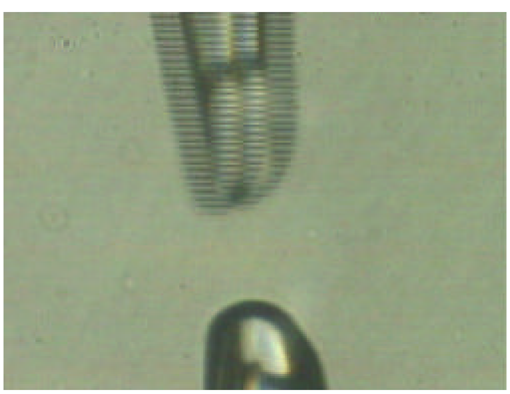

Fig. 2a: Vibrating electrode (upper) and stationary electrode (lower). Distance between two electrodes is 0.05 mm, and the amplitude of vibration is 0.02 mm.

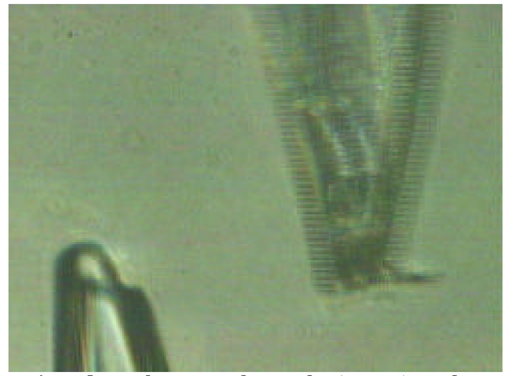

Fig. 2b: Vibrating electrode (upper) and stationary electrode (lower). Distance between two electrodes is 0.15 mm, and the amplitude of vibration is 0.02 mm.

3. RESULTS

Figure 3 exemplifies power spectra of the output voltage, when the electrode is vibrating at 150 Hz and the input voltage oscillates at 450 Hz. The spectrum at 60 Hz is the signal, which comes from electric power line. The local impedance was calculated from the spectrum at the frequency of vibration of the electrode.

The experimental data show that impedance increases with viscosity of sodium chloride aqueous solution (Fig. 4).

Figure 5 shows that local impedance with the vibrating electrode increases with frequency of the vibrating electrode. The tendency is remarkable in the sodium chloride aqueous solution including dextran of higher viscosity (>0.01 Pa s). Figure 6 shows that the local impedance with the vibrating electrode increases with viscosity of the solution. The tendency is remarkable with the vibrating electrode at higher frequency (>100 Hz).

Figure 7 shows experimental results, when total impedance of the circuit through solution including dextran was adjusted to that through saline solution with additional sodium chloride (0.26 mega-ohm).

Amplitude of vibration of the electrode was kept constant, which was confirmed with the optical microscope.

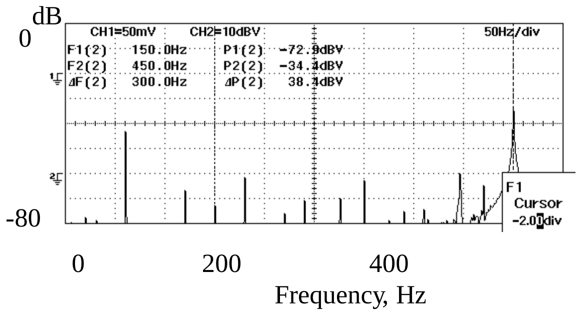

Fig. 3: Power spectra of the output voltage: vibration of electrode, 150 Hz: oscillation of input voltage, 450 Hz.

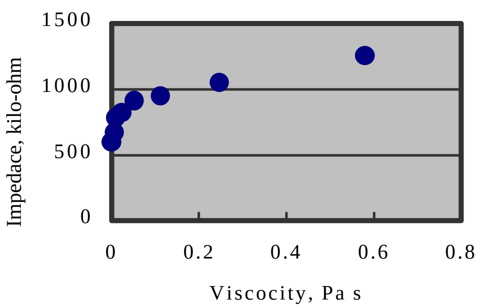

Fig. 4: Impedance with stationary electrodes as a function of viscosity.

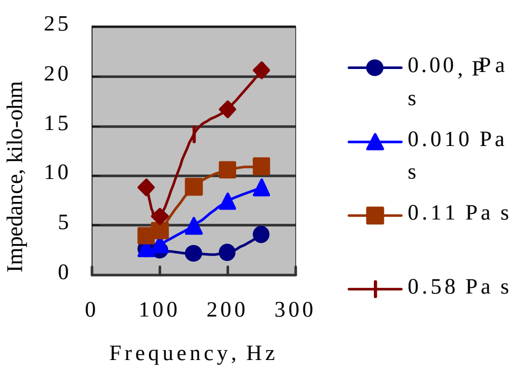

Fig. 5: Local impedance with vibrating electrode as a function of frequency.

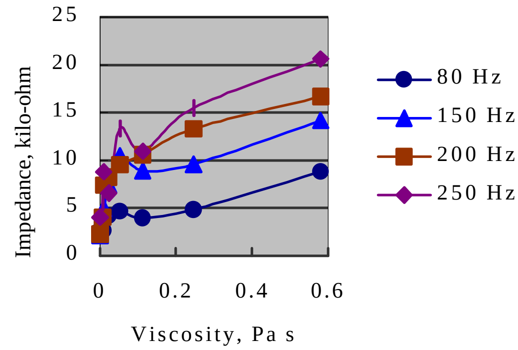

Fig. 6: Local impedance with vibrating electrode as a function of viscosity.

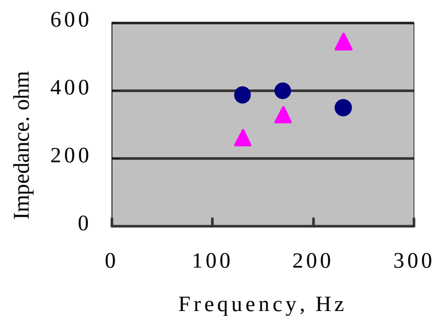

Fig. 7: Impedance with vibrating electrode as a function of frequency: 0.001 Pa s, circle; 0.28 Pa s, triangle.

4. DISCUSSION AND CONCLUSION

An electrode should be minimized to measure local impedance. The minimized electrode has high impedance, which varies with its morphology. A measurement system with vibrating electrode has been proposed in the previous study to pick up a signal independently of impedance of electrodes [7].

The previous study shows that impedance calculated from the output signal increases with the decrease in the concentration of sodium chloride in the solution. Impedance also increases with the amplitude of vibration of the electrode. The previous results also show that impedance depends on the variation of electrolytes and that the ratio of impedance between the potassium chloride (0.1 percent) and sodium chloride (0.1 percent) is similar to the value calculated from electric conductivity of chronological scientific tables [8].

The vibrating movement of the electrode might change the electrical property of an electrolyte solution. The effect of the vibration was evaluated with experiments, in which the output signals were compared at various frequencies of the electrode and at various viscosity of the electrolyte solution.

At lower vibrating frequencies (<100 Hz) of the electrode, both the frequency and viscosity do not affect output electrical signals.

At lower viscosity (<0.01 Pa s) of the electrolyte solution, both the frequency and viscosity do not affect output electrical signals of the present system.

On the other hand, the output electrical signal depends on viscosity at higher vibrating frequencies (>100 Hz). The output signal also depends on frequency at higher viscosity (>0.01 Pa s). The calculated impedance increases with frequency and with viscosity. This system can be applied to measure local viscosity of an electrolyte solution.

Impedance of an electrolyte solution depends on mobility of ion in the solution. The mobility depends on viscosity of the solution. The stirring with vibrating electrode might affect the mobility.

The experimental data show that the designed system is effective to measure mechatronic property of biological electrolytes.

5. ACKNOWLEDGMENT

This work was supported in part by a Grant-in-Aid for Scientific Research from the Japanese Ministry of Education, Culture, Sports, Science and Technology.

6. REFERENCES

[1] S. Hashimoto, N. Nagano, Y. Murashige, S. Yamauchi, "Measurement of cell distribution in organs with lissajous of impedance", ***Proceedings of the 5th World Multiconference on Systemics, Cybernetics and Informatics***, Vol. 10, 2001, pp. 443-447.

[2] Y. Wang, D.R. Haynor, Y. Kim, "A finite-element study of the measured impedance change in impedance cardiography", ***IEEE Transactions on Biomedical Engineering***, Vol. 48, No. 12, 2001, pp. 1390-1401.

[3] C. Grosse, M. Tirado, "Improved calibration of impedance analyzers for measurement on highly conductive liquids", ***IEEE Transactions on Instrumentation and Measurement***, Vol. 50, No. 5, 2001, pp. 1329-1333.

[4] J.D. Weiland, D.J. Anderson, "Chronic neural stimulation with thin-film, iridium, oxide electrodes", ***IEEE Transactions on Biomedical Engineering***, Vol. 47, No. 7, 2000, pp. 911-918.

[5] J.Z. Tsai, H. Cao, "Dependence of apparent resistance of four-electrode probes on insertion depth", ***IEEE Transactions on Biomedical Engineering***, Vol. 47, No. 1, 2000, pp. 41-47.

[6] J.Z. Tsai, J.A. Will, S.H.-V. Stelle, H. Cao, S. Tungjitkusolmun, Y.B. Choy, D. Haemmerich, V.R. Vorperian, J.G. Webster, "In-vivo measurement of swine myocardial resistivity", ***IEEE Transactions on Biomedical Engineering***, Vol. 49, No. 5, 2002, pp. 472-483.

[7] S. Yamauchi, S. Hashimoto, Y. Murashige, H. Oku, M. Sakai, T. Sahara, H. Otani, H. Imamura, "Measurement system for local electric impedance of gel with vibrating electrode". ***Proceedings of the 6th World Multiconference on Systemics, Cybernetics and Informatics***, Vol. 13, 2002, pp. 314-319.

[8] T. Sekiyama, S. Hashimoto, S. Yamauchi, Y. Morita, D. Kozaki, T. Sahara, Y. Wu, H. Otani, H. Imamura, "Measurement system for local electric impedance of biological electrolyte solution with micro-vibrating electrode", ***Proc. World Congress on Medical Physics and Biomedical Engineering***, CD-ROM, 2003.