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Automatic Sensing Device of Electrical Characteristics of Living Trees

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Abstract—The electrical impedance of a living tissue reflects its cell construction and physiological activity. For this purpose we developed an automatic sensing device of electrical tissue characteristics. The system is composed of a part measuring impedance at multifrequency points and a part analyzing parameters of dispersion of bioelectrical impedance. Impedances are measured at eight frequency points of 1 kHz–500 kHz. The parameters for Cole-Cole arc's law are determined automatically by a personal computer program.

I. INTRODUCTION

THE electrical impedance, dielectric constant, and resistivity of a living tissue reflect its cell construction and physiological activity [1], [2]. The research to measure the activity of living trees has been proceeding using bioelectrical impedance. In these cases, it is necessary to measure the frequency characteristics of electrical impedance rapidly and easily. After obtaining the frequency characteristics, parameters of dielectric dispersion systems can be determined, and the condition for activity of trees can be estimated. For this purpose we developed an automatic sensing device of electrical tissue characteristics. The system is composed of a part measuring impedance at multifrequency points and a part analyzing parameters of dispersion systems of bioelectrical impedance. Electrical impedances are measured at several frequency points, and equivalent resistance and equivalent reactance at each frequency point are obtained by a remote operation. The parameters for Cole-Cole arc's law are determined automatically by a personal computer program. This paper discusses the electrical properties of trees and the construction of sensing devices for them.

II. ELECTRICAL CHARACTERISTICS OF LIVING TREES

The electrical impedances of trees after being cut down are shown in Fig. 1. These results satisfy Cole-Cole arc's law the same as most biological tissues, which are represented by the following equation [1]:

$$Z = R_s + jX_s = \frac{Z_0 - Z_\infty}{1 + (j\omega\tau_m)^\beta} \quad (1)$$

where $Z_0 = \lim_{\omega \rightarrow 0} Z$, $Z_\infty = \lim_{\omega \rightarrow \infty} Z$, τ_m is the central relaxation time representing the relaxation phenomenon, β is

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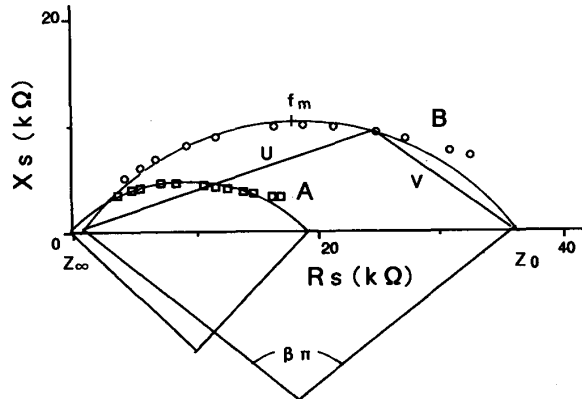


Fig. 1. Impedance vector loci of tree. (a) Five days after being cut down. (b) Seven days after being cut down.

a parameter representing the degree of deviation from Debye type, and ω is an angular frequency. This type of impedance can be expressed by the parallel equivalent circuit in Fig. 2. The parameters of the circuit are given as follows [3]:

$$\frac{1}{Z - Z_\infty} = \frac{1 + (j\omega\tau_m)^\beta}{R_2} = G_2 + g_p + j\omega C_p \quad (2)$$

where $G_2 = 1/R_2$, $G = 1/Z_\infty$,

$$g_p = \omega^\beta g_0, \quad c_p = \omega^{\beta-1} c_0 \quad (3)$$

$$g_0 = G_2 \tau_m^\beta \cos(\beta\pi/2) \quad (4)$$

$$c_0 = G_2 \tau_m^\beta \sin(\beta\pi/2) \quad (5)$$

where g_p and c_p are conductance and capacitance based on polarization, respectively. Fig. 2(b) is also the equivalent circuit satisfying the Cole-Cole circular arc's law. Resistors R_e and R_i of ionic conduction are resistances of the outer and inner cellular solution, respectively. If U and V in Fig. 1 are evaluated for each measurement value, the ratio V/U is described using a parameter α as follows:

$$V/U = (\omega\tau_m)^\alpha \quad (6)$$

If α equals β of the circular arc, the impedance is described by a linear equation in (1). When $\alpha = \beta$, the impedance is

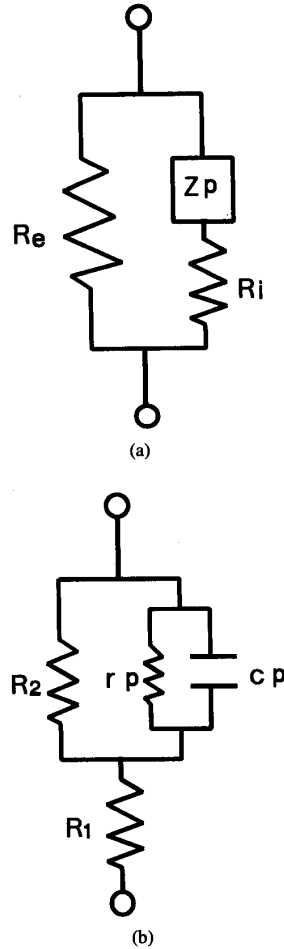


Fig. 2. Equivalent circuit of electrical impedance of tree.

nonlinear and described by the following equation:

$$Z = Z_{\infty} + \frac{Z_0 - Z_{\infty}}{1 + j^{\beta}(\omega\tau_m)^{\alpha}} \quad (7)$$

In the experimental results of some trees, α is almost equal to β . It is experienced that the biological impedance for large currents shows nonlinear characteristics [4]. In these cases, α is not equal to β .

Considering the cell constant K of the electrode, the results can be normalized in terms of the impedance z_n per unit length as follows:

$$Z = K z_n \quad (8)$$

For the electrodes in Figs. 3(a) and 3(b), the cell constants K are given as follows:

$$K_{n1} = \frac{\log(d_1/r_1)}{\pi l_1 + 4\pi \log(d_1/r_1)} \quad (9)$$

$$K_{n2} = \frac{\log(d_2/r_2)}{\pi(l_2 + r_2 \log(d_2/r_2))} \quad (10)$$

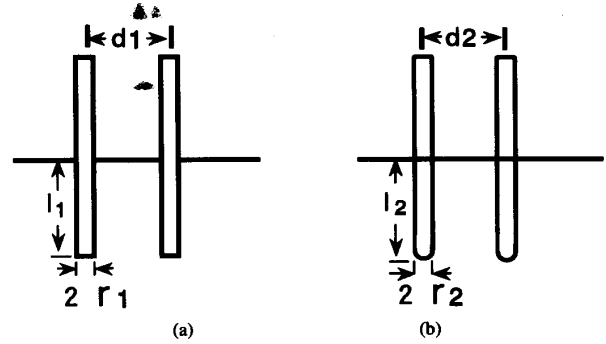


Fig. 3. Parallel rod electrode.

When $d_1 = l_1 = 20$ mm, and $2r_1 = 3$ mm, the value of the cell constant in (9) is 0.331. The experimental result using electrolytic solution gave the value 0.332. Both results almost agreed with each other. The limitation on size of test material influences the cell constant. The difference between (9) and (10) may be less than a few percent for test materials larger than 50 mm in diameter.

III. IMPEDANCE MEASURING METHOD

The block diagram of an automatic sensing device of electrical characteristics of trees is shown in Fig. 4. For precise and noise-free determining of impedance and for portability of the device, the frequency-domain method was utilized in this study. Furthermore, the constant current method is used in order to obtain impedance values directly, and the phase sensitive method is applied to the automatic division of resistive component R_s and reactive component X_s [5]. The ranges of frequency from f_1 to f_8 are determined as 1–500 kHz taking account for the frequency characteristic of tree impedance. Measurement frequency points are as follows: 1, 5, 10, 20, 50, 100, 200, 500 kHz, which are supplied by low-distortion sinusoidal waveform oscillators. The exchange of frequencies and phase shifters (PS) can be done manually or automatically by a computer program. A sine wave voltage from an oscillator is converted by a voltage-to-current convertor (VIC) into a sine wave current of constant amplitude to be supplied to the impedance Z . The current value through Z is about 100 μ A (rms). The data R_s and X_s in all frequencies are processed by an analog-to-digital converter (AD) and analyzed as shown in Section IV.

Brass electrodes are used for detecting electrical characteristics, that is, for measuring electrical impedance. The electrode polarization is not a serious problem because the measuring frequencies are high, and tree impedance is high compared with general biological tissues. Electrode type is the rod shown in Fig. 3. Applying the method of rod electrode to living trees means insertion along a small pilot hole. The smaller hole is less invasive and the tissue at the hole will recover after a long period.

Biological impedance is usually accompanied by time variation. Then, frequency characteristics must be measured rapidly. In this system, the elapsed time required for measurement in every frequency point is one second for obtaining steady

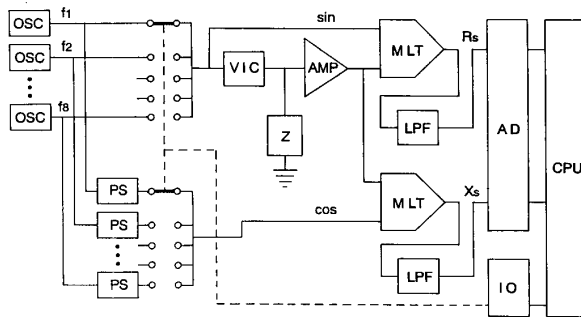


Fig. 4. Block diagram of automatic sensing device of electrical characteristics of trees. VIC is voltage-to-current convertor, PS is phase shifter, MLT is multiplier, LPF is low-pass filter.

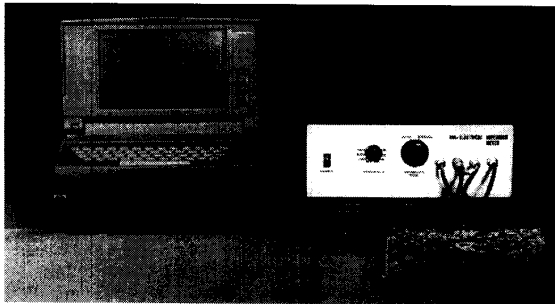


Fig. 5. Photograph of total system.

characteristics, and total measuring time is about 10 s. The impedance are analyzed just after measurement, and the results are shown on the CRT display. The photograph of the total system is shown in Fig. 5.

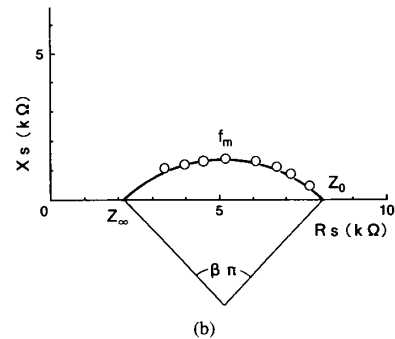
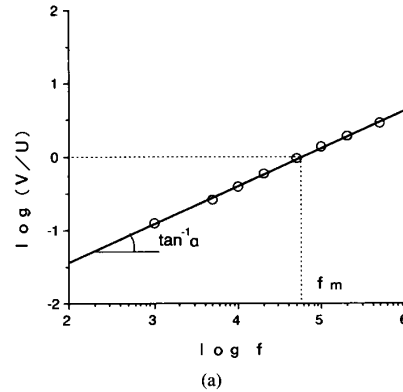
IV. RESULTS AND DISCUSSION

Parallel RC electrical circuits which simulated a tree impedance were measured by this device. One circuit consisted of resistance 20 k Ω and capacitance 100 pF. The other consisted of 40 k Ω and 310 pF. The impedance values are similar ones to trees. The relative errors between the measurement value and theoretical value of the arc size are less than 2%.

This system analyzes the impedance measurement results, and gives the impedance parameters characterizing frequency dispersion and parameters of the equivalent circuit. These results for pine trees just after being cut down are shown in Fig. 6. First, a preliminary check is done from Fig. 6(a) using (6), and α and f_m are determined. Next, the arc's plot is shown in Fig. 6(b), β and Z_0 , Z_∞ are determined, accompanied with the confirmation of appropriateness for all measurement results. Finally, the parameters of equivalent circuits and intrinsic parameters of tissue properties are evaluated and displayed, as shown in Fig. 6(c).

V. CONCLUSIONS

This device is able to measure and analyze bioelectrical impedance, which is required for noninvasive electrical tests



Impedance Parameters	
$Z_0 = 8.03 \text{ k}\Omega$	$z_0 = 24.19 \text{ k}\Omega$
$Z_\infty = 2.17 \text{ k}\Omega$	$z_\infty = 6.54 \text{ k}\Omega$
$F_m = 57.2 \text{ kHz}$	
$\beta = 0.483$	$\alpha = 0.488$
$R_1 = 2.17 \text{ k}\Omega$	$R_2 = 5.86 \text{ k}\Omega$
$r_0 = 3.90 \text{ M}\Omega$	$c_0 = 0.243 \mu\text{F}$
$R_0 = 8.03 \text{ k}\Omega$	$R_1 = 2.97 \text{ k}\Omega$

Fig. 6. Results obtained on microcomputer display. (a) Determination of α and f_m . (b) Cole-Cole arc's plot. (c) Impedance parameters.

of the activity of living trees automatically. The system is compact and easy to handle. We can use this device not only in the laboratory but also in the field. Although the tree impedances vary certainly with the change of activity of trees, they are influenced by many other factors. In that case, it is expected that this method establishes an inspection of living trees on the basis of data from trees and their analyses.

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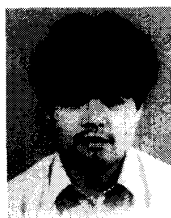
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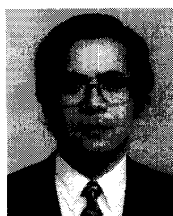
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