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Automatic sensing device of electrical characteristics of living trees

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Automatic Sensing Device of Electrical Characteristic of Living Tree

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Abstract — The electrical impedance of a living tissue reflects its cell construction and physiological activity. For this purpose was developed automatic sensing device of electrical tissue characteristic. The system is composed of a part measuring impedance at multi-frequency points and a part analyzing parameters of dispersion system of bio-electrical impedance. Electrical impedances are measured at eight frequency points of 1kHz to 500kHz. The parameters for Cole-Cole arc's law are determined automatically by personal computer program. If the cell constant dependent electrode size and electrode form is given, resistivity and dielectric constant will be calculated.

INTRODUCTION

The electrical impedance, dielectric constant and resistivity of a living tissue reflect its cell construction and physiological activity [1][2]. The researches to measure the activity of living tree have been proceeding using bio-electrical 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 system could be determined, and the condition for activity of tree could be estimated. For this purpose was developed automatic sensing device of electrical tissue characteristic. The system is composed of a part measuring impedance at multi-frequency points and a part analyzing parameters of dispersion system of bio-electrical 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. Tree satisfies the Cole-Cole arc's law as same as most biological tissues and the parameters for arc's law are determined automatically by personal computer program. This article are discussing the outline of electrical properties of tree and the construction of sensing device for it.

ELECTRICAL CHARACTERISTICS OF LIVING TREE

Equivalent circuit

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

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

where $Z_0 = \lim_{\omega \to 0} Z$, $Z_\infty = \lim_{\omega \to \infty} Z$, τ_m is central

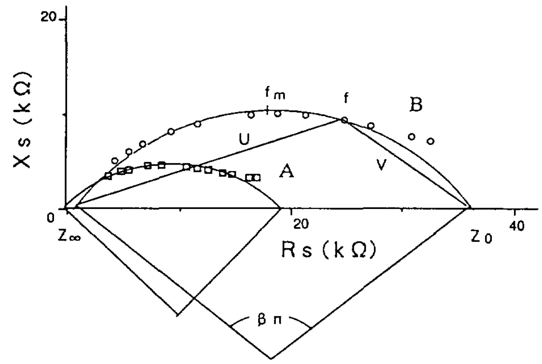


Fig.1 Impedance vector loci of tree.
A : five days after cut down
B : seven days after cut down

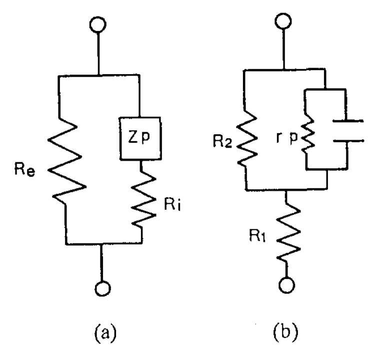


Fig.2 Equivalent circuit of electrical impedance of tree.

relaxation time representing relaxation phenomenon, β is 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]:

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

$$= G_2 + g_p + j\omega c_p$$

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

$$g_p = \omega^\beta g_0 \; , \; c_p = \omega^{\beta - 1} c_0 \tag{3}$$

$$g_0 = G_2 \tau_m{}^\beta \cos(\beta\pi / 2) \tag{4}$$

$$c_0 = G_2 \tau_m{}^\beta \sin(\beta\pi / 2) \tag{5}$$

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:

$$V / U = (\omega\tau_m)^\alpha \tag{6}$$

If α equals β of the circular arc, the impedance is described by a linear Equation (1). When $\alpha = \beta$, the impedance is non-linear and described by the following equation:

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

It is experienced that the biological impedance for large current shows non-linear characteristic [4]. In the experimental results of some trees, α is almost equal to β.

Cell constant of impedance measuring electrode

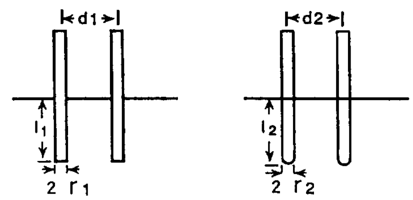
Considering the cell constant of electrode, the results can be normalized in terms of the impedance z_n per unit length as follows:.

$$Z = K z_n \tag{8}$$

For the electrodes shown in Fig.3 a and 3 b, the cell constants K_{n1} and K_{n2} are given as follows:

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

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



(a) (b)

Fig.3 Parallel rods electrode.

When $d_1 = l_1 = 2$ cm, and $2\ r_1 = 0.3$ cm, the value of cell constant in Eq.(9) is 0.331. The experimental result using electrolytic solution gave the value of 0.332. Both results almost agreed with each other. The limitation on size of test material influences to the cell constant. The difference from Eq.(9) or Eq.(10) may be less than a few percent for test material of larger than 5 cm in diameter.

IMPEDANCE MEASURING METHOD

The block diagram of impedance measuring circuit is shown in Fig.4. For precise and noise-free determining of impedance and for portability of device, frequency domain method was utilized in this study. Furthermore, constant current method is used in order to obtain impedance value directly and phase sensitive method is applied to the automatic division of resistive component Rs and reactive component Xs [5]. The block diagram of total system is shown in Fig.5. The ranges of frequency f are determined as 1kHz to 500 kHz taking account for the frequency characteristic of tree impedance as shown in Fig.1. Measurement frequency points are as follows: 1, 5, 10, 20, 50, 100, 200, 500 kHz, which are supplied by low distortion sinusoidal wave form oscillators. The exchange of frequencies can be done manually or automatically by computer program. The current value through the test materials is about $100\,\mu$A (rms).

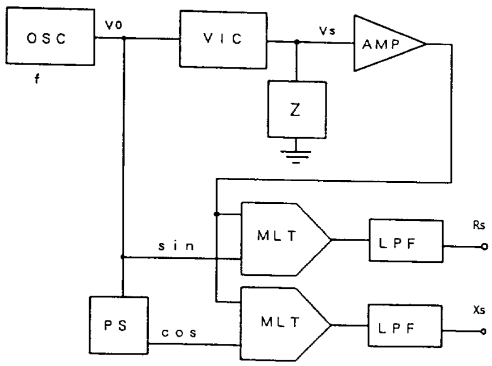


Fig.4 Block diagram of impedance measuring circuit.
VIC is voltage to current convertor, PS is phase shifter, MLT is multiplier, LPF is low pass filter.

Biological impedance is usually accompanied with 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 characteristics and total measuring time is about 10 s. The impedance analyses are proceeded just after measurement and the results are shown on the CRT display. The photograph of total system is shown in Fig.6. This device is operated by battery power and can be used for trees in field.

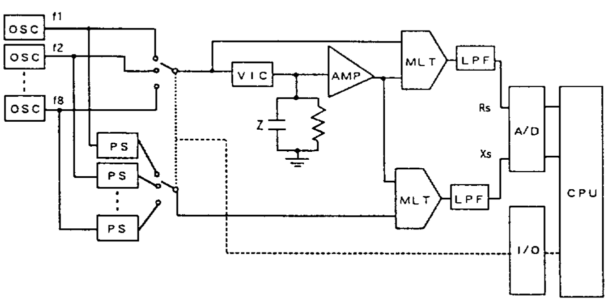


Fig.5 Block diagram of automatic sensing device of electrical characteristic of tree.

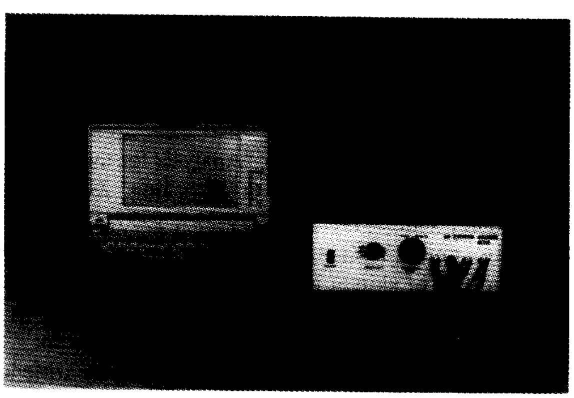
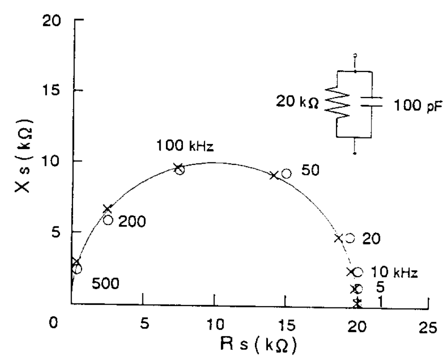


Fig.6 Photograph of total system.

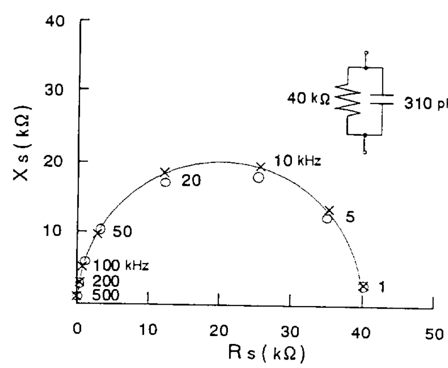
RESULTS AND DISCUSSIONS

Measurement of model

Parallel R-C electrical circuits which simulated a tree impedance were measured by this device. The impedance values are similar one to trees. The results were shown in Fig.7a and Fig.7b. The relative errors between the measurement value and theoretical value to the arc size are less than 2 %.



(a) model 1

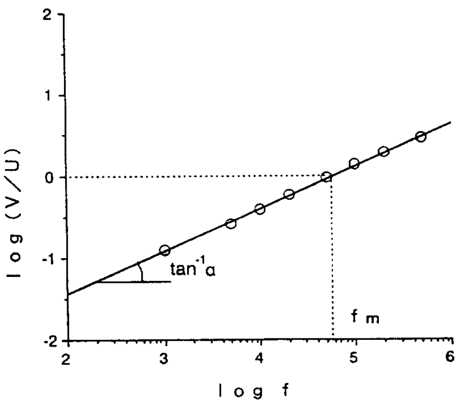


(b) model 2

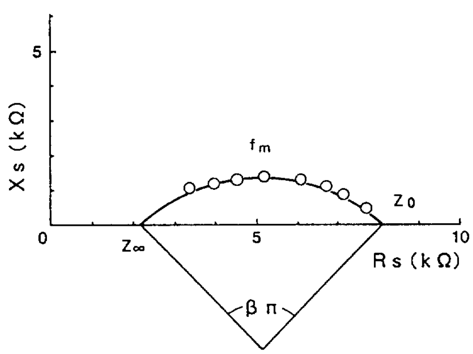
Fig.7 Measurement result of equivalent circuit.
○ : experimental value, × : theoretical value

Determination of impedance parameters

This system analyzes the impedance measurement results, and gives the impedance parameters characterizing frequency dispersion and parameters of equivalent circuit. These results of pine tree just after cut down are shown in Fig.8. First, preliminary check is done from Fig.8a using Eq.6, α and f_m is determined. Next, the arc's plot is shown in Fig.8b, β and Z_0, Z_∞ is determined, accompanied with the confirmation of appropriateness for all measurement results. If the result is imperfect, measurement is proceeded again from initial setting. Finally, the parameters of equivalent circuit and intrinsic parameters of tissue properties are evaluated and displayed as shown in Fig.8c.



(a) determination of α and f_m



(b) Cole-Cole arc's plot

Impedance Parameters	
Z_0 = 8.03 kΩ,	z_0 = 24.19 kΩ
Z_∞ = 2.17 kΩ,	z_∞ = 6.54 kΩ
F_m =57.2 kHz	
β =0.483,	α =0.488
R_1 = 2.17 kΩ,	R_2 =5.86 kΩ
r_0 = 3.90 MΩ,	c_0 = 0.243 μF
R_e = 8.03 kΩ,	R_i = 2.97 kΩ

(c) impedance parameters

Fig.8 Results obtained on microcomputer display.

CONCLUSIONS

The sensing device of electrical characteristic of living tree was developed. This device is able to measure and analyze bio-electrical impedance which is required for non-invasive electrical test of the activity of living tree automatically. The system is compact and easy handling. We can use this device not only in laboratory but also in field. Although the tree impedance vary certainly with the change of activity of tree, it is influenced by many other factors. Then, it is expected that this method establishes an inspection of living tree on the basis of many data in tree and their analyses.

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