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

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, $\beta$ is a parameter representing the degree of deviation from Debye type and $\omega$ 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]:

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

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

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

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

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

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

$g_p$ 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 $\alpha$ as follows:

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

If $\alpha$ equals $\beta$ 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:

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

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

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:

$$Z = K z_n$$

For the electrodes shown in Fig.3 a and 3 b, the cell constants $K_n1$ and $K_n2$ are given as follows:

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

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

[Diagram of 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.

**IMPEDEANCE 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).
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.

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 %.

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.

(a) determination of $\alpha$ and $f_m$

![Graph showing log (V/I) vs log f with a line and a point marked by a triangle.

(b) Cole-Cole arc's plot

![Graph showing Cole-Cole arc with points and labels.

(c) impedance parameters

<table>
<thead>
<tr>
<th>Impedance Parameters</th>
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<tbody>
<tr>
<td>$Z_0 = 8.03 , k\Omega$, $Z_0 = 24.19 , k\Omega$</td>
</tr>
<tr>
<td>$Z_\infty = 2.17 , k\Omega$, $Z_\infty = 6.54 , k\Omega$</td>
</tr>
<tr>
<td>$F_m = 57.2 , kHz$</td>
</tr>
<tr>
<td>$\beta = 0.483$, $\alpha = 0.488$</td>
</tr>
<tr>
<td>$R_1 = 2.17 , k\Omega$, $R_2 = 5.86 , k\Omega$</td>
</tr>
<tr>
<td>$r_0 = 3.90 , M\Omega$, $c_0 = 0.243 , \mu F$</td>
</tr>
<tr>
<td>$R_s = 8.03 , k\Omega$, $R_i = 2.97 , k\Omega$</td>
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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 live tree on the basis of many data in tree and their analyses.

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