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Determination of Electrical Parameters for Skin during Galvanic Skin Reflex from Continuous Measurement

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Synopsis

Skin impedance satisfies the Cole-Cole arc's law. The change of skin impedance during GSR (Galvanic Skin Reflex) can be expressed by the change of equivalent parallel resistance approximately. Using these characteristics, the complicated change of skin impedance during GSR can be determined continuously from the measurement value in one frequency point.

1. INTRODUCTION

The skin impedance is well various and changeable rapidly, so it is not easy to measure precisely the all frequency characteristics(1). In order to measure the all frequency characteristics, there are two methods as follows. One is multi-frequency points measuring method and the other is the fast fourier transformation (FFT) method from the response in time domain. However, the former demands very complicated device and the latter is not enough short time period of measurement for GSR.

This report describes the method which uses the characteristics of skin impedance and determines perfectly and continuously the all frequency characteristics from the measuring skin impedance of one frequency point. This method is convenient to apply for the case that an impedance changes rapidly in short time as GSR course.

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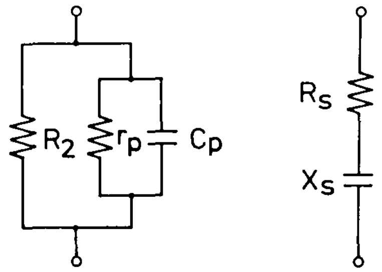
2. CHARACTERISTICS OF SKIN IMPEDANCE AND ANALYZING METHOD

The skin impedance satisfies the Cole-Cole circular arc's law and is expressed by the parallel type equivalent circuit as shown in Fig.1(a)[2]. R_2 is real resistance depending on ionic conduction , and parallel resistor r_p and parallel capacitor C_p are parts depending on dielectric polarization of the tissue and are expressed by the following equations:

$$\left.\begin{aligned} C_p &= \omega^{\beta-1}C_0 \\ r_p &= r_0/\omega^{\beta} \end{aligned}\right\} \qquad (1)$$



(a) (b)

Fig.1 Equivalent circuits of electrical skin impedance.

C_0 and r_0 are the values of C_p and r_p respectively at angular frequency w=1. The equivalent circuit of skin can be expressed also by the circuit of series type in Fig.1(b) and the parameters Z_L, R_s and X_s is given as follows:

$$Z_L = R_s - jZ_s = \frac{1}{1/R_2 + 1/r_p + j\omega C_p} \qquad (2)$$

$$R_s = \frac{1/R_2 + \omega^{\beta}C_0}{(\ 1/R_2 + \omega^{\beta}/r_0\ )^2 + (\ \omega^{\beta}C_0\ )^2} \qquad (3)$$

$$X_s = \frac{\omega^{\beta}C_0}{(\ 1/R_2 + \omega^{\beta}/r_p\ )^2 + (\ \omega^{\beta}C_0\ )^2} \qquad (4)$$

By eliminating the frequency from R_s and X_s, the impedance locus is expressed by the circular arc as follows:

$$\left(R_s - \frac{R_2}{2}\right)^2 + \left(X_s + \frac{R_2}{2r_0C_0}\right)^2 = \frac{R_2\sqrt{1+(r_0C_0)^2}}{2r_0C_0} \qquad (5)$$

The vector locus of skin impedance actualy moves on this circular arc as Fig.2, which is called the Cole-Cole circular arc. The parameters of the skin impedance can be determined from the arc's parameters (R_2, f_m, β) of measured circular arc by the following equations:

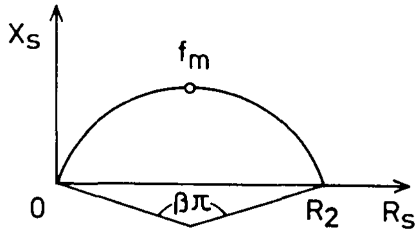


Fig.2 Cole-Cole circular arc of the frequency loci for skin impedance.

$$\left.\begin{aligned} C_0 &= \frac{T_m^{\beta} \sin(\beta\pi/2)}{R_2} \\ r_0 &= \frac{R_2}{T_m^{\beta} \cos(\beta\pi/2)} \end{aligned}\right\} \qquad (6)$$

where $T_m = 1/\omega_m = 1/2\pi f_m$ and $\tan(\beta\pi/2) = r_0 C_0$. T_m can be expressed by

$$T_m = \left(\frac{R_2 \sqrt{1 + (r_0 C_0)^2}}{r_0} \right)^{1/\beta} \qquad (7)$$

Consequently, R_s and X_s at arbitrary frequency point can be obtained from the mesurement parameters (R_2, f_m, β) by the following equations:

$$R_s = R_2 \frac{1 + (\omega T_m)^{\beta} \cos(\beta\pi/2)}{1 + 2(\omega T_m)^{\beta} \cos(\beta\pi/2) + (\omega T_m)^{2\beta}} \qquad (8)$$

$$X_s = R_2 \frac{(\omega T_m)^{\beta} \sin(\beta\pi/2)}{1 + 2(\omega T_m)^{\beta} \cos(\beta^{\pi}/2) + (\omega T_m)^{2\beta}} \qquad (9)$$

There have been some theories regarding the peripheral mechanism of GSR [3]. Today, it is generaly considered that the parallel resistance decreases by the activity of sweat glands. The results of following experiment conforms this theory.

The time changes of palm skin impedance were measured during 15 minutes, and the result is shown in Fig.3. The vector loci were measured at time T_1-T_5. Each circular arc was measured in a few seconds at ten frequency points. All loci of palm skin impedance satisfy the Cole-Cole circular arc same as general skin impedance. The parameters were obtained from the every circular arcs and shown in Table 1. From this result, R_2 is being changed between 50 and 90 kΩ along with the variation of skin impedance, but C_0 is changing only between 0.055 and 0.080 along with it. The degree of change of C_0 is smaller than R_2. In the case of analysis of skin impedance in short time (about 10 second) as the GSR course, C_0 or C_p can be considered as constant. The parameter β is constant and then r_0 is also constant from the relation $\tan(\beta\pi/2) = r_0C_0$.

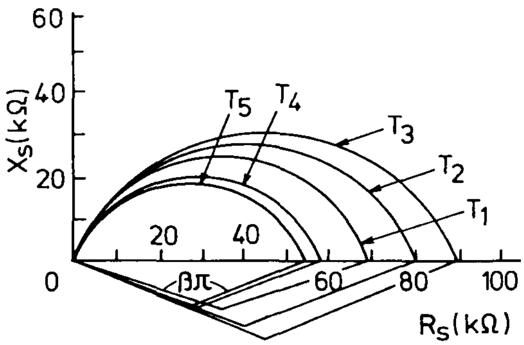


Fig.3 Time variations of circular arcs for palm's skin impedance.

Therefore, it is cosidered that the parameter relating to the skin impedance variations of a palm in short time is only R_2 . Under these conditions, the elements of equivalent circuit are determined from the measurement result of impedance at one arbitrary frequency and the variations of skin impedance over all frequency range can be analyzed.

3. MEASUREMENT AND ANALYSIS OF SKIN IMPEDANCE

Ag-AgCl electrodes were applied on the palm and forearm with redux cream paste. The palm skin impedances R_s and X_s at ten frequency points were measured after 30 minutes of applying the electrodes and the result was shown by the symbols o in Fig.4. In this time, the subject should be quite so as preventing from a generation of GSR. The impedance parameters were obtained from this experiment as follows: R_2 = 53.5 kΩ, f_m = 82 Hz, β = 0.842.

Next, the subject was suffered with stimulus of sounds and touch at every frequency points, and the impedance changes depending on the GSR were measured as indicated by the simbol ● in Fig.4. If the

Table 1 Change of paramerers according to the variations of skin impedance.

time	R_2 (kΩ)	β	f_m (Hz)	C_0 (μF)	C_p (μF) in 20Hz
T_1	68.3	0.767	213	0.0547	0.0177
T_2	80.3	0.750	174	0.0606	0.0181
T_3	89.0	0.739	133	0.0713	0.0202
T_4	57.3	0.747	229	0.0705	0.0208
T_5	50.4	0.743	235	0.0804	0.0232

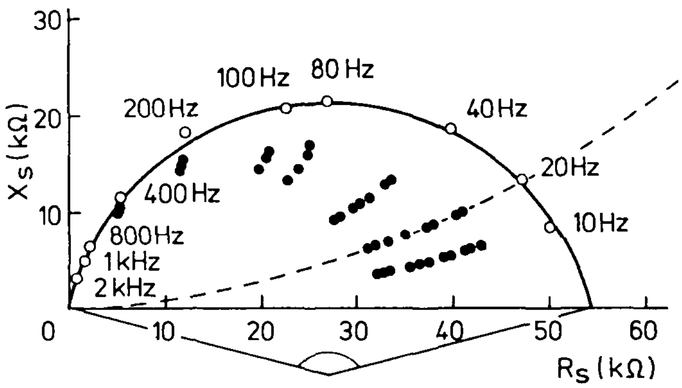


Fig.4 Experimental results of skin impedance loci at many frequency points caused by GSR.

points were connected along same frequency, for example 20 Hz, these were on the circle whose center was on the imaginaly axis. These also show that the changing parameter is only R_2 and the constants are C_0 and β.

Immediately after former experiment, giving stimulus to the subject, the wave form of equivalent series resistance R_s at 20 Hz during GSR course only recorded. One example of this wave form, which was expressed in Fig.5, was analyzed as follow. The wave form in Fig.5 was sampled with the time Δt of enough short reconstructing it. Now, we set Δt = 0.5 seconds and sampled data are R_{s1}, R_{s2}, ... R_{sn}, ... R_{s24}. R_2 is put as R_{2n} (n=1-24) corresponding to R_{sn}. As T_m is function of R_{2n}, R_{2n} can not calculate easy by R_{sn} in eq.(8). The calculation of R_{sn} from R_{2n} using eq.(7) and eq.(8) is direct and easy. So, we determined R_{2n} with microcomputer by the method of trial and error based on the characteristics that the variations of R_{2n} and R_{sn} are proportional in the low frequency range so as 20 Hz. R_{sn} and X_{sn} in arbitrary frequency can be calculated directly with eq.(3) and eq.(4) or eq.(8) and eq.(9) after obtained R_{2n}.

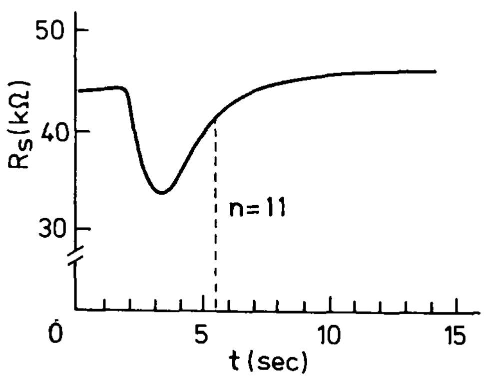


Fig.5 Wave form of R_s at 20 Hz during GSR course.

The skin impedances during GSR course were calculated at ten frequency points for every R_{2n} (n= 1, 2, ... 24) and shown with the symbol ● in Fig.6. The points for n = 11 are connected and form the small circle in Fig.6. These figures are almost agree with the axperimental results in Fig.4. All Cole-Cole circular arcs during GSR are displayed on three dimensions in Fig.7.

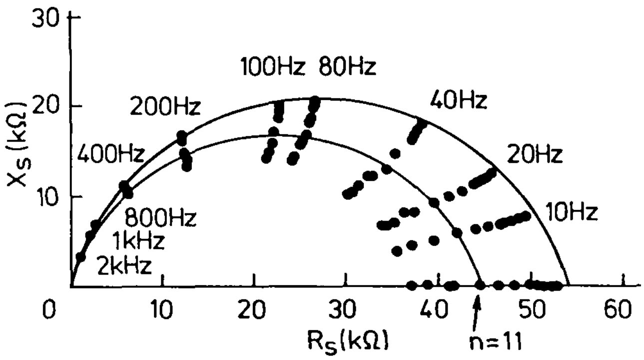


Fig.6 Calculated values of skin impedance loci at many frequency point during GSR course.

4.. DISCUSSIONS

The skin impedance variations were obtained over all frequency ranges during GSR. In order to study more detail the time variations at every frequency point, the wave forms of equivalent parallel resistance Rs and reactance Xs were calculated in Fig.8 (a) and (b). It was ever impossible that many frequency characteristics could be

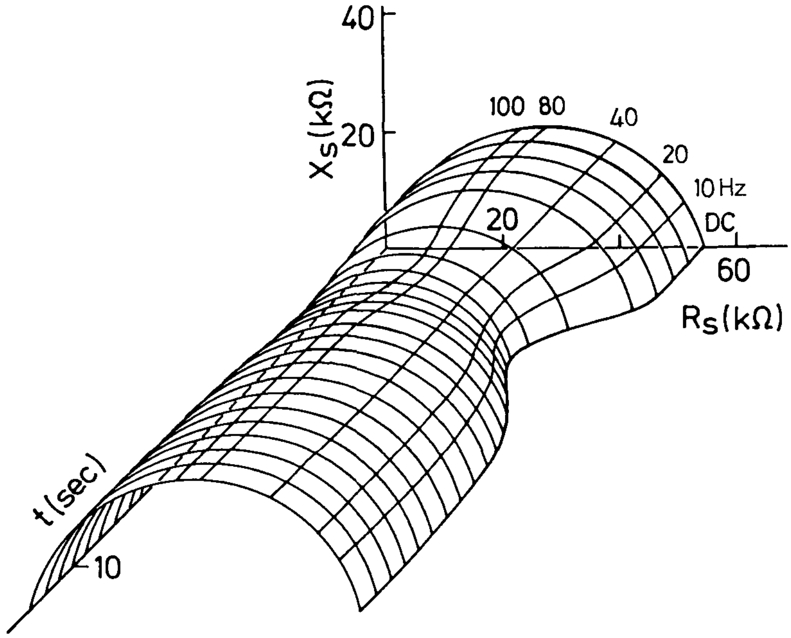


Fig.7 Variation of Cole-Cole circular arc during GSR course.

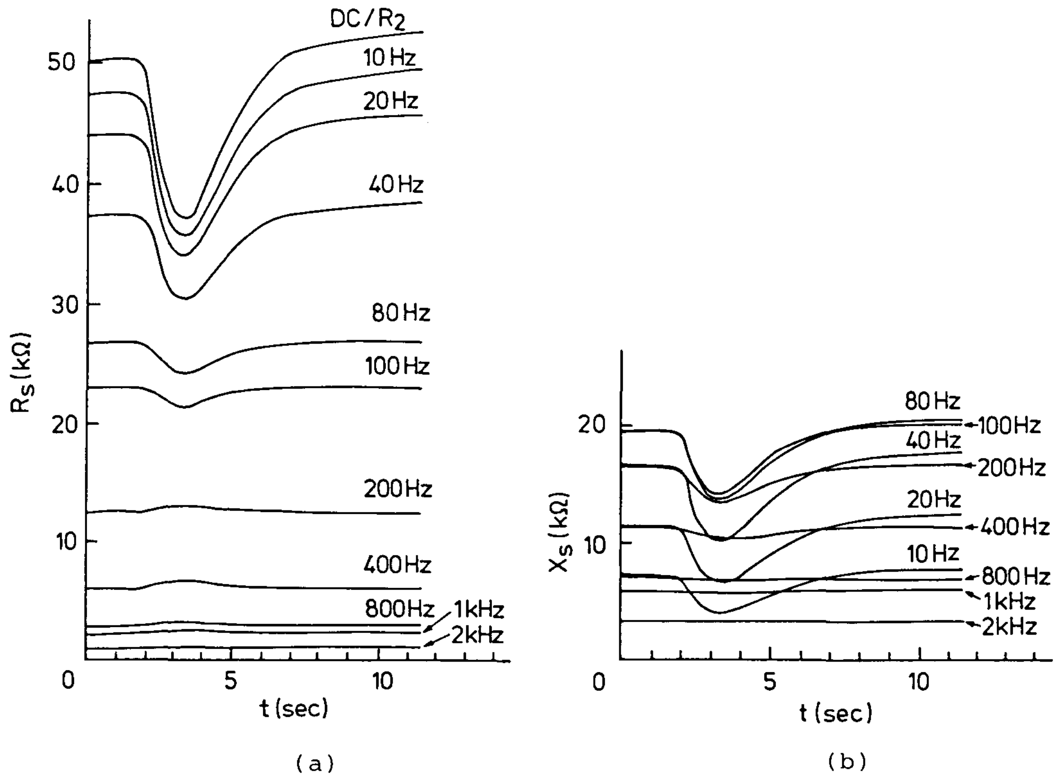


Fig.8 Wave forms of R_s and X_s at many frequency points during GSR course.

measured directly during rapid time variation as GSR course. The characteristics of impedance change in every frequencies could be cleared by this analysis on GSR. the change of R_s in low frequency range is proportional to the change of direct current resistance R_2. The change in higher frequency becomes smaller change than that in lower frequency. The polarity of a changes becomes inverse at the frequency among 100 and 200 Hz. The change at higher frequency is small. The change of reactance X_s is largest in the frequency range of about 100 Hz in which the level of reactance is maximum, and becomes small at the frequency of lower or higher than about 100 Hz. The wave form of X_s is analogous to the change of R_s. The measuring frequency of GSR used for AC method should be determined to round 20 Hz.

5. CONCLUSIONS

It was cleared that the impedance change in GSR course was depend on a change of parallel resistance from the analysis using the parallel equivalent circuit of the skin impedance. Using these characteristics of the skin, the impedance variations over all frequency range could be determined by the impedance measurement at one frequency point during GSR. The variation of skin impedance is larger when the measurement frequency is lower. The polarity of the change of R_s becomes inverse at a frequency over 100 Hz. The change of X_s is largest in the middle frequency of about 100 Hz. The wave forms in both changes of R_s and X_s are analogous. The measuring frequency of GSR used for AC method is preferable at round 20 Hz.

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