SURFACE RESISTIVITY OF HUMAN SKIN IN TROPICAL ENVIRONMENT

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ABSTRACT

Human skin surface resistivity may influence the decay processes of electrostatic charges in computer and control rooms and significantly contribute to electric shock hazards conditions. High temperature and humidity of tropical environment can significantly affect working conditions of operating personnel, resulting also in the change of electric resistance of the skin.

Fast industrialization and introduction of modern electronics in the coast area of East Africa is connected with the increase of electromagnetic interferences and hazards arising from electrical and electronic laboratories and control instrumentation of industrial plants. To meet the requirements for protection of equipment and personnel, knowledge of human skin electrical resistivity is needed. An original method of surface resistivity measurement has been worked out, several experiments on laboratory personnel performed and practical suggestion proposed.

1. INTRODUCTION

Skin resistance appears as an important factor in the evaluation of electric current by electric shock and static electricity charging and discharging processes. It is obviously known that electrical resistance of a human body depends mainly on resistivity of the skin. In moderate climate, resistivity of epidermis, the outer layer of skin is about 10^{-3} to 10^{-4} ohm.m. characteristic for dry and clean epidermis, which consists of horny layers of skin cells. In the tropics, skin surface is subjected to permanent influence of high air humidity and temperature, connected with intensive sweating, what results in the changes of ions mobility and surface electrical resistivity. Relationship between skin resistance and temperature and air humidity is yet not known. According to [1], human body resistance increases with an increasing of ambient air temperature 2 to 3 times when the temperature increases from

20°C to 40°C. Fig.1 shows the influence of air humidity on potential developed on operators in electronic industry [1], however there are no references concerning tropical environment. To evaluate skin resistivity of personnel operating electronic and control measurements equipment in genuine conditions within area of tropical climate a new measuring method has been here developed, several experiments performed and results discussed.
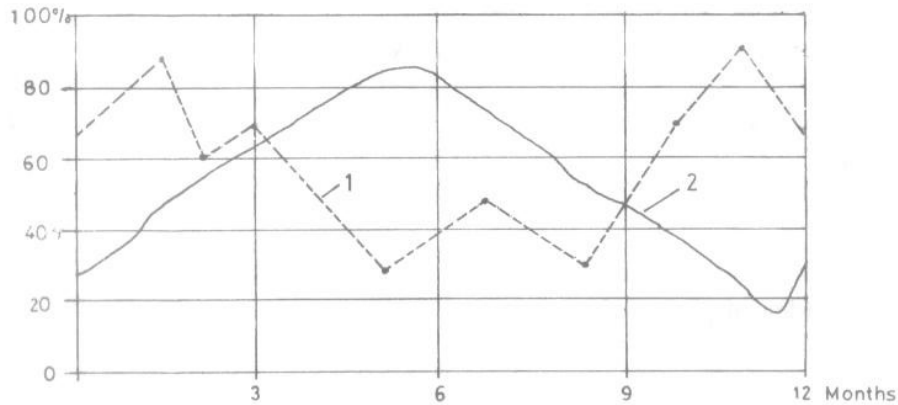

Fig.1 - Maximum values of electric potential of operators (1) and relative air humidity (2) recorded during one year [1].

2. MEASUREMENT METHOD

Considering skin area as large, continuous conductor, it could be assumed that its conductivity is mainly influenced by surface resistivity s. An electric current I, entering the skin at a given point A and leaving it at point B, generates electric field along the surface. For static conditions, electric field strength is a negative gradient of scalar potential V:

$$E = - dV/dx \qquad (1)$$

Assuming flat character of conductive surface, the potential at a radial distance r can be calculated as:

$$dV = (-Is/2\pi r) \, dr \qquad (2)$$

and therefore $\qquad V_r = (Is/2\pi) \, \ln(r_o/r) \qquad (3)$

where r_0 is an arbitrary chosen distance where potential equals to zero.
The potential at any point of assumed skin surface has been induced by current I entering and current -I leaving the surface (Fig.2).
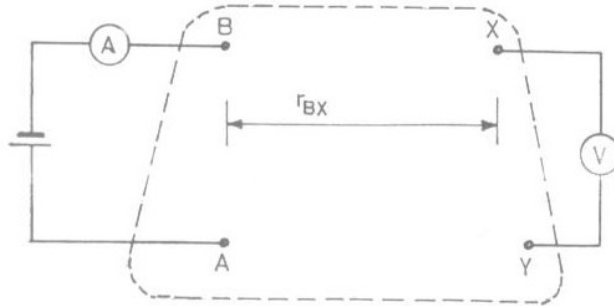

Fig.2 - Idea of proposed measuring method.

Therefore $\qquad V_x = (Is/2\pi) \ln(r_{Ax}/r_{Bx})$ $\qquad\qquad$ (4)

Voltage measured between any two points X and Y on the surface is a difference of relevant potentials V_X and V_Y as follows:

$$V_{XY} = (Is/2\pi) \ln[(r_{AX} \times r_{BY})/(r_{BX} \times r_{AY})]$$ (5)

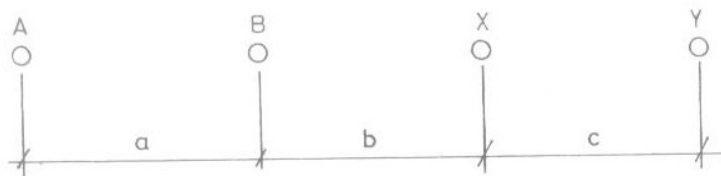Let us assume now that points ABXY lie on the line (Fig.3).

Fig.3 - Circuit according to equation (6).

It gives an advantage to choose measuring points out of equipotential lines.

Now:
$$V_{XY} = (Is/2\pi) \ln[(a+b)(b+c)/b(a+b+c)]$$ (6)

Transit resistance R_1:

$$R_1 = V_{AY}/I = (s/2\pi) \ln[(a+b)(b+c)/ac] \qquad (7)$$

To avoid the influence of contacts, let's change current direction on the surface by energizing it with current I, entering point X and leaving at point B. Correspondingly transit resistance R_2 can be calculated as:

$$R_2 = V_{AY}/I = (s/2\pi) \ln[(a+b)(b+c)/ac] \qquad (8)$$

the dimensions a,b,c fulfill the equation:

$$(a+b)(b+c) = b(a+b+c)+ac \qquad (9)$$

From (7) and (8):

$$\exp(-R_1/const) + \exp(-R_2/const) = 1 \qquad (10)$$

Considering that $\exp(-x) = 1 - x/1! + x^2/2! - \dots$ \qquad (11)

for $x \ll 1$

$$1 - R_1/const + 1 - R_2/const = 1 \qquad (12)$$

$$R_1 + R_2 = const = s/2\pi \qquad (13)$$

and $\qquad s = 2\pi(R_1+R_2) \qquad (14)$

If we assume that $R_1 = R_2 = R$, eq. (10) turns into:

$$2\exp(-R/const) = 1 \qquad (15)$$

$$const = s/2\pi = R/\ln 2 \qquad (16)$$

and

$\qquad s = (2\pi/\ln 2) R \qquad (17)$

Difference between values of s calculated from (14) and (17) can be evaluated to be of the order of about 30%.

3. EXPERIMENTS

We are required to evaluate the skin resistivity of laboratory personnel in genuine work conditions. Experiments were performed during May and June 1990 within Laboratories of High Voltage Technology and Electrical Machines of the University of Dar es Salaam. Laboratory rooms were not air conditioned, air temperature inside was practically uniform in the range 29 °C to 31 °C, air humidity was of 76% to 90%. Applying developed method of surface resistance measurement, there were about one hundred experiments performed. Transfer resistance was measured on laboratory staff using two different circuits (Fig.4), according to equations (7) and (8), after that surface resistivity was calculated from (17).
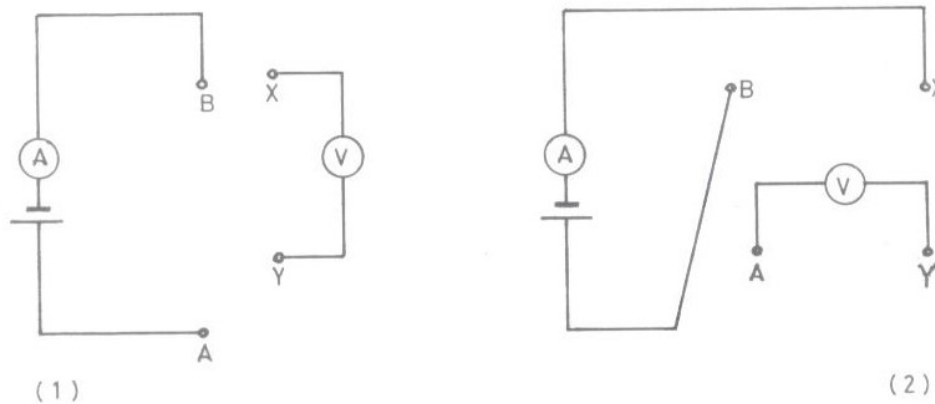
Fig.4 - Measurement circuits.

Electrode points A,B,X,Y were selected arbitrarily, but in general one of them is on the person's finger. The sequence of circuit energizing has been changing from AB (circuit 1) to BX (circuit 2). The other purpose of experiment was to investigate:
- an influence of work day on skin resistance,
- an influence of the changes of ambient conditions,
- individual's differences.

Working day hours are from 9 a.m. to 5 p.m. Changing of work ambient conditions was simulated by one or two hours stay in air conditioned room, with the temperature about 10 °C lower than in laboratory.

The measurement circuit was energized with a 5 V stabilized voltage source, applied directly to the point electrodes on skin surface. The measurement current was taken from 10 to 20 microamps, depending on contact resistance influence.

All experiments were performed on laboratory personnel, employed without heavy duties and whose skin was rather clean and dry.

4. RESULTS.

The measured transfer resistance varied from about 1 k.Ohms up to 25.6 k.Ohms. The mean value of transfer resistance is found to be 13.650 10^3 ohms with standard deviation of 6.60 and the number of evaluated samples 45. The histogram of the results obtained is presented in Fig.5.
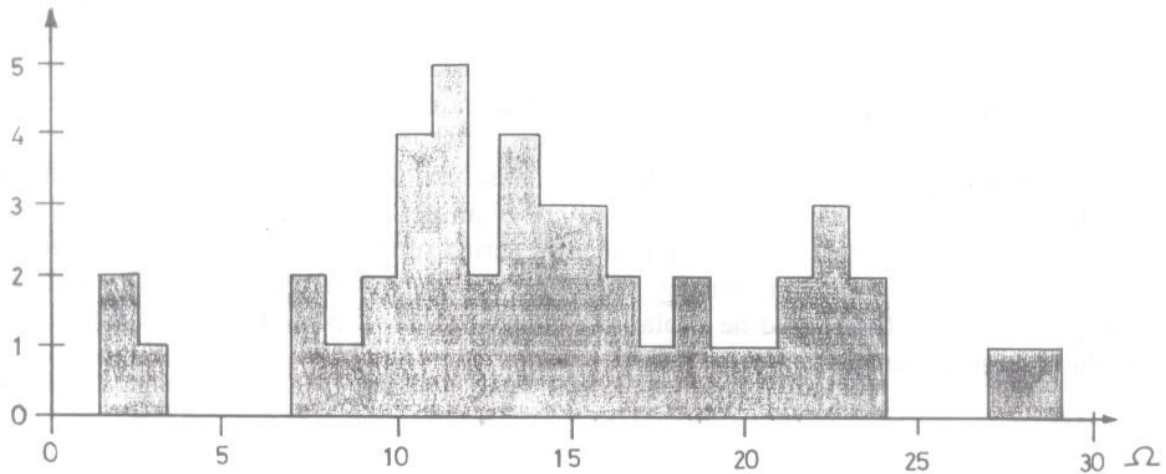
Fig.5 - Results histogram.

The mean value of skin surface resistivity was found to be 123.8 10^3 ohms.
Comparing to the given in literature 10^3 to 10^4 ohm.m value of the volume resistivity of epidermis, the experimentally found value of surface resistance is very low, in fact much lower than expected of any experience of the moderate climate. It has been also observed that the measured resistances are practically independent of the configuration of electrodes ABXY. The differences in the transit resistance measured on one individual are less than 20%. No particular difference of resistance for different individuals has been found.

There have been also several measurements performed on the same individuals, but using "strip" method of the measurements of surface resistivity (Fig.6). This method is not advised because of a strong influence of contact resistance. Results obtained were found to be 35.10^3 to 300.10^3 ohms and are in agreement with the values which have been measured using method proposed in this paper.
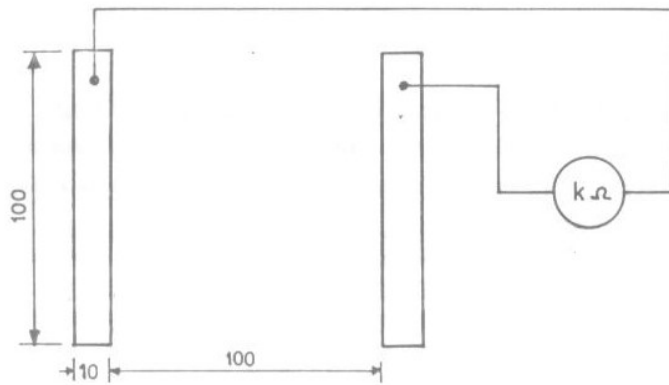
Fig.6 - "Strip" method of surface resistance measuring.

A significant change of resistance has been observed after the change of environmental conditions (Fig.7). For example, skin resistivity of an individual has been found to drop by about 40% of their initial value, within the time period of less than one hour after coming to work. Lower values of skin resistivity were observed on individuals leaving air conditioned computer rooms. These could be explained by an increase of perspiration and sweating due to the change of surrounding conditions.
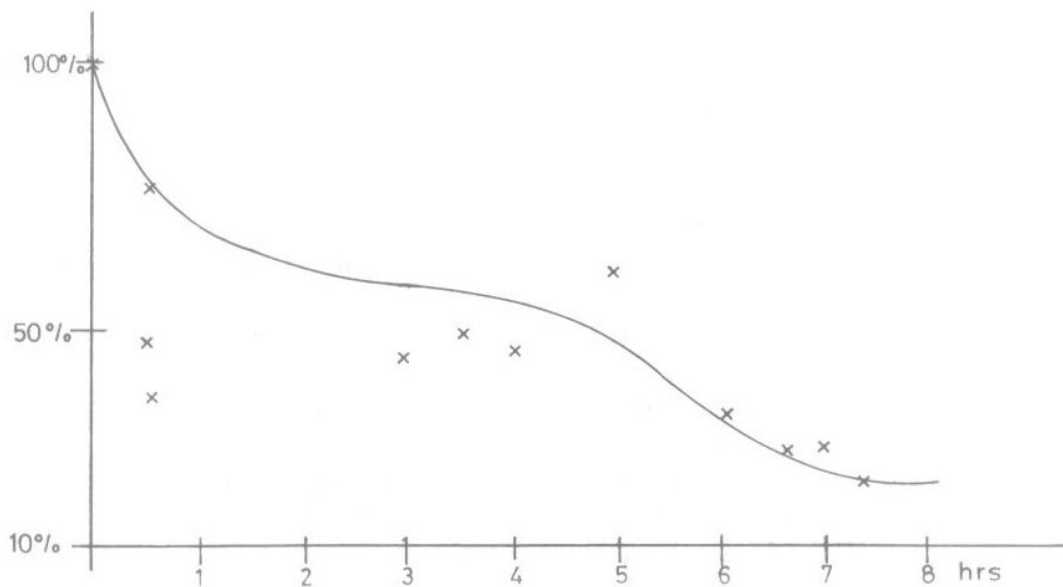

Fig.7 - Skin surface resistivity changes during work day.

5. CONCLUSIONS

In laboratory activities, employed personnel are generally not subjected to the significant changes of skin surface resistivity.

In tropics, within laboratory and control rooms, where not air-conditioned, surface skin electrical resistivity of the personnel is much lower than that in moderate climate conditions. The mean value of skin resistivity in tropics is found to be less than $200 \cdot 10^3$ ohms and is low enough to avoid harmful static electricity generation on operating personnel (lower than 1 Mohm [2]).

Fast and significant change of electrical resistance must be expected when an individual changes ambient conditions, for example after coming to work or when one spent some time in an air conditioned room. Low skin resistivity brings an increased risk of electric shock. In tropics and particularly when entering laboratory or production rooms after remaining in different than the ambient air temperature and humidity, personnel is exposed to the increased danger of electric shock. Low human electrical resistance in tropical environment introduces requirements for proper security measures and special careful maintenance of electrical installations.

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