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Category

Electrical

Title

Safe Limits of DC Voltages

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The technical content of this document has been approved by the relevant ARTC engineering authority and has also been endorsed by the ARTC Safety Committee.

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About This Standard

This document was produced by a Consultant as part of the investigation into the need for OHW structure to rail bonding (‘spark gapping’). It contains information pertaining to the effects of DC current on the human body, gathered from the literature around the world.

Document History

Primary Source – RIC Standard EP 00 00 00 08 SP Version 2.0

List of Amendments –

ISSUE	DATE	CLAUSE	DESCRIPTION
1.1	11/03/2005	Disclaimer	Minor editorial change

Contents

1 Objective

The objective of this document is to advise of the direct current voltage limits within which persons can expect to work safely. It pre-supposes that the only bare skin likely to be in contact with a conductor is on the hand(s) and that the person is wearing safety boots or shoes in reasonable condition. It does not deal with the prevention of consequential injuries such as from falls initiated by electric shock, nor does it suggest that the 'safe' conditions would be comfortable.

2 Preamble

Electric current affects the human body in many ways; those effects are covered in considerable detail in International Electrotechnical Commission Document 479-1 "The Effects of Electric Current on the Human Body" (IEC.479-1). That Document, which is based on investigation of accidents and on experiments, uses some special terms which can be simplified as follows:

(i) First there are those currents which can only just be felt. The upper limit of such currents (ie. when a person can just feel a 'tingle') is called "Threshold of Perception

(ii) 'Threshold of Ventricular Fibrillation' is the lower limit of current likely to cause the heart to cease functioning correctly. The threshold is not at a single value of current, but varies with duration.

(iii) 'Threshold of Let-Go' is the current at which it might not be possible to release the grip on a live object. Strictly speaking, that threshold is also a single value of current but, because of other factors, effectively it too varies with duration.

3 Experimental Investigations

1) For some years, as the result of investigations and experiments, the effects of electric currents on the human body have been known for both alternating current and direct current. For general purposes the measurement of current passing through the body is not practicable. It is better to measure voltage to determine whether it is safe to touch an item, but that approach requires the relationship to be known between voltage and body resistance.

2) Because of the more widespread use of alternating current, the relationship between body resistance and ac voltage was investigated first. The Standards Association of Australia (SAA) has used that information in codifying safe step and touch potentials for alternating current.

3) Recently, the IEC investigator completed experiments in which the resistance of human bodies was measured at various direct current voltages. The results of the voltage/body resistance tests for 5%, 50% and 95% of the population were obtained from SAA. The 5% set of values is used in this document (ie 19 out of 20 people have body resistance greater than the values given so that they would be "safer" than the case being considered).

4) IEC.479-1 makes the point that:

"the values are <u>so conservative</u> that the report applies to persons under normal physiological conditions, <u>including children,</u> irrespective of age and weight ".

4 Effects of Body Current

1) The effects of body current are shown on Attachment No. 1 which comprises Fig. 8 from IEC Publication 479-1 marked up to illustrate certain points.

2) The straight line designated “a” at 2 mA represents the Threshold of Perception which is described in IEC.479-1 as follows:

“The threshold of perception depends on several parameters such as the contact area, the conditions of contact (dryness, wetness, pressure, temperature), the duration of current flow and on the physiological characteristics of the individual. Unlike ac, only making and breaking of current is felt and no other sensation is noticed during the current flow at the level of the threshold of perception. Under conditions comparable to those applied in studies with ac, the threshold of perception was found to be about 2 mA. ”

3) When translated to Attachment No. 2 the corresponding voltage is approximately 6 Volts. The likelihood of detecting that voltage between hand and foot and from hand to hand gives an indication of the conservatism of the analysis.

4) Referring still to Attachment No. 1, Curve “c” defines the lower limit of Zone 4 and is known at Threshold of Ventricular Fibrillation. IEC.479-1 describes that threshold as follows:

(i) “The threshold of ventricular fibrillation induced by dc depends on physiological as well as on electrical parameters.”

(ii) “Experiments on animals as well as information derived from electrical accidents show that the threshold of fibrillation for a falling current * is about twice as high as for a rising current. For a current path hand to hand ventricular fibrillation is unlikely to occur.”

(iii) “For shock durations longer than the cardiac cycle, the threshold of fibrillation for dc is several times higher than for ac. For shock durations shorter than 200 ms the threshold of fibrillation is approximately the same as for ac, measured in r.m.s. values.”

(iv) “A curve has been constructed separating the zone where fibrillation becomes likely from the zone where less harmful effects are to be expected (see Attachment No. 1). That curve applies to a longitudinal rising current. With a longitudinal falling current the curve has to be shifted to a higher current magnitude by a factor of about 2.”

5) With situations in the field, one can never be sure whether a person’s hand (for example) might touch the more positive or the more negative conductor. Therefore, in this analysis only “rising current” values have been used. Such an approach can err only on the side of conservatism.

6) Threshold of Let-Go is of great importance and is described in IEC.479-1 as follows:

(i) “Unlike ac there is no definable Threshold of Let-Go for dc for current magnitudes below approximately 300 mA. Only the making and breaking

of current leads to painful and cramp-like contractions of the muscles. "

ii) "Above approximately 300 mA, let-go may be impossible or only possible after several seconds or minutes of shock duration. "

7) For practical purposes neither threshold of let-go nor threshold of fibrillation should be exceeded. On Attachment No. 1 threshold of let-go is represented by the straight line at 300 mA. However, 4.f.*ii*) indicates that at 300 mA several seconds might elapse befo re letgo can be achieved. After 500 msec the 300 mA line enters Zone 4 where ventricular * fibrillation might occur. That would, of course, be intolerable.

8) Because there can be no certainty in the general case that the source of voltage will be removed in less than 500 msec, (the point at which the 300 mA line meets Curve C) the concept of having a single value of let-go current was arguable. In the interests of conservatism, this analysis considers threshold of let-go as being "300 mA for the first 500 msec ramping to 140 mA after 2 secs". In practical terms, 140 mA (the long term, lower, limit for Zone 4) becomes the single value for let-go current.

*

Falling Current
Direct current through the human body for which the feet represent negative polarity.

Rising Current
Direct current through the human body for which the feet represent positive polarity.

5 Body Current vs Voltage

1) In IEC Publication No. 479-1, physiological effects have been described in terms of body current, but because it is desirable to know whether a situation is potentially dangerous, it is more useful to work in voltages which can be measured readily in the field. Table A shows those relationships in numerical form; Attachment No. 2, Curve A shows them graphically.

2) The abovementioned values are for measurement from one hand to one foot and from hand to hand (in all cases in the experiments hands and feet were bare). The values have been graphed on Attachment No. 2. The relationship is represented by Curve A.

3) It would be unusual for a person to stand on one foot while touching a live object. The more likely (and more conservative) case is for a person to stand on both feet and touch with one hand. The IEC experiments showed that body resistance in that case would be 75% of the figures shown. That relationship is represented by Curve B on Attachment No. 2.

TABLE A

Touch voltage vs Body Current		
Touch Voltage (dc) volt	**Total body resistance values that are not exceeded for 5% (percentile rank) of the population Ohm**	**Body Current I = E R mA**
25	2200	11.0
50	1750	28.5
75	1510	49.7
100	1340	74.6
125	1230	101.6
220	1000	220.0
700	750	933.3
1000	700	1428.0

6 Application to Workers

1) Workers are provided with safety boots which are replaced regularly and/or if damaged significantly. Supervisors should ensure that the practice is continued and that safety boots damaged in such a way as to reduce their integrity are changed as soon as possible.

2) Safety boots are designed primarily to provide physical protection. There is no suggestion that they should be used to permit live line working. When new, a boot has insulation resistance exceeding 10 megohms. The human body has a resistance from one hand to both feet of only 750 ohms at 220V, so significant electrical protection is provided incidentally. Such effects cannot be ignored.

3) With insulation resistance in the megohm range it could be assumed that the safety boots would be fully effective in insulating their wearer. However, safety boots do degrade with wear and conditions such as wetness. Therefore, in the interests of conservatism, it is appropriate to assume some lower value of insulation resistance for the boots.

4) In a recent investigation it was decided to assume that the boots' resistance would only equal the body resistance between one hand and both feet thus halving the current likely to be experienced at a particular voltage. That was a very conservative assumption; if 1500V was applied to a pair of boots their resistance would need to be only about 11,000 Ohms (22,000 Ohms each) to restrict current to the long term let-go value of 140 mA.

5) The relevant values for a person wearing safety boots, using the assumption made in the investigation, are shown as Curve C on Attachment No. 1. That curve at its intersection with the line marked "Long Term Limit for Let-Go", shows the long term let-go voltage to be 220V. The short term let-go voltage is 375V.

6) For hand to hand (Curve A), the corresponding voltages are 160V and 270V respectively. Although in 4.d.*ii*) mention is made that ventricular fibrillation is unlikely to occur for hand to hand currents, heavy burns and other pathophysiological effects could be experienced.

7) In the IEC experiments all surfaces were electrically clean. In practical situations coats of paint, fouling of surfaces, etc., would increase circuit resistance and thus reduce the body current.

7 Conservatism of This Analysis

1) In making this analysis whenever there has been an opportunity to choose, the more conservative choice has been adopted. Those choices are summarised in Table B.

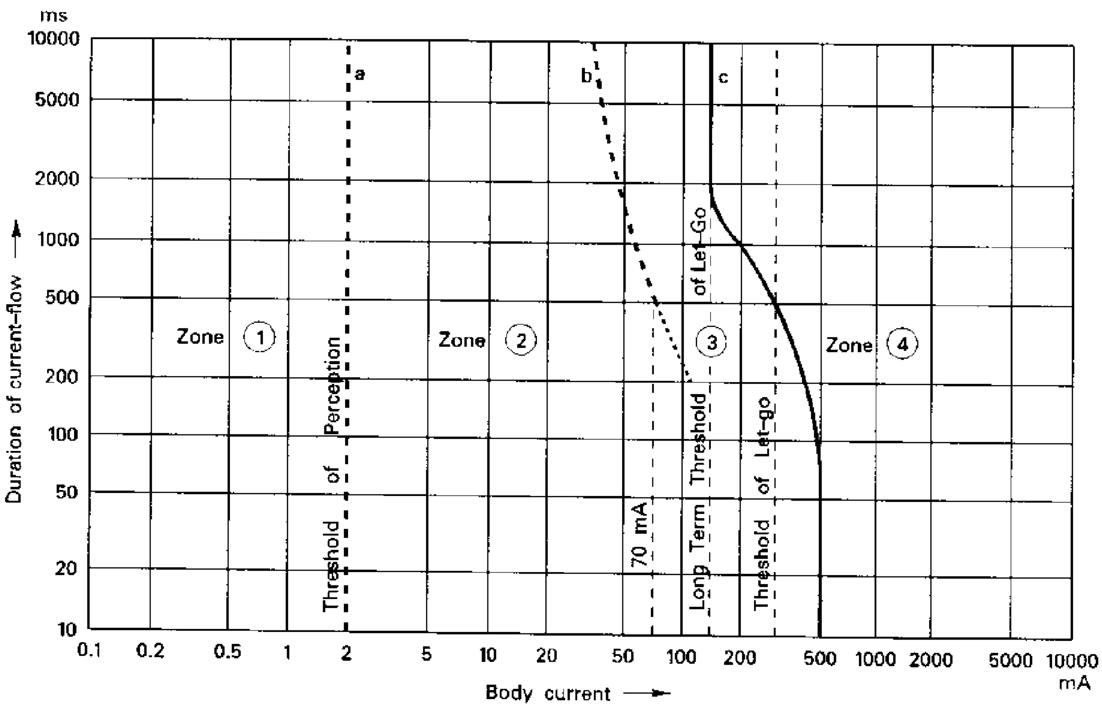
TABLE B - EFFECTS OF CONSERVATISM

IEC.479-1 states that the report applies to persons under normal physiological conditions, including children and the elderly (3d).	Workers, when on duty, are fit and in good health. Their ages range between 16 years and 65 years.
Total body resistance figures used are not exceeded by 5 percentile rank of the population (5b).	At least 19 of 20 in the population would experience body current lower than is suggested in the analysis.
Rising current values are used in the analysis (4e).	In the more general case, a person would be subject to falling current less stringent by a factor of 2.
Long term threshold of fibrillation current has been used as let-go current (4g).	In most cases, the shock of “making” current would be sufficient to cause a person to let-go. Only if the live conductor was grasped firmly would the long term value be applicable.
Resistance of safety boots has been taken to equal body resistance which, for one hand to one foot at let-go voltage values, is in the order of 1000 Ohm (6d).	Provided the boots are in reasonably good condition, it would be most unusual for the 10+ megohms of a new boot to deteriorate to 1000 Ohm.
All measurements in tests apply to electrically clean surfaces on the electrodes.	In practice, surfaces are dirty to some extent. The surface resistance would have the effect of reducing body current.

8. Attachment 1

ZONES OF PHYSIOLOGICAL EFFECTS

ZONE	PHYSIOLOGICAL EFFECTS
ZONE 1	USUALLY NO REACTION EFFECTS
ZONE 2	USUALLY NO HARMFUL PHYSIOLOGICAL EFFECTS
ZONE 3	USUALLY NO ORGANIC DAMAGE IS TO BE EXPECTED. INCREASING WITH CURRENT MAGNITUDE AND TIME, REVERSIBLE DISTURBANCES OF FORMATION AND CONDUCTION OF IMPULSES IN THE HEART ARE LIKELY.
ZONE 4	VENTRICULAR FIBRILLATION LIKELY. INCREASING WITH CURRENT MAGNITUDE AND TIME OTHER PATHOPHYSIOLOGICAL EFFECTS, FOR EXAMPLE HEAVY BURNS, ARE TO BE EXPECTED IN ADDITION TO THE EFFECTS OF ZONE 3.



NOTES: 1. – AS REGARDS VENTRICULAR FIBRILLATION, THIS FIGURE RELATES TO THE EFFECTS OF CURRENT WHICH FLOWS IN THE PATH FEET TO LEFT HAND AND FOR RISING CURRENT.

2. – BOUNDARY BETWEEN ZONES 2 AND 3 UNKNOWN FOR TIMES LESS THAN 500 ms.

TIME /CURRENT ZONES FOR D.C.

9. Attachment 2