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The determination of the electrical resistance of the human body under conditions to be met within underground mining

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THE DETERMINATION OF THE ELECTRICAL RESISTANCE OF THE HUMAN BODY UNDER CONDITIONS TO BE MET WITH IN UNDERGROUND MINING

by

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A

T H E S I S

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BIBLIOGRAPHY

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The use of electric wires in mines for power purposes is dangerous to human life. Deaths occur every year from electric shocks, and in most cases these accidents could have been prevented if some precaution had been taken by the victims, or if some care had been taken to protect them from coming in contact with live wires. Most workingmen accustomed to working around electric wires become careless and a lack of knowledge of the danger involved gives rise to the many accidents that occur.each year.

Special precautions are necessary in mines even where low or medium voltages are used. Everybody knows that high voltage wires are dangerous, and are carefully avoided; but many think that circuits carrying only a few hundred volts are not dangerous. This is a serious mistake because many deaths occur from pressures of 300 volts and less. In fact, a considerable number of accidents occur on coming in contact with circuits of less than 200 volts.

Electric circuits in mines are more dangerous than similar circuits above ground, on account of lack of space which increases the liability of coming in contact with the wires, but mainly due to the damp conditions of most mines. In order to receive an electric shock a person must place his body between two conductors of different electric pressures, or between one conductor and the ground. If the earth were dry and a person coming in contact between this dry ground and a live wire he would receive a much lighter shock than if the ground on which he stood was damp, because dry ground is a poor conductor of electricity, while wet or damp ground is a good conductor.

The object of this investigation is to determine just what resistance the human body would offer to an electric current under all the conditions met with in mines.

A Leeds and Northrup Wheatstone Bridge and correct to 1/10 of 1% was used in making the physics laboratory measurements and a portable testing set correct to 1/5 of 1% was used for other measurements.

The contacts used were two small brass cylinders about three-eights of an inch in diameter and seven inches long. With the above apparatus the following resistances were measured, parties being in dry room and under normal conditions:

			Ohms
Mr. A.	hand to hand	---------------	24000
Mr. B.	" "	---------------	19000
Mr. C.	" "	---------------	16000
Mr.D.	" "	---------------	8000
Mr.E.	" "	---------------	6000

It was noticed here that a small difference in pressure of the hands on the brass electrodes made a great variation in the resistance, so it was decided to have two "U" shaped grips made that required a certain pressure to bring their points together, so in this way different individuals would exert the same pressure. With this arrangement the following measurements were taken:

					Ohms
Mr.E.	hand to hand,	strong	grip	---------------	6700
Mr.A.	" "	"	"	---------------	13000
Mr.A.	" "	moderate	"	---------------	20000
Mr.A.	" "	gentle	"	---------------	26000
Mr.C.	" "	"	"	---------------	17000
Mr.C.	" "	moderate	"	---------------	15000
Mr.C.	" "	strong	"	---------------	13000
Mr.D.	" "	Gentle	"	---------------	8900
Mr.D.	" "	moderate	"	---------------	8000
Mr.D.	" "	strong	"	---------------	5000

The above resistances were all measured under same conditions and show that the resistance decreased indirectly with the area of contact, and shows a wide variation in the resistances of different persons, which may be attributed to a number of causes, such as the condition of the skin as to moisture it contained, callouses, cuts, etc.

At this point it was decided to try a contact from hand to tongue in order to obtain some data on what effect the nature of the skin would have in measuring the resistances of the same person, The following resistances were recorded:

	Ohms
Mr.A. with full grip on contacts ------------	20000
Mr.A. from tongue to hand -------------------	8000
Mr.C. full grip on contacts -----------------	17000
Mr.C. from hand to tongue -------------------	7000
Mr.F. full grip on contacts -----------------	13100
Mr.F. from tongue to hand -------------------	9000
Mr.G. full grip from hand to hand -----------	16000
Mr.G. from tongue to hand -------------------	9000

In all the above cases the tongue was pressed upon the contact so as to make a good connection. The tongue being damp gave rise to the question as to what effect a wet contact would have on the resistances of the person.

Two glass jars were arranged and filled with salt water (enough salt being put in the water so as to make it a good conductor) and the hands gripping the contacts were thrust down into water. Under this condition the following measurements were taken. First the person's resistance was measured from hand to hand with dry connection, then his hands were put under water.

	Ohms
Mr.H. dry contacts ------------------------	15000
Mr.H. wet under water ---------------------	1800
Mr.I. dry contacts ------------------------	11300
Mr.I. wet under water ---------------------	1800
Mr.C. dry contacts ------------------------	16000
Mr.C. wet under water ---------------------	1900
Mr.B. dry contacts ------------------------	19800
Mr.B. wet under water ---------------------	2200
Mr.G. dry contacts ------------------------	15000
Mr.G. wet under water ---------------------	1900

In the above measurements it did not make any difference in resistance if the contacts were gripped tight or not. The measurement shows what a great difference lies between wet and dry connections.

Another thing was noticed here, in case of the skin being broken on the hand under water that at this particular point more current seemed to flow; i.e., when there was no break in the skin the party could feel a burning sensation all over the surface of the hand and when the skin was broken this burning seemed to concentrate itself at that point. This would indicate that the skin offered a certain protection from low voltages or acted as an insulation for the body.

That the thickness of skin has a great deal to do with the resistance that the human body offers to an electrical current is shown by the following experiments. First the party was measured from hand to hand, then the same person measured from neck to hand, as the skin on the neck would be much thiner than on the hands.

			Ohms
Mr.C.	hand to	neck	9200
Mr.C.	hand to	hand	12300
Mr.F.	"	neck	9000
Mr.F.	"	hand	13990
Mr.A.	"	neck	12000
Mr.A.	"	hand	20000
Mr.D.	"	neck	9900
Mr. D.	""	hand	13400

The above would go to prove that the condition of ones skin is a more or less protection to electric shocks.

The next consideration was to measure the resistance of a person whose feet were damp. In order to accomplish this the person put on a damp sock and an old water soaked shoe, standing with the wet shoe on one electrode while one hand served as the other electrode. The following measurements were taken:

	Ohms
Mr.C. wet hand to wet hand -------------------	1900
Mr.C. wet foot to wet hand -------------------	2400
Mr.C. wet foot to dry hand -------------------	12500
Mr.C. dry foot to dry hand -------------------	19000
Mr.C. dry foot to dry foot -------------------	15000
Mr.C. wet foot to wet foot -------------------	9100

The following measurements were taken on parties coming in out of the rain whose shoes were damp, parties standing on electrodes:

		Ohms
Mr. J. from foot to foot (hob nails)	-------	99900
wearing two pair of woolen socks		
Mr.G. foot to foot wet	----------------------	21000
Mr.D. " "	--------------------	7000
Mr.F. " "	--------------------	3000
Mr.L. " "	--------------------	20000

The above measurements show a wide variation in resistance, due to different conditions of foot wear, for instance, J. having on boots that were hob nailed and wearing two pair of woolen socks, shows a resistance of 99900 ohms, this undoubtedly being due the woolen socks acting as an insulation and offering high resistance. Also in another case, G., where the party resistance was exceedingly high, was due to having cork inner soles. Again in other cases where the resistances were low in comparison to the above, was where their shoes were of thin soles and wet, this making a good contact.

Consequently, we may conclude that while persons working in the presence of live wires at times would be safe, while again they would not, all depending upon conditions.

The following measurements were made on parties that were working under different conditions:

	Ohms
Mr. N. hand to hand, greasy hands --------	27000
Mr.N. hand to foot, dry hands -----------	30000
Mr.B. hand to hand, greasy ---------------	20300
Mr.B. hand to hand, damp -----------------	11000
Mr.F. " " " " -----------------	12000

Temperature of above 60° F.

6th	party	hand to	hand,	slightly damp	-------	12000
7th	"	"	"	damp	--------	14000
8th	"	"	"	"	---------	16000
9th	"	"	"	"	---------	10000
10th	"	"	"	"	---------	17000

Temperature of above 74° F.

11th	party	hand to	hand, dry	----------------	20000
12th	"	"	"	---------------	19000
13th	"	"	damp	----------------	7000
14th	"	"	dry	----------------	13000
15th	"	"	"	---------------	14000

Temperature of above 60° F.

				Ohms
16th hand to hand, perspiring			----------------	6000
17th	"	"	---------------	5700
18th	"	" dry	---------------	17000
19th	"	" "	---------------	13000

In front of assay furnace.

Temperature 90° F.

The foregoing measurements show the resistance the human body offers under various conditions and in order to show how the resistance of each party under different conditions would be affected, it was thought best to show it in form of a table, which is on the following page. This table shows how for instance C. is affected by an electric current when his grip was strong, which showed a resistance of 13000 ohms; when his grip was medium, which showed 15000 ohms resistance; and when his grip was gentle, the resistance being 17000 ohms. It can easily be seen that the contact bears greatly on the ohmic resistance to which the passage of an electric current affords. It is then concluded that the resistance varies inversly as the area of contact, for when the grip was gentle the area of contact was

OHMIC RESISTANCE

	Hand to Hand Grip			Hand to Tongue	Hand to Hand		Neck to Hand	Hand to Wet Foot	Foot to Foot		Dry Foot to Wet Foot	Foot to Hand
	Strong	Moderate	Gentle		Wet	Dry			Wet	Dry		Dry
Mr. A	13000	20000	28000	8000	2500	20000	12000					
" B	12000	14000	17000		2200	19000						
" C	13000	15000	17000	7000	1900	16000	9200	2500	9100	15000	13000	19800
" D	5000	8000	8900	7000	2200	13500	9900	1100	7000	9900	15000	11000
" E	6700	8000	9000	5000	1800	7000		2300	3600	10000		9000
" F	10000	12000	15000	9000	2200	13900	9000	3000	1600	11000	14000	12000
" G	13000	12000	17000	9000	1900	16000						
" H	12500	13400	16000		1900	15000						
" J	9000	11000	13000		1800	11300			*99900			

*Hob-nailed boots, 2 pair woolen socks.

less than when the grip was strong, since in the gentle grip only parts of the palm of the hand was in contact, whereas in the other all or nearly all of the palm of the hand was in contact.

The table shows further in this case that the resistance from hand to tongue was about one-half of the resistance of hand to hand, which shows that the skin on the palm of the hand offers greater resistance than through the mucous membrane, the skin of the hand being much tougher. The resistance to the neck shows the same relation, being 9200 ohms as opposed to 16000 from hand to hand; the neck being tender.

The resistance of the same parties' hands in salt water was 1900 ohms, while hands dry was 16000. This shows that water and dampness is a very good conductor of electricity and is nearly 1/10 that of dry conditions. In all other cases where the resistance was taken from foot to foot, hand to foot both wet and dry, the case where conditions were damp showed a very low resistance as compared to the others.

In most mines conditions are generally damp and from the above a person working near electric wires must exercise greater caution than one working near electric wires on the surface.

The following experiment was performed on a dressed hog to see if the current varied under constant pressure. The resistance determined by a standard portable Leeds and Northrup testing set, was found to be 2000 ohms, contacts being across the shoulders. The hog was connected to a 220 volt D.C. circuit and a standard Western ammeter was connected and the following readings were taken:

When current was turned on	0.28	amp.
30 sec. later	.20	"
50 " "	.07	"
80 " "	.03	"

The skin of the pig was burning at (+) pole.

From the above data we infer that the resistance with a circuit averaging 0.12 amps. with pressure of 220 volts would be 1867 ohms, and the resistance from the set was 2000 ohms, which shows a good check. As the current was kept on, the amp. went down, which seemed to be caused by the carbon formed by the burning skin and was of a greater resistance. As thes seemed to be contrary to what we anticipated; i.e., that the current would rise, we decided to experiment on a calf at the time it was to be slaughtered.

The experiment was made on a six weeks old calf. A pressure of 158 volts was applied immediately after the animal had been killed, connection being made just back of the shoulders, and the ammeter showed the following readings:

Time		Amperes
2:30	Throat cut -------------------------	.05
2:31	-------------------------	.08
2:32	First noticed burning --------------	.10
2:33	Burning ----------------------------	.12
2:34	----------------------------	.15
2:35	----------------------------	.18
2:36	Burning severely -------------------	.25
2:37	Calf dead --------------------------	.25

This shows that the amperes went up gradually and at the time of death this would give the animal a resistance of 630 ohms as against 2000 ohms at .05 amperes when the animal was living.

A normal body has from 5000 to 15000 ohms resistance from hand to hand, when the hands are wet the resistance drops from 1600 to 2500 ohms; the resistance from hand to hand of men in the assay laboratory, some hands perspiring and some dry, ranged from 2000 to 14000 ohms; men in the chemical laboratory were about normal; men in boiler room with hands moist and greasy were from 11000 to 12000 ohms. From hand to foot, normal condition, resistance is from 9000 to 20000 ohms, and when the hands and feet are wet, the resistance drops to from 1000 to 3000 ohms. This shows with a voltage of 250 and resistance of 1100 gives a current of one-fourth of an ampere, which according to the experiment carried out on the calf would burn severely.

It was found that in the case of the person who wore woolen socks and whose resistance measured 99000 ohms, this would give about .0025 amp. with 250 volts, or practically no amperes. This would indicate that woolen socks would offer a good protection to an electrical current if a person should happen to step on a live wire.