ELECTRIC SHOCK PREVENTION

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ABSTRACT

Electric shocks are a serious problem in the mining environment. Because of extremely wide ranging use of electrically powered equipment in the mining industry, the hazard to personnel due to electrical shock and related injuries are not restricted to any single area but cover the entire spectrum of mining activity. Electrical accidents, resulting in personal injury, due to improper or complete lack of grounding of electrically operated mining machines, form a significant percentage of the overall electrical accident picture.

The object of this paper is to describe methods of detection of unsafe electrical conditions with respect to the grounding of electrically operated mining equipment. It also includes a discussion of prototype instruments which effectively monitor the condition of the grounding safety devices currently in use on mining equipment and warn of dangerous conditions as soon as they appear.

The paper is based on work accomplished under USBM Contract Number J0357115. The contract was initiated under the Pittsburgh Mining and Safety Research Center Program. It was administered under the technical direction of PM and SRC with Mr. Roger L. King as the Technical Project Officer. Mr. Daniel B. Dawkins was the Contract Administrator for the Bureau of Mines.

PERSONNEL HAZARD DUE TO ELECTRIC SHOCK

Much work has been done in the area of human response to electricity. The following values are given as a general indication of typical threshold values and serve only to define areas of interest for instruments being developed.

Threshold of perception to 60 Hz AC between major extremities - 0.5 mA.

Muscle disfunction "let go current" - 9 mA.

Respiratory paralysis - 30 mA.

Heart disfunction - 75 mA.

Cardiac arrest - 4 amps.

Hazardous potential threshold, skin contact - 40 V.

Skin contact resistance - 1K-5K depending upon conditions.

Body resistance between major extremities - 500 ohms (exclusive of skin).

Skin effects disappear as voltage increases, higher potentials being able to pierce the skin's protective layer.

The object of this paper is to discuss methods of detection of unsafe electrical conditions with respect to the grounding of electrically operated mining equipment. It also includes design information of prototype instruments which effectively monitor the condition of the grounding safety devices currently in use on mining equipment and warn of dangerous conditions as soon as they appear.

A device of interest is a voltmeter that is intended to be permanently mounted on the mining machine and continuously monitor the electrical potential of the frame of the mining machine relative to the earth. The device also contains a presettable threshold level which is capable of giving a warning or opening a relay contact whenever the threshold potential is exceeded.

Another is a device intended for use on DC operated machinery employing safety grounding diodes. The diode monitoring function is physically included in the machine mounted instrument housing with the single resulting package serving the dual purpose of frame potential measurement and safety diode condition monitoring.

GROUNDING DIODE CHECKING

Present Electrical Equipment

The vast majority of electrically operated mining equipment in the field today is still manufactured on a unit by unit basis. While basic form, fit and function of individual machines remain fixed for relatively long periods of time, the individual electrical components included in each machine produced are subject to slight but constant variation. This is true of virtually all manufacturers including even the larger volume equipment producers. The variations in machine components are often necessitated by the manufacturer's responsibility to delivery large expensive equipment on a regular schedule regardless of random inventory shortages of specific component types. "Equivalent" substitutions are made whenever necessary to expedite production. In addition, the extremely large volume of repaired and rebuilt equipment makes the exact parts complement or electrical schematic of any operating piece of heavy mining equipment difficult to predict. Any equipment intended for installation in existing mining equipment must be universal in application and easily adaptable to changing conditions.

Electrical Control Boxes

A large number of mining equipment manufacturers purchase entire control boxes, as a complete unit, from an independent supplier. These boxes are treated as a component part with the internal design particulars left to the box supplier. Here, also, actual numbers of particular internal components vary from unit to unit. However, as far as safety grounding diodes are concerned, virtually all diodes are functionally equivalent.

Grounding Diodes

Safety grounding diodes are used in DC powered mining equipment such as shuttle cards, to prevent voltage from appearing on the machine frame. They are connected between the frame and the DC return line so that if the hot side of the DC supply comes in contact with the frame, the diode will go into heavy conduction and shunt the power to ground via the safety ground lead and/ or the DC return until the breaker at the load center trips.

Although many different individual grounding diode part numbers are in current use, the basic electrical characteristics of all units are virtually identical.

Differences in part numbers are due to individual manufacturer's number systems, physical packaging differences between various units produced by the same manufacturer and difference in maximum voltage and current ratings of units installed in various machines. A typical practice followed by one control box manufacturer is to supply a single grounding diode on machines up to 50 hp, two diodes in parallel for 50-75 hp machines, and three in parallel for machines up to 100 hp.

1. Failure Modes of Grounding Diodes

Silicon rectifiers of the type used as grounding diodes are generally fabricated by either compression bonding techniques or brazed construction. Compression bonding involves mounting the actual semiconductor inside a welded case such that a least one contact to the semiconductor wafer is made through a compression type contact. Brazed construction involves use of hard soldering techniques. Field experience seems to indicate little difference between construction techniques with ultimate device failures generally being characterized by either a shorted diode junction or a device whose pigtail lead has burned open due to excessive current under fault condition. Little field information is presently available regarding partial failures of grounding diodes on mining equipment except for some cases involving the detection of excessive reverse leakage prior to ultimate device failure.

Failures may be classified as either electrical or mechanical nature.

a. Electrical Failure

(1) Overvoltage

Overvoltage failure of silicon power rectifiers results from the application of reverse voltages exceeding the avalanche breakdown rating of the diode. In safety ground applications, this most often results from the extremely high level short duration voltage transients so common in current mine power systems. Once the reverse blocking voltage of a device has been exceeded, current begins to flow across the semiconductor junction. The resulting high level localized power dissipation results in a burn usually near the passivated edge of the element. Continued or repeated application of excessive voltage spreads the burn area, finally resulting in complete device failure. External indications of overvoltage damage prior to complete device failure are a reduction in reverse voltage blocking capability and an increase in reverse leakage current as the junction deteriorates.

(2) Overcurrent

In the mine usage, overcurrent failure results from electrical fault currents flowing through the diode. Failure due to overcurrent results from excessive heat concentrated in the junction region of the semiconductor element resulting in a general degradation passivation. This damage can result from either large continuous currents or high surge currents for relatively short periods of time. The currents required to cause overcurrent failure are orders of magnitude larger than those involved in failure due to overvoltage. This is because of the low forward voltage drop of the diodes; however, the ultimate effect is very similar. Damage due to overcurrent usually encompasses the major portion of the junction area and is manifested, prior to total device failure, by a reduction in the reverse blocking voltage of the device and an increase in reverse leakage current. Very high surge currents result in bulk burns of the semiconductor material and produce almost instantaneous failure.

b. Mechanical Failure

(1) Loss of Hermeticity

This type of failure generally results from physical abuse or improper mounting, destroying the integrity of the package seal. Failure is generally very slow to appear as the effect of the broken seal is usually not immediately apparent. The broken seal allows internal contact materials to oxidize resulting in higher flow conditions. This results in device failure due to excessive temperature. This type of failure should be rare in safety grounding applications as the diodes involved are not intended for and do not generally carry large continuous forward currents. They are, however, often subjected to physical abuse. In safety ground applications, a possible result of contact oxidation progressing for an extended period of time would be a gradual increase in forward voltage drop of the diode, due to increasing internal resistances; followed by final device failure in the open state, due to complete loss of internal contact.

(2) Fractured Element

Excessive mounting torque or poor mounting surface condition can deform the device package and physically fracture the semiconductor element. This results in a sudden voltage type failure at the facture point. Excessive physical stresses present at the time of mounting may not immediately fracture the element but cause device failure at some later date from a sudden temperature change in the semiconductor element such as that normally induced by relatively mild current surges.

(3) Insufficient Mounting Torque, Poor Mounting Surface

Insufficient mounting torque or load force results in high temperature due to lack of heat transfer between the diode case and its heat sink.

This type of failure should be rare in safety ground usage because of the general absence of large continuous currents in these devices. Excessive temperature operation from any cause is detectable by a marked increase in reverse leakage as junction temperature rises. Leakage currents double for every 10°C increase in junction temperature. Leakage currents reduce as the junction temperature decreases provided maximum operating junction temperatures (approximately 190°C) are not exceeded.

VOLTAGE MEASUREMENTS

Earth Contact Resistance

A study was made to determine the earth contact resistance to be expected from earth electrodes of various types. This was done to gain insight into the magnitude of the problem associated with establishing a local earth reference in an operating mine from a moving piece of equipment. Measured values were obtained for four separate electrode configurations at two different locations in the Federal #2 Mine of the Eastern Associated Coal Company near Fairview, West Virginia. The electrodes tested included a metal whip antenna, a heavy chain dragging along the fllor, a conductive wheel, and a hoe or plowing type electrode. With the exception of the chain, separate measurements were made with the electrodes contacting the roof as well as the floor of the mine at each location. The two locations includes a recently mined area within 800 feet of the active face of the mine, and a second site near the base of the main shaft which had not been the scene of active mining for several years. A summary of the data is found in Table A.

Table A. Ranges of Earth Contact Resistances for Various Electrodes

Electrode	Range of Earth Contact Resistances	
	Floor	Roof
Whip	3K - 1000 M	3K - 2000 M
Chain	500K - 2000 M	-
Wheel	4K - 500 M	40K - 2000 M
Hoe	400K - 1000 M	400K - 250 M

In addition to the measured electrode resistance value, it was noted in the report that the earth potential within several feet of a line machine frame is significantly altered such that the immediately adjacent earth assumes the potential of the live frame.

This information was verified by other researches at West Virginia University during independent study work in the area of ground potential gradients near haulage rails in coal mines, and is attributed to the relatively high resistivity of the earth in and around the coal.

This finding is significant in that it definitely indicates that any frame potential measurement instrument intended for mine usage and using the earth as a reference must not obtain its earth reference point from directly under the machine but at some remote location. From present data, it appears that an earth conduction distance of 10-15 ft. from the frame is sufficient, and further testing may show the mine roof above the machine to be the most convenient location, even though contact resistance data indicates the roof contact in general to be of higher resistance than floor contact.

Machine Ground Contact Resistances

One parameter affecting the performance of any instrument monitoring frame and/or ground circuit potentials in mine applications is the contact resistance of the machine frame-earth interface. This is of interest because it provides a second ground contact path from the machine frame which does not include the cable ground conductor.

Investigations into ground contact resistances of various large open pit shovels and drag lines on soils of various resistivity gave measured ground contact resistances of from 100 ohms to less than one ohm. Estimates of the contact resistance of smaller, crawler mounted machines such as bulldozers, miners and loaders, having smaller total weight and corresponding smaller contact area, indicate expected values of ground contact resistance to be in the range of one ohm to 10,000 ohms.

Instruments designed to monitor frame potential and/or leakage currents must not be adversely affected by frame-earth contact resistance in this range, and may, in fact, be capable of using it to some advantage.

OPEN PIT GROUND CONDUCTOR VERIFICATION

It became apparent during the Phase I and Phase II investigations of our contract that an instrument designed to easily monitor the condition of long, open pit mining machine grounding conductors would be of interest to the Bureau of Mines. It also appeared that the sensors and techniques developed during this program may have application in this area.

Looking at the machine frame grounding system from the machine end of the trailing cable gives two electrical paths to earth. The first is through the cable ground conductor and the second is a parallel path from the frame to earth through direct frame-earth contact. It was desirable to design an instrument which can measure the cable ground path resistance regardless of the value of the parallel frame-earth path. Bendix did this through the use of a technique similar to that used to measure ground contact resistance of driven rods. Figure 3 shows a simplified schematic of the system.

If a small potential relative to earth is impressed on the frame of a piece of equipment in direct contact with the earth, a small current will flow. The ratio of the impressed frame potential to the resulting current flow would result in a measure of its earth contact resistance. If the earth contact is made by two separate paths, one directly to earth and one via the cable ground conductor, the ratio of the impressed frame potential to the current flow in only the cable ground conductor will result in a measure of only the cable associated earth contact resistance, including the ground conductor and ground bed resistances.

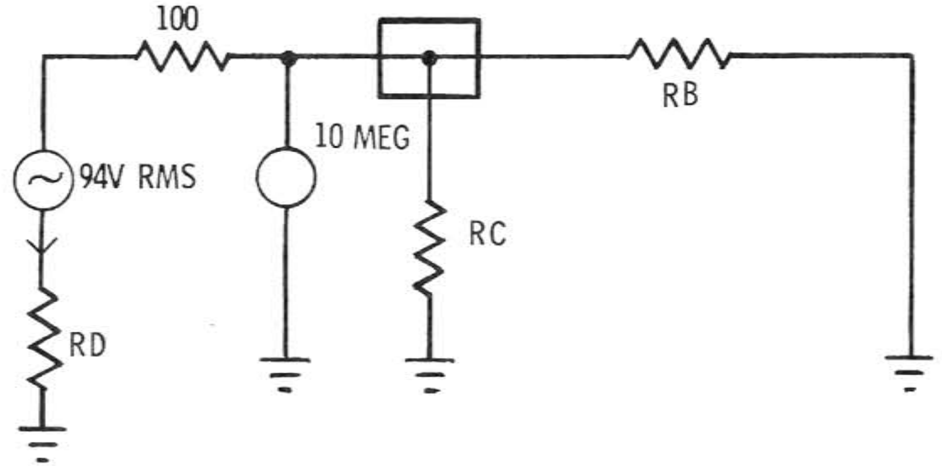
Measurements made in open pit metal mines by Pennsylvania State University indicate residual currents flowing in machine safety ground conductors due to induced voltages, capacitance effects, and ground potential gradients are generally less than 10 amperes, peak value. Since ground check measurements using this instrument will be made without the machine in use, values of residual currents flowing in the ground conductor at the time of measurement are expected to be quite low, with phase current being essentially zero. For this reason, the full-scale sensitivity of the cable current sensor may be kept quite low, allowing for accurate detection of the instrument-induced current variations which are expected to be in the range of 0.2 to 1 ampere.

The small suitcase sized prototype instrument is designed to measure the safety ground return resistance level, as seen from the machine end of the cable. The instrument is intended for open-pit mine usage and the resultant ground return resistance measurment would include any and all paths to earth, as seen from the machine frame, including the total trailing cable, the power center safety ground bed resistance, and the effects of any additional equipment tied to the same safety ground bed. The measurement does not include the earth contact effects of the machine frame at the measurement location. Use of the instrument requires the installation of a pass-through current sensor around the safety ground conductor of the trailing cable and requires the availability of some good quality earth contact within a reasonable distance from the machine location.

A battery powered current source is connected between the machine frame and the current probe. The impressed current is limited to less than 1 ampere. If a good quality current probe electrode, such as a buried metallic pipe or heavy piece of fuel-powered equipment (bulldozer) is unavailable within

OPEN PIT GROUND CONDUCTOR VERIFICATION

SIMPLIFIED SYSTEM SCHEMATIC



RB = Trailing Cable and Safety Ground Bed Resistance

RC = Machine to Ground Resistance

RD = Current Ground Rod Resistance

Let RA = RB||RC

Let R = RA + RD + 100

Current from Inverter = 94 ÷ R

Frame Voltage = Current X RA

RB = Frame Voltage ÷ Current in Cable

Figure 3

a distance of several hundred feet, a ground rod will have to be driven for use as the current probe. The current impressed between the current probe (earth) and the machine frame will divide and return to earth via the trailing cable ground conductor and the direct frame/earth contact. Figure 4 shows a simplified system block diagram.

The current flowing in the trailing cable ground conductor will be monitored using a pass-through current sensor. The electrical potential of the frame relative to an earth potential probe driven near the machine site is monitored employing a very high input resistance voltmeter (10 Meg).

The instrument current source is a standard 400 Hz inverter with a 100VA rating. A 100 ohm resistor has been placed in series with the convert output to limit the current to less than 1 ampere. Filtering is used to insure the system will measure only the 400 Hz components and not be influenced by 60 Hz stray currents.

CONCLUSIONS

Detection and prevention of electrical shock hazards is an ongoing program of great importance. The equipment and techniques described briefly in this paper are but one small effort.

The current field tests of the diode monitoring equipment will yield information as to actual operating environment characteristics of the system.

It is apparent that effort is needed to arrive at a viable way of establishing a local ground potential reference point in the mines to determine possible shock hazard conditions on the machines.

With respect to the Open Pit Ground Conductor Verification System, field tests are needed to prove out the equipment and techniques. It may be possible to use similar equipment to rapidly assess the condition of safety ground beds.

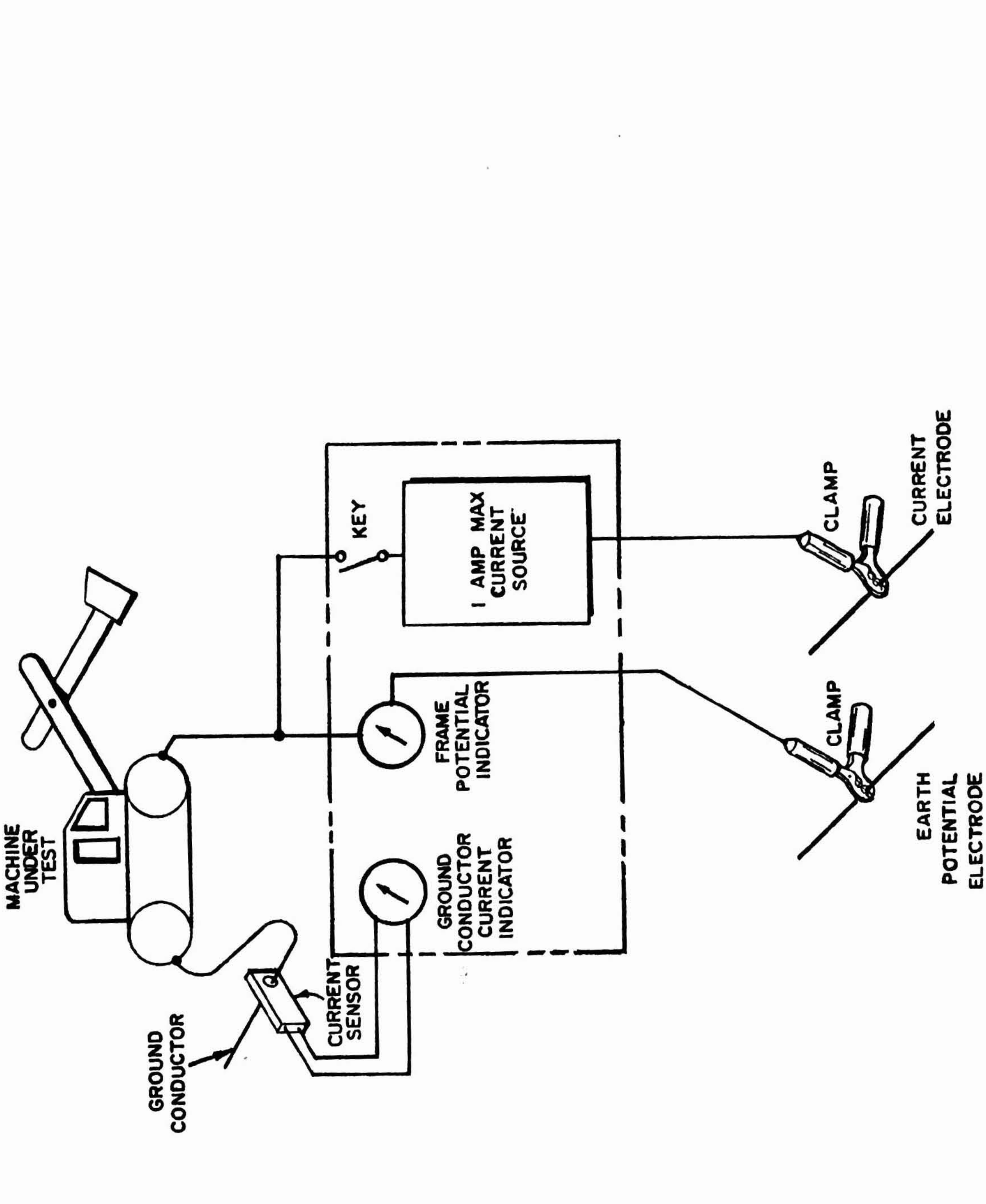
Continuing effort between the Bureau, industry, and the mining community will make the mines a safer and more productive operation.

ACKNOWLEDGEMENT

The information presented in this paper is based on work carried out under Bureau of Mines Contract J0357115 with Mr. Roger King as the Technical Project Officer.

REFERENCES

1) Final Report on Contract No. J0357115
Feasibility Study of Electric Shock Prevention



OPEN PIT GROUND CONDUCTOR VERIFICATION, BLOCK DIAGRAM

Figure 4