



NSW DEPARTMENT OF
PRIMARY INDUSTRIES

EARTHING INTEGRITY & ASSOCIATED PROTECTION

Part 1 - Controlling Touch Voltages and Arcing in Trailing Cable Circuits



INTRODUCTION

Two recent incidents one involving electric shock and one involving arcing in a hazardous zone have identified issues relating to providing an effective and reliable cabled earth connection, the setting of parameters on protection devices and the method of earth fault limitation.

BACKGROUND INFORMATION

To achieve safe electrical trailing cable systems in underground mines (coal and metalliferous) requires:

- Effective, high integrity earthing.
- Effective explosion protected properties of plugs and sockets.
- Effective electrical protection that:
 - limits earth fault currents,
 - detects earth faults and earth leakage,
 - automatically disconnects power when conditions are unsafe, and
 - detects ineffective earthing circuits.

Effective earthing.

In any electrical power circuit, the objective of effective earthing is to minimize the risk of electric shock. In power circuits used in underground coal mines, there is the additional objective of preventing explosions due to arcing to metallic structures.

AS/NZS3000:2000 *“Wiring Rules”*, recognises the importance of proper earthing, in particular, clause 5.2.5 states:

“The selection and installation of the equipment of the earthing arrangements shall be such that —

(a) the value of earthing resistance is in accordance with the protective and functional requirements of the electrical installation and expected to be continuously effective; and

(b) earth-fault currents and earth-leakage currents can be carried without danger, particularly from thermal, thermomechanical and electromechanical stresses; and

(c) it is adequately robust or has additional mechanical protection appropriate to the assessed conditions of external influence with Clause 3.3”

Clause 3.3 covers external influences from, ambient temperature, external heat sources, presence of water or high humidity, presence of solid or foreign bodies, presence of corrosive or polluting substances, impact, vibration, and other mechanical stresses.

All of the principles above are applicable to underground mine installations. In addition underground mine electrical systems and equipment, especially cables, are designed so that the most likely fault is a low energy earth fault. When this type of fault occurs, it is detected and the power is removed before a high energy phase to phase fault can develop.

To achieve high integrity earth paths in underground mines, earth connections and earth conductors must comply as a minimum with the relevant parts of the following standards:

- AS/NZS4871 series, Parts 1 – 5 “Electrical equipment for coal mines for use underground”
- AS1299 “Electrical equipment for coal mines – Flameproof restrained plugs and receptacles”
- AS1300 “Electrical equipment for coal mines—Bolted flameproof cable coupling devices”
- Note: The above standards refer to standards relating to explosion protection.
- AS1802 “Electric cables – Reeling and trailing – For underground coal mining purposes”
- AS/NZS 1972 “Electric cables – Underground coal mines – Other than reeling and trailing”

Note: All of these standards relate to coal mining equipment, however, this type of equipment is used widely in metalliferous mines and the principles used in these standards are applicable to metalliferous mines.

Electrical protection for coal mines.

The AS/NZS 2081¹ series of standards specifies requirements for earth continuity protection devices, earth leakage devices, and earth fault limiters, all of which contribute to the control of prospective touch voltages. AS/NZS2081 states:

“The key objectives of the AS/NZS 2081 series are as follows:

- (a) To ensure touch and step time/voltage levels are within acceptable limits.*
- (b) To minimize the risk of explosion due to arcing.*
- (c) To ensure earth return path(s).*
- (d) To ensure reliable operation under operating conditions.*
- (e) To ensure performance criteria are maintained under operating conditions.*
- (f) To minimize the risk of fires initiated by electrical arcing.*
- (g) To minimize exposure to electrical contact with live parts.”*

¹ Australian/New Zealand Standard AS/NZS 2081 Parts 1-5:2002: Electrical equipment for coal and shale mines—
Electrical protection devices.

Earth continuity protection.

The prime role of earth continuity protection is to detect ineffective earthing and remove the power from the affected circuit. Supplementary roles include automatic removal of power when plugs are inadvertently removed whilst energized, and machine control. The standard related to this type of protection is AS/NZS 2081.2:2002 *“Electrical equipment for coal and shale mines—Electrical protection devices Part 2: Earth-continuity monitoring devices”*. AS/NZS2081.2 refers to criteria in Australian Standard AS 3007.2—2004 clause 3.2.3² for “prospective touch voltage/operating time characteristics”, these characteristics then impose limits on the time taken to detect and clear earth faults.

It is important to realise that if earth continuity protection has an in-built delay in tripping when an ineffective earth is detected, the potential for excessive touch voltages for an unacceptable length of time can increase significantly.

Note: The standard permits a deliberately introduced delay of up to 500 milliseconds. For a 5 ampere earth fault limited system; if such a value was selected the maximum prospective touch voltage that is allowed is 90 volts rms, which in turn, requires the pilot-earth loop drop out resistance to be set well below 45 ohms as specified in the standard.

Earth leakage protection

This detects excessive leakage current to earth and automatically disconnects the power when excessive current flows. The standard related to this type of protection is AS/NZS 2081.3:2002 *“Electrical equipment for coal and shale mines—Electrical protection devices Part 3: Earth-leakage protection systems for use on earth-fault current limited systems (IT systems)”*. These devices often have the ability to adjust the trip times and it is possible to set the trip times to a level that allows unacceptable prospective touch voltage/operating time characteristics even with compliant earth continuity protection. Leakage trip currents must have a maximum setting of 10% of the rms value of earth fault limitation. For example, with 5 ampere earth fault limitation the maximum earth leakage trip value should be 500millamperes.

Earth fault limitation

Earth fault limitation is used to reduce the magnitude of touch voltages and to limit the amount of energy that can be released under the most common electrical fault, which is an earth fault. It also needs to be recognized that mining electrical equipment, in particular cables are designed so that the most likely fault is a low energy earth fault, and not a high energy short circuit fault.

Note: Earth connections in some equipment may only be rated for low values of current and sufficient mechanical integrity; they have been known to fail under conditions where two phase to earth faults have occurred.

There are two main types of earth fault limiters, purely resistive and those termed reactors (which have significant inductance). Earth fault limiters should be constructed in accordance with AS/NZS2081.5: 2002 *“Electrical equipment for*

² Australian Standard AS 3007.2—2004 Electrical installations—Surface mines and associated processing plant Part 2: General protection requirements.

coal and shale mines—Electrical protection devices Part 5: Earth-fault current limiters”

Where earth fault limiters are iron cored reactors, the initial earth fault current can be many times more than the steady state value (analogous to switching in a transformer on no load). It is common knowledge that past tests have revealed that the earth fault inrush current can be 10 – 12 times higher than the steady state value when iron cored reactors are used for earth fault limitation. Therefore, with high inrush currents, initial touch voltages and arc energy can exceed the steady state values by a significant amount. The touch voltage and arc energy diminish to the steady state value over a period of time (testing has shown that this time can be significant when considering touch voltages and clearance times - up to 300 milliseconds (15 cycles))

To limit the touch voltage, Clause 2.8, AS/NZS2081.5: 2002 states:

“The power factor of the earth-fault current limiting impedance, assuming zero cable capacitance, shall be not less than 0.65 lagging.”

Calculations show that with a 5 ampere earth fault limiter, with a power factor of 0.65 lagging, used on a 1000 volt system, the peak inrush current will be less than 11 amperes. Cable and fault resistance will reduce this value further. Older earth fault current limiting impedances with power factors lower than 0.65 lagging, have a resistance component that is reduced relative to the inductive reactance, and the peak inrush currents increases. When a resistor is used as the earth fault current limiter, the inrush current is limited to the steady state value, in this case, 5 amperes rms (a peak current of 7 amperes).

Restrained plugs and sockets (receptacles).

For operational purposes, mines use flameproof restrained plugs and sockets for ease of connection and disconnection. The Australian Standard AS1299 is the standard to which restrained plugs and sockets need to be constructed. These devices are designed for use with a pilot circuit and are designed so that if a plug was to be removed inadvertently the power would be automatically disconnected. This automatic disconnection utilizes the earth continuity protection (refer AS/NZS2081.2). These restrained plugs and sockets are designed to be used on earth fault limited systems and in conjunction with the protections specified in the AS/NZS2081 series of standards. As AS1299 is for flameproof plugs and sockets it refers to AS2380.2³. Because of the nature of their use, restrained plugs and sockets are designed to work as a “pair” and they have critical design features. These design features are:

1. When inserting a plug:
 - a. The plug and socket together must be flameproof before connection is made to the phase pins.
 - b. The first electrical connection must be an earth contact.
 - c. The second electrical connection must be the phase pins.

³ Australian Standard, AS2380.2:1991 “Electrical equipment for explosive atmospheres — Explosion protection Techniques Part 2: Flameproof enclosure d

- d. The final electrical connection must be the pilot pin.
2. When withdrawing a plug:
 - a. The plug and socket together must still be flameproof after the breaking of the phase pin connections.
 - b. The first electrical connection to break must be the pilot pin.
 - c. The second electrical connection to break must be the phase pins.
 - d. The third and final electrical connection to break must be the earth connection.

Note: The jacking screw of a receptacle plays an important role in maintaining flameproof properties; it is essentially a flameproof fastener.

Because plugs and sockets designed to AS1299 do not have an earth pin, the standard specifies requirements for effective earth connections in plugs and receptacles. As some of these earth connections are "scraping earths", clause 3.2.6 of AS1299 states:

"Scraping earth contact Tests shall be made to verify that the axial force necessary to insert into and withdraw from an earthing contact (when assembled in the casing) a mandrel of appropriate dimensions does not exceed 135 N nor is less than 45 N respectively. Where the earthing contact is a removable component, it may be tested separately in a simulated receptacle."

Basically insertion axial force should be between 45 and 135 Newtons, the withdrawal force should be a minimum of 45 Newtons and the insertion force should not exceed 135 Newtons. Any scraping earth axial force needs to be compliant for the service time of the equipment and any new receptacle that is only minimally compliant, may not remain in compliance after significant use. As well as having high integrity earth connections between plugs and receptacles, the earth connections within plugs and receptacles needs to have a high integrity. In restrained plugs, there are internal earthing arrangements that rely on sliding, scraping, butt or flange connections all of which need to have a high integrity of connection, as AS1299 is unclear on axial forces to guarantee scraping earth connections on the constituent parts of plugs, the values for the plug/socket scraping earth may be appropriate values to consider.

Summary.

An effective, high integrity earth path is essential for safety, and can be achieved by complying with standards for electrical equipment for use in coal mines. Any connection to the cabled earth path must be continuously effective; it is unacceptable to have an earth path by chance.

A high integrity earth, when used in conjunction with electrical protection as defined in the AS/NZS 2081 series of standards will ensure that touch and step potentials are within acceptable limits.

To adequately control touch voltages and arcing in extraneous earths, requires:

- A high integrity earth path from source to load.
- Earth fault limitation that conforms to AS2081.5 as a minimum.

- Earth continuity protection that conforms to AS2081.2 as a minimum.
- Earth leakage protection that conforms to AS2081.3 as a minimum.

If any of these elements are deficient, the risks of excessive touch voltages and arcing are not minimized.

INCIDENTS – Refer Safety Alert No. SA06-05

Two incident involving phase to earth faults on 1000 volt equipment in the hazardous zone at different underground coal mines have identified failure modes in Restrained Cable Plugs and Restrained Coupler Receptacles. Both incidents have resulted from ineffective earth connections.

Incident 1: Power supply to an electrically powered hydraulic pump tripped on earth leakage and an operator found the handle of a jacking screw on a Restrained Coupler Receptacle (Back to Back) welded to steel rib support mesh.

Incident 2: Power supply to a continuous miner tripped on earth leakage and a mine worker received a severe electric shock (there was a 200ms delay setting on the earth leakage relay). The mine worker was resting his left forearm on the rear of the miner and grasping a sheet of rib support mesh with his (gloved) right hand. The victim was transported to hospital in accordance with the mine's electric shock protocol and was allowed to leave after medical tests and examination determined that no permanent injury had occurred as a result of the shock and there was minimal risk of delayed arrhythmia.

CIRCUMSTANCES

Incident 1: The scraping earth connection between plug earth sleeve and receptacle body was found to be ineffective. The product is a Crouse-Hinds Macey 150 amp 660/1000 Volt Restrained Coupler Receptacle (Back to Back) and the scraping earth contact method is used on other Crouse-Hinds Macey receptacle products. Earth fault limitation on this circuit was 5 amperes, using a resistor.

Incident 2: Power supply to the continuous miner tripped at the load centre on earth leakage. A trailing cable plug was found to have an ineffective earth connection inside the plug body between the earth sleeve and the earth attachment mounted on the molded interior. The product is a CMI 300 amp 660/1000 Volt Restrained Plug with integral gland. Other plugs have similar internal earthing arrangements. Earth fault limitation on this circuit was 5 amperes, using a reactor.

AS/NZS 2081.2:2002 requires that the earth continuity monitoring device operate within 100 milliseconds when the loop resistance exceeds 45 ohms. In both incidents, the earth continuity monitoring device did not detect an open circuit earth due to environmental conditions, wet floor and continuous steel mesh rib support which combined to maintain a pilot earth loop resistance below the 45

ohm trip level of the earth continuity monitoring device. In incident 2, a PILOT CONTROL EARTH CONTINUITY RELAY was in use without a limiting resistor hence, the pilot to earth loop resistance before drop out was tested and found to be 130 ohms.

INVESTIGATION

1) **Incident 1:** The back to back coupler (photo 1 & 2) was examined at a cable repair workshop in the presence of the manufacturer. An earth sleeve from a plug was inserted into a receptacle of the coupler and an earth continuity test revealed an unreliable scraping earth contact.

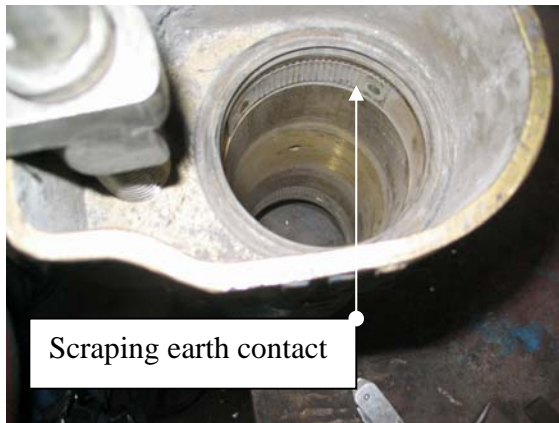


Photo 1



Photo 2.

2) **Incident 2:** The cable plug (Photo 3 & 4.) was disassembled at a cable repair workshop in the presence of the manufacturer. The earth sleeve was found to have an unreliable contact with the earth ring attached to the molded interior. The earth ring was manufactured to an incorrect diameter.

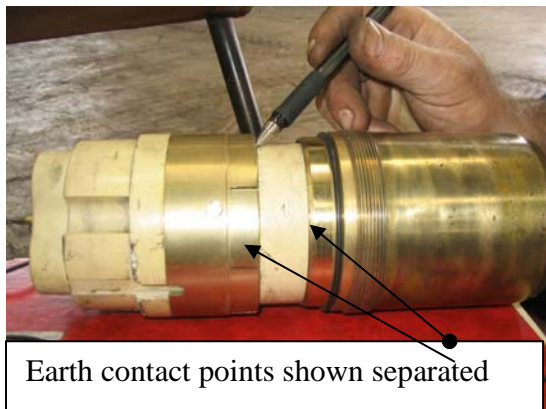


Photo 3.



Photo 4.

3) During the investigations a Crouse-Hinds Macey 300 Amp 660/1100 Volt Restrained Plug (Photo 5 & 6.) was examined. The design of this plug places a rubber 'o' ring between the nose cone and the internal earth ring. This arrangement compromises the compression between the interior earth ring and the plug body. Any loosening of the nose cone or degradation of the 'o' ring will affect earth integrity.

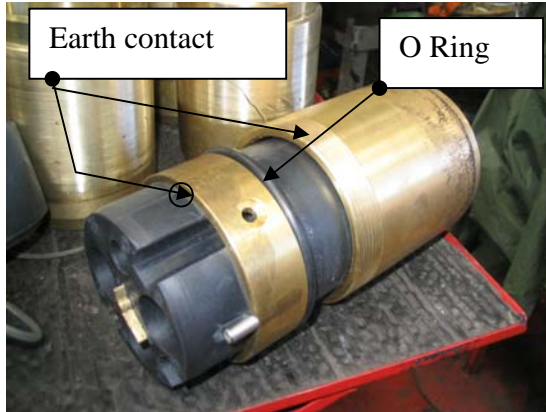


Photo 5.

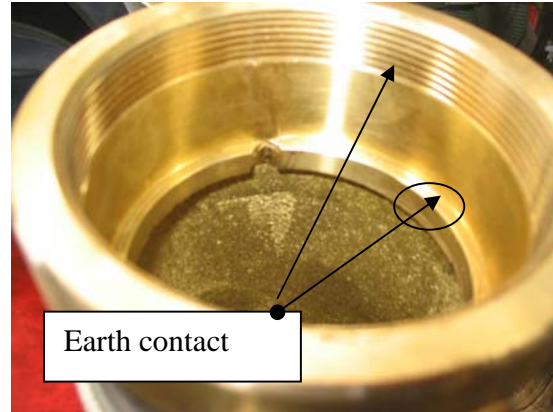


Photo 6.

Further advice on the construction, potential failure modes and earth continuity testing of restrained plugs is available on this website in the document "Earth Continuity for Restrained Plugs and Receptacles."

RECOMMENDATIONS

1. Mines need to ensure that tripping times for earth leakage relays and earth continuity relays are set to minimum values to achieve adequate prospective touch voltage/operating time characteristics.
2. Routine testing and recording of earth continuity needs to be carried out by competent people at a frequency sufficient to ensure that:
 - a. The earthing resistance is in accordance with the protective requirements and continuously effective, and
 - b. Earth fault currents and earth leakage currents will be carried without danger to persons from electric shock, effects of arcing or fire.

Note: It is recommended that insulation resistance testing is carried out at the same time.

3. Mines need to ensure that earth-continuity monitoring devices will operate when the pilot earth loop resistance exceeds a predetermined safe level for the parameters of the circuit being monitored. The maximum value of 45Ω may not be necessary on low resistance pilot/earth loop circuits. Mines should determine the minimum drop out value for earth continuity monitoring protection taking into account the actual pilot earth loop resistance of each circuit. The use of pilot (ON-OFF) control in conjunction

- with an earth-continuity protection relay must not compromise the operational criteria of the pilot earth continuity monitoring circuit.
4. Mines need to implement a program of testing earth fault limitation devices in use on underground transportable sub-stations. Where testing reveals non-conformance to AS/NZS2081.5 a program should be implemented to replace non-conforming earth fault limiters with conforming types.
 5. Mines need to immediately inspect equipment in service to confirm integrity of earth connections. The following techniques may be useful:
 - a. An accurate ohmmeter and a wire lead of known resistance will enable measurement of earth resistances from load centre to machines with the return path being the machine trailing cable and plugs. Any resistance value higher than the anticipated calculated value should be investigated. Cable earth conductor resistances are available from cable maker's data.
 - b. An earth continuity test using an earth sleeve inserted into a receptacle with the water seal in position. (This may reveal an unreliable scraping earth contact.)
 - c. An earth continuity test between earth sleeve (nose cone) of a cable plug and the phase barrier of the interior moulding. (This may reveal an unreliable internal earth contact.)

Note: The above tests will only detect immediate problems. Mines must ensure that all installations are effectively and continuously earthed. Fitting of additional earth bonds may be appropriate provided the explosion protection properties are not adversely affected.

6. Mines need to implement a program to strip, inspect and overhaul all receptacles and cables of these types. At these inspections, advice from the product manufacturers can be applied to assess compliance with Australian Standard AS1299 and to confirm the mechanical integrity of scraping and internal earth connections.

Note: Approved cable repair workshops are appropriate organisations to inspect and repair/replace restrained plugs.

7. Manufacturers need to immediately investigate the failures of their product to comply with AS1299, advise customers how to identify non compliant product in use and advise if it should be removed from service. Remedial modifications must meet requirements of AS1299.
 - a. In addition, the integrity of any internal sliding or non-bolted earth connection must be designed to maintain the requirements for scraping earth contact in AS1299 clause 3.2.6.
 - b. Criteria for earth path conductivity should address earth continuity and earth current capacity.
 - c. Manufacturers should issue instructions for in-service and overhaul maintenance that includes criteria for verifying safe condition of earthing arrangements.

8. Cable Repair Workshops and Approved Workshops receiving receptacles and cables of these types for repair need to apply information from the product manufacturers to assess the compliance of product and mechanical integrity of scraping and internal earth connections.
9. All stakeholders are encouraged to recommend changes to the Australian Standards committees for plugs and receptacles and for protection devices so that improvements can be made and applied to future generations of equipment.

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