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RESEARCH PAPER

Welding electrical hazards: an update

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Abstract Equipment damage from stray welding current and electrical shocks to welders (personnel welding) at a mine in northern Canada led to considerable investigative work which has shown that the potential is high for serious injury, death, major equipment damage, and fire. Root cause analysis of incidents established the common failure parameter as, or equivalent to, a terminal fault to earth ground on the welding power source. This was described in the first paper on this subject. Further incident investigation found that equipment damage and work stoppages cost industry millions of dollars in repair and lost production costs. Documentation of fatalities from around the world has proven that even though welding voltages are normally well below the 100 V maximum established by mining regulators to be a "safe voltage", welders continue to die due to contact of the welding electrode with their body. Additionally, in at least one documented case in Canada, a welder died from electrocution due to an electrical system fault created by the welder's own stray welding current. Much of the work represented in this paper comes from the authors' own experience augmented by supporting research of others. This paper looks at the electrical hazards of welding including high frequency/radio frequency, stray welding current, and electrical shock occupational injuries and fatalities from the welding electrode circuit. It considers the equipment damage and loss of life through stray welding current and considers industry, regulatory, and employer response in preventing these occurrences.

Keywords Electrical hazards · Welding fatalities · Stray welding current · Electrical fatalities · Equipment damage

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1 Introduction

Many welders view the "tingle" shock as a normal "inconvenience" or "discomfort" of their trade and do not see it as a hazard. In one[1] fatality report reviewed for this paper, the workers had become so accustomed to receiving shocks from the welding electrode that they disregarded the electrical shocks received from mining equipment which had been accidently energized by a 110/220 V of alternating current (VAC) circuit; one worker died as a result. All of the workers present had mistaken the shocks they were receiving from the 110/220 V fault as an electrode shock coming from their welding machine.

Heavy stray welding current damage to electrical wiring, machine bearings, crane cables, mobile equipment, and the like is all too common. A check on the internet[2] will identify various issues caused by stray welding currents. When welding machines are used in the north to thaw buried water lines, fires have been caused and electrical services destroyed and often not in the building under repair, demonstrating that welding currents which are allowed to flow indiscriminately, may cause unpredictable damage. Canadian electrical safety code bans this procedure for thawing pipes for this reason.

[1] USA Mine Safety and Health Association (MSHA) report (1998) Meigs #2 Mine, Albany, OH, USA. 23 July 1998.
[2] Technical Interpretation—pipe thawing (http://www.hrsdc.gc.ca/eng/labour/fire_protection/policies_standards/interpretations/2006_23.shtml).

With the ever-increasing importance of loss management in industry, more and more minor equipment damage and mild shocks are being subjected to root cause investigation. James C. Anderson and John H. Moore with input from Dr. Howell Runion published a [1] paper detailing a recommended format for electrical shock reporting and why it was important. Jurisdictions often set a voltage level when electrical shocks shall be reported to the authority having jurisdiction, unfortunately, electrical shock received from the welding electrode is normally below that value.

The Canadian company where the initial investigative analysis was performed produced a video "Welding Electrical Hazards" which was distributed on a complimentary basis to companies, regulatory bodies, standards organizations, and individuals throughout North America. It was highly regarded by individuals within mining regulatory bodies in both Canada and the USA. The video was based on the information gained in the study and on the findings described in the [2] paper by the original authors, Thesenvitz and Hisey.

The first paper was based on loss management work completed in northern Alberta, Canada. It covers work completed over several years. The information contained in this updated paper came from the original research and additional information and experiences the author has gathered over the 18 years since the original paper was written and presented. The author has been personally associated with many of the incidents discussed in this paper in either a consultative or investigative role.

1.1 Incident types

This paper discusses electric shocks from the welding electrode (both injurious and fatal), how and why it occurs, and how to prevent it occurring in the workplace. Additionally covered is the phenomenon of stray welding current. Property and equipment damage occurs as a direct result of stray welding current; this led to a fatality in one incident discussed here. The how and why stray welding current occurs and how to prevent it from occurring is explained. An incident is discussed where high frequency, radio frequency welding (HF/RF) transmit in the very high frequency (VHF) range may have caused excessive heating to medical implants in a welder's body.

2 Electric shocks

2.1 Electrical shock from welding circuit

During[3] interviews with workers who earn their living welding, many admit to regularly experiencing electrical shock, while others claim to never receiving shocks from their welding electrode. Many who receive electrical shock on a regular basis work in damp or wet and/or an elevated temperature environment. Information showing that welders receive electrical shock from the welding electrode can be found in the [4] occupational injury reports from both developed and developing countries.

2.2 Electrode electrocutions

The USA has had [5] fatalities due to electrocution from the welding electrode, the latest one as of this writing in mining 27 July 2011 [6]. Australia reports that they have had approximately 28 documented fatalities in the years 1958 through 2011[7] [3]. Some countries do not define the actual fatality cause and report all electrocutions as either low voltage or high voltage, making it difficult to use their statistics in this paper. Many jurisdictions refuse to believe that the very low voltage from welding electrode circuits can kill, and worker fatality investigations involving welding machines are occasionally flawed providing misleading information.

The paper by Peng and Shikui [4] considers seven fatalities caused by electrocution from the welding electrode and provides detailed autopsy reports on each of the victims providing investigators and medical examiners a basis for decision making. During discussions[8] the author had with Dr. Howell Runion (University of the Pacific, Stockton, CA, USA), as a follow-up to a fatality investigation, Dr. Runion maintained that all electrical shock of sufficient current to kill was in fact traceable through the human body.

During fault conditions[9] in the welding circuit, the welder may receive [5] electrical shock from the work lead clamp, a grounded power tool, the work piece, or the electrode. The source of all these shocks is the welding electrode terminal. The welder only expects shocks to come from the electrode. Often the welder reports these shocks as a problem with power tools or as a problem with the electrical power supplies to his or her work area. Electricians not familiar with the phenomena of stray welding current will not look for welding causes and either diagnose an electrical problem that does not exist or will consider the welder as being mentally deficient and therefore

[3] Interviews the author conducted during follow-up on occupational injury reports.

[4] USA MSHA reports (see fatality charts); Verdict of Ontario Coroner Jury Mayorga fatality, 4 Aug 1994.

[5] See charts depicting welding electrode shock fatalities.

[6] MSHA Coal Mine Fatal Accident Investigation report: fatality #12—27 July 2011.

[7] Welding Technology Institute of Australia, Glen Allan, email on 12 April 2012.

[8] Telephone discussion between the author and Dr. Runion 1995.

[9] Fault conditions: examples of what the author considers fault conditions in a welding circuit are shown later in this paper and were originally described the previous paper by Thesenvitz and Hisey. The reader should study the line drawings of typical welding circuits in this paper to better understand how this phenomenon occurs.

ignore the complaint. Incidents of this type were recorded and demonstrated in the video[10] "Welding electrical hazards".

The author has on occasion inspected standard 120/240 VAC lightweight power tool cords used in the vicinity of welding and found the ground conductor overheated and the ground pin on the connector plugs destroyed—the likely cause—stray welding current which should have been carried within the welding cables designed to contain it.

2.3 Occupational injury electric shock—not fatal

In September 1997, the author was asked to review occupational injuries which had been reported during July and August 1997 for the purpose of identifying those with serious potential. The company employed approximately 5,500 persons at the time in all aspects of a mining, extraction, and oil refinery operation. Summer was the typical time for major shutdown/rebuild projects.

During this period, a total of nine occupational injuries were treated as electric shock from the welding electrode. Four in the opinion of the author had serious potential for electrocution. Three of those had been sent from the onsite medical facility to the local community hospital where they were treated and released. Two of the occupational injury reports were selected for review. Interviews were conducted with the victim and/or the witnesses.

2.4 Occupation injury report #1 (29 July 1997)

The victim had been welding on a large process flood water line using manual metal arc welding/shielded metal arc welding (MMAW/SMAW) process. The welding machine make and model were not reported but all in use at the time were transformer-type direct current (DC) output with open-circuit voltage (OCV)/no-load voltage in the range of 63–80 V DC, specifications on the ripple current were not available. The victim was wearing cotton coveralls and welding gloves and not much else due to the extremely hot humid work area in the extraction plant. Typical temperatures in this plant area were in the 35–38 °C range. It was near 1600 hours, which was 8.5 h into a 12-h work shift, the victim said that his coveralls were wet with perspiration. To complete the weld, the victim squeezed himself into a very restricted work space in a crouching position with his back wedged tightly against a catwalk hand railing. In the process of changing an expired short stub electrode, the hot end of the electrode pierced the welding glove on his left hand burying itself into the fleshy part of his left hand between the thumb and forefinger. The victim reported that he could feel "arc current going into my body". He felt unable to move and was certain he was going to die. Fortunately, this victim was able to free himself from the predicament he was in by a rocking motion with his legs. He was given emergency first aid at the onsite medical facility and then sent to the local hospital. The occupational injury report stated that the burn was fully cauterized, no exit burn was identified. The report from the hospital was not available.

2.5 Occupation injury report #2 (5 August 1997)

This incident occurred in the same extraction plant as the 29 July 1997 occupational injury. The welding machine make and model were not reported but all in use at the time were transformer-type DC output with OCV/no-load voltage in the range of 63–80 V DC, specifications on the ripple current were not available. The welder was using MMAW/SMAW process. The victim was wearing cotton coveralls and welding gloves. The work environment was very hot and humid, the incident occurred at 1920 hours, over 11 h into a 12-h work shift. The victim's coveralls were wet with perspiration. The working temperatures were in the 35–38 °C range.

The victim was welding in an elevated position on the side of a large metal process tank. He had used his safety harness as a working belt and had tied himself to the permanent steel vertical ladder on the side of a large steel tank. In the process of repositioning, the victim placed the electrode holder someplace on his body with an electrode still in place. A witness saw the electrode holder with the electrode still in place fall to the floor and recognized that the victim was in trouble. Fellow workers that took him down reported that he was initially unresponsive. The victim was revived while first aid was being summoned. He said that felt he felt "shaky" and "just wanted to sit down".

He was given emergency first aid at the onsite medical facility and then transported to the local hospital. He did not return to work at that site. There was no report of burns and the report from the hospital was not available.

2.6 Electrocutions from contact with electrode 22 July 1969–27 July 2011

The following two charts depict 11 electrocutions by shock received from the welding electrode. The fatality reports these charts were prepared from have been gathered from the USA, Canada, and Australia. The USA Mine Safety and Health Association provided the oldest reports manually from their records, which is greatly appreciated.

- All were male welders, ages 21–45 (in one case the age was not given—just that he had considerable experience).
- All were using manual metal arc process (MMAW/SMAW).
- All fatalities occurred in high-temperature months (May to September in North America, December for Australian

[10] Welding Electrical Hazards video released by Syncrude Canada Ltd in 1994

victim) for the occurrence location; 10 of the 11 fatality reports claimed the victims were perspiring heavily and or were working in elevated temperatures and humidity.
- Personal protective equipment (PPE) was mentioned in these fatality reports. Six reports said that gloves were either faulty or not being worn, one additional report listed PPE as a deficiency; however, both those wearing gloves and those not wearing gloves died.
- The OCV ranged from 50 to 83.3 V for the welding machines used (one did not report voltage level).
- All received electrical shock which appeared to pass across the chest (one report from Canada, 4 August 1994 did not state the flow of current; however, the report placed part of the blame for the electrocution on the metal ladder on which the welder had been standing, because of the way the welder was working—current flow was either hand to hand or hand to foot, across the chest).

There are similarities between the 11 electrocution fatality reports and the two occupational injury reports

- Both were male (ages were not recorded during the interviews, but the author recalls one as being in mid 30s and the other as early 40s).
- The process used was MMAW/SMAW.
- Injuries occurred while working during summer months (July/August) in hot humid environments with significant perspiration present (If in an Australian jurisdiction, both victims were working in a Category C environment according to Australian Standard AS 1674.2—2007).
- OCV/no-load voltage of the welding machines was 63–80 V DC (typical of what was in use on the project). There was no data gathered as to the ripple current present in the DC welding machines.
- Current flow was across the chest according to information provided by the one victim and from the witness reports.

The main difference was that the second group of workers did not die.

The study on electrocution by low voltage by Pens and Shikui studied seven electrocutions from electric shock received from the welding electrode. A review of that paper showed that;

- All were male welders between the ages of 20 and 41.
- All were using manual metal arc process (MMAW/SMAW).
- All were working during summer months in hot humid environments.
- OCV/no-load voltage of the welding machines was 47–75 V
- Three of the welding machines involved were DC—one was alternating current (AC) and two were not stated. There was no data gathered as to the ripple current present in the DC welding machines.
- All of the contact points noted involved current flow across the chest

2.7 Other considerations

- Older type DC output transformer type welding machines will have ripple significantly higher than 10 % and from an electrical safety perspective are regarded as having a similar hazard level to AC output welding machines. Refer to AS 1674.2–2007 and AS/NZS 60479.1–2010 (IEC/TS 60479–1, Ed. 4.0 (2005)).
- Immobilization occurs at relatively low currents with AC and high ripple DC, approximately 1/3 of current levels documented as threshold of ventricular fibrillation (refer to AS/NZS 60479.1–2010).
- Assuming a large moist contact area, the current exit point would be indeterminate for a current of the order of 2 mA (threshold of sensation) to possibly 200 mA or more, depending on welder body resistance.
- Recent work carried out at the University of Wollongong by Professor John Norrish has shown that moisture levels as low as 5 % weight in weight (w/w) in cotton drill clothing is sufficient to enable conduction of potentially fatal currents from a welding power source.

2.8 Stray welding current contribution to these accidents

In three of the accident reports used here, stray welding currents were possibly present as the welding return lead was less than 2 m and the electrode leads in two of the accident reports were approximately 60 m and approximately 45 m. In one of these, the electrode lead had been improperly spliced and had a high resistance connection that existed in both the electrode and return leads. It is unknown what factor this may or may not have played in the incidents (Table 1).

3 Stray welding current

3.1 Equipment damage from stray welding currents

Over a period of several years at the mine, where the initial investigative work took place, there have been several equipment damage incidents investigated which were determined to be caused by high welding currents flowing astray. Stray welding current is defined as: “Any welding current which flows outside the designed welding circuit”. Ideally, welding current should flow from the welding power source through the properly sized electrode welding cable in good electrical condition, transfer via the welding arc into the work piece, travel a very short distance through the work piece (metal being welded), and flow into the welding current return lead

Table 1 Fatalities from welding electrode electrical current

Country	Accident date	Age	Gloves worn	Conditions wet/damp/dry	AC welding current	DC welding current	Welding machine OCV (V)	Method of weld	Contact point on body	Gender	Notes
USA	22 July 1969[a]	21	Not mentioned in report	Clothing was damp from perspiration and from lying on wet steel floor; work area was very confined	No	Assumed to be DC, remarks (neg/pos)	73 V	MMAW/SMAW	Facial/nose and left side face/worker was lying in prone position on his back on steel chute	Male	Stray weldingcurrent possible factor due to return lead 5 ft long. Electrode lead was 46mt long.
USA	9 May 1972[b]	45	Yes but they were wet and worn with holes	Wet from rain water work area confined. Rain water was diverted into conveyor pan on which worker was kneeling.	Yes	No	80 V	MMAW/SMAW	Lap or underarm victim working in kneeling position on steel conveyor pan	Male	Electrode position was not determined, victim was observed during welding operation
USA	13 June 1973[c]	31	No	Weld area had been washed recently, work area very confined. Report did not indicate condition of clothing	No	Assumed to be DC from remarks (solid state AC unit)	Not stated in report	MMAW/SMAW	Facial electrode contact, victim was face down prone position on steel chute	Male	Also laceration of left chin
USA	27 August 1980[d]	36	Not mentioned in report	very hot 40.5–42.2 °C victims clothing was soaked with perspiration	Unknown Welding machine was capable of both ac/dc but which was selected was not specified in report	Unknown Welding machine was capable of both ac/dc but which was selected not specified in report	80 V	MMAW/SMAW	Electrode lying on chest, victim lying on back on steel air duct	Male	Electrode holder was defective; stray welding current possible due to return lead connected to building steel electrode lead 64mt long 1/0 copper weld lead
USA	5 May 1981[e]	26	No	Victims clothing was impregnated with perspiration and salt dust. (very wet and conductive)	Yes	No	50 V	MMAW/SMAW	coroner's report, small burn on chest and another on left shoulder blade, victim lying on salt covered expanded steel flooring	Male	Electrode holder in the victim's bare right hand; electrode was lying on chest, victim lying on back. Coroner's report indicated acute cardio respiratory collapse
Canada	4 August 1994[f]	34	Not mentioned in report	Humid extremely sweaty environment	Not stated but from information appears most likely to have been AC	No	Not stated in report	MMAW/SMAW	Not stated in report	Male	Victim received electrical shock while welding, on ladder, passed out and was pronounced

Table 1 (continued)

Country	Accident date	Age	Gloves worn	Conditions wet/damp/dry	AC welding current	DC welding current	Welding machine OCV (V)	Method of weld	Contact point on body	Gender	Notes
											dead on arrival at the hospital
Australia	14 December 1997[g]	Unknown reported as having considerable experience	No	Hot and humid	Implied by report as AC but not stated	No	Unknown	MMAW/SMAW	Burn mark on neck Victim lying on back welding cables under body, electrodeholder in right hand on chest, electrode touching neck	Male	Electrode holder was reported as defective. Information came from Mining Wardens Inquiry
USA	30 August 2000[h]	36	No	22.2 °C, confined work area not noticeably wet	No	Yes	83.3 V	MMAW/SMAW	Victim lying on right side on steel conveyor, burn on second finger left hand	Male	This was a gouging operation, 3 gouging rods had been used and 4th installed in electrode holder
USA	16 September 2002[i]	43	Yes	Victims clothing was wet from rain which was falling, temperature was 35 C. Welding location was a confined space	No	Yes	79.5 V	MMAW/SMAW	Electrode holder in hand electrode lying on victim's chest, victim lying on a metal screen, burn marks on left side of chest and right side of body.	Male	Current flowed across chest left to right.
USA	6 August 2003[j]	44	No	Ground was wet form recent rain, victim was lying on ground. Air temperature was 22.2 °C. Victim had been sweating heavily.	Yes	No	Not measured but the welding machine depicted in the report pictures was older AC machine which should have an approximate 80 OCV maximum.	MMAW/SMAW	Death certificate listed death as Electrocution. No contact points were identified. Victim was sitting on the ground leaning against steel wagon frame he was welding on which was 21 in. above the ground.	Male	Toxicology performed indicated that the victim had elevated levels of an enzyme that is released when muscles are damaged, consistent with an electrocution.
USA	27 July 2011[k]	39	Not mentioned in the report, although the citation did say that the employer must provide proper PPE in the future, indicating	The area had been wetted down to prevent fire and was still wet. The air temperature was "very hot" and the victim had been sweating profusely.	No	Yes	71.8 V	MMAW/SMAW	Electrode was in the victims mouth, left foot and right leg in contact with pipe being welded and his back resting against the plant structure	Male	Mouth was locked closed around electrode;welding electrode lead 60mt, #1 AWG; stray welding current possible factor due to return lead 1.2mt long. Work lead connection point

Table 1 (continued)

Country	Accident date	Age	Gloves worn	Conditions wet/damp/dry	AC welding current	DC welding current	Welding machine OCV (V)	Method of weld	Contact point on body	Gender	Notes
			that PPE was missing.	Lighting was poor, and the victim was in his 13 h of work that day.							was rusty and high resistance connection; electrode cable was spliced with high resistance connection. There were 18 damaged areas on the electrode cable were the bare conductor was exposed, including 2 located within the work area of the victim.

[a] United States Bureau of Mines report. Tioga Mine, West Virginia; 22 July1969

[b] United States Bureau of Mines report. Eastern Coal Corp, Kentucky; 9 May 1972

[c] United States Bureau of Mines report. Camp Bird, Colorado; 13 June 1973

[d] United States Bureau of Mines report. Alamo Cement Plant, San Antonio, TX, USA; 27 Aug 1980

[e] United States Bureau of Mines report #16-00246 Belle Isle Mine St. Mary Parish, Louisiana; 5 May 1981

[f] Ontario Ministry of Labour letter dated 28 Oct 1996; Coroner of Inquests file #14857; Verdict of Coroner's Jury fatality Report on death Aug. 4, 1994 Holy Family School Bolton, Ontario

[g] Findings and recommendations of reviewers and mining warden following an inquiry into fatal injuries received by Phillip Anthony Fowler at Cannington mine on 14 Dec 1997 (mines.industry.qld.gov.au/safety-and-health/Phillip-FOWLER.htm)

[h] USA Mine Safety and Health Association (MSHA) Report Mark Sand and Gravel Co., Fergus Falls, MN, USA. I.D. 21-00645 Fatal Accident, 30 Aug 2000

[i] USA Mine Safety and Health Association (MSHA) Report Plaza Materials Corp. Pasco County, FL, USA. Mine I.D. No. 08-00956, 16 Sept 2002

[j] USA National Ag Data Base (nasdonline.org/document/1858/d001793/farmer-dies-when-electrocuted-while-welding-feed-bunker.html)

[k] USA Mine safety and Health Association (MSHA) report, Mike Dover Corporation (LVQ), Superior Processing, Inc., Superior, West Virginia

via a properly prepared surface and return lead clamp, then back to the welding power source.

Some of these incidents investigated were very minor in nature, nothing more than a burnt ground wire in the electrical cord of a power tool. Others have been more significant such as damaged electrical cable armoring and melted jacket of a length (more than 150 m) of 600-V three-phase armored cable between an electrical distribution room and a welding receptacle which was mounted on a concrete column in an extraction plant. One incident of stray welding current which the author consulted on took the life of a 32-year-old male.

A company reported via their safety[11] bulletin that a ground cable on an electric motor was burned and other cables in the cable tray were damaged. The problems were traced back to welding return leads not properly installed or too small to contain the welding current.

Not all incidents will involve electrical parts. In one incident investigated by Thesenvitz and Hisey for the previous paper, a shop crane cable was "smoked" by conduction of welding current while it supported a component being welded. Also, many machine bearings have failed, with welding current being the identified cause.

In an incident follow-up conducted by Thesenvitz and Hisey, several large mine haul truck engines were destroyed, a highway sanding truck was destroyed by fire caused when welding currents entered the equipment wiring during a period of maintenance welding. On large diesel engines, the author found that electrical current that caused significant damage was traceable though the crankshaft and telltale signs of welding current appeared on main bearing cap surfaces, connecting rods and pistons. Each situation may be different depending on the amount of welding current transiting the engine. Following extended welding repair on the haul truck frame and/or box, the engines used as examples self destructed after several operating hours in the field due to engine bearing failure. Mining haul truck engines at the time of writing cost approximately $411,000.00[12] to overhaul and $588,500.00 to replace when destroyed. This is for a medium-sized haul truck engine; the large 460 t trucks will be significantly more (Figs. 1, 2, and 3).

3.2 Stray welding current damage to rolling element bearings

David Stevens in his [6] articles on bearing damage by the passage of electric current publishes some of the best pictures of welding electric arc damage to rolling element bearings (antifriction bearings). If the equipment is in the operating mode, the failure mode will not differ from circulating electrical current damage due to electric motor design issues.

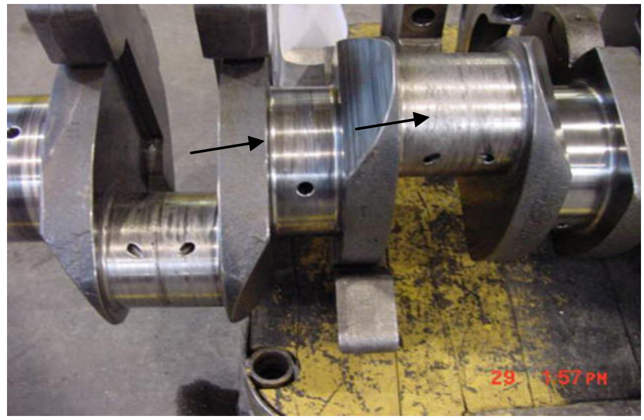


Fig. 1 The welding current entered or exited the engine through the crankshaft during maintenance welding on the haul truck box and frame areas. The bearing journal in the center is a main bearing journal; the one to the *right* is connecting rod bearing journals. This engine was configured as V 16, so there are two connecting rods on a common journal

However, if the equipment is stopped when the welding current flows across a bearing race, then the damage will be similar to that noted on the main bearing caps of the hauler engine, definite arc flash pits. When the bearing is disassembled, it can be examined with a 10–30 power-magnifying glass. Welding current will appear in an antifriction[13] bearing as pitting with smooth bottoms which are typical of any electrical metal arc. A before and after vibration analysis will quickly show up the change which has occurred in a bearing which has suffered welding current damage. Like all failures, identifying failure early, before total destruction, helps the investigator greatly in identifying the cause, and therefore the solution.

3.3 Work stoppage from stray welding currents[14]

A large manufacturing facility in Ontario, Canada suffered work stoppages when workers refused to work after the retractable steel cable personal safety systems were seen to be arcing to nearby structural steel. This facility which manufactured diesel locomotives used numerous welding machines in the manufacture of the basic diesel locomotive structure as well as in their smaller part fabrication areas.

[11] BHP Welding Safety Bulletin March/April 2002 #20

[12] Based on 793 Caterpillar Haul Truck engine costs from Finning Caterpillar, Edmonton, Alberta, Canada 2012

[13] David Stevens IEng, MIET, FIDiagE, MICML. Damage caused by the passage of electric current. (http://www.vibanalysis.co.uk/technical/electric/electric.html); Bearing failures and their causes—bearing damage—passage of electric current (http://www.skf.com); Passage of electrical current (http://www.fag.de).

[14] Stray current can occur whenever there is a parallel path from the arc to the welding machine. Parallel paths exist in many situations and often cannot be eliminated. Parallel paths will carry little or no current if there is a low resistance path to the welding machine, as provided by a return cable of sufficient capacity located as close as practicable to the welding activity

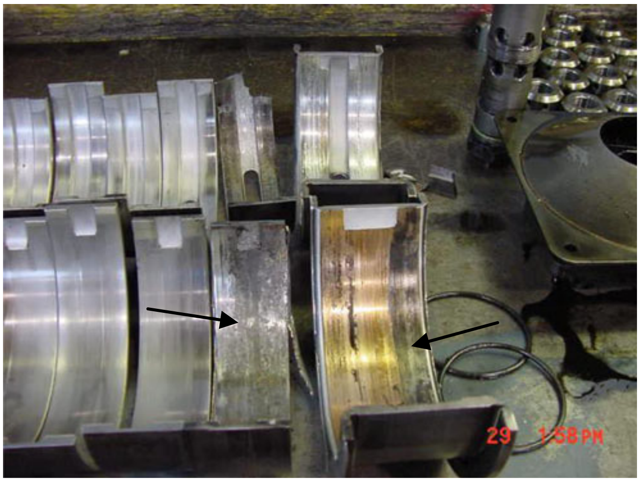


Fig. 2 Bearing inserts shown here. From the right, main bearing, then connecting rod bearings. The first 2 bearing inserts have seen heavy current flow

An engineering firm was hired and given the task of hunting down the cause or causes. A detailed report was provided. There were many instances of individual welding machines contributing to the overall problem. Poor work lead connections, substituting of 11-gauge steel metal strips for 4/0 AWG copper welding return lead cable, poor work lead clamps, poorly designed welding setups all contributed to the overall problem. Welding return lead faults were the sole cause of stray welding current and the electrical arcing to the safety cables first discovered by the workers. The root cause was disregard of proper work lead placement and type by management, engineering, and the welders; as in this situation, many of the causes were actually designed into the welding work stations.

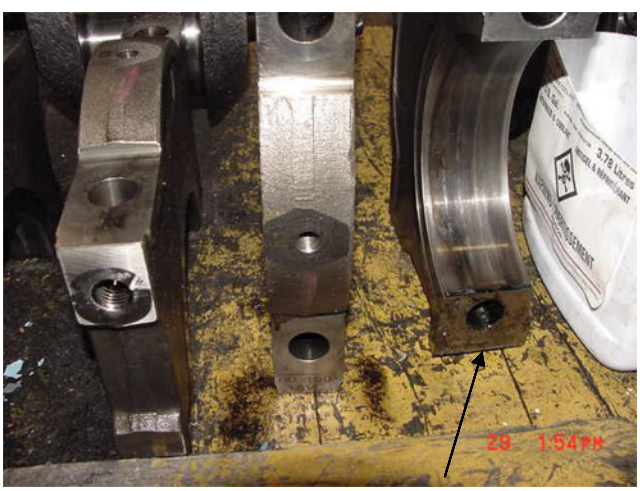


Fig. 3 This is a phenomenon which has occurred repetitively in large diesel engines damaged by stray welding currents. Welding arc is present on the mating surfaces of main bearing journals and the engine block even though these are tightly torque bolted joints

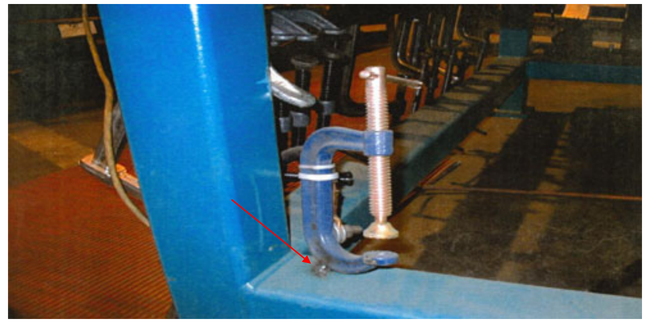


Fig. 4 This standard "C" clamp is only tack welded to the welding work bench. Based on a 4 V drop, a 60 m length of 4/0 AWG welding cable will carry 400 A of welding current, the tack weld will carry much less, forcing the excess current to flow elsewhere to get back to the welding machine if there is an alternative "parallel" path. This situation was found in the Ontario, Canada manufacturing facility

Multiple paths existed for the various welding currents from the numerous welding machines. These failures become additive and the whole building structure became alive with a multiple of current paths. Applying OHM's law (voltage= resistance×amperage), the resultant voltage difference was viewed as electric arc flashes when the metal safety harness lanyard touched two different sections of building structural steel (Figs. 4, 5, 6, 7, 8, and 9).

3.4 Electrical system damage from stray welding currents

In Cambridge, Ontario, Canada[15] on 1 November 2001, a young millwright welder was welding in a new factory building structure which was nearing completion. The welding machine was powered from a 600-V three-phase electrical subservice system which had been recently installed.

The welding machine was connected to power via an electrical extension cable and a metal cord connector. Welding was occurring some distance from the welding machine, exact cable lengths were not recorded by the initial investigator. The welding work lead connected the welding circuit to a foundation bolt at the base of building structural steel near the welding machine, forcing the welding current to find its own path to complete the circuit.

During the investigation following the electrocution of the millwright welder, inspection showed welding current flowing in the electrical ground circuit had melted electrical conduit fittings in the 600-V electrical service system. The molten and overheated metal conduit fittings caused the insulation on the electrical phase conductors to melt, shorting the 600-V phase to electrical ground (348 VAC phase to ground) and blowing the 400 A main system fuses. Sufficient stray welding current had been flowing long enough to fail the #6

[15] Ontario Occupational Health and Safety Report on Cambridge fatality, 1 November 2001.

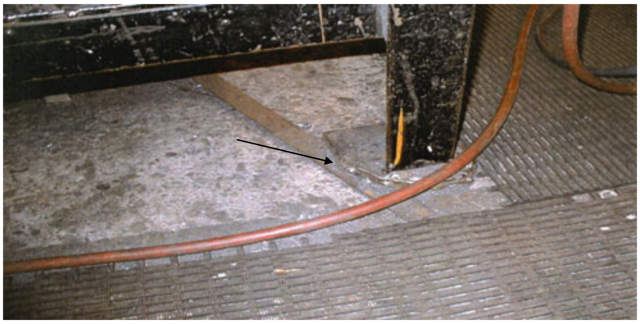


Fig. 5 Multiple welding machines were connected to a common return flat bar. Here, we see the circuit passing by another work station so the work bench leg was simply welded to the 11-gauge flat bar. This situation was found in the Ontario, Canada manufacturing facility

Fig. 7 Well-designed, very neat installation; however, this 11-gauge steel flat bar would not carry equivalent current to a 4/0 copper weld lead, so the excess current found another parallel path. This situation was found in the Ontario, Canada manufacturing facility

AWG ground conductor, which was bonding the 30 amp disconnect feeding the welding machine power circuit.

An electrician was called to fix the electrical problem. Simultaneously, the millwright welder proceeded to trouble shoot the loss of power to his welding machine. The electrician replaced the main fuses and energized the system. This caused welding power circuit to have 348 VAC flowing in the electrical ground circuit due to contact of a phase conductor with the failed electrical ground conductor in the welding machine disconnect switch. The millwright welder was found with the 600 V cord connector male end in one hand and the female end in the other hand; 348 VAC flowing across his chest and heart from hand to hand. He was dead. During the investigation, measurements taken between the 600 V connector at the welding machine and the building steel measured 850Ω. With a phase to ground voltage of 347 V, the 850Ω resistance would allow 400 mA of current flow. Respiratory arrest will occur at 20–50 mA, ventricular fibrillation 50–150 mA at 60 Hz according to the Canadian Centre for Occupational Health and Safety.

Additionally, electrical circuits which had not been powering the welding machine showed signs of arcing and

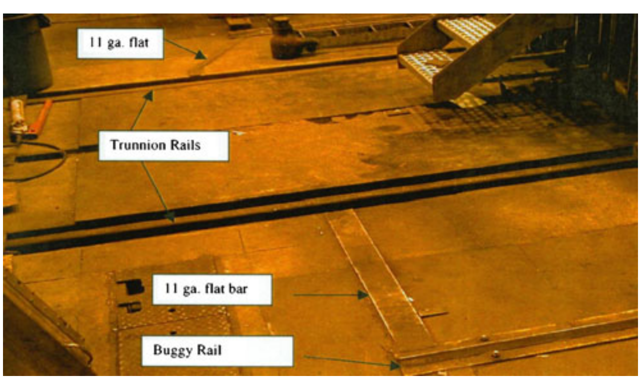


Fig. 6 More 11-gauge flat bar intended to replace 4/0 AWG copper welding cable. It will not carry the equivalent current, so the excess current found another parallel path. This situation was found in the Ontario, Canada manufacturing facility

welding current flow in the ground circuit demonstrating that multiple welding current paths existed. The pictures and drawings that follow tell the story (Figs. 10, 11, 12, 13, 14, and 15).

3.5 How stray welding currents occur

One needs to examine the following welding circuit diagrams to understand the leakage points the welding current may escape from. The fault conditions described are taken from the original paper by Thesenvitz and Hisey.

Figure 16[16] describes the typical welding circuit; we have shown a typical industrial power supply for Canada as a 600-VAC three-phase connection. This would be similar in other jurisdictions, with the exception the voltage may change to 460 or 380 VAC depending on which country the welding machine is situated in. The welding machine is shown as bonded to electrical ground via the green conductor on the right shown attached to the machine frame ground.

The welding electrode is fed from a standard DC welding machine unit—with a typical output of 60–80 V DC, the voltage is typically stepped down through a transformer and rectified via a three-phase rectifier. The circuit is completely isolated from electrical ground as designed.

This drawing depicts the welding current as all contained within the designed circuit; it is assumed that welding is in progress with current flow through the work piece.

Note that for MMAW machines[17], Canada limits design OCV to 80 V rms for AC welding machines and DC welding machines with greater than 10 % ripple current. DC welding machines with 10 % or less ripple current are allowed 100 V average OCV. Australia has similar standards.

In Fig. 17, which we choose to call fault condition #1, we depicted a connection between the work lead terminal and the frame of the welding machine, this could be an intentional

[16] All drawings come from original document [2], original drawings all by Thesenvitz.
[17] CSA C22.2 no. 60-M1990

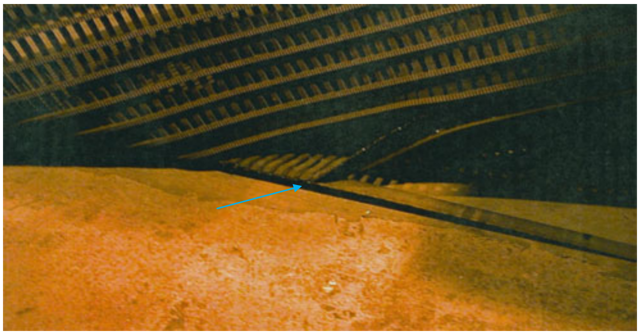


Fig. 8 The steel 11-gauge flat bar had overheated and the rubber floor matting had melted and stuck to the flat bar. This situation was found in the Ontario, Canada manufacturing facility

connection, it could be accidental as the work lead is often coiled as a loop on the side of the welding machine with the work lead clamp touching the welding machine metal frame. This situation can also arise if there is damaged insulation on the work return cable. It is assumed in this drawing that the power tool is electrically grounded.

With the work lead connection not properly in place, welding may still occur as there is a current path through the electrical ground conductor in the power tool and through the power cord to the welding machine, although neither of these conductors are designed or capable of carrying welding current for very long. The power cord to the welding machine would normally contain a #8 AWG or #10 AWG copper ground conductor; the power tool cord would typically have a #12 AWG or #14 AWG copper ground conductor. If there is no power tool present, and the work piece is connected to electrical ground, then the current will still flow through the welding machine power cord electrical ground conductor.

In Fig. 18, which we chose to call fault condition #2, a connection between the electrode lead terminal and the frame of the welding machine is depicted. This is not a condition that anyone expects to occur, yet it was found to be a very common condition anywhere welding is occurring. It could be caused by a welding machine connected for dual purpose operation with a wire feed (MIG) gun sitting in a welding machine mounted holder and the welding machine set to MMAW/SMAW mode, which would cause all connected equipment to be alive at electrode voltage. The MIG cup holders originally are insulated but over time they may become contaminated, chipped and contact with ground usually as a high resistance connection allows partial welding current to flow undetected.

Fig. 9 Arcing can be seen at the point of contact where the standard "C" clamp is in contact with welding work bench steel, visually demonstrating the lack of good contact. This situation was found in the Ontario, Canada manufacturing facility

This condition may occur anytime the electrode cable is coiled on the side of the welding machine. Possible contact points being an electrode left in the holder or a damaged or poorly insulated electrode holder or damaged insulation on the welding cable. The welding machine must be energized for current to flow.

With an electrode terminal fault (fault condition #2, shown in Fig. 19), the return lead clamp becomes alive at the welding machine OCV/no-load voltage when the welding machine is energized. The welder does not consider the uninsulated return lead clamp to be alive. The worker only needs to contact a ground plane to receive electric shock. This could be the building steel or the work piece in contact with electrical ground.

This condition shown in Fig. 20 is an electrode terminal fault (fault condition #2) except the work lead is shown attached to the work piece which is isolated, from electrical ground. The example given is a mine haul truck; however, the same would be true for any rubber tired equipment or similar situation. The return lead clamp becomes alive at the full welding machine OCV/no-load voltage when the welding machine is energized. The welder would not expect the work piece to be alive. The worker only needs to come in contact with a ground plane to receive an electrical shock. The ground plane could be the building steel or the earth itself.

Figure 21 demonstrates how welding current can enter the building electrical system. Electrical system ground/bond wires are connected directly and indirectly to the building structure. Additionally, electrical systems are made up of metal conduits, armored cables, and metal cable tray systems. When the welding return lead is not connected close to the point of weld, welding current is forced to find its own path back to the source. If welding is in progress, the current has found a path, but the path the current has followed is often unknown. This was the situation in the new construction building in Cambridge, Canada where the young welder died. His own welding current damaged the electrical system.

This was also the situation at the Canadian plant where the workers safety harness was arcing to building steel because of the multiple current paths within the building steel system.

If welding leads are the same length and they are taped together, so that both leads must go to the same location, this situation will be less likely to occur.

3.6 High frequency/radio frequency welding

High-frequency alternating current is used in numerous processes from the medical field to various techniques for joining

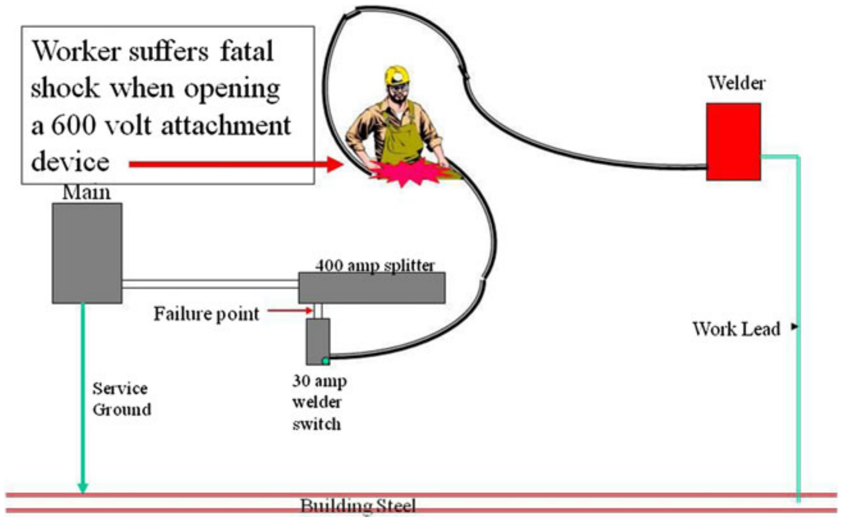
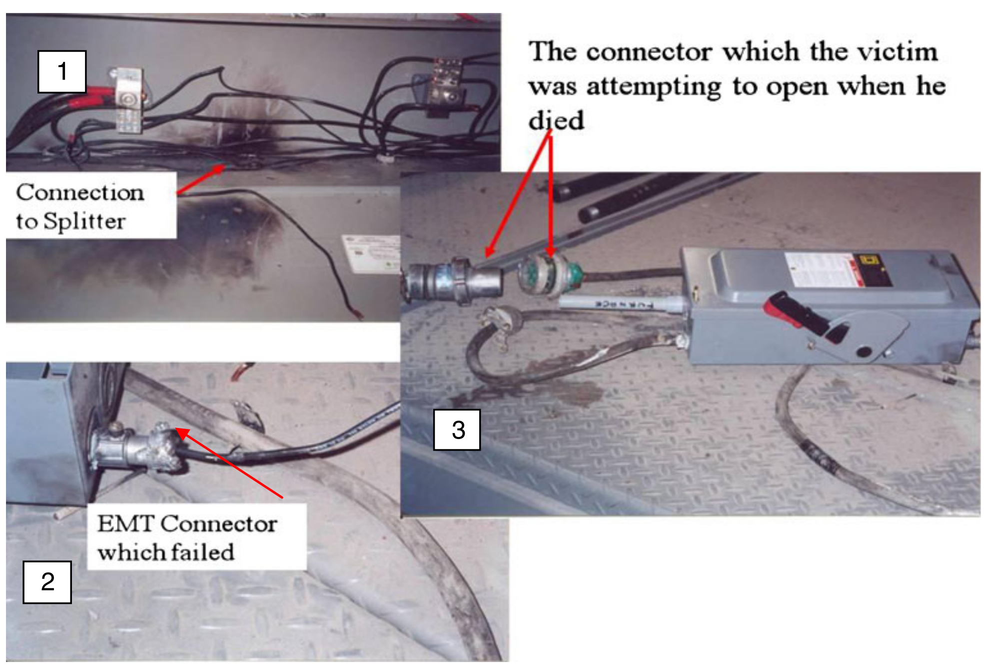


Fig. 10 Two things occurred simultaneously; the electrician was researching the power failure and the welder was trouble shooting his welding machine. After the main power had been restored on a faulty circuit feeding the welding machine, the welder disconnected the male/female cord connector feeding the welding machine. Due to the initial fault in the electrical service feeding the welding machine, the welder received a 347 VAC shock at 400 mA across his chest and died

materials [7]. Materials that can be successfully HF welded into tube and pipe include carbon steels, stainless steels, aluminum, copper, brass, titanium, aluminum, and various plastics. In the medical field, this concept is found in magnetic resonance imaging (MRI) units. These high-frequency generators are actually simple radiofrequency generators operating in the VHF range (30–300 MHz) and capable of transmitting radio waves similar to a radio transmitter. Quoting from a Lincoln Electric [8] Square Wave TIG 275 power source manual "The spark gap oscillator in the high frequency generator, being similar to a radio transmitter, can be blamed for many radio, TV and electronic equipment interference problems. These problems may be the result of radiated interference. Proper grounding methods can reduce or eliminate radiated interference." Most operator manuals warn about maintaining the correct setting for spark gap oscillators as changing this setting will change the frequency and have caused transmissions on public frequencies, which is unlawful in most jurisdictions.

In tungsten inert gas (TIG) welding, the high-frequency generator can be set to work in either continuous mode or in arc start only mode. In modern welding machine design, when

Fig. 11 The electrical conduit connection which melted due to stray welding current flowing through it. The molten metal caused the insulation on the electrical wiring to fail. *1* The electrical splitter where the conduit in *2* was originally installed at the time the stray welding current began to flow. The *black area* in *1* is from the electrical explosion when the #10 AWG copper phase conductors contacted the grounded metal electrical splitter box (see picture #4 below)



arc start only mode is selected, the HF/RF is used only to start the arc and then is automatically shut down when the arc current is established. The HF/RF is superimposed on the welding circuit using approximately 3,500 V high-frequency AC. In continuous HF/RF, the high-frequency generator operates throughout the welding process.

High-frequency current has a characteristic which causes it to concentrate its flow along the surface (skin effect) which makes it ideal for welding aluminum. With the HF turned on the weld will stay at the surface of the aluminum sheet, without HF, the weld will sink, burn through and generally look ugly [7].

Radiofrequency welding[18] is the process by which electromagnetic energy is used to permanently bond thermoplastic materials together. This is different than other processes as the desired result is a hermetic, cohesive bond between the polymers. This type of welding can only occur between highly dipolar materials that are excited by an alternating magnetic field.

While the term high-frequency welding is normally associated with the joining of metals and the term radiofrequency welding is associated with the joining of plastics, both share the use of a radiofrequency generator as does the medical MRI unit[19]. Documentation on the effects of RF on the human body is plentiful, but documented records of actual workplace accidents during welding were unavailable to the author at the time of writing.

During a conference the author participated in during the late 1990s, the author was made aware of an incident causing health problems while the victim was welding using a TIG process. The incident reportedly occurred at a welder training facility in the City of Calgary, Canada, while the student was welding aluminum. This required the high frequency generator to be in the continuous mode. The victim complained of a severe burning sensation in his head. The victim had previously suffered head trauma which had required the installation of two separate plates of unknown material in his skull. It is suspected but not verified that the plates became heated by the RF transmitted by the welding machine high-frequency generator causing the victim unbearable pain and unrecoverable brain trauma.

While attempting to understand what had occurred, a second individual with a metal pin of unknown size or material in his leg used a similar setup and welded until he felt the heating effect in his leg. There was no long-term harm reported. These incidents were reported by a reliable person who had been present at both incidents. The Canadian Standards Association (CSA) standard W117.2–2006 Safety in welding cutting and allied processes, in section 5.1.8 warns of the possibility of thermal heating due to the radiofrequency being transmitted by the high-frequency generator in welding machines so equipped.

There are documented instances of medical problems and even death occurring during medical examination procedures using an MRI. A thesis by Sung-Min Park for his doctorate while attending Purdue University Graduate School list three potential risks for MRI procedures; his greatest concern is for RF-induced heating [9]. This fact is supported by further studies and analysis and published in the *IEEE Transactions on Magnetics* [10].

There is evidence that radiofrequency will induce heating and the presence of metal will accentuate the effect; users of welding equipment with high-frequency generators installed must be aware of the negative outcomes that may occur in workers with metal implants or wired in devices such as pacemakers or defibrillators.

4 Prevention of stray welding current and electrode shock

Canadian standards for welding safety CSA W117.2: 2006 section 6.3.2.4[20] state: "the work lead shall be connected as closely as practicable to the location being welded upon to ensure that the welding current returns directly to the source through the work lead. The work lead should be connected to the work in sight of the piece being welded upon, preferably connected directly to the same plate, pipe section, or work piece with which the welding arc is in direct contact. The work lead shall have the same cross-sectional area as the greater portion of the welding cable."

Iron with a conductivity value of 1.04×10^7 S/m, has a conductivity of approximately 18 % of that of welding cable annealed copper. Copper conducts electricity[21] more than five times better than steel, and in bolted building steel joints with paint and rust in the bolted connection, that number could easily increase to seven times or greater. However, when provided with a number of poor choices due to improper use of welding lead connections, electricity will flow always in the path of least resistance. Buildings, vehicles, and equipment all contain various metals in the form of piping, wiring systems, and structural members. Welding current will find a circuit back to the source

[18] Dielectrics is an established leader in thermoplastic welding for the medical device industry, and best known for our expertise in Radio Frequency Welding(also referred to as "RF welds", "dielectric sealing", "high frequency" welding, or "heat sealing") (http://www.dielectrics.com/rf-welding-radio-frequency-welder-heat-sealing.html).

[19] Limits of human exposure to radiofrequency electromagnetic energy in the frequency range from 3 KHz to 300 GHz, commonly referred to as Safety Code 6. publications@hc-sc.gc.ca. Health Canada's radiofrequency exposure guidelines

[20] CSA W117.2: 2006 available from Canadian Standards Association (http://shop.csa.ca/).

[21] http://www.ndt-ed.org/EducationResources/CommunityCollege/Materials/Physical_Chemical/Electrical.htm

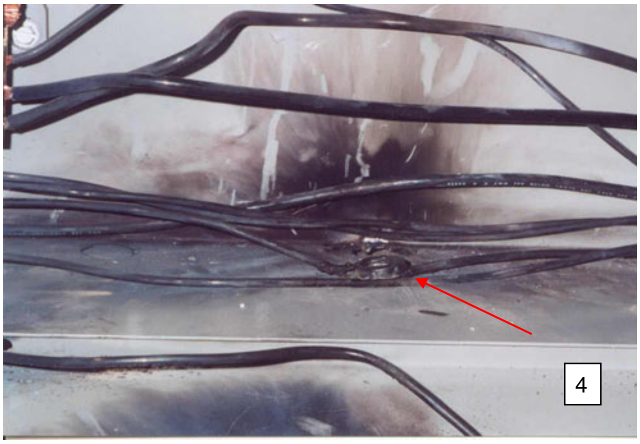


Fig. 12 *4* This is a close-up of the damage shown in *1* of Fig. 11. The *red arrow* indicates the location the partially melted conduit shown in *2* of Fig. 10 had been installed. Notice the localized melting of the insulation on the electrical wiring

if a path exists. Because of a high resistance return path, a welder will often report this as a "cold arc" and increase the current setting of the welding machine to "make it hotter".

This circuit may have many paths as the welding current is distributed throughout the multitude of electrical conducting elements found in the building, equipment or vehicle. The welder only sees the arc which is required to complete the welding task. The path which stray welding current is following is invisible most of the time. Unless an incident occurs, damage is often not discovered until later.

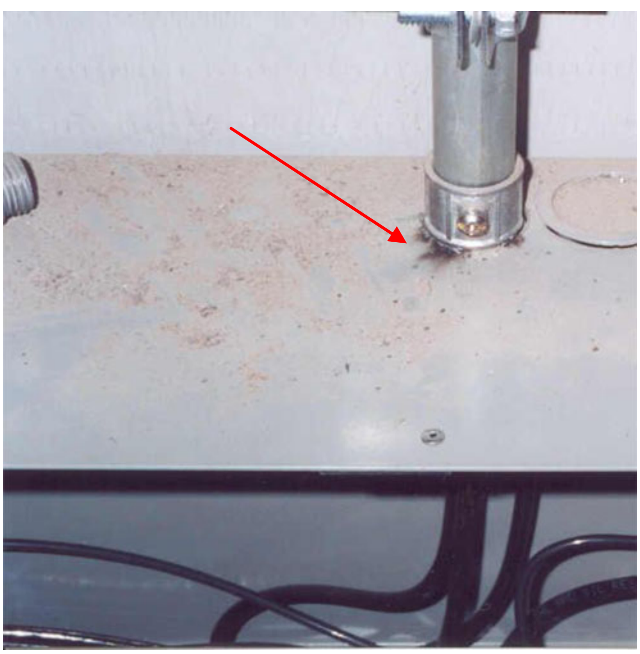


Fig. 13 Signs of stray welding current are seen in this picture. This electrical circuit was part of the building electrical system, but not a part of the electrical circuit feeding the welding machine

Fig. 14 Inspection of the cord connector supplying power to the welding machine revealed electrical insulation was in normal condition. Excess welding current flow would be expected to cause over heating damage

It is imperative that all welders and others involved in the welding trade understand how to keep welding current contained

Fig. 15 The *arrows* point to bare places on the welding electrode cable which was found in use on the work site. Welding cable is an electrical conductor and as with any electrical conductor, must have good insulation qualities. The welding current may have exited the welding cable and entered other current paths (Note that electrocution can occur from contact with just one strand of wire in a welding cable. Welding currents are at least three orders of magnitude higher than currents that are lethal.)

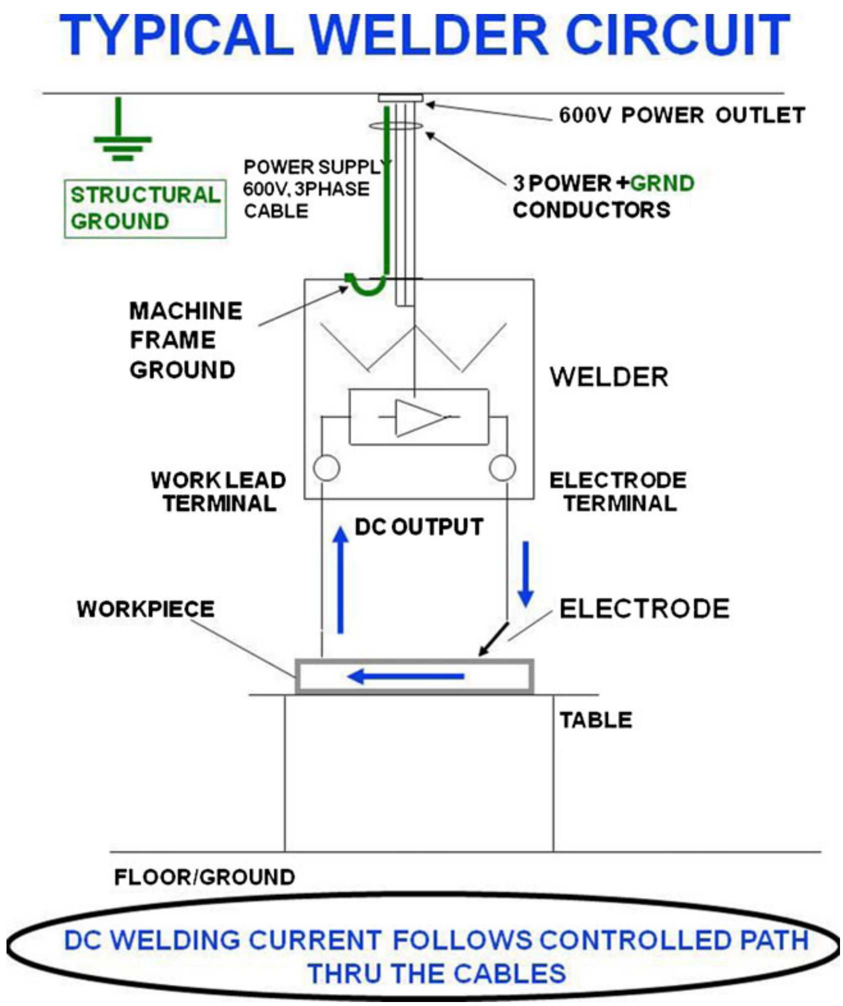


Fig. 16 Typical welder circuit

within a designed welding circuit. Welding machines are designed with two welding leads; those leads should be bundled together and taken to any weld location as one lead. Where the electrode lead goes the return lead shall also go. It is a policy which should be enforced on all worksites.

When possible, there should never be more than a few centimeters between the electric arc and the return lead connection. In all cases, the return lead must be connected via a clean purposely created connection point and as close as practicable to the point of arc. Both welding leads must be regarded as any other electrical conductor, the integrity of the insulation system and the conductor is vital to both the success of the welding process as well as ensuring that the electrical current remains within the welding cable. Welding leads have a definite life span and should be regularly inspected and replaced when their condition deteriorates.

4.1 Use of double insulated electrical power tools

Electrical power tools used by the welder such as grinders should be of an approved double insulated type. Since the double insulation provides a high level of safety from electric shock, these power tools are designed without a ground wire. With no connection between the power tool frame and electrical ground, stray welding current cannot flow, removing this as a potential shock hazard as well as preventing damage to the light weight power cord feeding the grinder (see the fault condition drawings).

4.2 Understanding electrical system damage caused by stray welding current

It is necessary for the electrician who is responding to a situation that may involve stray welding currents, to investigate the integrity of the electrical grounding circuit of the welding machine and of the 120/240 V circuit if a grinder or other power tool was involved. If the electrical service power has failed, it is imperative that all work stop and a thorough investigation of the electrical distribution integrity is conducted by competent electricians and/or electrical engineers knowledgeable about stray welding current. The complete electrical system should be investigated for damage. This

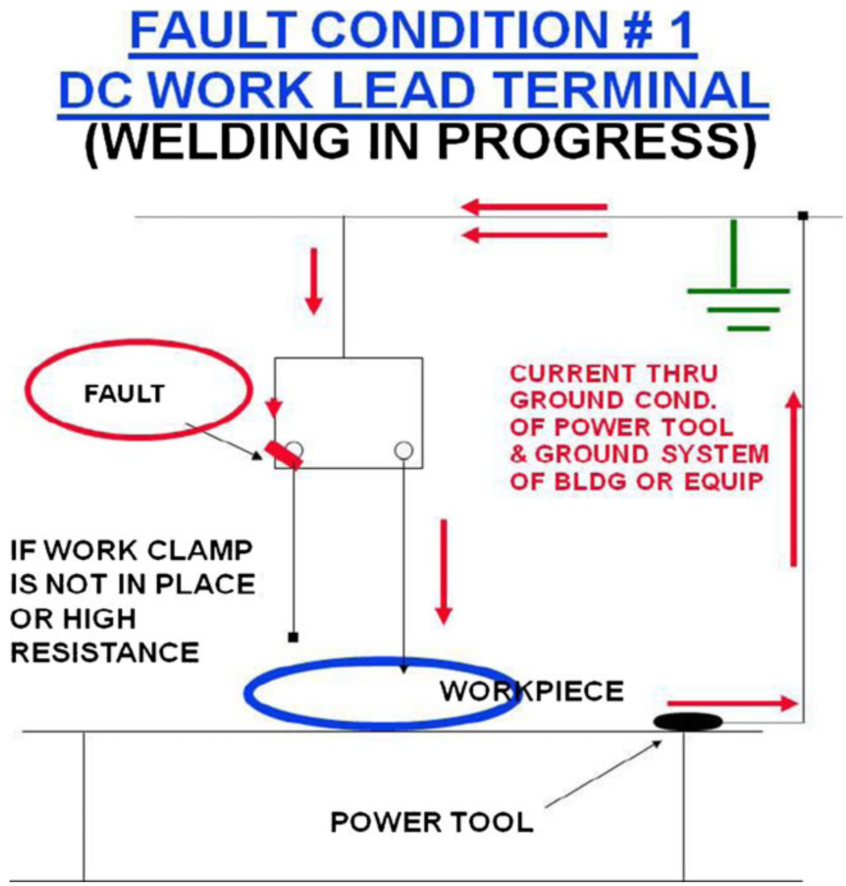


Fig. 17 Fault condition #1, DC work lead terminal (welding in process). This drawing describes a stray welding current situation. This drawing also depicts a power tool lying on the work bench which for a welder would typically be a grinder which is used constantly in the welding trade

point cannot be stressed enough! Energizing the electrical system without full knowledge of the system integrity may cause current to flow at system voltages in electrical bonding systems intended to flow ground currents, with the possibility of fires and fatalities.

Australian standard AS 1674.2–2007 section 5 specifies minimum requirements for resistances of the welding circuit and earthing. Of particular importance is the note which is attached to table 5.1.2. Because of the dangers of stray output currents damaging fixed wiring, every 12 months the integrity of the fixed wiring should be inspected by a licensed electrical worker.

4.3 Use of proper personal protective equipment

Welders need to be properly dressed with dry fire retardant clothing and dry high-quality welding gloves. The ultraviolet rays from the welding arc are substantial and will quickly create a surface burn resembling very bad sunburn, yet in about 40 % of the accident reports reviewed for this paper, the victim welder did not wear welding gloves. Wearing dry gauntlet type welding gloves will prevent the weld arc UVR skin burn and will minimize electric shock. Welding gloves do not have an electrical rating and their use will not guarantee the prevention of electric shock. During the research period for the first paper, a rubber work glove was designed for the welder to wear inside the gauntlet style welding glove; the glove was not electrically certified. A water-resistant barrier between the welder's hands and the electrode was maintained. Because of the strenuous work which a welder performs it is not practical to use a glove which is certified.

Ian R. W. Dick in his paper “An investigation into the causes and prevention of electrocution suffered as a result of operation of welding equipment” experimented with various types of welding gloves to understand which were effective in protecting the welder from welding electrode shock when wetted with sweat or other moisture. He found that all the gloves he tested were good insulators when new and dry; however, when wetted with perspiration, only the very best heavy leather, lined welding gloves provided any level of safety. He concluded that only gloves with replaceable liners provided an adequate level of safety and then only when the liners were changed frequently to ensure they were always dry. This supports the original findings of Thesenvitz and Hisey.

In the workplace, personal protective equipment should be the last line of defence. Engineering controls and work procedures

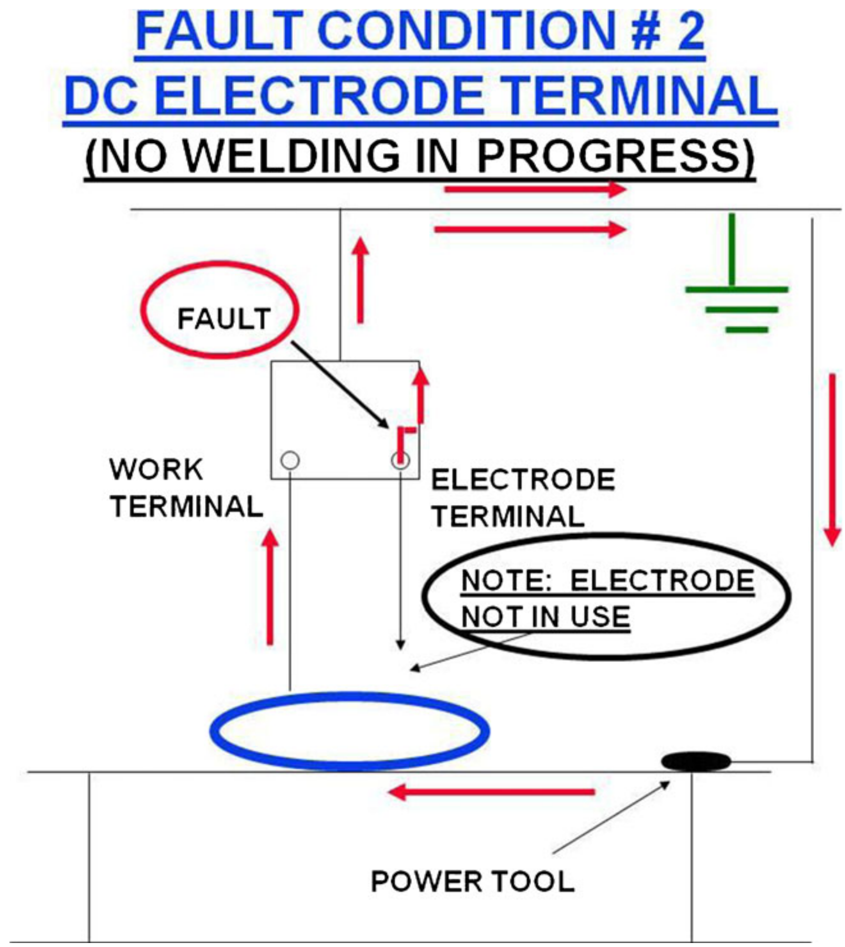


Fig. 18 Fault condition #2, DC electrode terminal (NO welding in process). This drawing describes a stray welding current situation

should provide the protection a worker needs; however, in the case of the MMAW/SMAW welder, the welding glove is the only line of defence. When a welder's glove fails or when the welder fails to wear proper gloves, he/she is at extreme risk of receiving electric shock.

4.4 Welding machine design

There is at least one welding machine manufacturer who has marketed a welding system which was designed to use the workplace steel as a return path for all welding current. This is single power source feeding multiple sub-unit welding machines. By design, this unit creates multiple current paths in the building or structure in which it is used. Manufacturers need to consider the damage that welding machines can do in the field and consider changes which can be made to increase the level of safety welding machines provide.

The allowable open circuit/no-load voltage should be as low as is reasonably achievable. The issue of electrical current sine wave and heart rhythm interaction then will not matter as the voltage will be too low to push current through the human body at a level sufficient to cause muscle contraction and/or heart stoppage. Welding machine open circuit/no-load voltage should be limited to a very low limit, preferably 10 V, either AC or DC.

Welding machines should be designed as failsafe, if the output voltage is above the design limit open-circuit volts the unit should not operate. Contact between the electrode and the return lead at the time of energizing should indicate a fault and fail to provide output. Current flow detected in the primary power cord ground conductor should cause the welding machine to indicate a fault and cease operation. If the welding circuit resistance is too high, a fault should be indicated.

Add-on voltage reducing devices such as the Shock Stop unit[22], designed and manufactured by DDC Technology Ltd. of Canada, are capable of providing failsafe operation with a 6–10 V OCV. Other voltage-reducing devices are available, some which provide a similar level of safety.

The implementation of the voltage-reducing device (VRD) is an example where aftermarket manufacturers have created change in the welding machine market place. The VRD was designed and marketed as an add-on to the welding machine many years before welding machine manufacturers

[22] Model A720-ST-USS for utility powered welders (http://www.shockstop.ca).

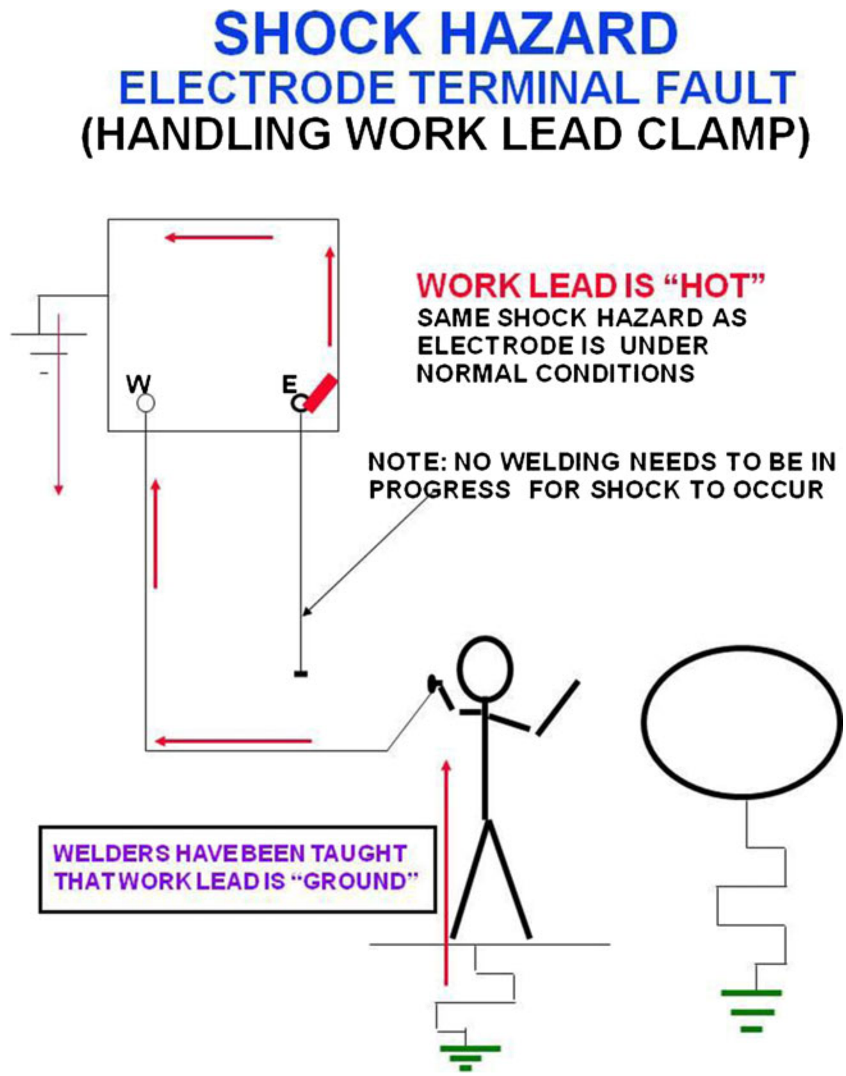


Fig. 19 Shock hazard electrode terminal fault (handling work lead clamp). A worker caught in this situation is set up to receive a full open circuit/no-load voltage electrical shock from the welding machine. Note that there is an issue with widespread colloquial use of incorrect terminology where the work cable is referred to as the “earth” or “ground”. This leads to muddled thinking and even electricians often are confused about the function of the work cable. It is not universally understood that there is a need to keep both the electrode and work cable connection away from contact with anything other than the work. Adherence to this principle will prevent the opportunity for low resistance alternative “parallel paths” and subsequent stray currents to exist

considered the VRD a viable option. The use of VRDs is recommended by CSA Standard W117.2 in Canada and their use is required in Australia by Australian Standard AS 1674.2–2007 for all category C environments and in category B environments depending on welding machine open circuit/no-load voltage. When selecting a VRD,[23] ensure that it is rated for the specific welding machine. Many welding machine manufacturers now manufacture welding machines with a VRD circuit built-in[24].

[23] http://www.msha.gov/S&HINFO/TECHRPT/ELECTRICAL/weldertest.pdf; U.S. Department of Labor Mine Safety and Health Administration Technical Support Approval and Certification Center Electrical Safety Division Evaluation of Welding Voltage Reduction Devices Technical Assistance PAR 0088369, 24 March 2003. (http://www.wtia.com.au/pdf/TGN-M-02%20Voltage%20reducing%20devices.pdf; http://www.shockstop.ca; http://www.safetac.com.au/faq.html).

[24] Built-in VRDs are commonplace in Australia, most North American manufacturers supply a line of machines with built-in VRDs, but they are not in common use.

4.5 Reporting of electrical shock

What is not measured cannot be managed is an old management adage, this is also true about electrical shock incidents in the field of welding. The idea that welders receive shock as a normal part of their job must be changed. Employers/regulators must consider contact with the open circuit/no-load voltage of the welding electrode as an electrical shock incident which is reportable.

Companies which consider all forms of electric shock hazardous will have or develop reporting guidelines. At least one company takes welding shock seriously and has reporting policies and has a form[25] for recording electrical shock received by welders. When accidents of any nature are reported, corrective actions are easily put

[25] BHP Welding Safety Bulletin #21 May/June 2002, page 5, significant incident safety occurrence, electric shock from welding machine

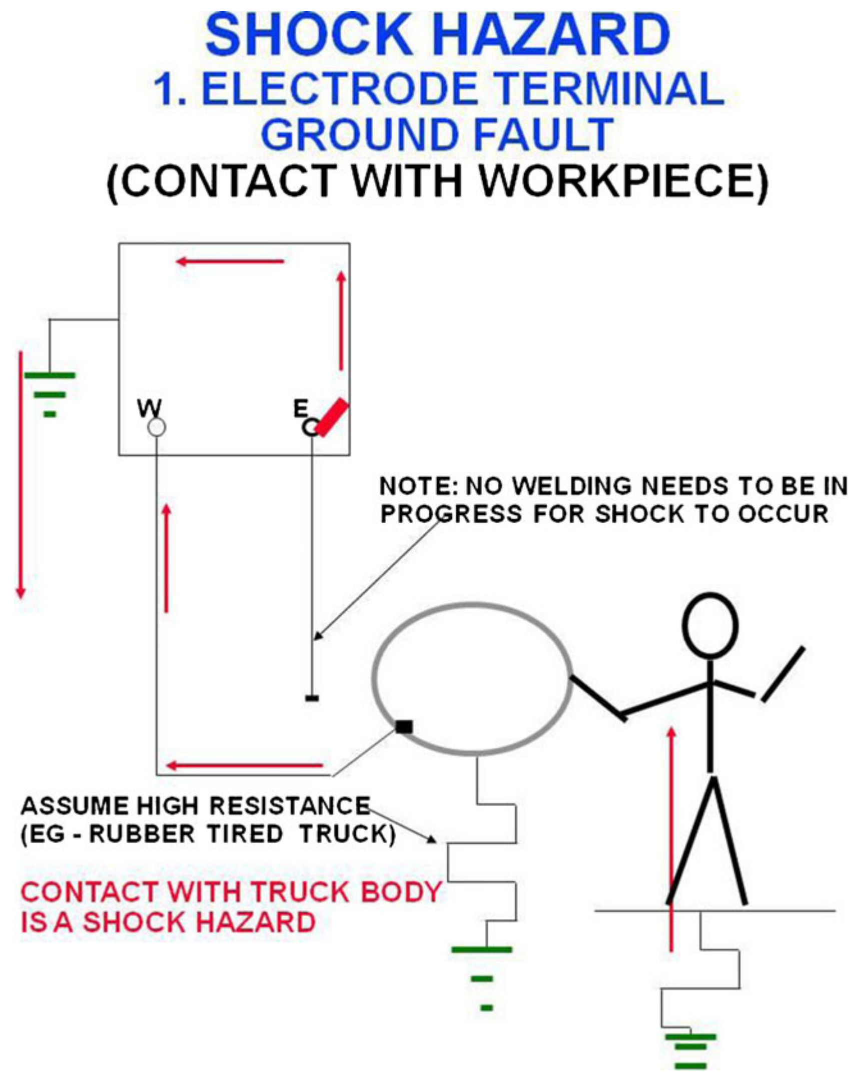


Fig. 20 Electrode terminal ground fault (contact with workpiece). A worker caught in this situation is set up to receive a full open-circuit voltage electrical shock from the welding machine.

in place to prevent recurrence. Frank E. Bird, George L. Germain in their book Loss Control Management: Practical Loss Control Leadership, claim a 1-10-30-600 relationship between incident/accidents; 1—fatality, 10—serious accident, 30—reportable accidents, 600 incidents.

Conoco Phillips Marine conducted a study in 2003, which demonstrated a large difference in the ratio of serious accidents and near misses. They found that for every fatality, there were 300 reportable injuries, and they estimated that there were 300,000 at risk behaviors. Accepting welding shock as normal is an at risk behavior.

Training of occupational health and safety personnel in the hazards of welding electrical shock will ensure that they are equipped to provide adequate triage for welding electric shock[26].

[26] Taken from AS 3859–1991 which has been superseded by AS/NZS 60479.1:2010 (www.ee.uwa.edu.au/~ews/EffectsOfElectricity/EffectsOfElectricityOnTheHumanBody.htm).

The Australian report—Effects of electricity on the human body says "*It is absolutely imperative to seek medical attention after receiving a severe shock because internal body parts that may have been burnt may release poisonous toxins after a few days which may kill the person even if they seem healthy*."

4.6 Welding environments

Australia has analyzed various welding environments and came to the conclusion that some are very different than others. This is an approximation of what is contained Australian Standard AS 1674.2–2007 (Safety in welding and allied processes Part 2: Electrical).

A category "A" environment (lower risk) is where the risk of electric shock or electrocution is low and the likelihood of the welder or other personnel being in contact with the work piece, a live part of the welding circuit is low. Most fabrication

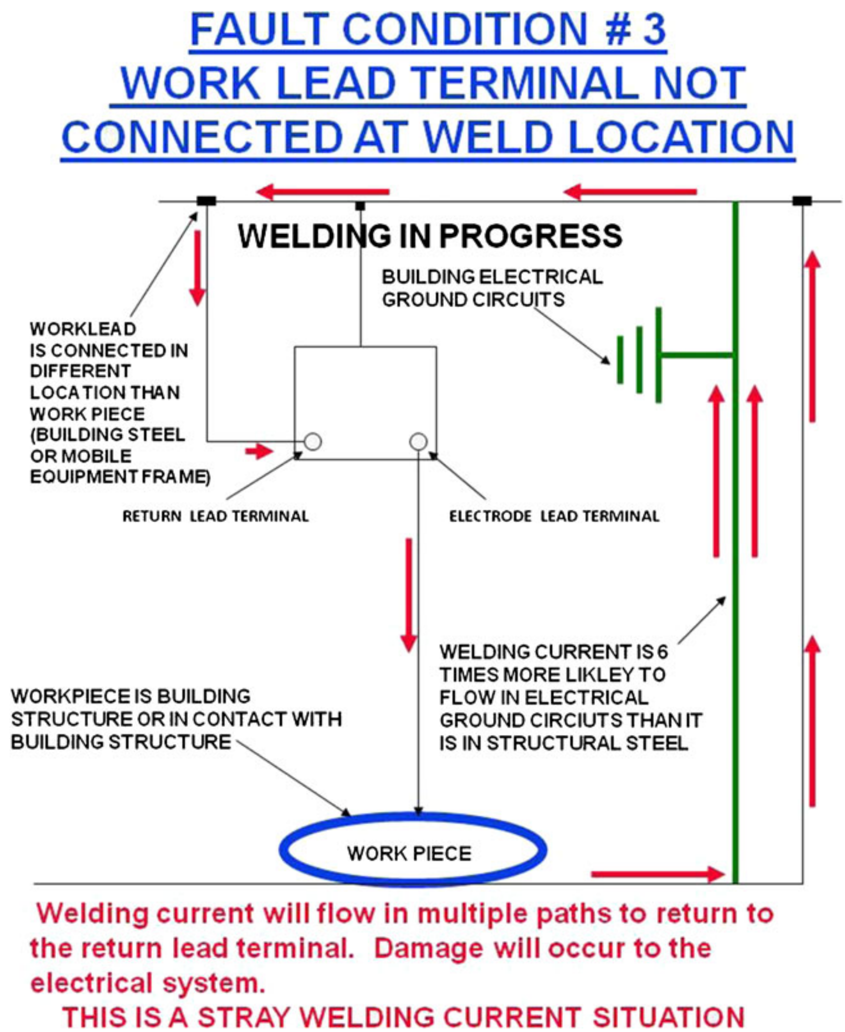


Fig. 21 Fault condition #3, work lead terminal not connected at weld location. This drawing describes a typical stray welding current situation

facilities would not make this category. Manufacturing facilities could make this category in most situations.

A category "B" environment (medium risk) is one where the welder's body could come in contact with the work piece or structure—most welding in fabrication shops and maintenance welding which is not category C would fall into this category[27].

A category "C" environment (high risk) is one where the risk of an electric shock or electrocution by the welding circuit is greatly increased due to low body impedance of the welder combined with a significant risk of the welder contacting the work piece or other parts of the welding circuit. This would be any environment which was damp or wet or where the welder was likely to perspire a lot. Australia lists any work environment over 32 °C as a high-risk environment[28].

[27] There is an explanatory note provided in Australian Standard AS 1674.2–2007 for category B. Note that such an environment may be found where the ambient temperature is less than 32 °C and

(a) Freedom from movement is restricted, so that an operator is forced to perform welding in a cramped position (e.g., kneeling, sitting, and lying), with physical contact with conductive parts (e.g., the work piece)
(b) There is a high risk of accidental or unavoidable contact by the operator with conductive elements, which may or may not be in a confined space as defined in AS/NZS 2865

[28] There is an explanatory note provided in Australian Standard AS 1674.2–2007 for category C as follows. Note that low body impedance is likely in the presence of water, moisture or heat, particularly where the ambient temperature is above 32 °C. In wet, moist, or hot locations, humidity or perspiration considerably reduces the skin resistance of human bodies and the insulating properties of personal protective equipment accessories and clothing.

Categorization of welding work environments allows regulators and employers to adequately manage welding work place hazards.

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