Development of an overhead power line contact alarm for mobile equipment

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Abstract: This paper describes research by the US National Institute for Occupational Safety and Health's Pittsburgh Research Laboratory to develop an overhead power line contact alarm system for mobile equipment. Analysis of accident reports revealed that many workers were unaware of a power line contact until after an injury occurred, suggesting that many injuries could be prevented by an alarm system that alerts operators and other nearby workers when a line has been contacted. Sensing electric current flow through mobile equipment chasses, and measuring electric field strength between equipment chasses and ground, were studied as possible techniques for detecting power line contact. Experiments involved using these techniques to monitor energised cranes and dump-bed trucks, operating on commonly encountered types of road and work area surfaces. Sensing current flow proved inadequate when operating on a high-resistivity surface such as asphalt, but electric field measurement was more reliable, performing well on several different surface types. Additionally, electrical characteristics of the cranes and trucks were examined, and this confirmed that, in a power line contact accident, the primary hazard to personnel is simultaneously contacting the equipment and ground. A prototype power line contact alarm system was constructed and tested.

Keywords: contact alarm system, cranes, electrical burn, electrical injury, electrical shock, electrocution, overhead power lines, safety, truck safety.

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1 Introduction

This report describes research by the US National Institute for Occupational Safety and Health's (NIOSH) Pittsburgh Research Laboratory (PRL) to develop an on-board alarm system to detect overhead electric power line contact by mobile equipment, such as cranes, trucks, and drill rigs. Research at NIOSH, PRL addresses health and safety issues in the US mining industry. During the 1990s, approximately 20% of all mining electrocutions resulted from high reaching mobile equipment contacting overhead electric power lines (Cawley, 2003). Figure 1 illustrates a typical power line contact accident involving mobile equipment. Detailed analysis of these accidents found that 56% of the injured miners had contacted the equipment and ground simultaneously after the power line contact had occurred, and were unaware of the shock hazard (Homce *et al.*, 2001). These workers could have avoided injury had they simply known *after the fact* that the equipment had become energised. This research therefore proposed to develop a practical and reliable on board system for high-reaching mobile equipment that can alert operators and nearby personnel after a power line is contacted. Commercially available power line *proximity* alarms, which are devices designed to warn when equipment has come within a preselected distance from a line, are in theory a more effective solution to this problem. In reality however, they are not widely used due to perceived performance limitations and high initial cost. In contrast, a *contact* alarm, while not designed to avoid all related injuries, could be a reliable, affordable, and practical alternative. This report describes experiments that tested and refined the technology needed for a practical power line contact alarm system, as well as the design of a prototype system.

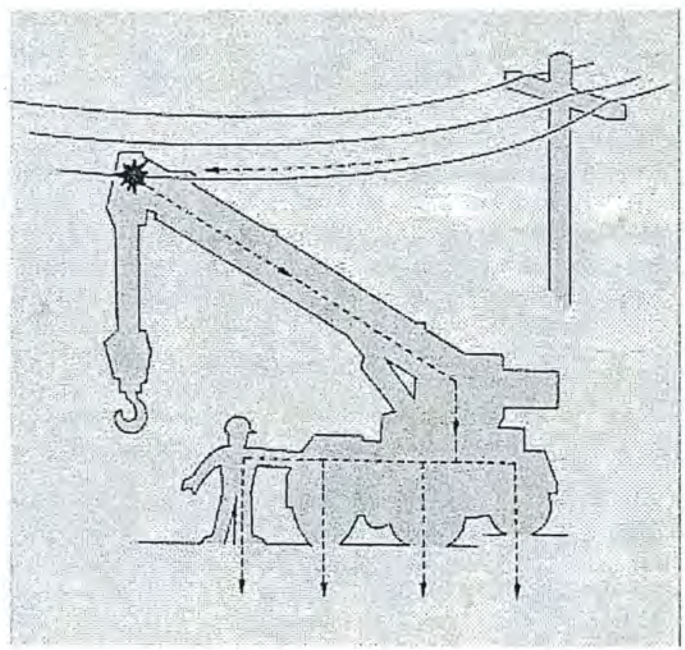

Figure 1 *Electrical current flowing through a mobile crane and worker, in a typical overhead power line contact accident.*

2 Initial feasibility study

An initial feasibility study investigated methods to measure current flow to ground through energised mobile equipment, as a means to detect power line contact (Sacks *et al.*, 2001). In this work, current flow was measured as a function of voltage applied to a small Pettibone rubber-tyred mobile crane and a Ford F-800 dump truck, operating on undisturbed turf, a crushed stone road, and an exposed massive limestone formation.[1] These experiments found that: (1) using a heavy electrical conductor to bridge a large pivoting joint on equipment, such as a dump bed pivot or a crane boom base pivot, provides a convenient point at which to employ a simple current transformer to measure on board current flow, (2) on turf and crushed stone, even at relatively low voltages (less than a few hundred volts), current flow to ground was usually sufficient to reliably indicate an energised chassis, and (3) on massive limestone, current flow to ground was too low to allow accurate measurement (Sacks *et al.*, 2003). These results indicated that further investigation of current flow to ground through heavy mobile equipment was needed, extending experiments to include other types of equipment and operation on other common surfaces, such as concrete and asphalt roadways.

3 Experiments and results

The experimental programme under this research examined several areas. Prompted by findings from the original feasibility study, a series of experiments further studied the total current flow to ground that can be expected for energised mobile equipment operating on several types of road/work area surfaces. A related series of experiments determined how much of the total current could be diverted through a conductor bridging a crane boom pivot or truck dump-bed pivot, for measurement. The combined results of these two investigations indicated that measurement of current flow to ground, under some circumstances, was not a reliable indicator of an energised equipment chassis. Based on this finding, an alternative method to detect power line contact was examined, specifically, detection of increased electric field strength between an equipment chassis and ground. This work also used different equipment types operating on several different surfaces, and showed electric field measurement to be more reliable than detecting current flow. Additional experiments measured the voltages to which an equipment operator may be exposed, within a cab or along an egress path, during a power line contact. While this last area was not critical to the development of a power line contact alarm, it does directly relate to worker safety during a power line contact.

3.1 PRL specialised experiment site

A specialised experiment/test site was constructed at PRL to study the total electric current flow to ground through equipment, and the detection of electric fields beneath equipment, during power line contacts. The site allowed controlled comparisons of the effect of road/work surface type and manner of ground contact. The site is on a remote, level, grass-covered area several hundred feet from the nearest roadway or actively used structure, with no known buried pipes, conduit, or debris. Five 30 ft × 50 ft (9.1 m × 15.2 m) pads were constructed at the site to replicate common roadway and work area surfaces, including reinforced concrete, asphalt, compacted crushed stone, bare earth, and an undisturbed turf area. The concrete, asphalt, and crushed stone surfaces conform to

Pennsylvania Department of Transportation standards for secondary road construction. Based on a measured soil resistivity of approximately 200 ohm-ft (6096 ohm-cm), a driven-rod electrical ground bed was designed and installed a minimum of 226 ft (68.9 m) from the pads, and provided a 3 ohm connection to remote earth.

3.2 Pivot joint shunt current flow experiments

The use of electrical current flow through mobile equipment as an indication of power line contact requires a simple, reliable, and practical method for current measurement. One method is the use of a current sensor on an electrical conductor, or *shunt*, bridging a pivoting joint such as a crane boom pivot or dump-bed pivot. This relies on the diversion, through the shunt, of sufficient current for accurate measurement. A series of experiments was completed that measured the amount of current carried by such shunts when electric current was passed through various types of equipment.

The mobile equipment used included an International F-1850 tandem axle 12 ton (10.9 tonne) dump-bed truck, a White Roadboss tractor-trailer combination 23 ton (20.9 tonne) dump-bed truck, a Grove RT-522 22 ton (20 tonne) rough terrain crane, and a Grove IND-2535 35 ton (31.8 tonne) industrial crane. Both cranes were rubber-tyred units, and no crawler-mounted equipment was used in this research. The RT-522 crane and White Roadboss-trailer combination are shown in Figures 2 and 3. On the trucks, a shunt was placed from the dump-bed to the truck frame. On the cranes, a shunt was placed between the base section of the boom and the main boom pivot supports on the turntable. Except as noted in results, the shunt was a 36 in (91.4 cm) piece of #2/0 AWG (American Wire Gauge) stranded copper cable, with secure mechanical connections. The sensor used to monitor current through the shunt was a window-type current transformer (CT) with a ratio of 100/1, designed to measure currents as low as a few mA ac. The CT output was terminated across a nominal 100 ohm resistor, and the voltage drop across the resistor was measured with a digital multimeter.[2] Figure 4 shows the shunt and CT in place on the RT-522 crane.

Figure 2 *Grove RT-522 rough terrain crane used in experiments.*

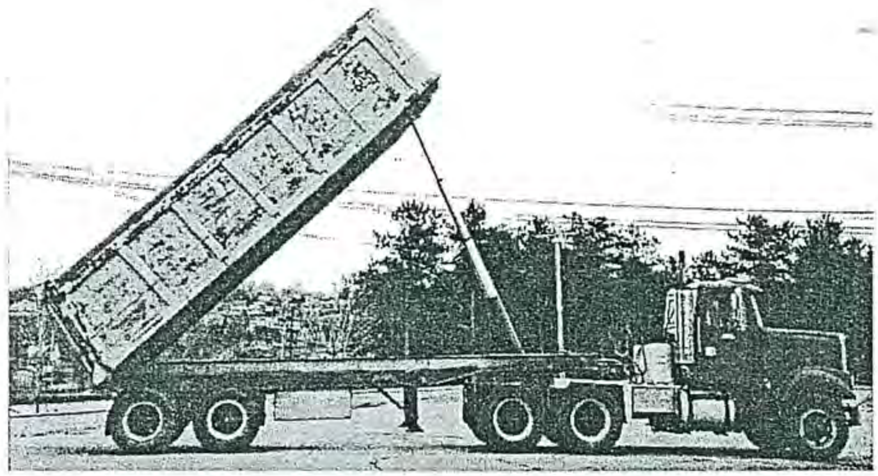

Figure 3 *White Roadboss tractor-trailer combination dump-bed truck used in experiments.*

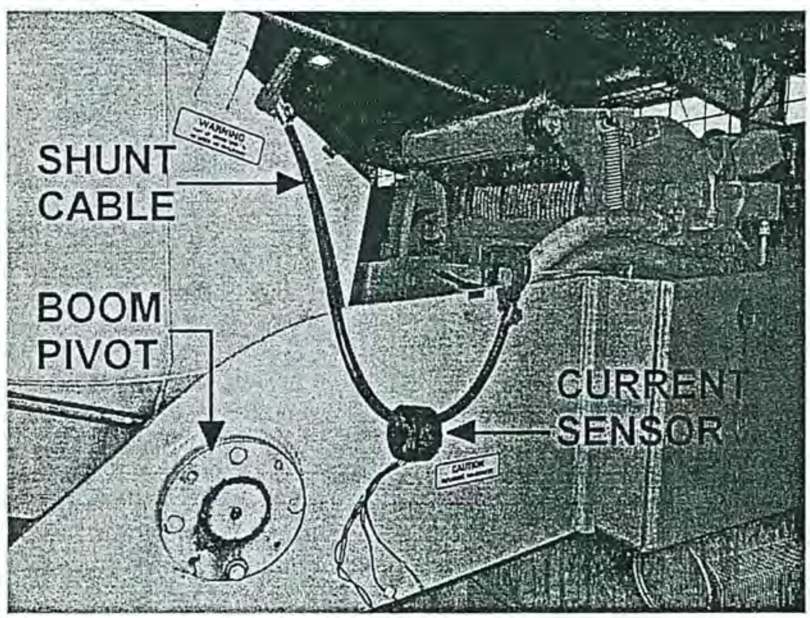

Figure 4 *Shunt conductor with current transformer, bridging the main boom pivot on the Grove RT-522 crane.*

An adjustable 60 Hz a.c. power source was used, with one lead attached to the top front edge of the bed on the trucks and to the tip of the boom on the cranes, and the return lead attached to the frame on the trucks and to the stabiliser support framework on the cranes. Experiments injected 10 A a.c. total current through each machine and measured current flow through the pivot joint shunt. Total current was monitored directly at the power supply on a series-connected digital multimeter. The boom or bed position, motion, and loading were varied to examine the effect on shunt current flow. Other factors examined were shunt resistance and the effect of surface moisture.

Experiments for the White Roadboss-trailer combination and International tandem trucks were conducted with beds empty and also loaded with road salt to approximately 16 tons (14.5 tonnes) and 10 tons (9.0 tonnes), respectively. Bed angles ranged from horizontal to 50°. Beds were raised and lowered several times prior to data collection, and readings were recorded at 10° intervals over 3 raise/lower cycles. Although the amount of current through the shunt varied widely with changes in truck load and bed elevation, the level for any given set of conditions was generally stable over time, and current level changes from one experimental condition to the next were typically gradual and uniform. Results from the dump-bed truck experiments are summarised in Table 1.

Table 1 Results of dump-bed truck bed pivot shunt current experiments.

Truck	*Range of current flow levels, diverted through bed pivot shunts (percent of total current flow)*			
	Bed loaded		Bed empty	
	High	Low	High	Low
White tractor-trailer	89.3%	9.4%	90.0%	51.6%
International F-1850	88.3%	7.8%	87%	9.7%

The RT-522 crane was configured for lifts at 38% and 73% of maximum load chart capacity. Crane load chart limits and overhead clearance in the test site building allowed a 40° to 50° vertical boom movement for unloaded and 38% load experiments, but only a 5° movement for the 73% load. The IND-2535 crane was operated unloaded only, due to a hydraulic system problem. As with the truck dump-beds, crane booms were raised and lowered several times prior to data collection. Readings were taken at approximately 2° intervals for 73% load experiments, and 10° intervals for all others, over a minimum of 2 raise/lower cycles. The shunt current for any given set of conditions was generally stable over time, and current level changes from one reading to the next were typically gradual and uniform. Results from the crane experiments are summarised in Table 2.

Two other experiments were conducted to assess shunt performance. The first, run on the IND-2535 crane, significantly reduced the shunt resistance by replacing the 36 inch (91.4 cm) #2/0 AWG shunt conductor with three parallel 18 in (45.7 cm) #4/0 AWG conductors. This change had no significant effect on the amount of current carried by the shunt. Another experiment, on the RT-522 crane, measured the effect of simulated wet weather conditions (surface moisture) on the current diverted by the shunt. In this experiment, the boom pivot area and lift cylinders on the turntable were subjected to a heavy water spray, and the boom moved through a 20° elevation change, while monitoring current through the shunt. No reduction in shunt current resulted from the wet condition.

Table 2 Results of crane boom pivot shunt current experiments.

Crane	*Range of current flow levels, diverted through crane boom pivot shunts (percent of total current flow)*			
	With load		No load	
	High	Low	High	Low
Grove RT-522	1.9%	0.9%	1.6%	0.8%
Grove IND-2535	(no test)	(no test)	2.1%	0.9%

The shunt current experiments yielded several important findings. Under conditions where electric current flows through the chassis of a dump truck or crane, a conductor (shunt) bridging the dump-bed pivot or crane boom pivot can divert part of this current, and provides a convenient point at which to mount a CT. Current flowing through such a shunt is generally stable for a given boom/bed position and loading and, in these tests, was unaffected by moisture on the pivot joint. Most importantly however, the current carried by the shunt can be as little as 0.8 % of the total flow through the machine chassis. Since the CT designed and built for the proposed line contact alarm system has a practical lower measurement limit of 5 mA, *total current flow to ground* for the mobile equipment and conditions examined so far, would have to be *600 mA or more* for reliable detection.

3.3 Current sensing experiments

A series of experiments was conducted to measure total current flow to ground for electrically energised mobile equipment operating on several types of surfaces. Combined with the pivot joint shunt experiment results, these experiments determined whether monitoring current flow to ground during a line contact is a reliable means to trigger a power line contact alarm. The experiments were conducted at the PRL test site, using the RT-522 crane and White Roadboss-trailer combination previously described.

The asphalt and concrete surfaces were clean and dry for all experiments, and soil conditions ranged from dry to slightly moist. The power source for the experiments was a 6500 W portable generator supplying an adjustable 0 – 240 V a.c. transformer which in turn, powered a custom built 220/9000 V step-up transformer. The final 60 Hz a.c. output was adjustable from 0 to 9000 V a.c. Applied voltage was monitored across the transformer output using a high voltage probe and digital multimeter, and current was measured with an in-line digital multimeter on the ground connection. The high potential output lead was connected to the mobile equipment, and the ground lead to the site ground bed.

For the crane, the high potential lead was affixed to the tip of the boom, which was elevated 10° above horizontal and extended approximately 2 ft (61.0 cm), with no suspended load. This position avoided the lower extreme of boom elevation and extension ranges, while still being convenient for experiment electrical connections. The crane frame and all wheels were connected with jumpers to provide a low resistance path shunting the hub assemblies, to prevent possible damage due to arcing among hub components. Previous experiments indicated that almost all of the electrical resistance presented by mobile equipment results from tyres and/or ground contact, so these connections had no measurable effect on results. Experiments were run for three conditions on the crane: on tyres only, on stabilisers (outriggers) only with the foot plates directly on the work/road surface, and on stabilisers only with the foot plates bearing on a 4 in (10.2 cm) layer of dry wood blocking. The only exception was for operating on asphalt with the stabilisers deployed (without wood blocking). In this case, to avoid damage to the asphalt, the stabilisers were placed in solid contact with the surface, but did not support the entire crane weight. For experiments using the White Roadboss-trailer combination, the high potential lead was connected to the front upper edge of the dump-bed, and the empty bed was raised to approximately 35° above horizontal. Similar to the crane boom, this avoided the lower extreme for the dump-bed range of motion. All wheels were connected to the frame with jumpers as described above for the crane. In addition, the trailer frame and bed, and the trailer and tractor frames were connected together to afford a consistent low resistance across the dump-bed pivot and the fifth wheel joint.

Data were collected for both the truck and crane on each of the five surfaces, by raising the applied voltage level at 500 V a.c. increments, and recording the total current flow to ground. Data collection was generally stopped at 4000 V a.c. or 1 A a.c., whichever was reached first. The 4000 V a.c. maximum was imposed to reduce the chance of tyre damage from tracking and arcing, and 1 A a.c. is the maximum output for the step up transformer.

For these experiments, the total current flow to ground varied widely for a constant applied voltage level, depending primarily on the road surface type, and for the crane on the manner of ground contact. Currents ranged from 1 A at 47 V a.c. for the crane using unblocked stabilisers on undisturbed turf, to less than 9 mA at 4000 V a.c. for the crane on tyres only on asphalt. On tyres alone or on wood block-supported stabilisers, the crane conducted well below 600 mA at 4000 V a.c. on all surfaces except undisturbed turf. In general, the dump-bed truck allowed at least 600 mA to flow to ground at 1000 V a.c. or below for all surfaces except asphalt. The most important result for both pieces of equipment was the extremely low current to ground when parked on the asphalt road surface. Fitzgerald reported a bulk resistivity for 22 asphalt samples that averaged 1.53×10^{13} ohm-ft (4.67×10^{14} ohm-cm) (Fitzgerald, 2000). Our findings are consistent with this high resistivity. Detailed results of these experiments are presented in Figures 5 to 8. Based on results from the earlier pivot joint shunt experiments, a minimum of 600 mA a.c. total current needs to flow through a machine chassis to allow reliable detection. Ideally, this minimum level should flow at an applied voltage of approximately 2300 V a.c. or less. This is the line to neutral voltage for a nominal 4160 V a.c. system, the lowest voltage commonly found on distribution level overhead power lines. These experiments showed that *for equipment on a high resistivity surface, such as asphalt, or when crane stabilisers are supported on dry wood blocking, insufficient current flows to allow detection of a power line contact.* This suggests that current measurement used alone is not a viable approach for a power line contact alarm.

3.4 Electric field sensing experiments

As the limitations of current sensing became apparent, electric field measurement was investigated as an alternative technique for detecting mobile equipment power line contact. An electric field exists between any two bodies of unequal potential. In this case one body is an energised mobile equipment chassis, and the other the road/work surface which is at or near earth potential. Measurement of this electric field was proposed as a method of detecting an overhead power line contact. Electric field measurement is the basis for commercially available *proximity* warning devices, but has inherent practical limitations that make accurate determination of distance to a power line difficult under varying conditions. In contrast, it was felt that the goal of detecting an energised chassis was a more manageable task, since the difference in under-chassis electric field strength between an energised and safe condition should be distinct, even at voltages below those likely to be present on an overhead power line.

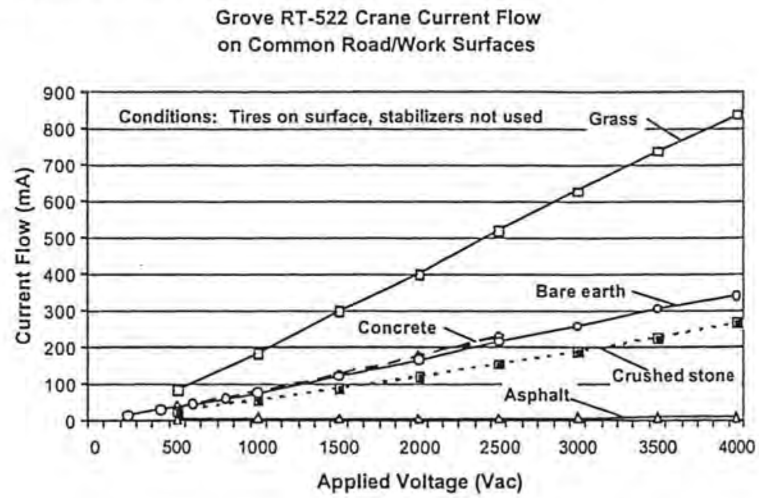

Figure 5 *Current flow through the Grove RT-522 crane, on tyres only, on five different surfaces.*

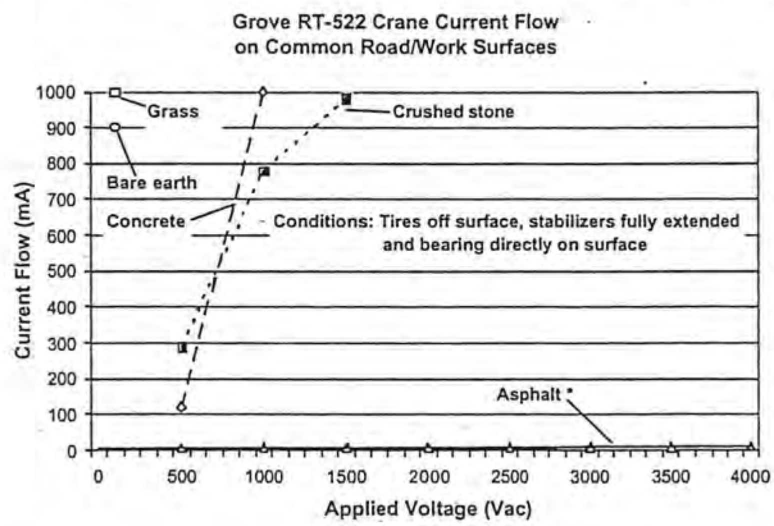

Figure 6 *Current flow through the Grove RT-522 crane, tyres off surface, on fully extended stabilisers bearing directly on five different surfaces. * On asphalt, stabilisers were only in light contact.*

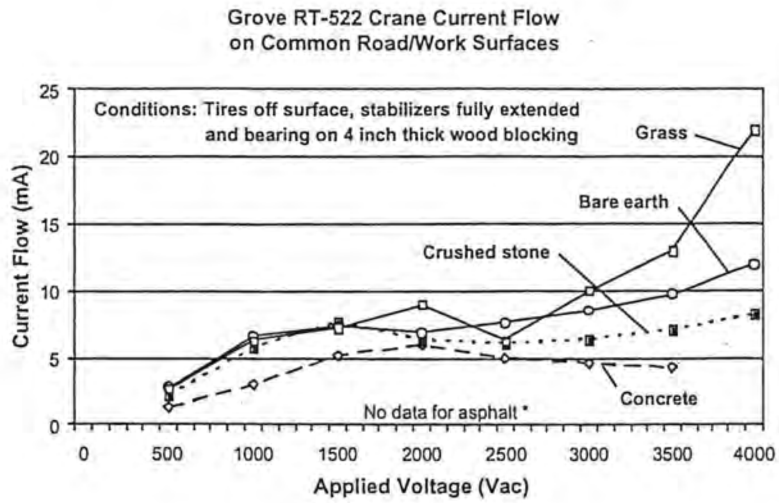

Figure 7 *Current flow through the Grove RT-522 crane, tyres off surface, on fully extended stabilisers bearing on 4 inch thick wood blocking, on four different surfaces. * Based on data for the RT-522 on tyres only, current flow through wood blocking support on asphalt would have been lower than that on all other surfaces.*

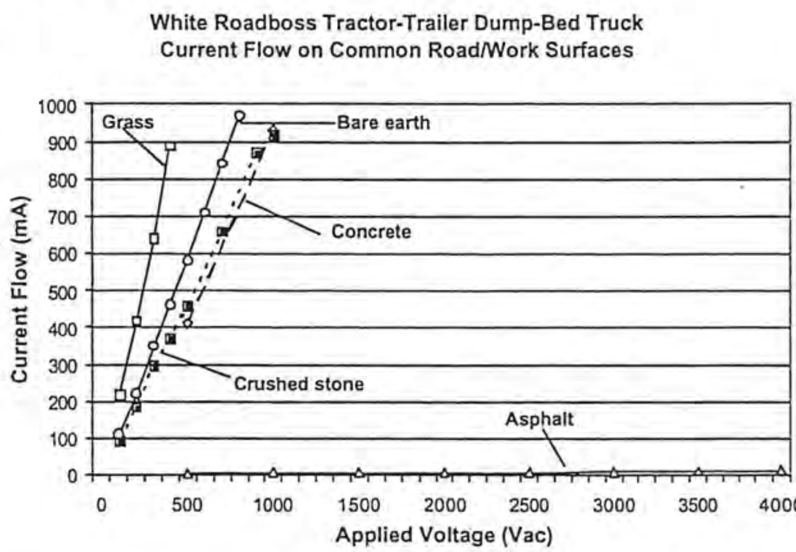

Figure 8 *Current flow through the White Roadboss tractor-trailer dump-bed truck, on five different surfaces.*

Initially, two commercially available, handheld, non-contact voltage detectors were examined in the PRL Mine Electrical Laboratory (MEL). Such devices are used by electricians as a quick means to assess if a circuit is energised. Both devices could detect 450 V a.c. at a distance of approximately 14 in (35.6 cm) from a single conductor and approximately 30 in (76.2 cm) from a square plate. These results suggested that electric field sensing was feasible for the distances and voltages that could be expected when monitoring the electric field below an energised truck or crane. To further study the suitability of electric field measurement for power line contact detection, a specialised sensor/alarm unit was designed, built, and used for experiments on the RT-522 crane and White Roadboss-trailer combination, parked on both concrete and asphalt surfaces. Results from these experiments allowed refinement of the circuit design and selection of sensitivity ranges. An improved design was then implemented in a prototype power line contact alarm system, consisting of a sensor assembly and control module.

The prototype testing was conducted on the RT-522 crane and the White Roadboss-trailer combination at the PRL test site. Since the voltage levels needed for these tests were much lower than for earlier current flow detection experiments, the 6500 W generator and adjustable 0- 240 V a.c. transformer were used as the power source, omitting the 220/9000 V a.c. step-up transformer. The high potential lead was attached to the truck bed front top edge or the crane boom tip, and the return lead to the site ground bed. The wheels were not connected to the frames with jumpers, as in current measurement experiments, due to the much lower voltages involved. The tractor and trailer frames, as well as the trailer frame and bed on the truck, however, were connected as described for the current measurement experiments. The applied voltage was monitored with a digital multimeter at the adjustable transformer output. For each test, the electric field sensor assembly was magnetically attached to the equipment undercarriage, with the assembly case connected to the equipment frame with an external lead. The sensor assembly case was positioned so that it would be protected from damage, as would be necessary in actual deployment, but the sensor probe was allowed to project below adjacent conductive chassis components. For most tests, the sensor probe was positioned 24 in (61.0 cm) above the road surface. The alarm system was powered by a 12 V d.c. automotive battery, with the negative lead tied to the equipment frame. The signal cable connecting the control module and sensor assembly was routed along the equipment exterior, close to the frame and body.

Tests involved gradually increasing the applied chassis voltage, and recording the level at which the alarm activated. Data were collected for both the crane and truck on four surfaces, including variations in ground contact for the crane, and using three different sensitivity settings for the field sensor (the undisturbed turf surface was omitted due to its similarity to bare earth in prior test results). At maximum sensitivity, alarm activation ranged from 37 V a.c. for the crane on tyres only on concrete, to 95 V a.c. for the truck on dry bare earth. In general, the alarm system activated at lower chassis voltages for the crane than for the truck. Also, reducing ground contact resistance for the crane by lowering the stabilisers had little effect on the alarm activation voltage. The electric field strength needed *at the system sensor* to activate the alarm system, was later experimentally quantified in the MEL, using a parallel plate electric field generator constructed to SAE specifications (SAE, 1995). The sensor assembly was positioned so that the case and alarm system circuitry common were at the same potential as the upper plate, and the probe protruded into the field, just below the plate. The alarm activation levels for a range of system circuitry sensitivity settings were documented in V a.c./m. The results for all tests are detailed in Figures 9 and 10.

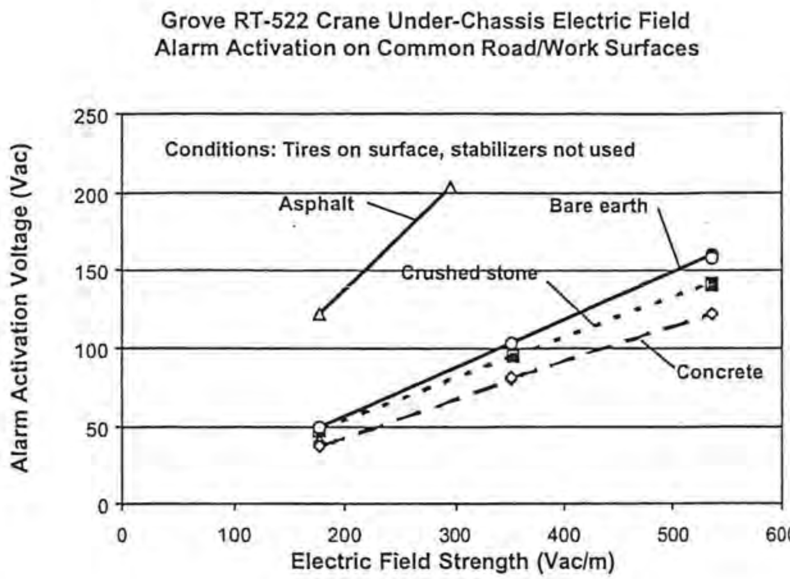

Figure 9 *Alarm activation voltages (chassis voltages) for under-chassis electric field measurement, on the Grove RT-522 crane, on tyres only, on four different surfaces. Multiple data points for each surface type represent different alarm circuitry sensitivity settings.*

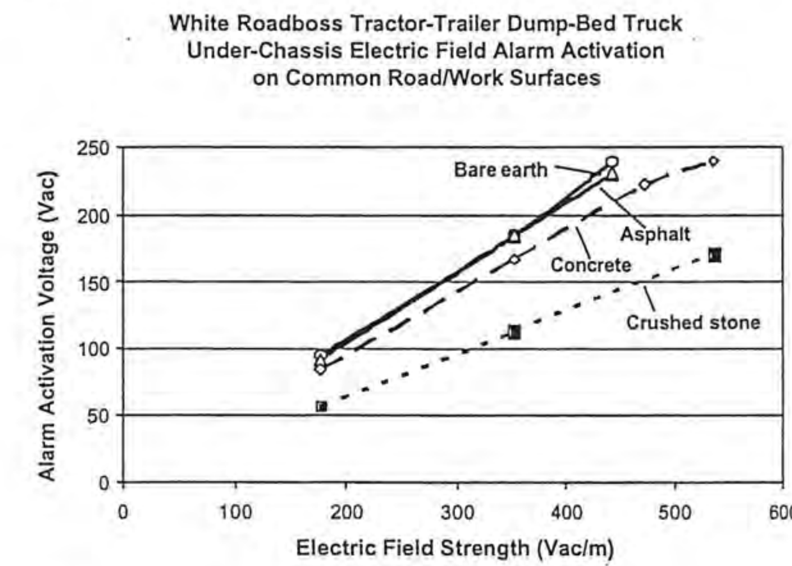

Figure 10 *Alarm activation voltages (chassis voltages) for under-chassis electric field measurement, on the White Roadboss tractor-trailer dump-bed truck, on four different surfaces. Multiple data points for each surface type represent different alarm circuitry sensitivity settings.*

Another series of experiments was conducted at the MEL to determine the likelihood of false alarms when equipment equipped with the electric field measurement-based line contact alarm is operating near a power line (with no direct contact). In these experiments, the RT-522 crane and White Roadboss-trailer combination were individually positioned 10 ft (3.0 m) below a single-phase a.c. power line. For equipment positions both parallel and perpendicular to the line, the voltage was gradually raised to 42 kV a.c., while monitoring the electric field sensor assembly alarm-activation circuitry. Laboratory equipment limited the maximum applied voltage to 42 kV a.c. line to ground, which represents one phase of a nominal 73 kV a.c. (line to line) three phase system. 10 ft (3.0 m) was a slightly conservative distance since it is closer than either MSHA or OSHA[3] permits equipment operation from a 73 kV a.c. overhead line, which are 10 ft – 10 in (3.3 m) and 12 ft - 0 in (3.7 m) respectively (MSHA, 2004; OSHA, 2004). Positioning equipment parallel to the 42 kV overhead line induced the highest field strength beneath the equipment, with 15 V a.c./m for the truck and 92 V a.c./m for the crane, at the sensor probe, which translate to 8% and 52% of the minimum alarm activation level, respectively. Additionally, these steady-state values were not exceeded when the line voltage was raised from 0 to 40 kV a.c. rapidly (in approximately 3 seconds). One additional experiment was conducted with the crane parked parallel to the line, but with the boom raised so that the tip was approximately 3 in (7.6 cm) from the line. In this case the induced field at the sensor probe was 138 V a.c./m, or 78% of the minimum alarm activation level. These results suggest that false alarms are not likely when operating at legal distances from power lines.

Electric field measurement proved a reliable method for detecting an energised equipment chassis. Performance was good irrespective of the type of surface on which the equipment was operating (varying resistivities), or the means of surface contact, such as rubber tyres, metallic stabiliser pads, or dry wood blocking. Measuring changes in the electric field that exists between an energised equipment chassis and the ground can be a reliable indicator of a power line contact.

3.5 Chassis potentials during power line contact accidents

In an equipment-power line contact situation, dangerously high voltages are usually present between the equipment chassis and the ground, and can also be present as step potentials on the surface of the ground near the energised equipment. Therefore, in the absence of a fire hazard, an operator should stay on board the equipment in the event of a line contact, until the line/equipment is de-energised. Researchers felt that the validity of this assumption should be verified, by investigation of the possible shock hazard present *on board* cranes and trucks when electric current flows through them. This work measured the voltage differentials arising from current flow in the operator cab and along the path an operator would follow to exit and dismount equipment. Experiments placed 10 A d.c. current through the RT-522 and IND-2535 cranes, and the White Roadboss-trailer combination, and measured the resulting potentials between selected points within the cabs and along operator egress paths (d.c. current facilitated accurate measurement of the low voltage levels involved). When the potentials were extrapolated to 1000 A d.c. of chassis current, a maximum operator exposure of 3.4 V d.c. resulted. This finding supports the common recommendation that, if possible, an operator should remain on the equipment in the event of a power line contact. In most cases, nearly all of the power line voltage appears across equipment tyres and ground contact, making contact of the equipment and ground simultaneously, the primary hazard. Table 3 summarises the results.

Table 3 Results of mobile equipment on-board hazardous voltage experiments. Values for 1000 A d.c. current through crane and dump truck chasses, extrapolated from 10 A d.c. measurements.

Mobile equipment	*Maximum voltages across likely touch and step points*	
	Operator control area	Operator egress area
Grove RT-522 crane	0.7 V	0.4 V
Grove IND-2535 crane	1.2 V	0.0 V
White tractor-trailer	3.4 V	2.2 V

4 A prototype power line contact alarm system

This research culminated in the design and construction of a prototype power line contact alarm system for concept demonstration and field testing. The system consists of a control module, one or more sensor assemblies, and audible/visible alert devices as needed, with hard wire interconnections. The control module, to be mounted in an operator cab, features a power-on light, an alarm reset button, a system power fuse, and an audible alarm. As shown in Figure 11, the control module manages all system input power, sensor signals, and alarm activation. The system can employ an electric field sensor assembly alone, or in combination with a current sensor assembly. The electric field sensor assembly is a single enclosure with the sensor probe protected in a Teflon block at the base of the unit, and is shown in Figure 12. The current sensor assembly consists of a #2/0 AWG shunt, a custom 100/1 ratio current transformer, and an enclosure housing circuitry to process and assess the CT output signal. Warning devices such as strobes and horns can be powered directly from the control module. Design of the prototype system was constrained by time and resources, but the following features are suggested as important elements for a marketable general purpose power line contact alarm system:

- The system should reliably alert an operator and other nearby personnel when a piece of mobile equipment has become electrically energised, specifically from an overhead power line contact.
- Of the methods studied, electric field measurement is the most reliable for detecting an energised equipment chassis. Electric current measurement can be effective for some applications, but should only be used in combination with electric field measurement.

Figure 11 *Control module for the prototype power line contact alarm system.*

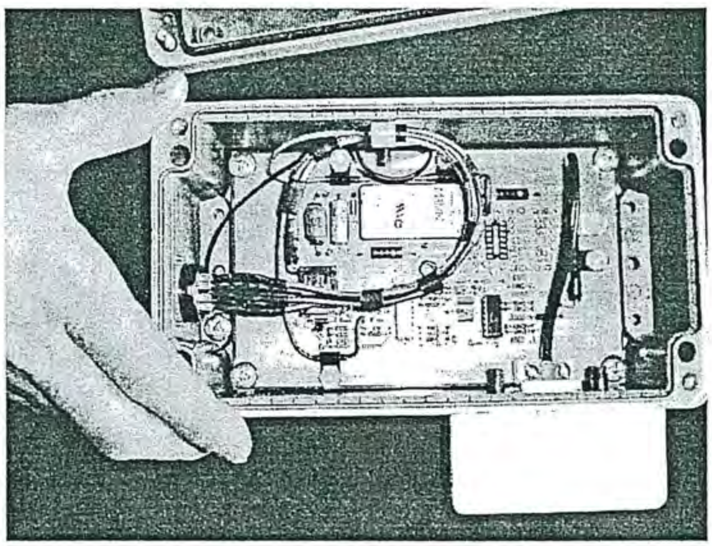

Figure 12 *Electric field measurement sensor assembly for the prototype power line contact alarm system.*

- The system should automatically be active any time the protected equipment is in use, and it should have a manual reset, a manual and power-up test mode, and battery back-up power.
- Communication between system components should be wireless or carried over the mobile equipment electrical system, to accommodate barriers such as crane turntables and tractor-trailer fifth wheels.

- System failures should result in an alarm or other safe state.
- Audible alarms should ideally include voice enunciators so that personnel clearly understand the hazard present.
- System installations should include conspicuous signs with clear messages explaining the alarm system, on the interior and exterior of the mobile equipment.
- Personnel operating or working near protected mobile equipment should be trained in power line hazard recognition, contact alarm operation, and the proper response to a line contact accident.

4.1 Commercialisation

One commercial firm, HVP Systems, Inc., has added power line contact detection as a feature on their line of power line proximity warning devices, based in part on NIOSH research (HVP Systems, 2002). Although this is an effective use of the contact alarm concept, PRL researchers feel that a practical and affordable stand alone power line contact alarm system could find much broader use in mining, construction, and other industries.

5 Summary

In many mobile equipment-power line contact accidents, injury could have been avoided had the equipment operators and nearby workers simply known, after the fact, that a power line had been contacted. The NIOSH PRL conducted research to develop an overhead power line contact alarm system for mobile equipment. Two power line contact detection methods were investigated, measuring current flow to ground through mobile equipment, and measuring the electric field present between an equipment chassis and ground. Current flow measurement is unsatisfactory when equipment is on a high resistivity surface, such as asphalt, but electric field measurement can reliably detect an energised equipment chassis under most common conditions. Work also confirmed that operators are unlikely to be exposed to a shock hazard if they remain on board equipment during a line contact. A prototype power line contact alarm system was designed and constructed. The power line contact alarm concept and techniques developed in this research have been employed as a feature on a commercially available power line proximity warning system.

Notes

1 Use of manufacturer or product names does not imply endorsement by NIOSH.

2 All instrumentation and probes used in experiments are annually calibrated to NIST traceable standards.

3 United States Mine Safety and Health Administration (MSHA) and Occupational Safety and Health Administration (OSHA).

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