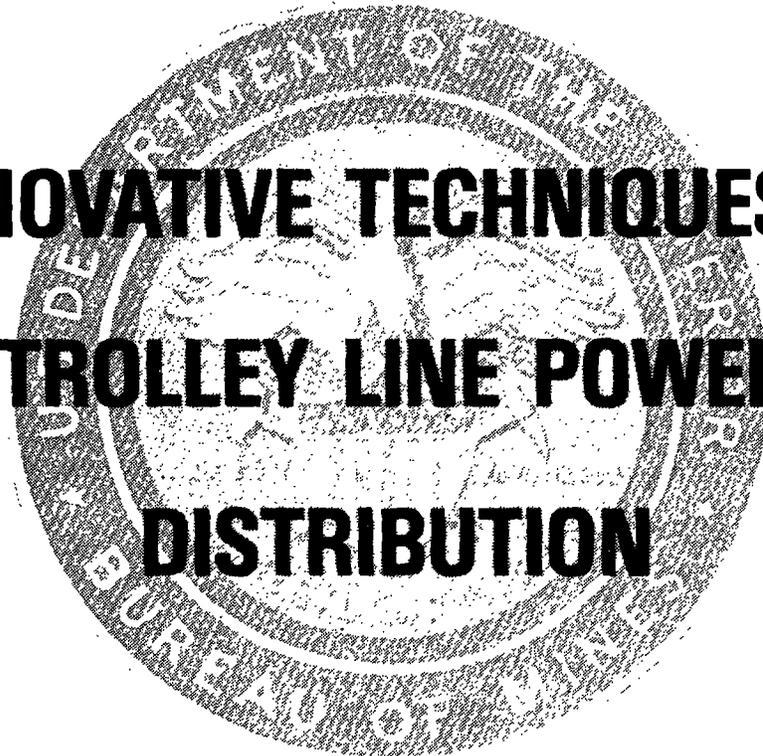


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May 1981**



**INNOVATIVE TECHNIQUES IN
TROLLEY LINE POWER
DISTRIBUTION**

Bureau of Mines Open File Report 49-82

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Foster-Miller Associates, Inc.
350 Second Avenue
Waltham, Massachusetts 02154

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16. Abstract (Limit 200 words) This report describes the results of investigations into four specific areas related to trolley wire power distribution in coal mines. Prototype devices or designs were developed in each area. In addition, a brief survey was made in an attempt to assess the future of mine trolley systems, and data was collected and reviewed in an attempt to analyze the nature of trolley wire related accidents. Other options for decreasing the risks associated with trolley systems that arose during the study are briefly discussed in the appendices. These include insulating equipment and miners from return and/or energized conductors and use of a segmented trolley wire with local control of current delivering capability.				
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FOREWORD

This report was prepared by Foster-Miller Associates, Inc., (FMA), Waltham, MA under USBM Contract No. J0188083. The contract was initiated under the Coal Mine Health and Safety Act. It was administered under the technical direction of Pittsburgh Research Center with George J. Conroy acting as Technical Project Officer. Mr. A.G. Young was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period 28 August 1978 to 27 February 1981. This report was submitted by the authors in May 1981.

No patentable features were identified; no patent applications are contemplated.

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EXECUTIVE SUMMARY

This report describes the results of research in four areas related to coal mine trolley wire power systems. In the first area, shielding or insulation of the conductor, commercially available products were surveyed and the one thought best for coal mine use was identified. In addition, ten new concepts were proposed, evaluated, and compared. The second area, high-speed insulator failure detection, resulted in recommendation of a hand-held, infrared detection system. A proposed method of vehicle mounting for high-speed scanning is described. In the third area, dual-wire trolley systems, three electrical configurations for dual-wire systems were evaluated. Preliminary hardware designs are presented. In short, dual-wire systems offering substantial safety advantages appear relatively complex. The fourth area, insulator fault indicators, resulted in the development of several designs and prototypes. All are intended to detect the flow of excessive current into the mine roof and to identify the faulty insulator.

As a by-product of the above described work, information was obtained on the future of mine trolley wire systems and on the nature of trolley-wire related electrical accidents. Brief comments on these topics are offered in Section 6, Summary of Conclusions. Other options for decreasing the risks associated with trolley wire systems are briefly described in appendices. These include increased use of protective equipment for men and machines and the proposed design of a segmented trolley wire system offering local control of current delivering capability.

1. INTRODUCTION

Underground power distribution systems utilizing a single bare conductor at a potential of 300 to 600V have long been perceived as a significant hazard in coal mines, presenting two major types of risk:

- a. At one level are risks to individuals ranging from electrocution and death to less severe shocks and burns caused by direct personnel contact with the bare conductor.
- b. At a second level are safety hazards and property damages resulting from trolley wire-related mine fires. These fires are usually associated with major faults caused by wire or roof falls, inadvertent wire contact with grounded equipment frames, or similar mishaps. However, they may also result from high leakage currents flowing into combustible material over prolonged periods.

Other problems resulting from the use of present trolley wire systems are:

- a. Difficulties involved in trying to detect ground fault conditions
- b. Stray ground currents in the mine
- c. Maintenance problems involving upkeep of guarding and shielding, insulators, and rail bonds.

As a result of concern about threats to mine safety at a time of revived interest in coal as a national energy resource, the U.S. Bureau of Mines (USBM) contracted to Foster-Miller Associates, Inc. (FMA) the task of investigating several approaches to improved trolley wire safety in coal mines.

The scope of work as prescribed by the contract called for examination of four specific areas:

- a. Partially insulated trolley wire
- b. Scanning systems for insulator fault detection

- c. Dual-wire trolley systems
- d. Insulator fault indicators.

The work plan was limited to these areas to round out studies of trolley wire-related innovations being conducted by the USBM.

As work on the FMA program progressed, discussions with USBM personnel and industry representatives led to a broadening of the study to include two additional areas:

- a. Assessment of the future of trolley wire systems
- b. Analysis of the nature of trolley wire-related electrical accidents.

In addition, two other options for increasing trolley wire safety arose in the course of the study and were briefly investigated. They were:

- a. Insulating equipment and miners from the return
- b. Use of a segmented trolley wire with local control of current delivering capability.

This report presents conclusions and recommendations regarding these areas and identifies those appearing to merit additional research. In general, the major program goals have been met.

2. FACTORY MOLDED TROLLEY WIRE INSULATION

This portion of the project studied methods of insulating or shielding the trolley wire. Dangers of uninsulated conductors supported by insulated hangers are:

- a. Injuries to human beings as a result of electrical burns or shock
- b. Fires resulting from current leakage and/or major faults.

In the process of gathering information, the FMA project staff was unable to identify any other industrial application of electricity that permits equivalent exposure of accessible, unshielded energized wire. To a certain extent, the nature of power utilization in underground haulageways requires some exposure to make the system work, and the existing systems, it must be stated, are the utmost in simplicity. In designing conceptual approaches to shielding, it became apparent that shielding adds complexity. This complexity may create additional hazards and risks, such as those associated with sustaining collector shoe contact with a shielded conductor or maintaining and repairing the shielding. This is not to suggest that shielding and insulation is not a good idea; indeed, insulation offers possibilities for improved electrical safety which warrant further testing. Any future testing, however, should include assessment of the "illusion of safety" that might be created by such insulation.

2.1 Identification of a Commercially Available Product

A survey of products used in conjunction with overhead crane installations revealed that several types of shielded trolley wire are manufactured and commercially available. Of these, "Span-Guard,"* manufactured by the U.S. Safety Trolley Corporation, Pittsburgh, PA, offers the most promise for application to mine trolley systems. This product utilizes two curved lips of flexible plastic material attached to the wire with hard plastic clamps and adhesive. This offers virtually complete protection of the conductor when the lips are closed (see Figure 1). However,

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the USBM.

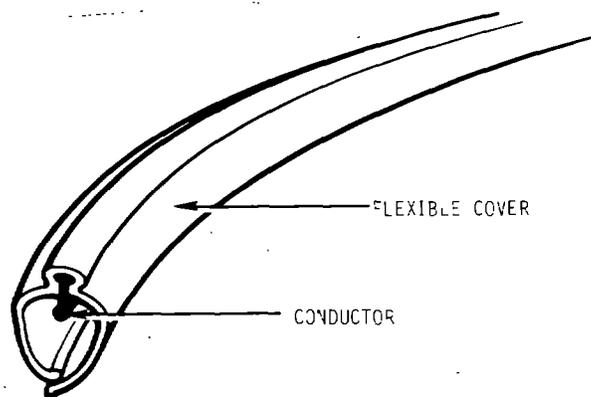


FIGURE 1. - United States safety trolley span-guard.

two important modifications are necessary before this product can be evaluated in an underground mine:

- a. Modification of the shielding to accommodate the shape of mine trolley wire. The shielding, as is, would come very close to fitting figure-eight-type wire, but would not fit the grooved-type wire. Alternatively, wire hangers, clamps, dead ends, etc., could be modified to accept the U.S. Safety Trolley-type trolley wire. This approach would, however, be very expensive on a large scale.
- b. Modification of the collector shoe, harp, and/or the shielding to eliminate points of wear and abrasion between pole top and shielding.

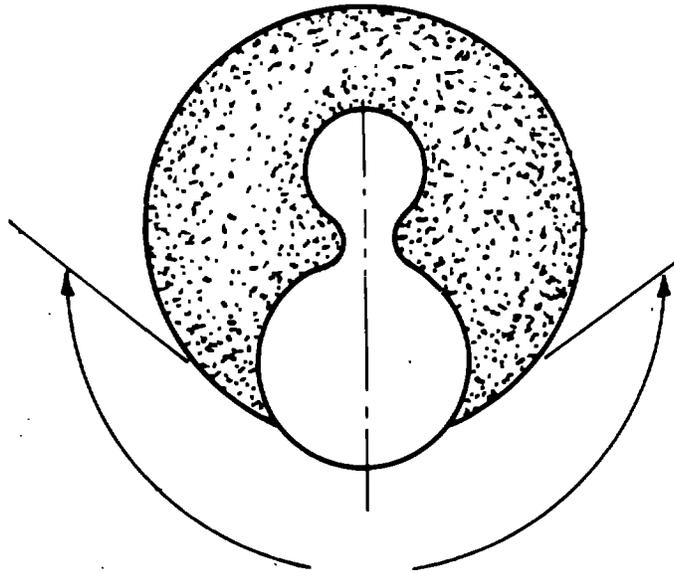
Both of these modifications are necessary to ensure an adequate underground trial. It is recommended that any further action on this concept begin by evaluation of these modifications.

2.2 Retrofitting or Molding Insulation to Trolley Wires

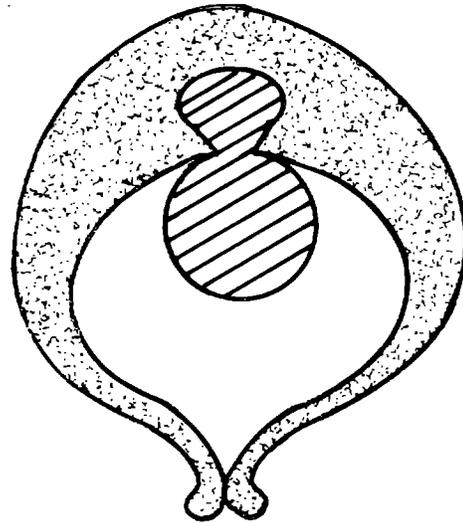
Ten concepts examined for retrofitting are depicted in Figure 2. Analysis is given in Table 1.

2.2.1 Procedure and Analysis

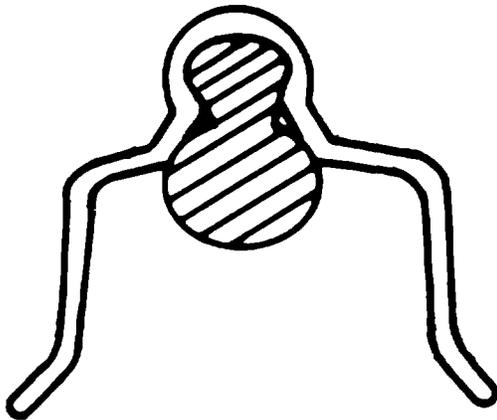
These concepts have been compared using the following criteria: initial cost and/or produceability, effectiveness against electrocution and accidental ignition of fires, ruggedness in use, ease of maintenance, and unknowns to be resolved in development.



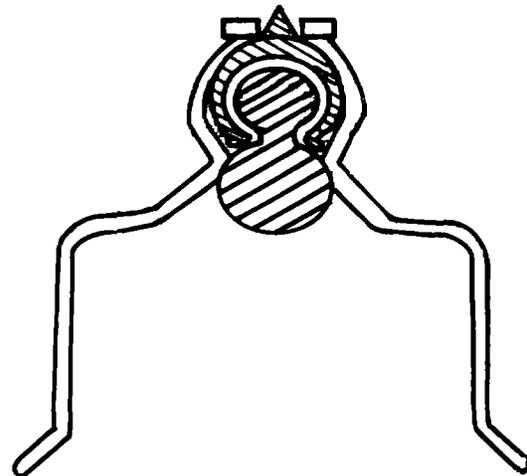
a) CONCEPT 1 - INTEGRAL PARTIAL INSULATION



b) CONCEPT 2 - TOTALLY COVERED PROTECTOR



c) CONCEPT 3 - SNAP-ON PROTECTOR

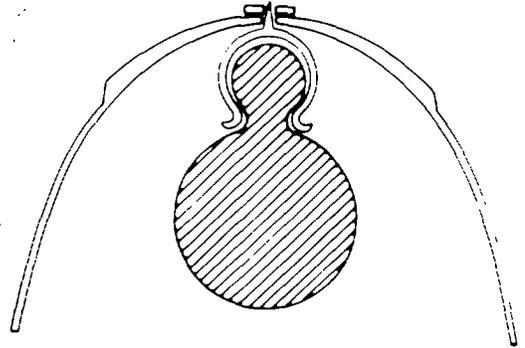


d) CONCEPT 4 - SNAP-ON WITH INTERNAL CLIP

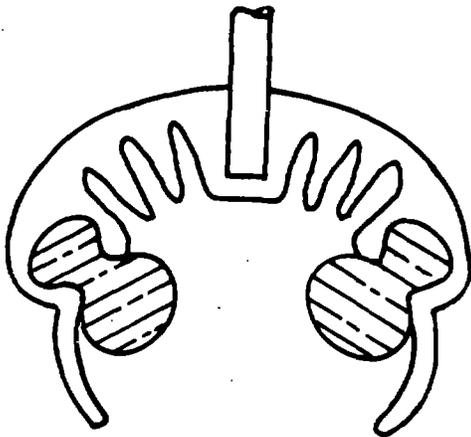
FIGURE 2. - Guarding concepts.



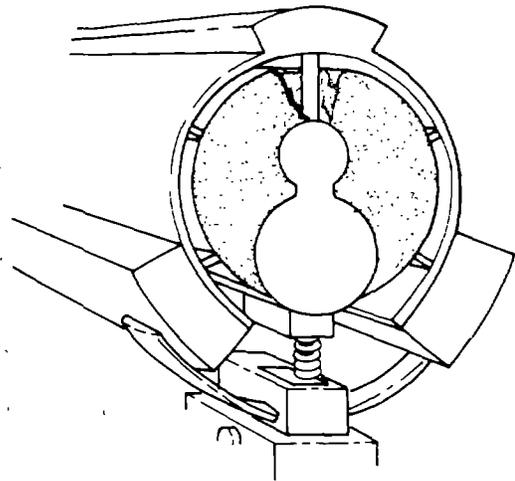
e) CONCEPT 5 - SNAP-ON WITH EXTERNAL CLIP



f) CONCEPT 6 - STANDARD TROLLEY GUARD WITH SPECIAL INTERNAL CLIP

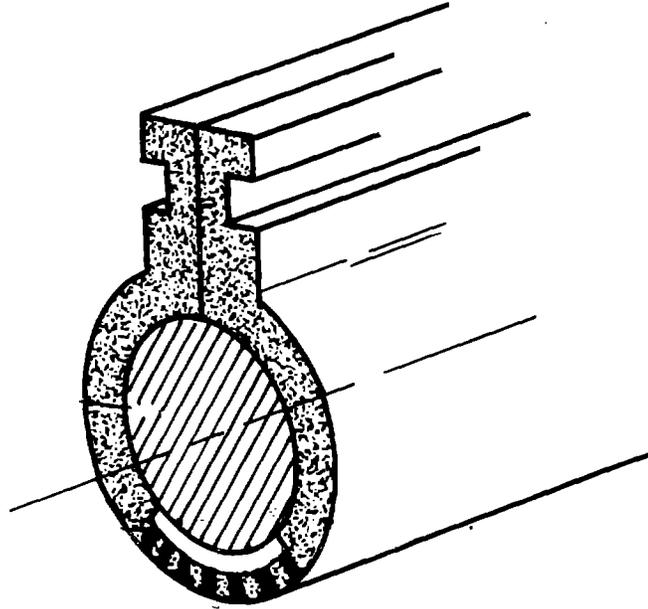


g) CONCEPT 7 - DUAL-WIRE GUARD

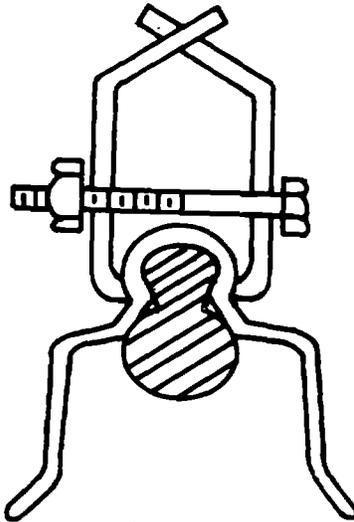


h) CONCEPT 8 - COAXIAL WIRE

FIGURE 2 . - Guarding concepts (continued).



i) CONCEPT 9 - FORCE CONTACTING GUARDING INSULATION



j) CONCEPT 10 - SNAP-ON GUARD WITH EXTERNAL CLAMP FOR RETROFIT

FIGURE 2. - Guarding concepts (continued).

TABLE 1. - Comparison of wire guardings

Characteristics to consider	Concept No. 1	Concept No. 2	Concept No. 3	Concept No. 4	Concept No. 5
Initial cost, practicability	Added process steps for wire manipulator, new hanging hardware	Extra step, unique to wire size. Modified wire shoe. Cut and press onto existing wire with special tool, flare & opening	Simple extraction unit-one for each wire size. Cut and press onto existing wire with special tool.	Clips sized to wire. Guard may be universal size. Placed on existing wire. Special tool for clip installation.	Extraction made to wire size. Clamped clips. Cut and press on wire. Special tool.
Time to replace/modify installation stage	Replace all trailing wire, may put insulation to use standard or use hanging	-	-	-	-
Expected life: Time to cut repair.	Long life if there is no separation of wire/insulation	-	-	-	-
Flexibility	Slightly better than unguarded 25 deg exposure angle	Excellent protection & 2 deg exposure angle	115 deg exposure angle	110 deg exposure angle	110 deg exposure angle
Problems: Probability of contact from below, or exposure angle	Cannot short from above, not safe in falls.	Cannot short from above, safe in falls.	Cannot short from above, not safe in falls.	Cannot short from above, not safe in falls. See also No. 4	Same as No. 4
Problems: Probability of contact from above, or exposure angle	Impervious to pole hits.	Safe in any direction	Pole hit may disengage	Pole hit may disengage	In hoop
Time to repair. Time, number of men, cost steps.	Only severe damage can foul shoe	Disable with tool shoe. Power off. Special tool to repair, readily available	May foul shoe. Power off. Special tool to repair	May foul shoe. Power off to repair	Same as No. 4
Repair cost: Parts most likely to need replacing	Replace sections of wire	Can be replaced in section, use standard hangers	Before in section, use standard hangers	Sealate sections, clamp nut.	Same as No. 4
Time to repair. Time, number of men, cost steps.	Power off, loosen hangers, reattach wire	Power off to repair	Power off to repair	Power off	Power off
Repair procedure safe? Safe to repair with wire cut	Cannot repair hot	Can insulate steel or handle of essential tool	Same as No. 2	Not safe	Same as No. 2
Frequency of repairs: Time between failures?	Long time between failures	-	-	-	-
General comments	New fabrication technique? How to hang? Will separation occur?	Will edit to prepare lists of plastic lists? Expected life? Frequency of repair?	Flexibility remaining? Expected life? Frequency of repair?	Expected life? Frequency of repair?	Expected life? Frequency of repair?

TABLE 1. - Comparison of wire guardings (continued)

Characteristics to compare	Concept No. 6	Concept No. 7	Concept No. 4	Concept No. 9	Concept No. 10
<p><u>Initial load bearing capability</u> Parts: Varies unique for each wire size. Labor: Time to replace/modify clips. Expected life: Time to first repair</p>	<p>Standard wire cover with two internal clips. Clips, sizes to wire and standard covers. Cut cover and press clips, special tool.</p>	<p>How manufacturing process, new shoe design, new hangers, replace all trolley wire, change car wiring and power supply outputs. Same life as new wire.</p>	<p>How manufacturing process, new shoe design, new hangers, replace all wire, change car wiring, change power supply outputs. Same life as new wire.</p>	<p>New manufacturing process, new hangers, replace all wire.</p>	<p>Plastic extrusion clamps. Clamp onto existing wire. Longer than standard cover.</p>
<p><u>Effectiveness</u> Effectiveness: Prob ability of contact from below, or escape wire. Parts: Contact from above protected in case of roof fall.</p>	<p>Same as No. 3</p>	<p>Cannot short from above. May catch in a fall and short.</p>	<p>Excellent protection. Cannot short from above. Can short in a fall.</p>	<p>120 deg. Cannot short from above. Can short in a fall.</p>	<p>120 deg. Cannot short from above. Can short in a fall.</p>
<p><u>Supports</u> Pole hits, falls trolley? Will pole tear at amount, or no damage? 10 to 40 lb. Does damaged wire dis-able trolley?</p>	<p>Can tear or distort. Fouls since</p>	<p>Hard to damage with pole. Same as No. 1</p>	<p>Hard to damage with pole. Damage will foul shoe.</p>	<p>Hard to damage with pole. Only severe damage will foul shoe.</p>	<p>Pole hit may dislodge or tear. Tear may foul shoe.</p>
<p><u>Repairs</u> Parts used: Parts most likely to need replacing. Time to repair: Time, number of men, repair skill? Repair procedure, safe: Safe to repair with wire hot? Frequency of repairs: Time between failures?</p>	<p>Clips and cover. Power off. Not safe. Same as with standard cover or better.</p>	<p>Replace sections of wire. Power off, rehang, tension. Not safe to repair hot. Infrequent.</p>	<p>Sections of wire. Power off and hang new section of wire. Unsafe with wire hot. ?</p>	<p>Replace sections of wire. Power off, fit, and rehang. Safe to hang with wire hot (not a recommended procedure). ?</p>	<p>Extrusion and clamps. Car and clamp (no special tool). Safe to install with wire hot (not a recommended procedure). ?</p>
<p><u>General Unknowns</u></p>	<p>Make clips so they do not slide on wire. Expected life?</p>	<p>Many new components to design? System integrations? System reliability not known?</p>	<p>How to produce co-axial design? Hanger design? Shoe design?</p>	<p>Expected life? How to produce new design? Contact resistance? Internal arc damage?</p>	<p>Expected life? Frequency of repair?</p>

Concept No. 1 was eliminated because of the large angle of exposure of the conductor. No. 2 protects the wire, but requires modification of the pickup shoe, and would be troublesome in re-trolleying. It would also foul the trolley line when torn. No. 6 (the standard wire cover) is not rigid enough to prevent contact from below; the internal clips may allow shorting from above as well. Concepts No. 7, 8, and 9 would require extensive redesign of other system components, including replacement of all trolley wire. The snap-on protectors (no. 3, 4, 5, and 10) are best, and No. 10 appears to be the easiest to install and maintain. There are two fabrication possibilities: extrusion and molding. Molding allows use of laminated materials, which permits combination of desirable material properties; hence, it is preferred.

2.2.2 Conclusions and Recommendations

Concept No. 10 (Figure 2j) involves a snap-on protector shield that is firmly clamped to the wire and was found most suitable. Advantages of this method are ease of installation and maintenance.

A molding (rather than extrusion) method of production is recommended since it permits use of laminated materials with a wider choice of desirable properties.

2.2.3 Further Considerations of a Force Contacting System

The concept of a force contacting system (Concept 9, Figure 2i) merited further analysis because of its potential for completely insulating the conductor wire.

To further study the potential of such a system, the FMA project staff considered the possibility of molding a single overhead wire so that pressure exerted upward by the trolley pole would deflect the bottom conductor-impregnated insulation through an air gap and into contact with the main current carrying wire (see Figure 3). This would allow current to flow only at the point of pressure application while the remaining surface of the wire remained electrically insulated.

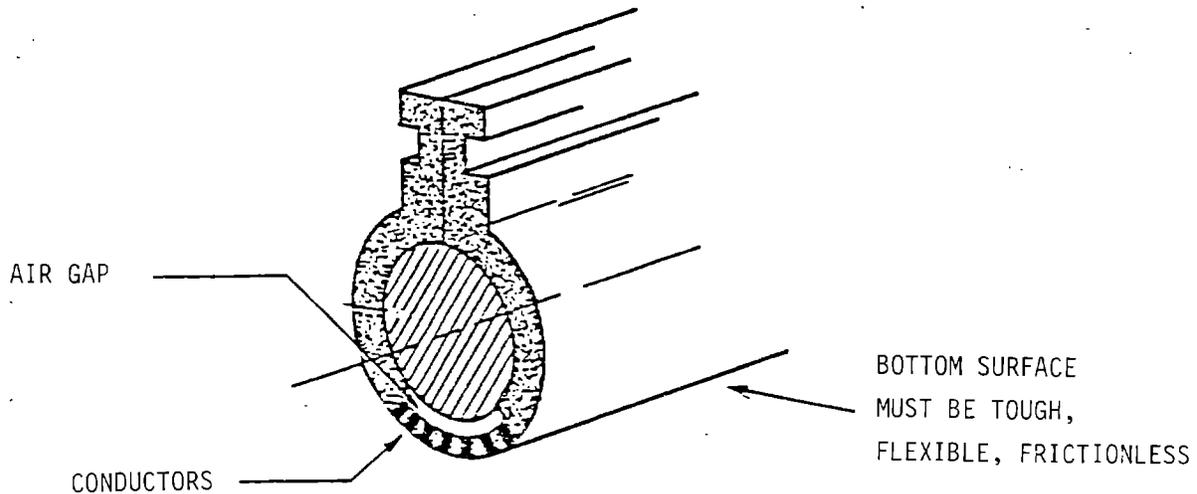
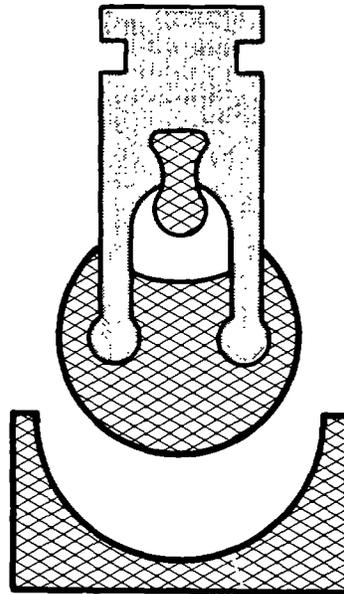


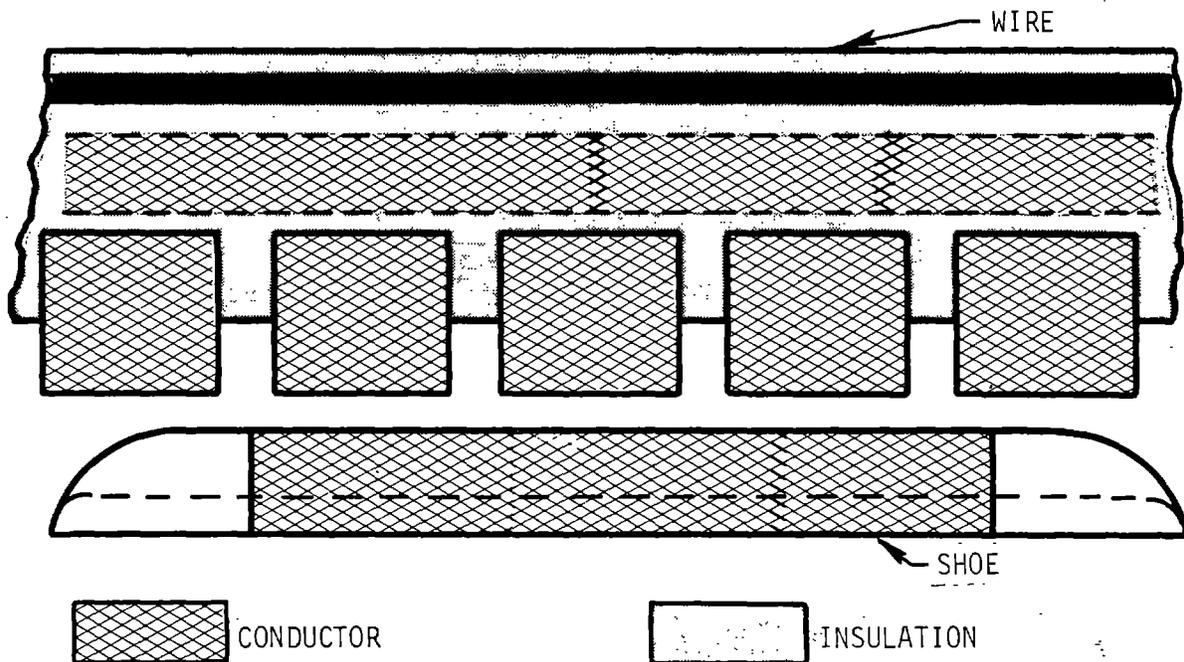
FIGURE 3. - Force contacting guarding insulation.

As originally conceived, the wire, especially the bottom surface of it, performs several functions. It guides the trolley shoe and thus has to be relatively tough and frictionless in order to avoid rapid wear. It also must deflect approximately 1/4 in. under the relatively low upward load of the trolley pole. We found no commercially manufactured product available combining the durability and the flexibility that this design requires. (Several of the new "super" plastics were considered for their low extrusion profile availability. They all proved too stiff for our purposes.)

At this point, it was decided to alter the design rather than trying to tailor a material to fit the original design. In keeping with the pressure activating concept, we offer the design in Figure 4. The main current carrying element is similar to the overhead wire presently used in many mines. The bottom contacting surface, over which the trolley shoe slides, is made of segments of the same material as the main power line, and is held in place by extruded lobes of insulating material. The required gap of approximately 0.2 to 0.25 in., necessary to prevent arcing, is



a) CROSS-SECTION



b) OVERALL VIEW

FIGURE 4. - Alternative design concept.

maintained through a combination of gravity and the stiffness of the insulating material. Since the insulating material does not come into direct contact with the sliding shoe, there is no abrasion; hence, its rubber-like consistency can be tailored to fit our needs for flexibility only. A vinyl plastic compound may be used for the insulation. As shown in Figure 4, the trolley shoe has insulated sections at each end to prevent arcing as each successive conductor is pushed against or released from contact with the main power line. The shoe is long enough to contact several conductors simultaneously, preventing arcing during transition of current passage from one conductor to the next.

The design in Figure 4 combines available conductive materials with an insulation material that is reasonably easy and inexpensive to extrude. Its safety factor is relatively high. Outer conductors are energized only when an upward pressure is applied equal to or greater than that applied by a trolley pole. (This pressure varies from vehicle to vehicle, but is in the range of 10 to 40 lb.) Pressure applied from the side, as in the case of a worker accidentally brushing a hand or arm against the wire, should not create a hazard since the geometry prevents the gap decreasing sufficiently to allow current to flow.

Finally, one problem inherent in all pressure activating systems is the internal arcing that occurs when the trolley pole pressure diminishes for an instant (as when the spacing between the tracks and the overhead wires suddenly increases). This force reduction allows the conductors to separate from the main power line, causing an arc. The ramifications of such arcing on system life could be accurately assessed only through prototype testing.

3. AUTOMATIC, HIGH-SPEED, LOCAL EVALUATION OF INSULATOR QUALITY

Since early and automatic detection of current leakage and excessive temperatures on or near faulty insulators could greatly simplify surveillance tasks in underground haulageways, the FMA staff examined two approaches and produced a design for one such system.

3.1 Electrical Methods

An initial review of electrical methods of detection made it clear that such systems would not be practical. Two key considerations were:

- a. Contact resistance at the contact point to the trolley wire
- b. Electrical noise in the system.

Since both effects would overwhelm any system designed to detect small leakage current while moving along the wire, attention was directed to infrared methods.

3.2 Infrared Methods

The proposed design utilizes a commercially available infrared heat detector (Model 955 "Fire Finder," manufactured by Dyn-optics, Inc., Laguna Beach, CA)* in conjunction with a standard electrically powered mining vehicle to locate faulty insulators or hot spots in the mine roof at a relatively high rate of speed. In addition to providing an audible signal to the vehicle operator, the system would visibly mark the location of an insulator fault.

3.2.1 Background of Infrared System

Buildups of contaminants on electrical insulators result in insulator breakdown and current leakage. The leakage current may

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the USBM.

produce a temperature rise in and around the insulator which can be detected with infrared thermometry. Infrared devices are well established as a means of locating problem areas. They are used in the power industry to detect "hot spots" which indicate faulty equipment, and in mines to locate hidden water sources and loose sections of roof.

Two types of infrared devices are commonly used:

- a. Infrared thermometers
- b. Infrared viewers.

The thermometer converts radiated energy to direct temperature readings. The viewer converts radiated energy to corresponding levels of light detectable by the human eye and displays it on a viewing screen.

3.2.2 Implementation Plan for Infrared Detection System

To test the feasibility of infrared detection, the FMA staff conducted a 10-day trial with an infrared thermometer (Model 955 Fire Finder).

The test unit was set for threshold alarm at approximately 160°F. Performance calculations assumed the unit to be mounted approximately 4 ft from the wire end on the trolley pole of the scanning vehicle.

Response Time and Field of View

After fixing the Fire Finder approximately 4 ft from a wall and establishing a "sensing envelope," hot solder drops were allowed to fall past an adjustable aperture over the field of view. Based on several observations it was determined that the fall distance required to trigger the alarm was 1.8 in. ±0.1 in. or approximately 4.6 cm (see Figure 5). Using the formula $S = S_0 + 1/2 gt^2$ and solving for time where $S_0 = 0$ and $g = 980$ cm/sec² yields:

$$t = \sqrt{\frac{2s}{g}} = \sqrt{\frac{2(4.572)}{980}} = 0.096 \text{ sec} \pm 0.001 \text{ sec.}$$

This figure corresponds with the manufacturer's claim of less than 0.1 sec response time. Also, the size of our sensing envelope compared favorably with the manufacturer's claim of an 8- to 9-in. field of view at a distance of 4 ft.

Scanning Vehicle Maximum Speed

Knowing the reaction time and view angle of the Fire Finder, it is possible to calculate the maximum speed of the scanning vehicle for various orientations of the trolley pole. The worst case, and hence the slowest scanning speed, would occur when the trolley pole is perpendicular to the overhead wire. The best case, assuming a trolley pole length of about 6 ft, would occur when the end of the trolley pole was about 1 ft above the top of the scanning vehicle (see Figure 6).

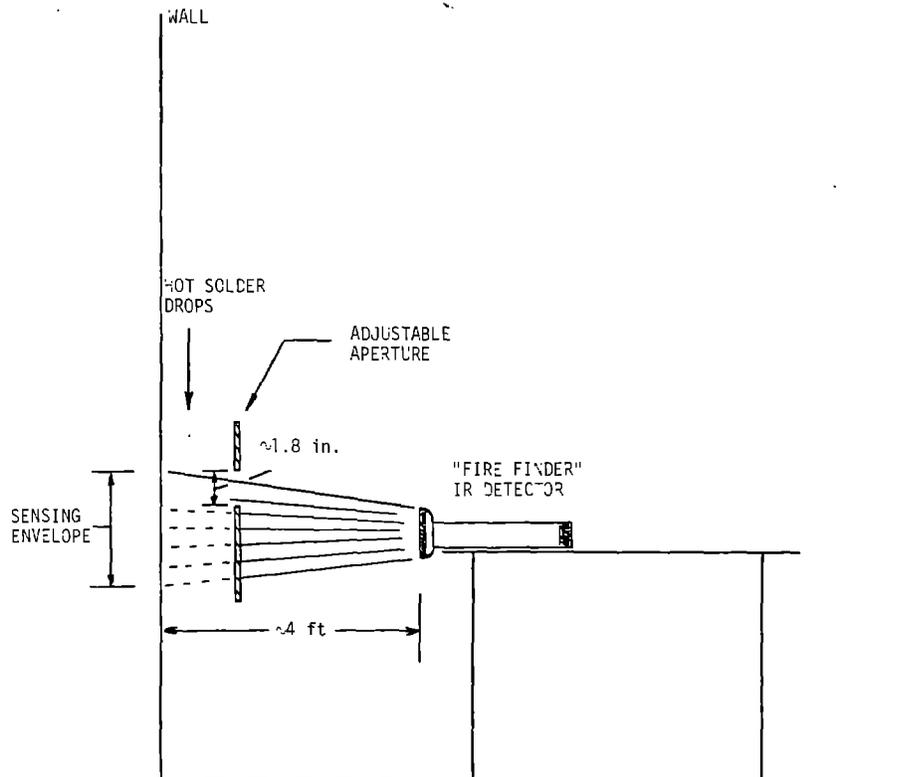
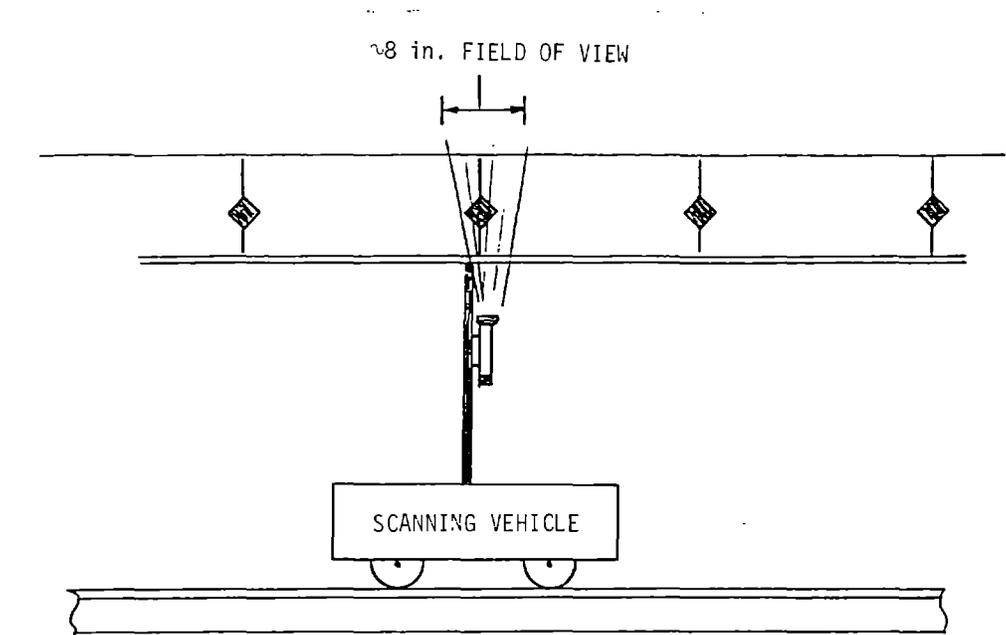
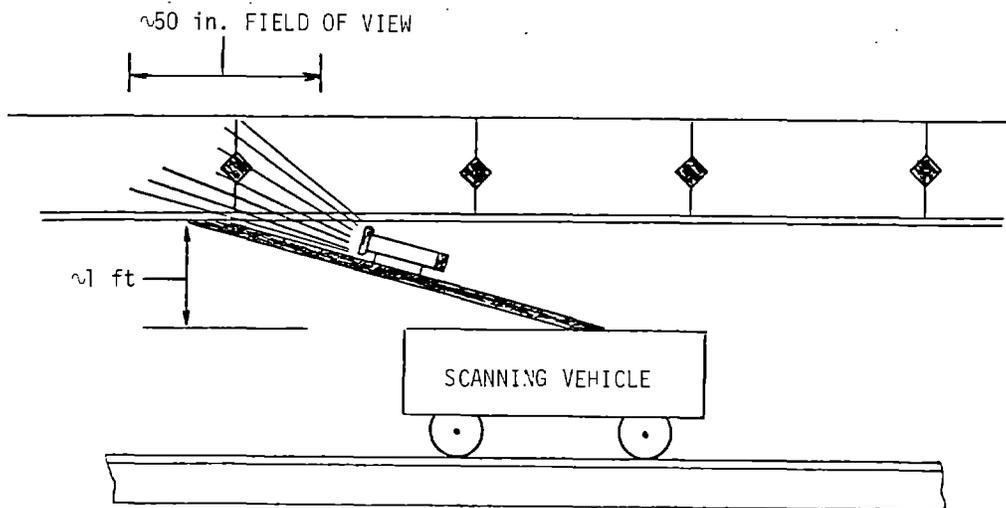


FIGURE 5. - Experimental schematic.



a) WORST CASE



b) BEST CASE

FIGURE 6. - Infrared scanning.

For the worst case, with a field of view of approximately 8 in., the maximum scanning velocity is:

$$V_{\max} = \frac{S}{t} = \frac{0.67 \text{ ft}}{0.096 \text{ sec}} = 6.8 \text{ ft/sec or } 4.6 \text{ mi/hr}$$

For the assumed best case, with a field of view of approximately 50 in., the maximum scanning velocity is:

$$V_{\max} = \frac{4.16 \text{ ft}}{0.096 \text{ sec}} = 43.4 \text{ ft/sec or } 29.3 \text{ mi/hr}$$

This best case velocity is intended to be used only as an upper limit, and to give perspective to the range of operating speeds. In actual use, to assure thorough scanning, an operating speed range of 4 to 10 mi/hr could be established.

Visual Indication of Hot Insulator

As an additional aid in marking a hot spot, and to reduce "stop-time" during the scanning inspection, an electromechanical device could be attached to the scanning vehicle. It would be triggered by the signal of the alarm, putting a spot of paint on the rail near the point in question (see Figure 7). In this way, a trailing maintenance crew could locate the faulty insulators (provided that the work was done before the paint marks were obscured).

What follows is an explanation of how the device would work, a breakdown of the components, and suggestions concerning component availability.

Components and Operation

The primary components are as shown in Figure 8. Basically, it consists of a relay, a solenoid, an actuator bar and a can of spray paint, all mounted on a board. Because the signal from the Fire Finder is too weak to drive the circuitry on its own, a switching transistor, sensitive to the weak incoming signal, is used to trip the relay. The relay triggers the solenoid, which is powered by its own battery. The solenoid, by pulling on the actuator bar, depresses the spray can nozzle, thus applying the paint.

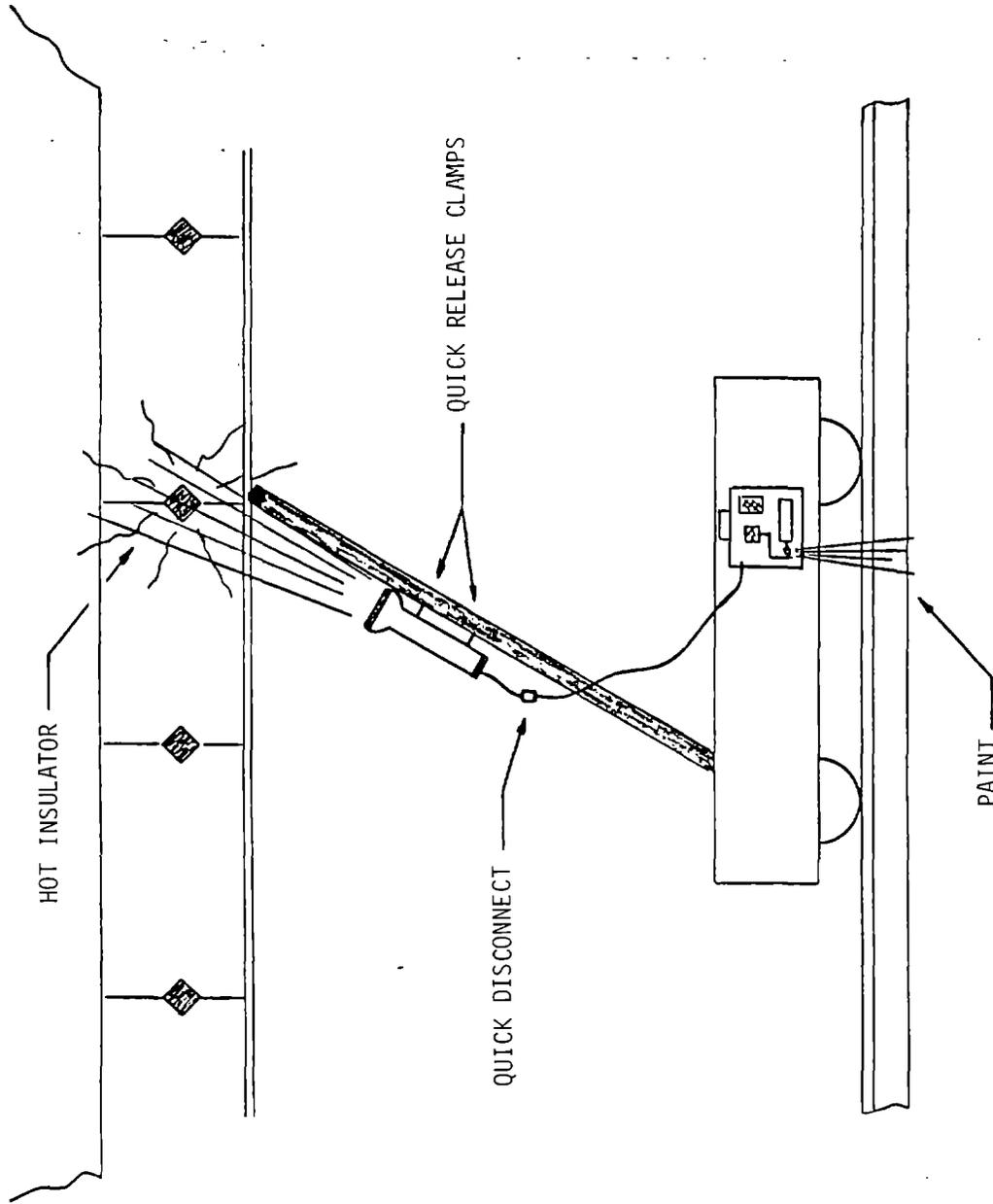
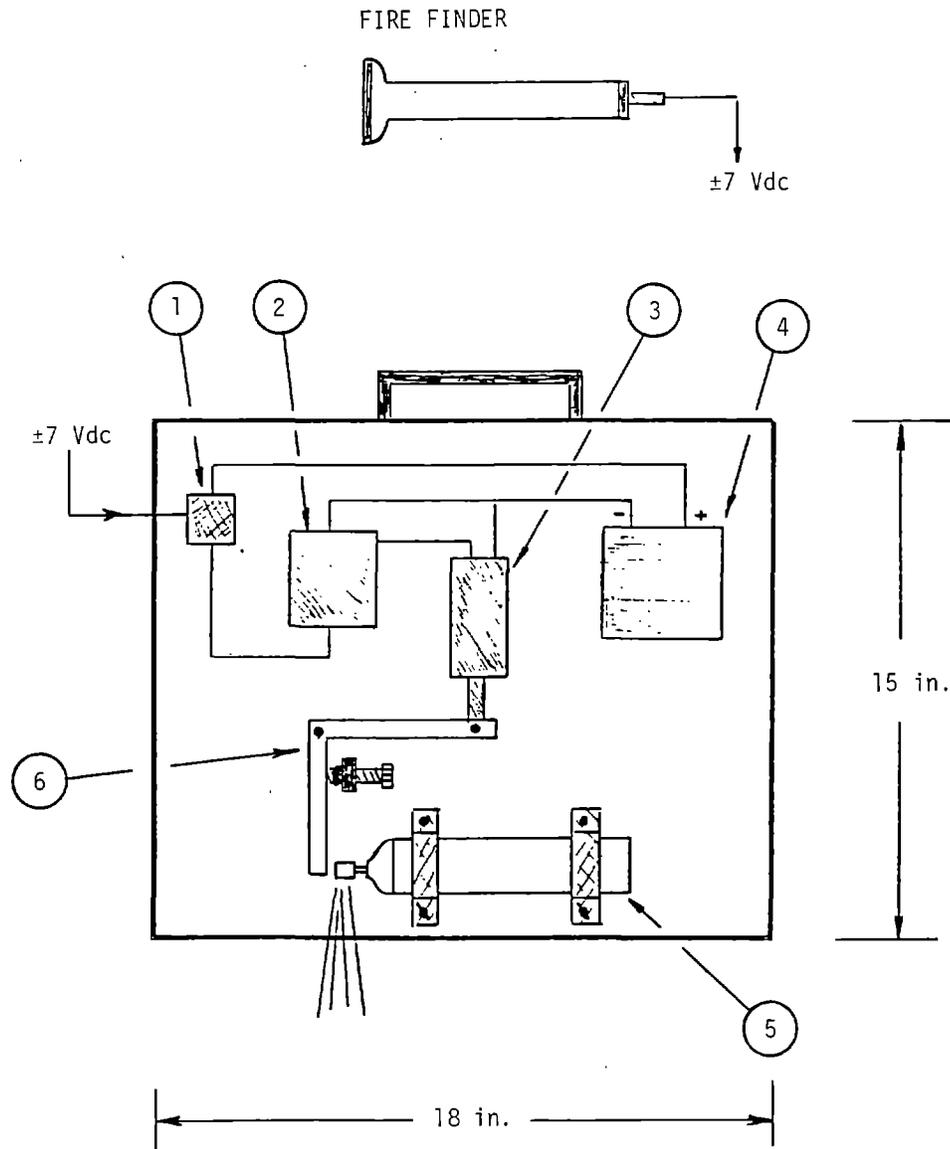


FIGURE 7. - Faulty insulator marking.



LEGEND:

1. SWITCHING TRANSISTOR
2. RELAY
3. SOLENOID
4. BATTERY
5. SPRAY PAINT CAN
6. ACTUATOR BAR AND LIMITER

FIGURE 8. - Schematic of paint marker.

Some components that may be used for this device are listed below:

- a. Relay - 12 Vdc, DPDT contacts, plugs into tube socket for easy exchange, approximately 110 mA current draw.
- b. Solenoid - 12 Vdc, 80 oz pull force at 1/8-in. stroke, less than 1A current draw.
- c. Battery - 12 Vdc, 4.5 Ahr rating.

Remaining hardware, consisting of a switching transistor, actuator bar, actuator limiter, paint can mounting brackets and circuit wiring, could all be compactly mounted onto a wooden board complete with handle for ease of carrying. The board itself could then be quickly attached to the side of a mine vehicle.

As shown in Figure 7, the infrared detector could be mounted with quick release clamps and quick disconnect wiring so that the operator, if it became necessary, could remove the Fire Finder to make a more thorough inspection of the area for hot spots not directly overhead.

This device is intended to designate a general area of trouble due to faulty insulators rather than to identify precisely which insulator is bad. Because the paint marking device is fixed, while the trolley pole orientation changes, the paint spot will not always be directly below the faulty insulator, but will be in the vicinity.

3.3 Conclusions and Recommendations

Table 2 compares some specifications of the portable hand-held units and the units suitable for permanent vehicle mounting. Either type, hand-held or vehicle-mounted, could be used for locating faulty insulators on trolley lines. The hand-held units are presently used in similar applications. The units suitable for vehicle mounting are used primarily in manufacturing processes where the unit is held stationary and the material or object being measured is moving. Vehicle mounting of those infrared thermometer devices presents alignment problems. If a ΔT or absolute temperature of an object is to be measured, then the device must be aligned such that insulators remain in, and preferably fill, the field of view long enough to give a ΔT or absolute temperature. If the unit is only required to warn the operator of a "hot spot" by sounding an alarm or flashing a light, then alignment is less critical since the unit has only to detect a temperature rise above ambient.

TABLE 2. - Infrared detectors

Device	Temperature range	Target size at range	Response time (sec)	Type of display	Power source	Weight (lb)	Mounting	Price
WALL DLS-14X	0° to 400°F Target 10° to 100°F (Ambient)	1.6 in. diam at 7 ft 6 in. diam at 10 ft 1.2 in. diam at 20 ft	1	Digital (L.C.)	Battery 4 hr	3	Hand-held	1750
RAYTEK RANGIR R-140	0° to 200°F and 200° to 600°F Target Others Available	15:1 at 4 deg 6 in. to "	2	Digital	Mercury Batteries (2)	2	Hand-held	860
WALL	40° to 140°F Target (0° to 100°F) (Ambient)	1.6 in. diam at 7 ft 6 in. diam at 10 ft 12 in. diam at 20 ft	1	Digital (L.C.)	Battery 4 hr	3-1/2	Hand-held	1895
RAYTEK RANGIR R-38	60° to 250°F or 20° to 120°F Target Others Available	15:1 at 4 deg 6 in. to "	2	Analog	Mercury Batteries (2)	3	Hand-held	660
MILRON* Model 15	-20° to 350°F -20° to 200°C Target (0° to 120°F) (Ambient)	<2 deg beam 1 in. to 5 1.6 in. at 7 ft 0.3 in. at 10 ft 16.0 in. at 20 ft	1	Analog	Battery 1000 hr	1 3/4	Hand-held	1010
HUGHES** MODEL 645	to 200°F 200° to 1500°F Reps. Filter	18 deg horizontal 7.5 deg vertical 0 ft to "	Instantaneous	Visible Infrared display	Battery Action Cyl. Lasts 4 hr.	7-1/4	Hand held (100 million)	7500

* Intrinsically safe.
1 to 20 in. range standard
Others optional
** NSA Approved
Approval No. 26-1847

TABLE 2. - Infrared detectors (continued)

Device	Temperature range	Target size at range	Response time (sec)	Type of display	Power source	Weight (lb)	Mounting	\$
WALL 115A 170	200 to 600° Target 10° to 100° (Ambient) ...	10 deg at 0 to 3 ft, Standard 0 to 20 ft optional	1	Analog	Battery 4 hr	2	Hand-held	1395
DYN-OPTICS, INC. "FIRE FINDER" MODEL 955	> 160°F	1 ft ² at 20 ft	0.1	Audio Alarm	Battery (2 to 9 Vdc) Dry Cells	1.2	Hand-held	529
FARNES THERMATRACE 12-750	10°C, 30°C, 100°C, 300°C 1000°C	TR 24 deg 4.3 in. at 10 ft 8.5 in. at 20 ft 32.5 in. at 50 ft	Instantaneous. 1/4 deg > 1/2 deg ft	Visible Display and "A" Trace	Battery 4 hr Rechargeable or etc	9	Hand held	-
RAYTEK IC-814A	30° to 300°F 0° to 150°C	15:1 at 4 deg 12 in. to ∞	1	Digital Analog (Remote)	115/230 Vac 24 Vac	-	Permanent	-
LAND ORL 15/2/1	0° to 600°F 0° to 300°F	2.4 in. at 3 in. 4.7 in. at 6 in. 5.6 in. at 9 in. 7.2 in. at 12 in. 10.2 in. at 18 in. 13.2 in. at 24 in.	2	Recorder (Remote)	115/230 Vac	-	Permanent	-
FARNES "THERMAL MASTER" TT-900	Down to 32°F Ambient to 150°F	1 deg or 0.5 deg	-	Digital (Remote)		-	Permanent	-

Permanently mounting an infrared thermometer unit on a vehicle does not offer a clear advantage over the use of hand-held units. Vehicle-mounted units offer unwarranted complexity both in operation and maintenance. Use of the device is also then limited to one function: that of scanning trolley lines.

The hand-held units are designed specifically to be used under conditions similar to present mining usage. They are rugged, compact, and lightweight. If proper temperature ranges are selected, the hand-held unit can be used in and around a mine to aid in trouble-shooting equipment problems and in regular maintenance. One clear advantage of the hand-held units is quick calibration check by aiming at an object of known temperature. The hand-held units also ensure that the operator is actually scanning what he wants to scan since he must aim the unit at the object he wishes to measure. With a vehicle-mounted detector, a maintenance crew might scan an entire section of trolley line not knowing that the unit was misaligned.

4. DUAL-WIRE TROLLEY SYSTEM

Use of dual-wire trolley systems in underground coal mines has been discussed for many years. The principal advantages of such a system would be:

- a. Decreased risk of fire due to high current faults which fail to trip protective devices. These faults occur with roof falls, grounded equipment frames contacting the wire, faulty insulators, etc.
- b. Decreased risk of electrocution or serious shock due to inadvertent contact with bare energized wire. Those most exposed to such hazards are motormen and trip-riders whose work requires proximity to unguarded trolley wire
- c. Improved ground fault detection and protective action
- d. Elimination of stray ground currents in the mine. These currents, in addition to creating obvious hazards where blasting caps and powder are used, can affect the operation of ground fault detectors on other equipment, particularly ac conveyor belt drives
- e. Elimination of rail return. In addition to drastically reducing stray ground currents, this advantage also eliminates need for (and reliance upon) rail bonding.

A variety of electrical configurations meets the technical demands of a dual-wire system. The FMA project staff selected three configurations for detailed consideration. In evaluating the three configurations, the staff weighed effectiveness in providing the advantages cited above, practicality of construction, and vulnerability of system safeguards to select the "best" electrical configuration.

Problems not solved by choice of the electrical system were addressed in the mechanical design of the system's components.

4.1 Selection of Electrical Configuration

The three electrical configurations chosen for evaluation are shown in Figure 9.

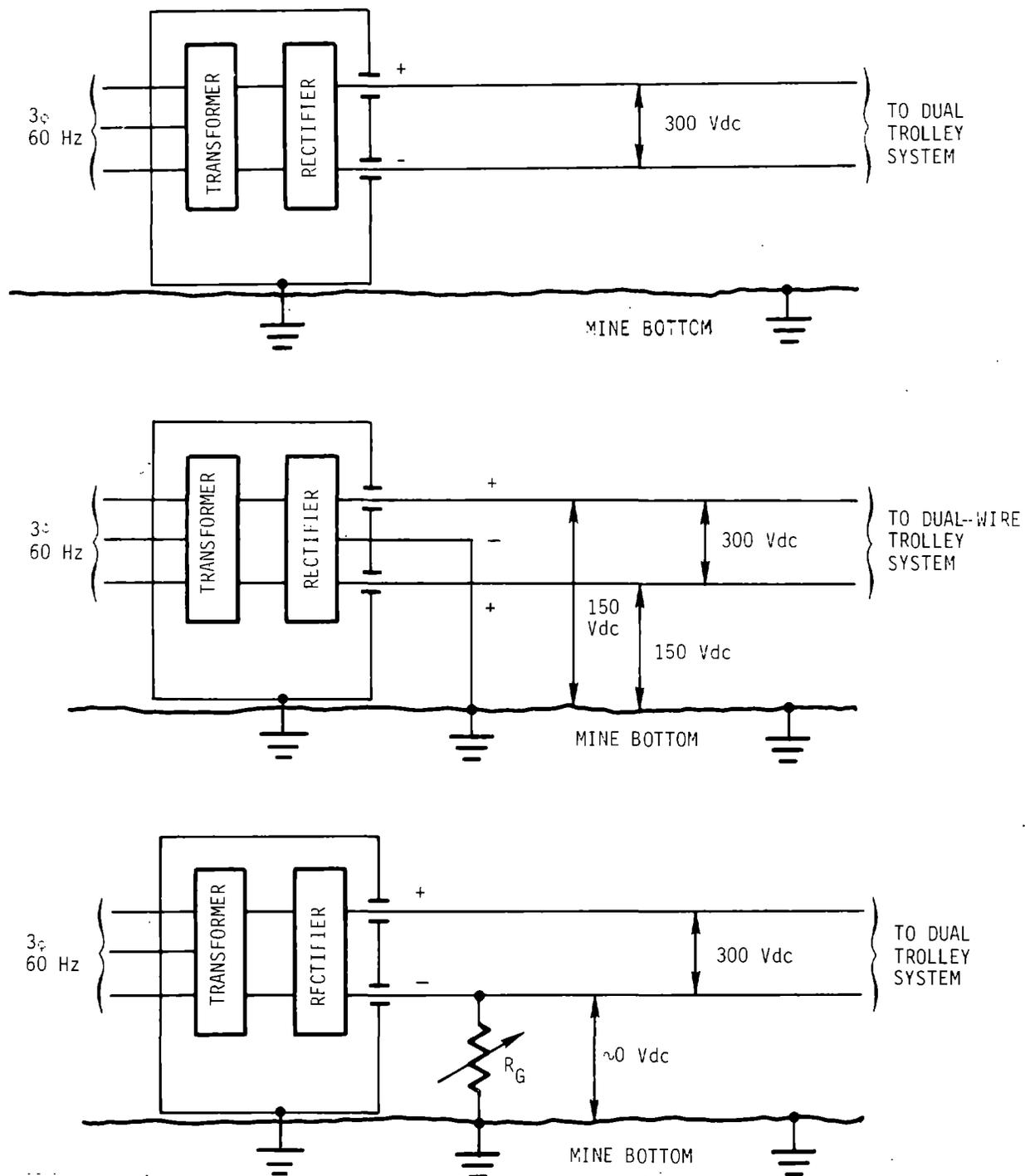


FIGURE 9. - Three possible electrical configurations for a dual-wire system.

All three systems eliminate the need for rail bonding and virtually eliminate stray ground currents. Their effectiveness in providing the other advantages of a dual-wire system is discussed in the following subsections.

4.1.1 Advantage No. 1 - Decreased Risk of Fire Due to High Current Faults

The advantage for the three systems is as follows:

- a. *System 1* - This system provides protection from high current faults if either conductor is contacted separately. However, if both conductors are contacted simultaneously (for example, by equipment frames, falling on the rail, etc.) high currents could flow, especially if the faulting material were grounded and ground fault detection devices were bypassed. The likelihood of simultaneous faults occurring would depend upon several factors, most notably wire spacing and shielding. If existing hardware were used to construct such a system (see Figure 10) such simultaneous faults would probably occur.
 - b. *System 2* - The voltage from either conductor to ground, in this system is high enough (150 Vdc) to deliver enough current to pose a fire hazard. However, this fault current should be easily detected in the ground wire at the rectifier, and power removed quickly. Simultaneous faults would also be a problem for System 2.
 - c. *System 3* - The return conductor is virtually at ground potential and should offer no fire hazard if faulted. The positive conductor could deliver current to ground, but this current would be limited by R_G (in the milliamp range). This fault could also be detected by monitoring current through or voltage across R_G . Simultaneous faults would again present a serious hazard should they occur.
-

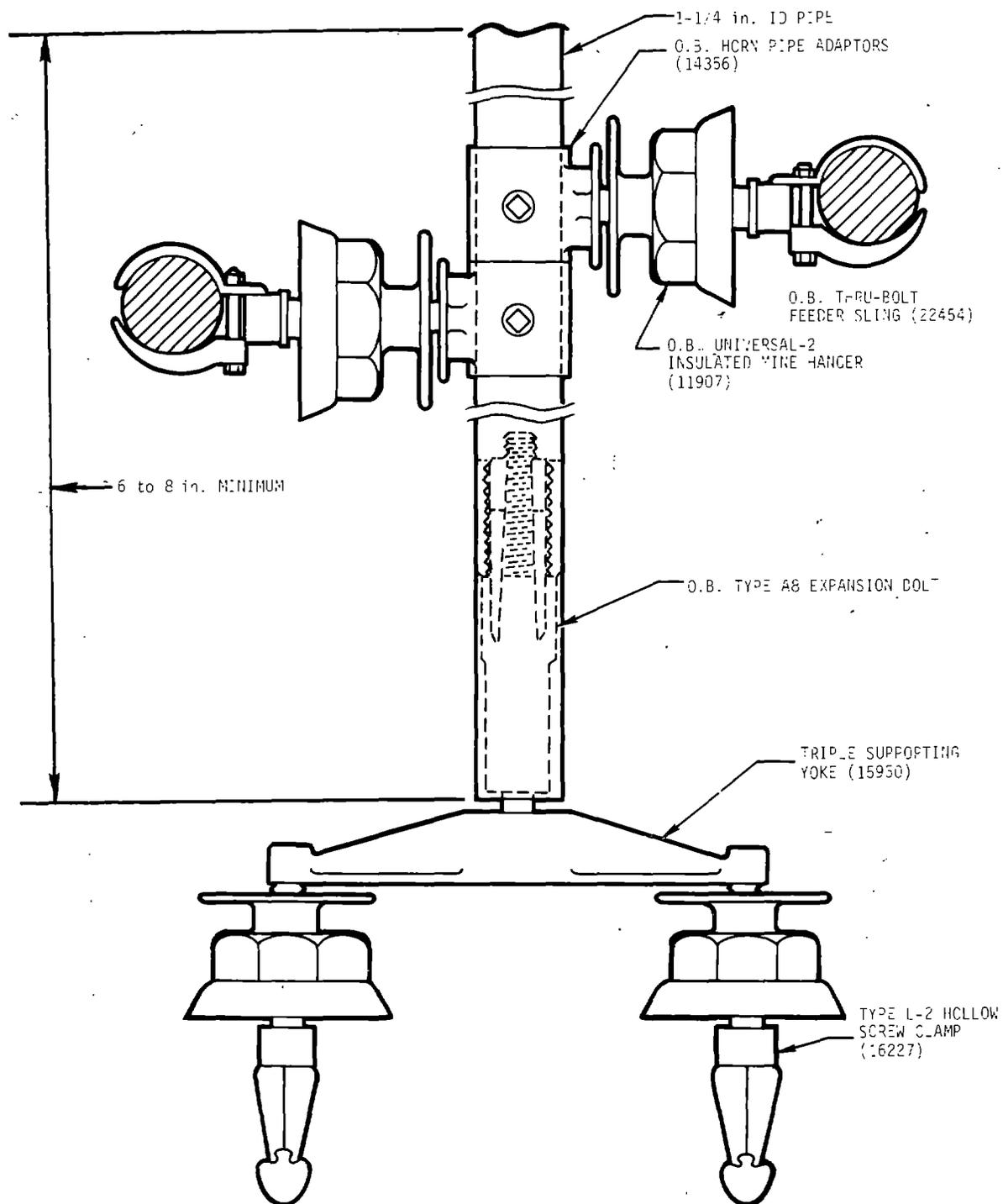


FIGURE 10. - A possible dual-wire system currently available.

All three systems offer fire hazard protection for single-conductor ground faults, but none offers inherent protection from high currents in the event of simultaneous faults.* Construction using existing hardware does not seem to offer any additional protection from this hazard. Therefore, this problem should be addressed in the mechanical design of the system components.

4.1.2 Advantage No. 2 - Decreased Risk of Electrocution or Serious Shock

- a. *System 1* - The shock hazard from each conductor will be quite low if the conductors are perfectly isolated from ground. However, if isolation is not perfect, significant shock hazard may be associated with either conductor. "Good" insulators, of the type used with existing single-wire systems, may allow small currents to flow to ground when their surfaces are contaminated with dust and moisture. The magnitude of these "leakage" currents depends upon the resistance to ground of the insulator. The leakage resistance of several contaminated insulators was measured using a 300 Vdc bridge circuit and found to be on the order of 1 M Ω . Many of these insulators in parallel could result in an equivalent leakage resistance for the system of only a few thousand ohms (see Appendix C). The equivalent circuit is shown in Figure 11. The shock hazard would change

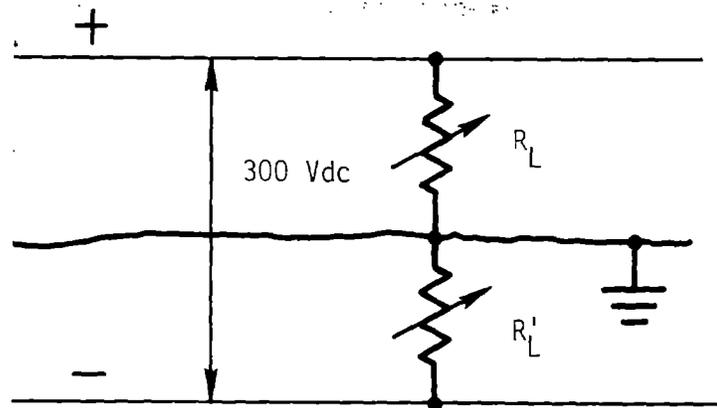


FIGURE 11. - Equivalent circuit - System 1.

*This result should not be too surprising. Ground faults in existing single-wire systems are positive-return faults because the ground (earth) is the return. In a dual-wire system, the return is simply relocated from the ground (earth) to a conductor which is usually envisioned as being in proximity to the positive conductor. The likelihood of positive-return (simultaneous) faults under these conditions may be greater than it was with the single-wire system.

with variations in leakage resistances, R_L and R_L' (see Appendix D). Shock hazard under these conditions would be serious since miners might mistakenly assume that it was "safe" to touch one of the wires. (A miner contacting both conductors would be subject to severe shock regardless of the system used.)

- b. *System 2* - This system offers a reduced (150 rather than 300 Vdc) but still potentially lethal shock hazard to ground when compared to the present single-wire systems. This would reduce the severity of single-wire shocks but hazards of dual-wire shocks would increase. It is unlikely that ground fault detectors could be made sensitive enough to protect a miner from this shock hazard. The isolation problem, as described above under System 1, would not exist with this system, although poor isolation would probably interfere with low level ground fault detection.
- c. *System 3* - The third system would offer no shock hazard from the return conductor, which should be virtually at ground potential. The positive conductor would be at 300 Vdc, but ground fault current through a miner would be limited by R_G . If R_G is kept high (several thousand ohms), shock currents could be limited to less severe levels. Isolation of the return wire must be maintained at a high level in order not to provide alternate paths for the flow of fault current. This level of isolation would be difficult to obtain with existing hardware. However, it should be possible to design a suitable conductor/insulation system. A simple circuit to monitor the return wire and assure isolation is described in the next subsection.

This analysis once again points to the importance of guarding against simultaneous contact of both conductors. In addition, a high degree of isolation is desirable in each system. As noted earlier, these problems will be addressed in the mechanical design of the system.

4.1.3 Advantage No. 3 - Improved Ground Fault Detection

This advantage, for the three systems, is as follows:

- a. *System 1* - Ground fault detection in this system would be similar to that of an ungrounded three-phase ac system. Detection could be accomplished by monitoring the voltage between each conductor and ground. Grounding either conductor would produce no current flow (assuming a high degree of isolation). However, if

the second conductor is then grounded, high fault current would flow, just as if a simultaneous fault had occurred. Should the detector fail to remove power in the event of a fault (due to component failure or intentional misuse*), unexpected danger would be present along the entire length of the other conductor.

- b. *System 2* - This system offers a very simple ground fault detection system. Ground current can be monitored as it returns through the grounded center tap. However, depending upon the degree of isolation of the conductors, a "normal" current flow may exist and decrease the sensitivity of the system. Voltage fluctuations due to jarring loads would also serve to prevent low level (or fast) fault detection and power removal.
- c. *System 3* - Ground fault detection for the positive conductor in System 3 could be accomplished by monitoring current and/or voltage at resistor R_G . Fault current would also be limited by the value of R_G . This ground fault detection system depends upon a high degree of isolation of the return conductor, as previously noted. A simple circuit to monitor the return conductor could be added to assure isolation. Referring to Figure 12, a constant voltage source is used to drive a reference current, I , through R_G . The voltage across R_G , V_{RG} , can be used as a reference voltage to detect ground faults on either conductor. A ground fault on the positive conductor would increase V_{RG} , while a ground fault on the return conductor would decrease V_{RG} . Circuit protective devices can be opened when variations in V_{RG} are detected.

4.1.4 Summary

As mentioned above, the mechanical design of the dual-wire system will address the problems of adequate isolation and simultaneous faults. Based on the analysis briefly summarized above, System 3 was chosen as the most desirable alternative. However, it should be noted that the dual-wire system components presented in the next subsection will work with any of the systems. In

*When it was discovered that in the event of a single fault, power could be restored without any flow of fault current the temptation would be great to disable the ground fault detector and resume operations while the fault was being located.

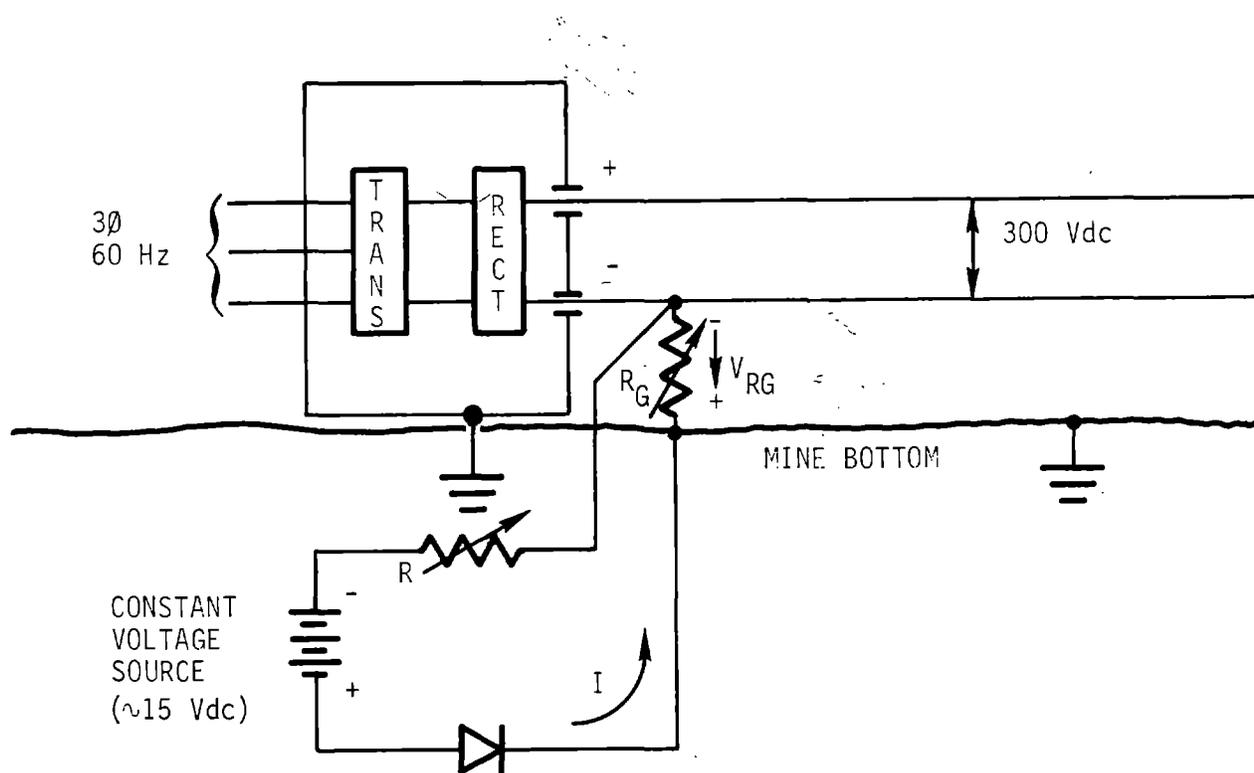


FIGURE 12. - Ground fault detection - System 3.

addition, modifying the electrical system of a prototype installation in order to evaluate each system should not be difficult.* Such testing would certainly be necessary in order to choose the best electrical arrangement for a particular mining situation.

4.2 Mechanical Design of the System

While a dual-wire trolley system could be fashioned from existing hardware,** several considerations favor design of new hardware. In addition to increased isolation and protection, as mentioned in subsection 4.1, these include:

*For that matter, "hybrid" systems - such as a high resistance, grounded center tap, power supply - could also be evaluated in a test installation.

**One such system was employed in conjunction with rubber-tired shuttle cars in a potash mine in New Mexico. See Bird, Howard J., "Electrical Power Distribution System, Potash Mine and Refinery," Duval Sulphur and Potash Co., Carlsbad, NM, U.S. Department of the Interior, U.S. Bureau of Mines Information Circular 7917, Washington, DC, 1959.

- a. Spatial considerations
- b. Simplification of installation and maintenance
- c. Ease of manufacture
- d. Lower costs.

The system described below features a proposed insulator/hanger with enclosed conductors, a proposed dual-shoe pole top, provision for modifying vehicles to accommodate polarity changes, and a proposed transfer mechanism that may offer an alternative to frogs. An installed system is pictured in Figure 13. The transfer mechanism consists of a transfer arm or cam (mounted to adjacent hangers at a turnout), a follower arm (mounted on the back of the pole-top collector), and a flexible drive shaft and gearbox used to rotate the follower arm to right turn, left turn, and rest positions. Detailed operation is described in subsection 4.2.3. It should be noted that other means of transferring the collector to adjacent wires may be more desirable (for example, frogs or manual transfer). The mechanism described here is offered only as a possible alternative to these more conventional means.

4.2.1 Insulator/Hanger

Design criteria for the insulator/hanger were:

- a. Compactness
- b. Preset conductor spacing
- c. No exposed energized parts
- d. Long leakage paths
- e. Ease of installation and maintenance
- f. Simplicity from a manufacturing perspective.

The insulator/hanger assembly is shown in Figure 14a and b. It is made of insulating material and is designed to accept two insulated feeder cables and two totally shielded trolley wires (in this case, the United States Safety Trolley Span-Guard described in subsection 2.1). Completely insulated conductors allow for compact spacing, increased isolation, and provide protection against simultaneous faults. Although the system is essentially double-insulated, insulation failure detectors were designed (in conjunction with other parts of this program). They attach to the insulator by means of "banana" plugs and can be easily removed for repair or left out if deemed unnecessary. These indicators are described in subsection 5.3.

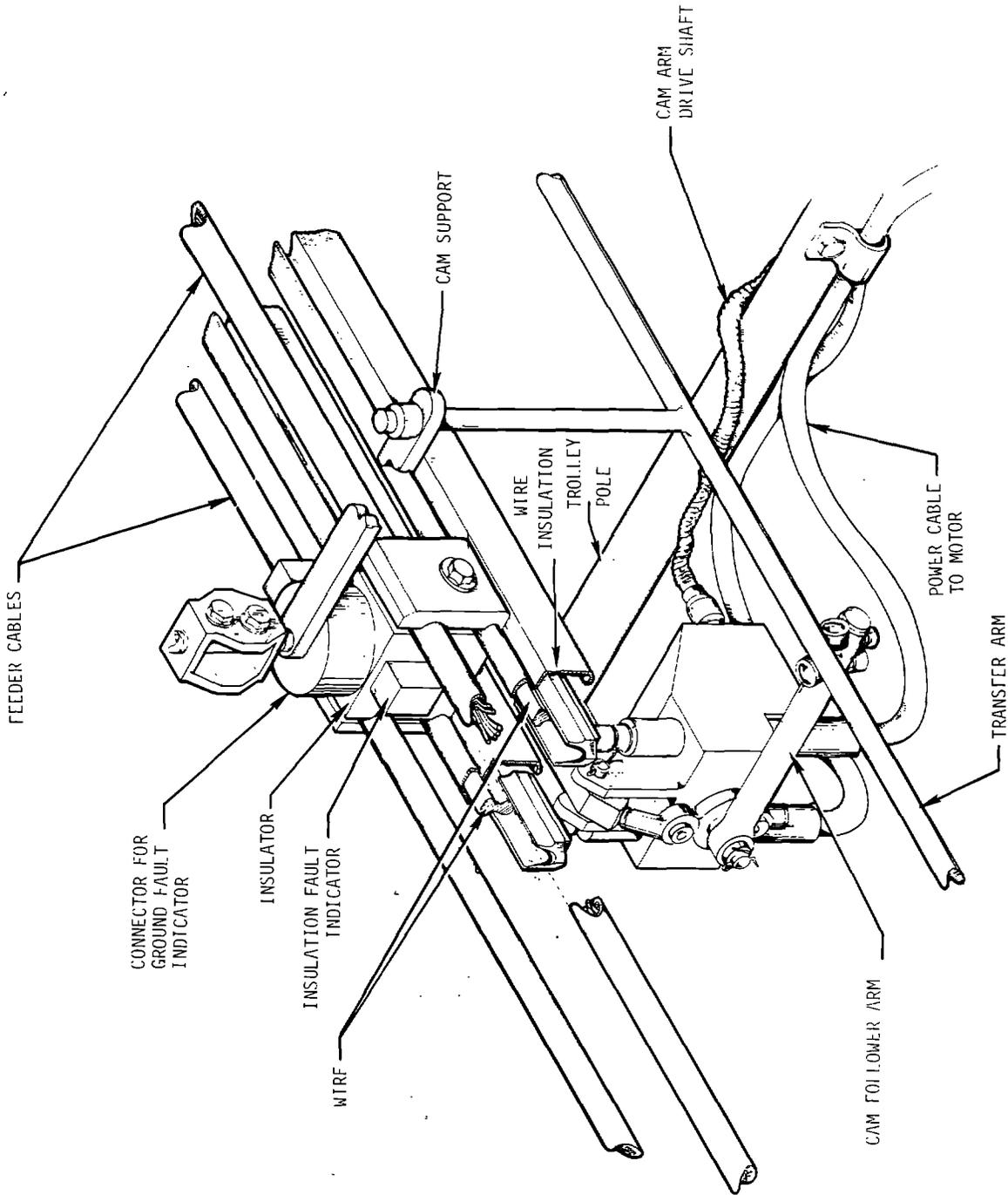


FIGURE 13. - Dual-wire mechanical pictorial.

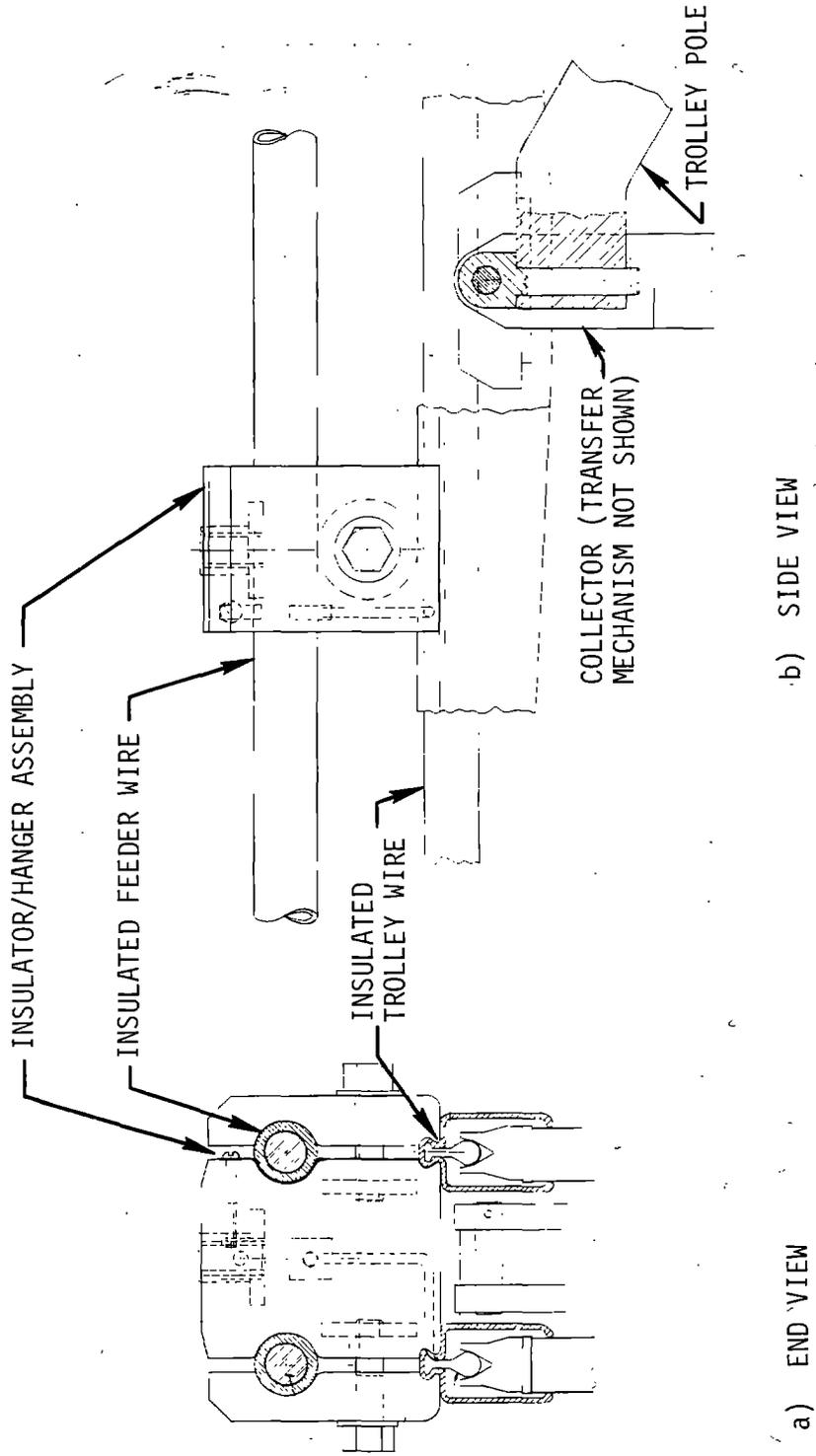


FIGURE 14. - Insulator/hanger assembly.

Current does not flow from the feeder wire to the trolley wire at each hanger. The hanger is composed of, and both wires are covered with, insulating material. Separate electrical connections between the wires must be made at appropriate intervals.

The next step in the development of the insulator/hanger would be prototype modeling to select materials and optimize dimensions.

4.2.2 Dual-Shoe Harp

A proposed design for a dual-shoe harp is shown in Figure 15. The shoes are spring-loaded to assure good wire contact. Vertical and horizontal pivots and an axis of rotation in the same plane as the bottom of the trolley wire assure smooth operation. Prototype construction and testing would be necessary to refine the dynamics of this design.

Attached to the harp are a gearbox and transfer arm. They are components of a proposed transfer mechanism described in the following subsection.

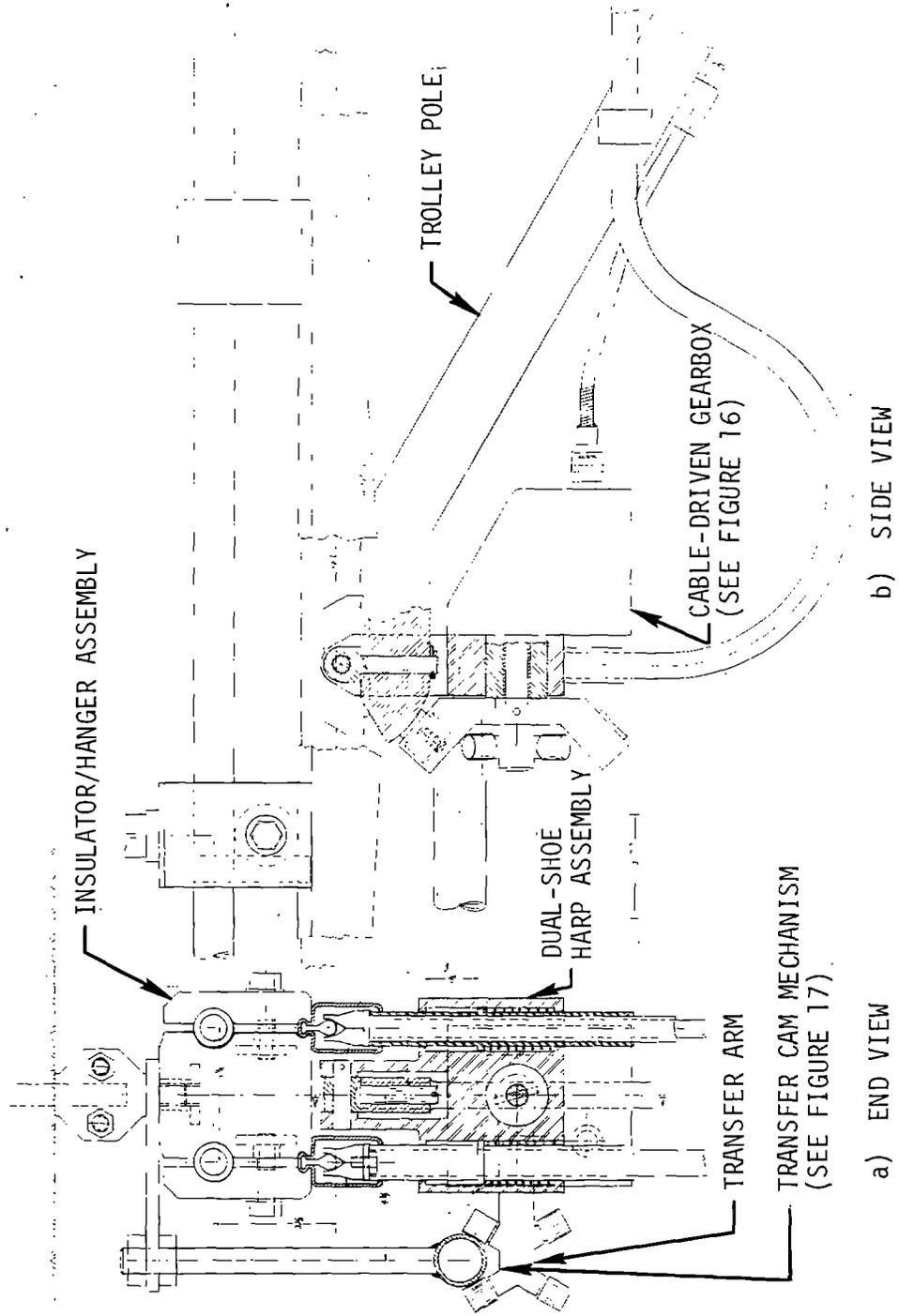
4.2.3 Transfer Mechanism

In a single-wire system, the transfer of the trolley pole from one wire to another is accomplished by either manual movement or with trolley wire frogs. In a dual-wire system, problems develop with the manual method.* Dual-wire frogs are available, but are generally designed with a much larger horizontal spacing in mind than is available in an underground mine. Development of a dual-wire frog to match the spacing of the system presented in this section is possible and may be the best solution. However, a concept is proposed as an alternative and is briefly described below.

The proposed system employs a long cam along the travel direction to guide the dual-shoe harp off the straight wire and onto the turn-out wire. Figure 15 shows the components of the transfer mechanism in relation to the other parts of the dual-shoe harp. Figure 16 shows the cable-driven gearbox and Figure 17 depicts the linear stages of the transfer by showing the cam in plan and elevation views.

To effect a transfer, the operator rotates the transfer arm from its rest position at the rear of the gearbox into its locked, horizontal position. Rollers on the transfer arm engage the

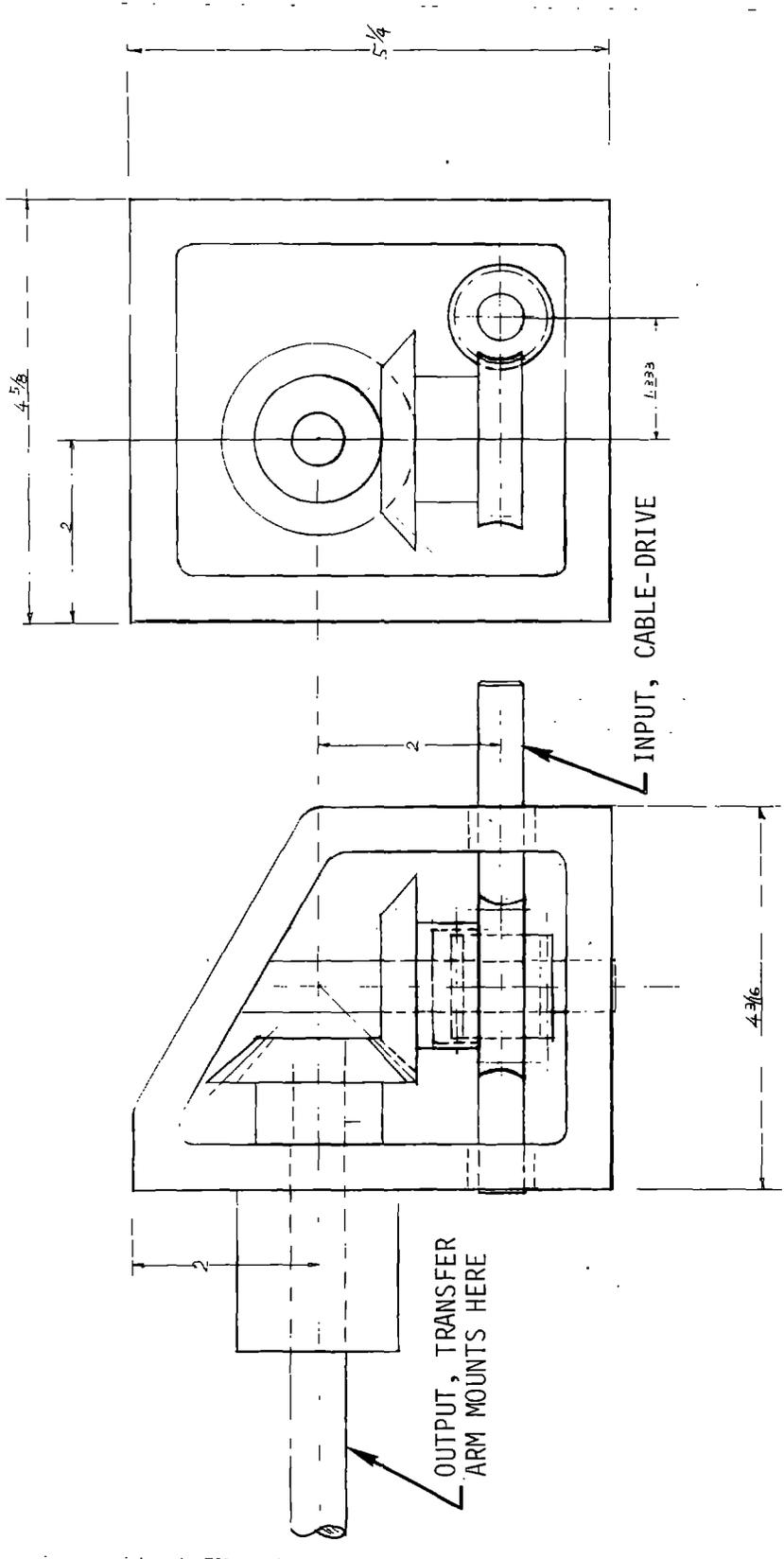
*Alignment of the shoes with both wires, especially in a shielded wire system, might be a difficult task to perform manually.



b) SIDE VIEW

a) END VIEW

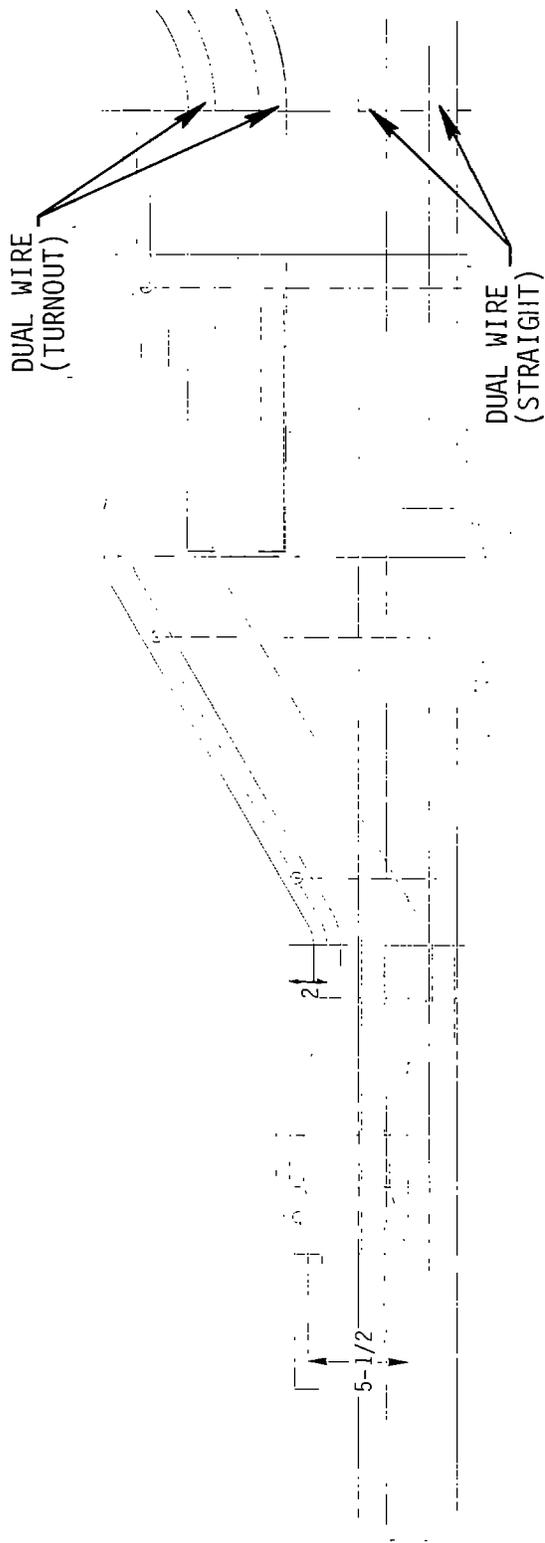
FIGURE 15. - Dual-shoe harp assembly.



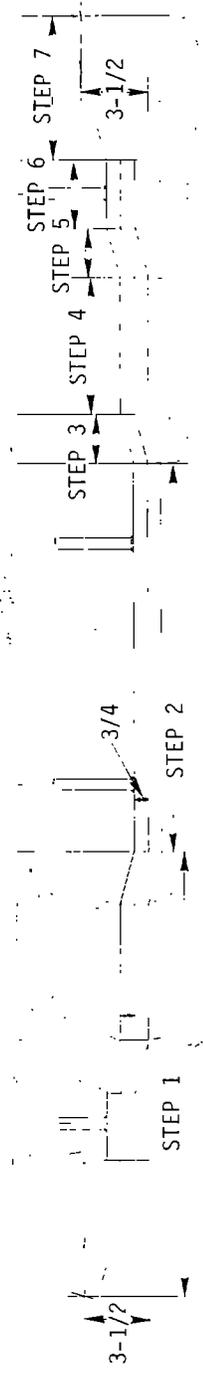
a) SIDE VIEW

b) FRONT VIEW

FIGURE 16. - Cable-driven gearbox.



a) TOP (PLAN) VIEW



b) SIDE (ELEVATION) VIEW

FIGURE 17. - Linear stages of transfer mechanism.

cam, which guides the dual harp from the straight wire onto the turnout wire. The cam forces the harp down from the straight wire, transfers the harp horizontally to underneath the turnout wire and guides the harp up through the insulation shield onto the turnout wire. When the transfer is complete, the operator restores the transfer arm to its rest position.

4.2.4 Polarity Reversal

Problems associated with polarity reversal could occur in a dual-wire system at turnouts and dead ends. Reliance on manual or mechanical systems to correct polarity reversal is unacceptable. Consequently, a bridge rectifier installed on the power input terminals of each vehicle would be necessary (Figure 18). With this system, either polarity dc (or even ac) may be used. Vehicle controls will always work conventionally.

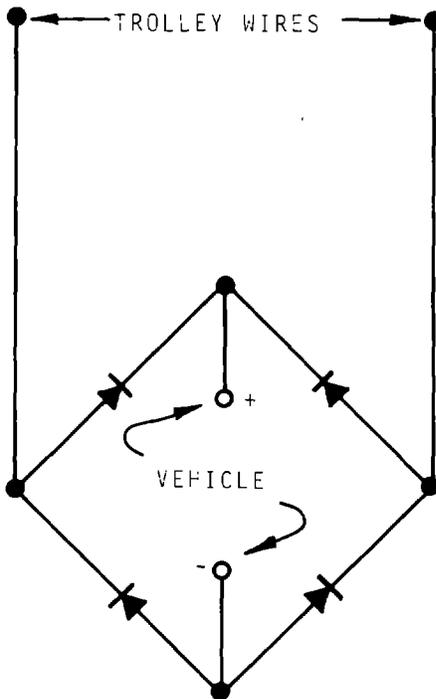


FIGURE 18. - Bridge rectifier for polarity reversing.

4.3 Conclusions and Recommendations

The proposed dual-wire system, if developed, would offer many advantages over presently used single-wire systems. It is recommended that additional study of these concepts begin with prototype development and testing in actual or simulated mine conditions..

Some additional points of importance that emerged from this study are:

- Simple dual-wire systems, such as might result from retrofitting an existing system with a separate return conductor using existing hardware, do not offer as many advantages as was originally assumed.
- Interest in dual-wire systems among mine operators and equipment manufacturers is low to nonexistent.
- Any dual-wire system will be much more complex than present systems and will require more expense and expertise in installation, maintenance, and operation.

5. INSULATOR FAULT INDICATORS

Faulty insulators increase the risk of fire in underground haulageways. Two types of failure can occur:

- a. Sudden catastrophic failure leading to major faults or possible wire falls
- b. Gradual loss of insulation integrity due to dust and moisture contamination, cracking, or material degradation allowing the flow of leakage currents into the roof or surroundings. The heating and drying effect of this leakage current may lead to mine fires and/or roof falls.

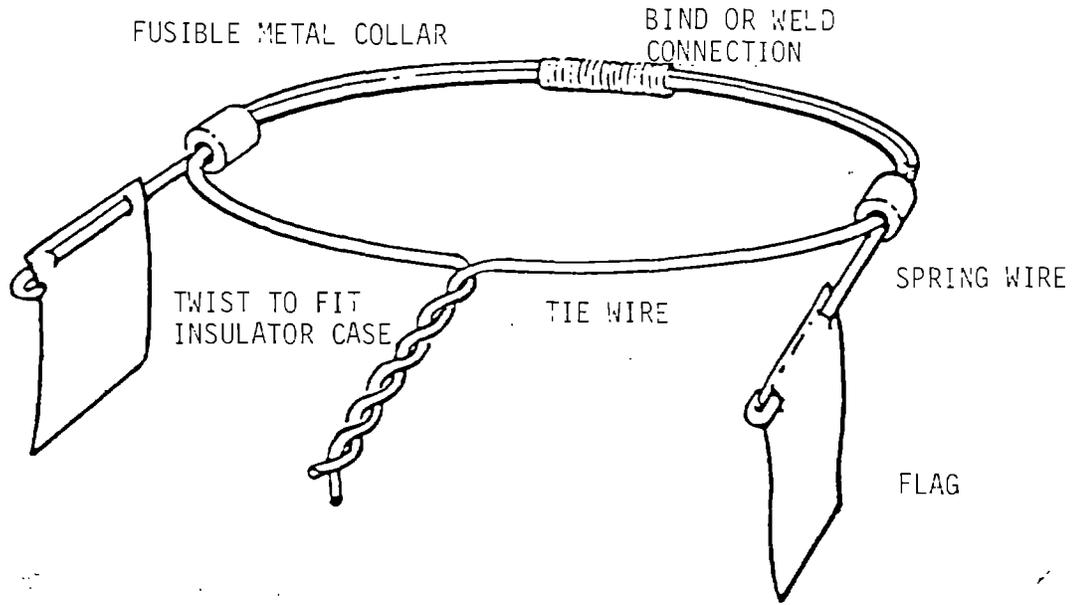
Development of insulator fault indicators was a major goal of this project and was addressed in two parts:

- a. Automatic detection and signaling by means of a vehicle-mounted scanner, as described in Section 3
- b. Indicator devices attached to hangers, as described in this section.

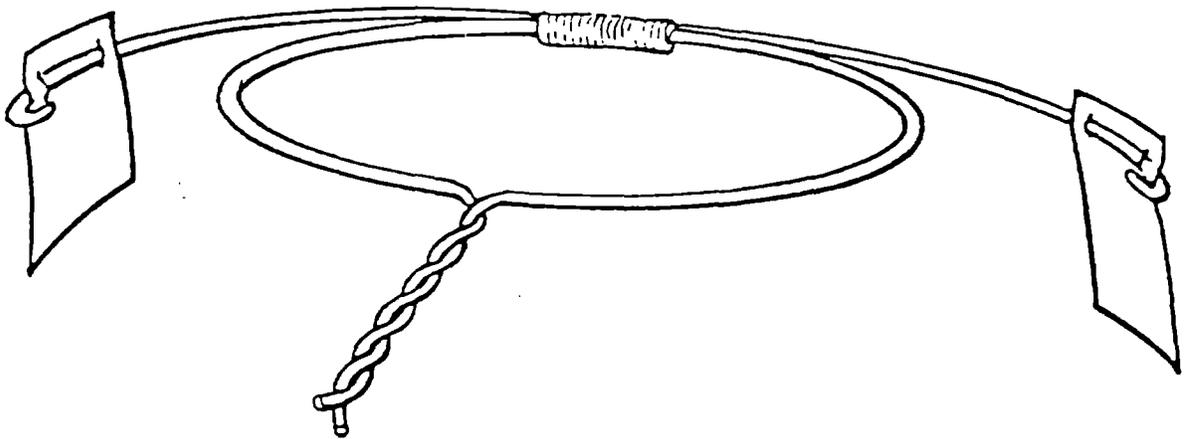
Research on this problem went through a number of stages, each of which yielded a device of increasing complexity. The simplest device, dubbed the "turkey popper," features visible flags that pop into view when a thermally overheated fuse melts; the "puck popper" in two variations provides electrically triggered indications (visible or audible) of a faulty insulator; and finally, the Insulation Failure Indicator, designed for use with the dual-wire trolley system described in Section 4, but adaptable to single-wire systems as well. Each design will have useful functions in appropriate settings.

5.1 Description of the Turkey Popper

This thermally activated device, shown in Figure 19, consists of two highly visible flags attached to a spring that is wired to the insulator. Fuses constructed of metal with a low melting temperature hold the spring to the retaining wire; when the insulator overheats, the fuses melt and the flags pop into view. Advantages of such a device are low cost of production and ease of installation - a simple pair of pliers is all that is required for installation.



a) TURKEY POPPER AS INSTALLED AROUND BODY OF INSULATOR



b) TURKEY POPPER OPEN AFTER ACTIVATION

FIGURE 19. - Turkey popper.

The problem with this approach is that when an insulator fails, the limiting resistance is not necessarily the insulator. It might be, for example, the resistance of the roof material. In this case, overheating occurs in the roof, possibly igniting coal, while the insulator body remains relatively cool with temperatures below those necessary to trigger the turkey popper. Other problems are that rapid failure of the insulator could lead to fire before the indicator is seen, and operation of the indicator does not act to interrupt the flow of leakage current.

5.2 Description of the Puck Popper

The puck popper was designed to be triggered electrically instead of thermally. As shown in Figure 20, the device consists of an insulating disk which mounts on top of the insulator. A hole in the side contains a fuse-retained spring and a highly visible flag. Excessive electrical current melts the fuse retaining the flag, permitting it to pop into view. Although this device is designed to work with existing insulators, the concept could probably be integrated into the design of the insulator itself.



FIGURE 20. - Puck popper installed on an insulator.

Some advantages of this concept are:

- a. Reacts to current flows and thus is independent of the location of the hot spot
- b. Indicates the failure, then acts as an insulator until a repair is made
- c. Indicates failure with geometry change, audio or visual indication, or any combination of the three
- d. Compatible with existing insulators
- e. Can be detected by a high-speed, vehicle-mounted detector.

Further development would be necessary to determine the best insulation and fuse material, proper spring tension, and appropriate current ratings.

5.3 Audio Version

To illustrate that the puck popper concept could be used with other types of indicators, an audio version was designed and modeled. Basically the same as a puck popper, the audio puck contains, instead of a spring and flag, a small solid-state tone generator that is activated in the event of current leakage. The tone could be detected audibly (in the absence of vehicle noise), or by electronic means in conjunction with a vehicle-mounted detector.

5.4 Description of the Insulation Failure Indicator

The Insulation Failure Indicator (Figure 21) was designed primarily for the dual-wire system hanger (see Section 4). It was designed to:

- a. Detect current leaking from the positive to the return conductor (indicating a break in the insulation of the trolley or feeder wires)
- b. Detect current leaking to ground (indicating a failure of the insulating capacity of the dual-wire hanger itself).

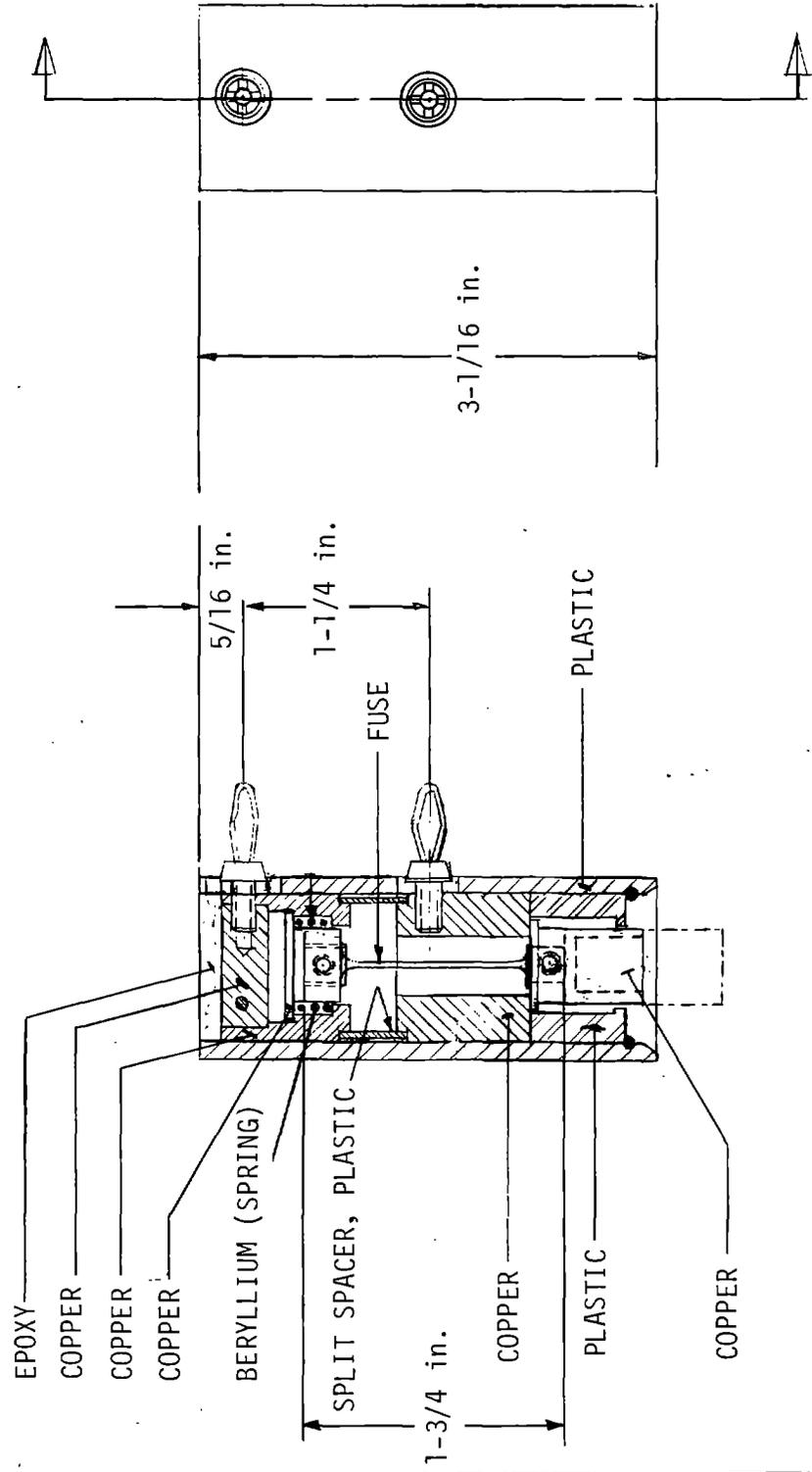


FIGURE 21. - Insulation failure indicator.

A failure of the second type would be detectable only after the occurrence of a failure of the first type.

The device consists of an outer case containing an electrically-activated, gravity-operated visible indicator. The assembly plugs into the dual-wire insulator using standard banana jacks.

As mentioned earlier in this report, these indicators are not necessary for the successful operation of the dual-wire system. In fact, due to the "double-insulated" nature of the dual-wire system and the increase in complexity that comes with the use of the indicators, the redundant protection they offer would probably be desirable in only the most unusual mining situations.

5.5 Adaptor

In order to allow the Insulation Failure Indicators to be used with single-wire systems and conventional trolley wire insulators, an adaptor was designed (see Figure 22). The adaptor is similar in design to the puck popper, but, instead of an indicator, is fitted with female plugs to accept the Insulation Failure Indicator.

5.6 Conclusions and Recommendations

The designs offered above represent relatively low-cost approaches to faulty insulator detection. Careful study of operating systems would identify characteristics contributing to insulation deterioration and failure. This knowledge might in turn lead to other equally effective devices. Absence of firm information and/or data providing an assessment of the seriousness of insulator failure limited this study. Without further study of the manner in which faulty insulators contribute to hazard conditions, it is difficult to make specific recommendations. Thus, while the FMA project staff believes the proposed designs meet program goals of detection, unanswered questions about the nature of the problem deserve consideration before such systems and devices become matters of policy.

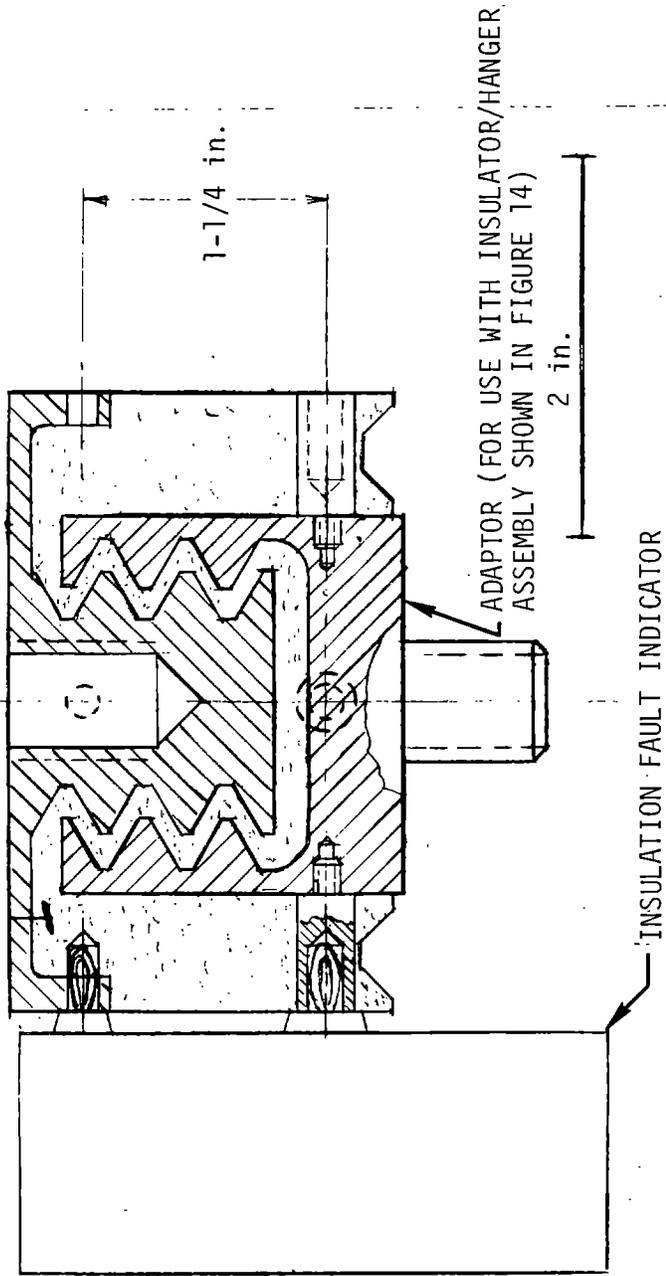


FIGURE 22. - Adaptor for insulation failure indicator.

6. SUMMARY OF CONCLUSIONS

6.1 Partially Insulated Trolley Wire

The project staff established criteria for insulated trolley wire, examined a number of commercially available systems and identified one that seems to hold promise for successful application. In addition, 10 methods for retrofitting or molding insulation to trolley wires were evaluated, and one was selected as offering the greatest number of potential advantages, based on the established criteria.

6.2 Scanning Systems for Insulator Fault Detection

FMA designed a system to mark the location of faulty insulators automatically. In this design, a commercially available infrared detection device is attached to a service vehicle trolley pole with the output connected to a system that releases a spray of bright paint at the faulty insulator location.

6.3 Dual-Wire Trolley System

The use of dual trolley systems in underground coal mines has been discussed for many years. The principal advantages are:

- a. Decreased risk of fire
- b. Decreased risk of electrocution and shock
- c. Improved ground fault detection
- d. Elimination of stray ground currents
- e. Elimination of rail return.

The project staff determined that a variety of electrical and mechanical configurations were possible. The approach taken here was to examine the most promising electrical configurations, evaluate them in light of their ability to provide the above advantages, and select the "best" one. Problems that could not be solved by choice of the electrical system were addressed in the mechanical design.* This design includes:

- a. Insulator/hanger
- b. Insulated conductors

*It was determined that use of existing hardware would not offer a satisfactory system; therefore, a new mechanical system was designed.

- c. A proposed dual-shoe pole top
- d. Provision for modifying vehicles to accommodate polarity change
- e. A proposed transfer mechanism that may offer an alternative to frogs.

Prototype testing would be necessary to further evaluate and improve the design and to establish applicability in particular mining situations. An artist's conception of the dual-wire system is shown in Figure 23.

6.4 Insulator Fault Indicators

This concept had four phases of development and yielded four fault detection systems, as described below:

- a. The first device, dubbed a turkey popper, is simply flagged wires held in place by a bond of low melting-point metal. At the critical temperature, the bond melts and highly visible flags pop into view. Because it was determined that leakage currents can cause heating in the insulator support rod or in the roof (points of high resistance) without heating the insulator (hence, the turkey popper), this design was set aside.
- b. The second detector uses an electrically-activated visible indicator. In this model is a thin disk of insulating material (called a puck popper) inserted between the top of the insulator and the hanger bolt. The disk contains a spring-mounted, highly visible indicator that is triggered by the flow of excessive leakage current across the insulator. In addition to providing a visual indication of an insulator fault, the disk acts as a backup insulator until the faulty insulator can be replaced.
- c. In a variation of b above, an audio alarm was built into the disk instead of the spring-mounted indicator. The tone resulting from current leakage can be detected audibly or electronically.
- d. As the insulator fault indicators and the dual-wire system were under development, it became apparent that fault indicators might be desirable in the dual-wire system

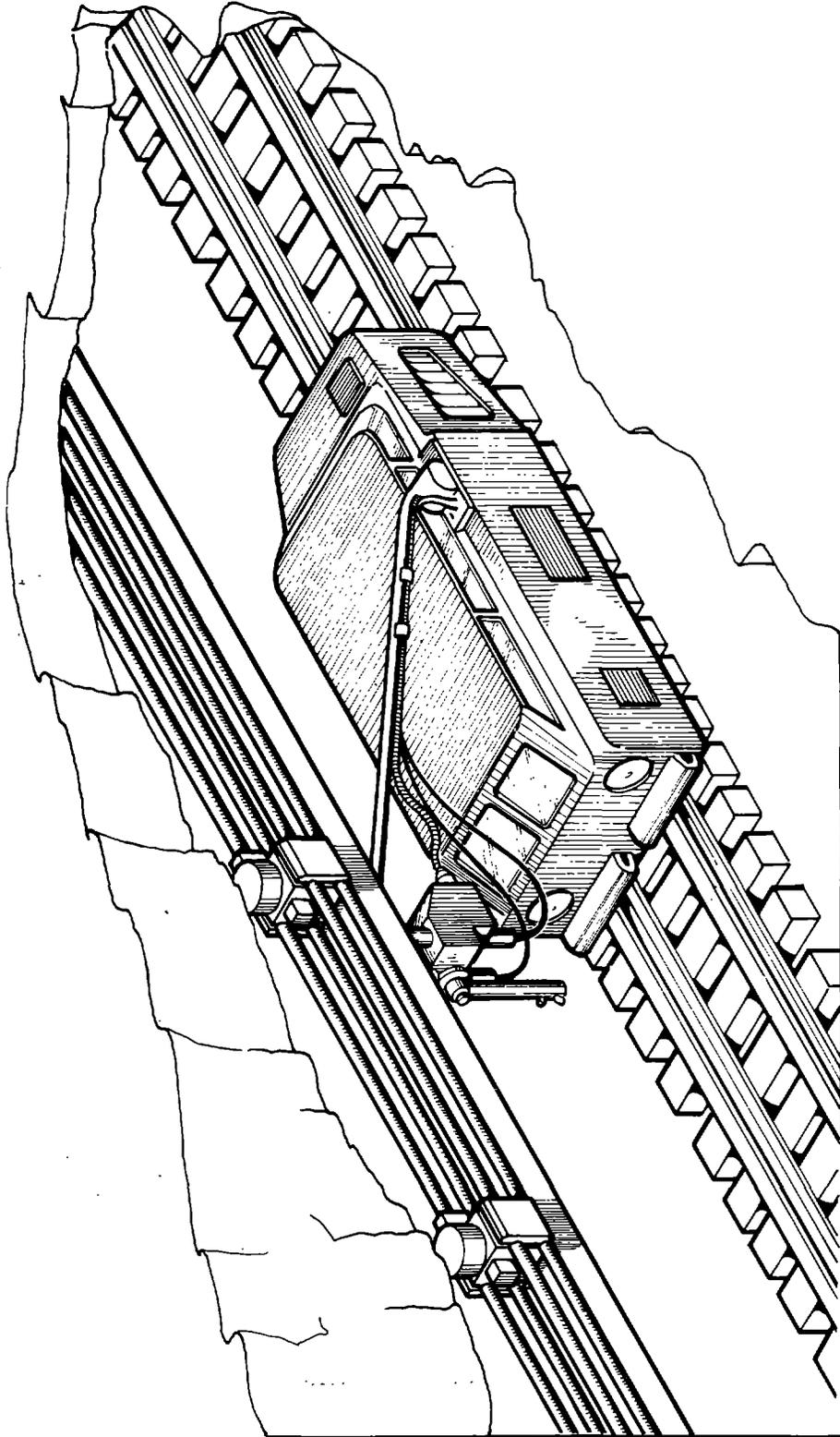


FIGURE 23. - Artist's conception of a dual-wire system.

to permit detection of insulation failure. As a result, the FMA project staff designed Insulation Failure Indicators (IFI) as accessories to the dual-wire system.

The indicators, which plug in to the dual-wire hanger, consist of a fuse link, which, when broken, allows a reflective indicator to drop into view. The IFIs are not necessary for successful operation of the dual-wire system.*

An adaptor was designed to allow the use of the IFI with single-wire systems and conventional insulators.

6.5 Assessment of the Future of Mine Trolley Wire Systems

An assessment of the future of trolley wire systems, based on a brief survey of mine operators and equipment manufacturers, indicates that the situation is basically static. No dramatic increases or decreases in the use of trolley wire systems is expected. Although belt haulage has replaced rail haulage in many mines, most of those contacted agreed that rail systems were still essential for transport of men and supplies. The implication is that massive change - in terms of introducing systems or retrofitting on a wide scale - is not as likely as it would be if trolley wire use were rapidly expanding. This situation could change depending upon unforeseen shifts in the mining industry (for example, toward increased underground production, the introduction of compelling regulations, or changes affecting the future use of battery vehicles, belt haulage, or diesel-powered vehicles).

6.6 Analysis of the Nature of Trolley Wire-Related Electrical Accidents

The FMA project staff acquired a variety of data reporting trolley wire accidents that clearly merits more analysis. The information is incomplete and hence inconclusive. However, it does appear that mortality from electrocution via contact with trolley wires is not a major factor in mine safety statistics. Indeed, a partial analysis of accident data suggests that mortality is associated to a greater degree with fires that result from major trolley wire faults than from direct contact with exposed conductors. Related injuries, such as eye and skin burns, also appear to greatly outnumber serious shocks or electrocutions. To an extent, this may be due to the obvious nature of and a

*The dual-wire system presented in Section 4 is essentially a double-insulated system. Under "normal" mining conditions, the additional protection provided by indicators may not be deemed necessary.

healthy respect for this ever-present danger on the part of miners.*

6.7 Other Possible Options for Increased Trolley Wire Safety

In the course of the project work, several other possible options arose that seemed to offer the promise of increased trolley wire safety. Two of those items were briefly explored and are described below and in the appropriate appendices:

- a. *Options for Insulating Equipment and Miners from the Return Circuit* - Analysis of available data indicated that the majority of trolley wire-related electrical accidents occur on or near rail vehicles, with the vehicle frame providing the necessary ground contact. As a result, FMA staff studied the possibility of insulating both machinery and workers to reduce the probability of establishing a good return path for fault current. Both approaches offer interesting possibilities for saving lives and decreasing accident frequency and severity. Results of a preliminary study are presented in Appendix A.
- b. *Use of Segmented Trolley Wire with Local Control of Current Delivering Capability* - In trying to devise ways to guard the exposed current carrying wire from contact with miners, equipment frames, or ground, a system was suggested that limits the ability of the bare conductor to deliver current. The system consists of an insulated feeder cable which feeds current through "electronic switches" to the bare wire, which is segmented and insulated into sections (~100 ft long). The vehicle, or vehicle operator, automatically sends out signals to "turn on" a segment of the wire as it approaches, and segments "turn off" automatically after the vehicle has passed. With this system, most of the exposed wire, for most of the time, would be incapable of delivering current to a fault. This system is more fully described in Appendix B.

*One of the remarkable aspects of mine safety is the relatively low mortality rate associated with this exposed, energized conductor. It has been suggested that extensive modification, while rendering the system actually safer from the point of view of potential human shocks, might also create the illusion that the system is actually safer than it is, and thus lead to a second generation of safety problems resulting from an increase in carelessness.

6.8 Conclusions and Recommendations

The genesis of this study lies in the apparent hazards of an exposed high-power trolley wire. In response to these hazards, new alternative designs are offered for potentially safer trolley wire systems, visible indicators of faulty insulators and improved wire guarding and shielding techniques. During the development of these techniques, doubts arose about the actual severity of the hazards being addressed. To resolve these doubts, it is recommended that a study be performed analyzing existing trolley wire accident data and reporting techniques. This study will identify which of the hardware presented in this report warrants additional development and introduction underground.

APPENDIX A

INSULATION OF MINERS FROM RETURN CIRCUIT

The possibility of isolating locomotive, jeep, and mine car frames from the return circuit was investigated. While this was felt to be technically feasible, difficulties involved in monitoring for fault conditions and preventing the occurrence of hazardous situations appear formidable. This investigation led to a consideration of isolating equipment from energized circuits, and isolating miners from both energized and return circuits. While the development of this type of protection would effectively "shield" the trolley wire from contact with miners and equipment, further study in this area is beyond the scope of this contract.

A.1 Comments on Isolating Locomotive, Jeep, and Mine Car Frames from the Trolley System Return

A.1.1 Where Would Insulation Be Needed?

Insulation would be needed as described below:

- a. 27-ton (or larger locomotives with swivel trucks:
 1. At the swivel
 2. At the truck hanger brackets
 3. At some point in the brake rigging
 4. At the coupling (possibly).
- b. 11-ton, 8-ton, and other small locomotives:
 1. At the axle boxes (where the frame sits on the axle bearing block)
 2. At the motor support bolts
 3. At some point in the brake rigging
 4. At the coupling (possibly).
- c. Jeeps:
 1. At the journal bearings or some other point in the suspension system

2. At the motor mount
 3. At some point in the brake system.
- d. Mine cars:
1. At truck swivels or king pins
 2. At the truck side bearing rollers
 3. At the coupling (possibly).

Insulation of all these points would probably be feasible using a variety of nylon, plastic, or rubber sleeves, bushings, washers, and bearing pads. However, a way to indicate a loss of insulation integrity and an energized frame condition would also be needed.

A.1.2 Advantages and Disadvantages

The advantages and disadvantages of insulation are described below:

- a. Advantages:
1. Added safety for operators (or other miners) if caught between the trolley wire and equipment frames
 2. Lessened fire hazard from trolley wire contacting equipment frames.
- b. Disadvantages:
1. Insulation would probably not be too costly or difficult to install and maintain, but the fault indicating systems (which must be very reliable) could be. This problem would be especially severe for mine cars, due to harsh operating conditions, lack of a power source, etc. If mine car frames were left grounded, locomotives would have to be insulated at the coupling, probably the most difficult point to maintain. Exempting mine cars lessens the impact of the above advantages.
 2. What does one do with a locomotive or car that becomes energized? Special procedures or a way to quickly remove the power or ground the frame would be needed.

3. A "floating frame" would be against all conventions and standard practices regarding safety grounds.
4. Isolating the frames would increase the complexity of the equipment.
5. Conversion of all existing rolling stock would be required.
6. Transportation of powder and blasting caps would require special precautions.

Disadvantages seem to outweigh advantages. Frame isolation would probably not compare favorably (in safety, cost, reliability, complexity, etc.) to isolating the miner from equipment frames, other returns, and power sources (via shields, covers, protective or insulating clothing, etc.).

A.2 Comments on Shielding Miners

The purpose of trolley wire shielding is to protect miners and equipment (mostly miners) from contact with the energized wire. To this end shielding is hung on the wire at selected "danger" points - since it is usually impracticable to shield all wire in a large mine.

As an alternative, why not shield people and equipment? This would effectively shield all the trolley wire in the mine, plus provide miners with additional protection in other areas of the mine (that is, from trailing cables on sections, equipment electrical faults, etc.)

A.2.1 What Would Be Needed to Shield a Miner?

The following items would be necessary to shield a miner:

- a. *Insulating hat* - Already available and in use
- b. *Insulating gloves* - Available
- c. *Insulating boots* - Available. All miners wear boots. Some wear rubber boots, particularly in wet areas

- d. *Insulating jacket or shirt (see Figure A-1) -*
Would need to develop (if not already available) a comfortable shirt or jacket from an insulating material.
- e. *Insulating pants or coveralls (see Figure A-1) -*
Would also need to develop a comfortable, insulated pair of work pants or coveralls.

Management could provide the shielding either free or at cost, perhaps in lieu of (or combined with) the present clothing allowance. Miners could benefit from the increased safety, as well as the possibility of having high quality, inexpensive work clothes. Insulating clothing, if made available, could be required just as hard hats and steel-toed shoes are now.

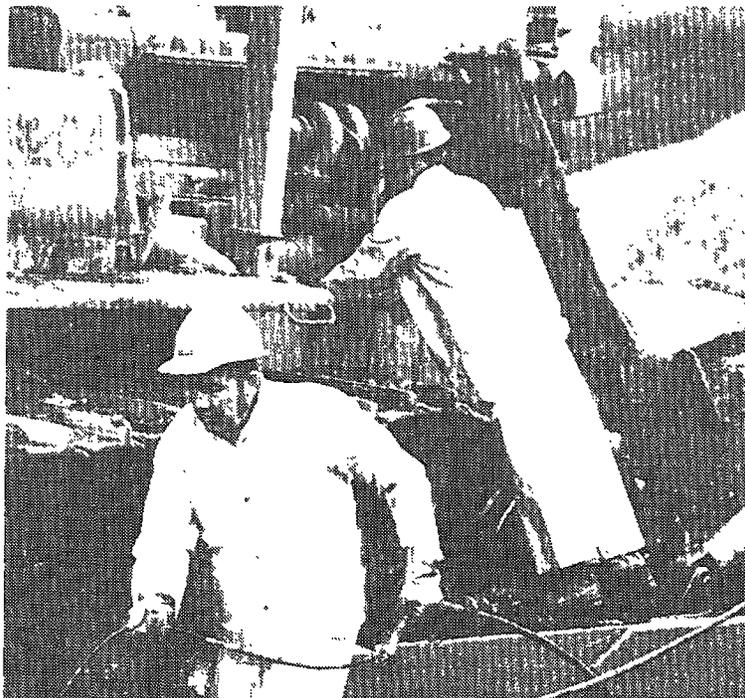


FIGURE A-1. - Protective suit (courtesy of UniRoyal, Inc. - suits not approved for electrical work at this time).

A.2.2 What Would Be Needed to Shield a Piece of Equipment?

The following items would be necessary to shield equipment:

- a. A rubber or plastic strip directly under the trolley wire, or perhaps over the entire top of the locomotive
- b. Develop a "spray-on" or "paint-on" insulating coating that could be applied to major areas, such as locomotive tops, mine car bodies, jeeps, etc. Design this shielding system such that torn or damaged places could be repaired or "touched up" by equipment operators or anyone else (applied with a paint brush, spray can, etc.).

A.2.3 Advantages and Disadvantages

The advantages and disadvantages of shielding are discussed below:

a. Advantages:

1. Effectively shields all the trolley wire, not just selected spots
2. Provides protection to miners from other electrical hazards
3. Many required insulating items are available; some are voluntarily used by miners now for shock protection (for example, rubber boots)
4. Could provide double insulation protection in many circumstances. For example, if a motorman contacts the trolley wire, he would be insulated at the point of contact, as well as at the return (probably the motor frame). If the equipment is shielded at this point, we will have even more protection
5. Repairs to this type of shielding would not require de-energizing wires, special tools or knowledge, etc. - anyone could do it
6. Would not obstruct or hinder trolley pole operation

7. Acceptance and use by miners should be good, given the protection from uncomfortable shocks that would be provided. Use should be good since miners generally do not remove their boots, pants, shirts, coveralls, etc., during the shift.

b. Disadvantages:

1. Offers no protection against shorting the trolley wire to the rail.
2. A high degree of personal protection could promote carelessness with electricity among miners.
3. Some way to test insulation properties of clothing articles would be needed. Perhaps a wear indicator, such as brightly colored inner layers that would show wear spots, could be used.

APPENDIX B

SEGMENTED TROLLEY WIRE WITH LOCAL CONTROL OF
CURRENT DELIVERING CAPABILITY

This system, illustrated in Figure B-1, is a single-wire system using a rail return. However, it differs from a conventional system in the following ways:

- a. The feeder cable is insulated, not bare.
- b. The trolley wire is segmented and connected via insulating splice joints. The segments are shown approximately 100 ft long, but could be longer or shorter, depending upon the particular mine situation.
- c. Current is fed to the mine vehicle from the feeder cable via the bare, segmented trolley wire. This current can be "turned on" or "turned off" by local radio control of the "current control box" (essentially a solid-state switch).
- d. The vehicle (or operator) is equipped with a small garage-door type RF transmitter to activate the "current control box." (The vehicle is identical in all other respects to existing equipment.)

The system operates as follows: the operator turns the RF transmitter on; this activates the current control box for the segment of wire directly above the vehicle. As the vehicle moves toward the next segment, it is turned on, allowing the vehicle to proceed. When the load is removed from a segment, it turns off and delivers no current until turned on by another transmitter.

The current control box is shown in Figure B-2.

The box is modular in design and can be unplugged for easy replacement, repair, or removal from the circuit. The circuit consists of a fuse, high-powered silicon controlled rectifier (SCR) mounted on a heat sink, a radio-controlled gate relay, an RLC snubbing circuit (to prevent turn on if the output is suddenly grounded), and a flashing light to indicate the turned on condition.

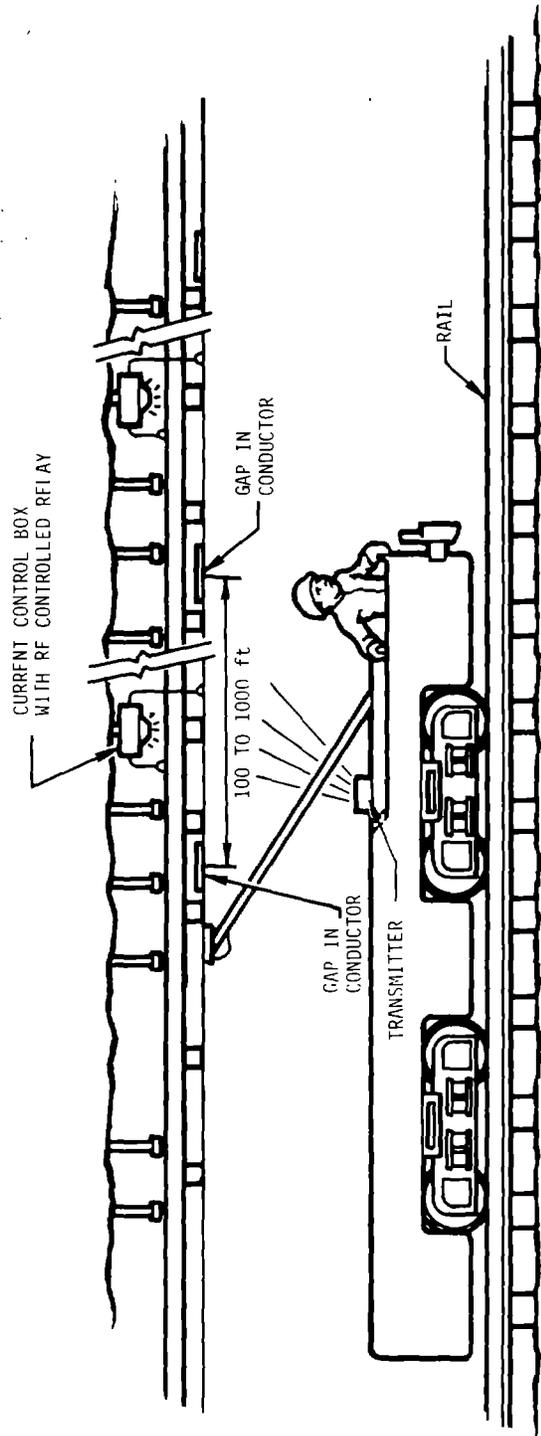


FIGURE B-1. - Segmented trolley wire system.

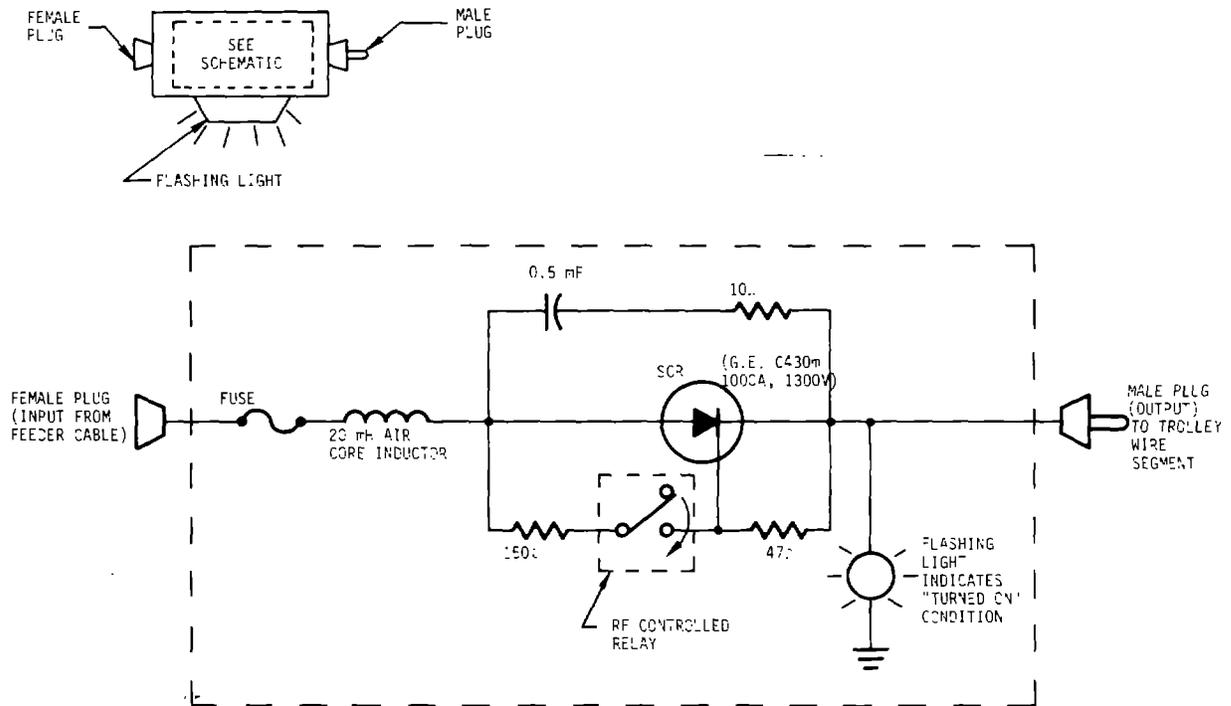


FIGURE B-2. - Current control box.

The most expensive component is the SCR.* A conservative estimate for the cost of the box is \$500. Advantages of the system would include:

- a. Power is delivered by the exposed conductor only when needed by a vehicle in the immediate area.
- b. Leakage current of the SCR is on the order of 1 mA, thus protecting from serious shock or high current faults when the turned off conductor is grounded.

*For example, a General Electric high-powered silicon controlled rectifier (No. C430) rated at 1000 ARMS up to 1300V costs approximately \$50 (R.E. Locher, General Electric ECSD Office, Wellesley, MA).

- c. The system could be retrofitted or applied to selected portions of existing or new mines (for example, in very low sections where trolley wire clearance is minimal).
- d. The control box could be modified to prevent turn on of a faulted wire segment.
- e. The RF transmitters could be used as "keys" to mine vehicles, limiting unauthorized operation.
- f. The RF transmitter could also be used as, or in conjunction with, a dead-man control.
- g. By using multiple boxes with different current delivery capacities, activated by different RF frequency signals, the power available from the wire could be selected or limited according to load size.

The chief disadvantage would be, of course, the increase in complexity relative to existing systems. However, proper sizing of the components should make high reliability achievable. When coupled with the modular design and flexibility of the system, this should mitigate the undesirable effect of increase in complexity.

APPENDIX C

SHOCK HAZARD VARIATIONS AS A FUNCTION OF GROUND LEAKAGE CURRENTS

The shock hazard posed to a person contacting either conductor of a dual-wire system will depend on the degree of isolation of the system from ground. Shown here is the relationship between the system resistances and the human resistance. Some numerical examples are presented to show the magnitudes of system resistances which may occur. In Figure C-1, R_L and R_L' represent the amount of leakage resistance to ground from each conductor. Leakage can occur at individual insulators, in trolley powered vehicles, illuminating and signal light circuits, or any other connected load.

The resistance of a man, R_M , is generally accepted to be a minimum of 500Ω (liquid contact), 1500Ω for the perspiring hands of a worker, and higher values dependent upon many factors.*

Figure C-2 shows the equivalent circuit and gives an expression for I_m , the current flow through the man. Figures C-3 through C-7 show the magnitude of the current through the man as a function

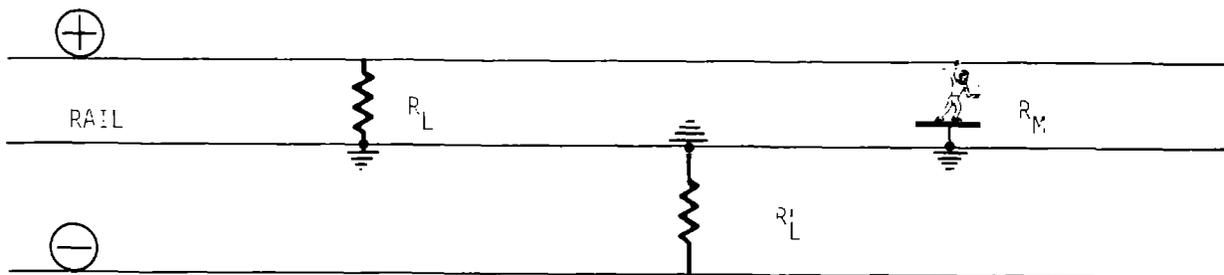


FIGURE C-1. - Basic circuit.

*Ford, W.D., et al., "Investigation of Ground Fault Circuit Interrupter," Construction Engineering Research Laboratory, University of Illinois, Urbana, IL, (September 1970).

$$I_m = \frac{V}{R_M + R'_L \left(1 + R_M/R_L\right)}$$

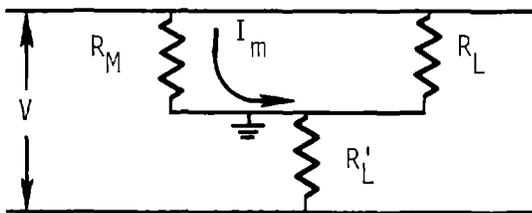


FIGURE C-2. - Equivalent circuit.

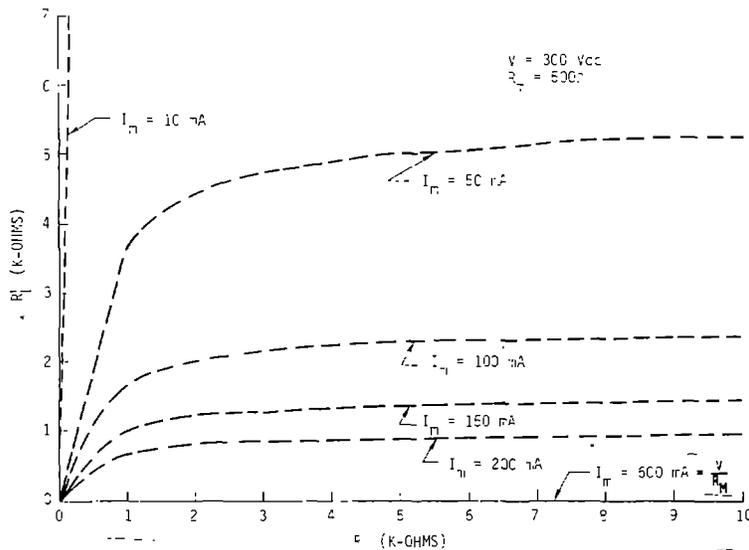


FIGURE C-3. - I_m (current flow through the man in Figure C-1) for changing values of R_L and R'_L , with $R_M = 500\Omega$.

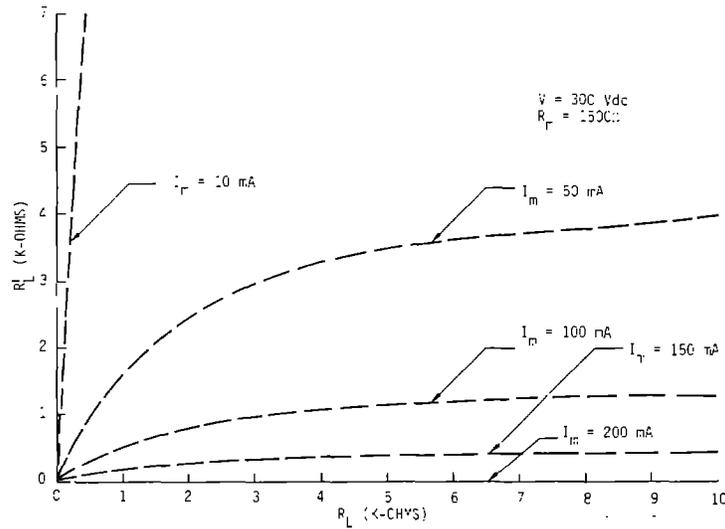


FIGURE C-4. - I_m (current flow through the man in Figure C-1) for changing values of R_L and R_L , with $R_M = 1500 \Omega$.

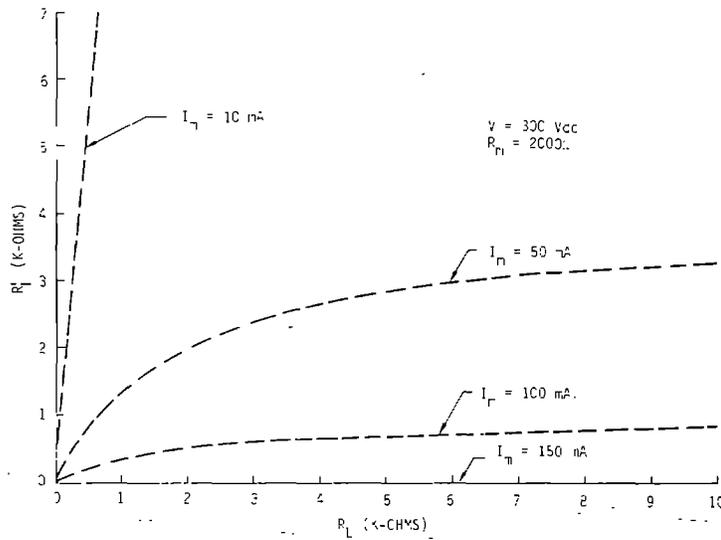


FIGURE C-5. - I_m (current flow through the man in Figure C-1) for changing values of R_L and R_L , with $R_M = 2000 \Omega$.

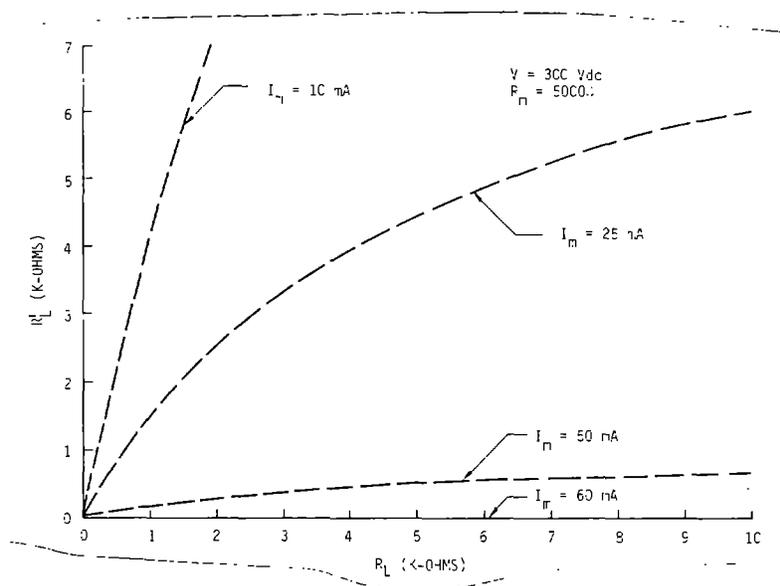


FIGURE C-6. - I_m (current flow through the man in Figure C-1) for changing values of R_L and R_L , with $R_M = 5000 \Omega$.

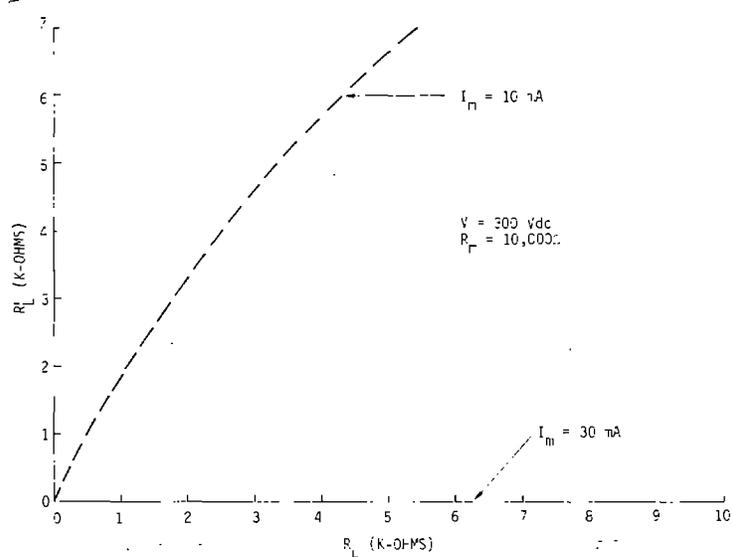


FIGURE C-7. - I_m (current flow through the man in Figure C-1) for changing values of R_L and R_L , with $R_M = 10,000 \Omega$.

of the parallel resistance, R_L , and the series resistance, R_L' , for a 300-Vdc system and various values of the man's resistance, R_M .

If values of R_L and R_L' can be calculated or measured, these plots will give the shock current available for various arbitrary degrees of human resistance (R_M). For instance, if 300 insulators support each section of wire, and each insulator has 1 M Ω resistance to ground, then:

$$R_L = R_L' = \frac{1M \times 1M}{300(1M)} = \frac{1M}{300} = 3.3 \text{ k}\Omega$$

Likewise, if each of the insulators has 10 M Ω resistance to ground, then:

$$R_L = R_L' \approx 33 \text{ K}\Omega$$

For 400 1M Ω insulators:

$$R_L = R_L' \approx 2.5 \text{ K}\Omega$$

For 1000 1M Ω insulators:

$$R_L = R_L' \approx 1 \text{ K}\Omega$$

Since large trolley systems have many insulators in parallel, wire isolation from ground can be poor. Unsymmetrical leakage faults can also occur. As R_L' goes to zero, I_m goes to V/R_m , the maximum available current for the particular R_M .

To determine the potential safety of a dual-wire system built with existing hardware, typical leakage resistances should be monitored on existing sections of trolley wire. If these resistances are relatively low, then significant shock hazards may exist from either wire in such a dual-wire system.