A PASSIVE MEANS TO DETECT HOT TROLLEY INSULATORS

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Faulty insulators on mine trolley/track haulageways may allow the flow of leakage currents into the mine roof and ultimately result in combustion of the local roof material. The National Institute for Occupational Safety and Health (NIOSH), Pittsburgh Research Laboratory (PRL), has devised a passive means to detect overheating insulators on direct current systems. The detector consists of a spring-loaded cartridge that ejects a reflective streamer of white Teflon tape when subjected to elevated temperatures. The cartridge assembly can be easily installed over the outer metallic shell of an existing trolley line insulator. If an insulator overheats due to ground leakage currents, the visible streamer alerts mine personnel traveling on the haulageway.

An insulator and surrounding strata that are subject to leakage currents may be discolored, have an odor, or exhibit no physical evidence of deterioration. Leakage currents from the trolley wire into the roof strata can heat the insulator as well as the immediate area in which the suspended bolt is anchored. If not detected and corrected, this may result in ignition of roof coal and a catastrophic mine fire. The likelihood of such fires on dc trolley systems can be minimized if deteriorating insulators can be promptly detected and replaced.

A number of thermal indicating concepts were considered at the outset. These included paint-filled capsules, an encapsulated liquid, a reflective polymer, a bimetallic strip, and a spring-loaded cartridge held in place with wax. Each was evaluated and critiqued for worthiness prior to construction of the prototype. A preliminary idea involved mounting a clear fluoropolymer shroud around the insulator body (Figure 1). Paint-filled capsules would be contained within the shroud adjacent to the insulator housing. An overheating insulator would cause the shroud to shrink around the capsules. The capsules would be pierced by adjacent sharp protrusions, releasing paint over the exterior of the insulator. This passive technique had several advantages. It

APPROACHES

A thermal indicator must activate in the presence of leakage currents at the lowest practical temperatures. However, it must not react to other sources of heat such as idling mine locomotives. Reliability dictates that it be simple in both design and function. Ideally, it should be a passive device that requires no external power to operate. The same environmental contaminants that contribute to leakage currents must not interfere with indicator function. Finally, installation of the indicator on the insulator must not introduce new hazards.

Figure 1. Thermal detection using point-filled capsules.
required no external power to activate and the shroud material was flame retardant. However, the capsule and shroud assembly would be difficult to install without removing the insulator from service. In addition, the paint might be difficult to detect once the shroud was covered with dust.

Another concept involved placing antifreeze inside a plastic tube which would be wrapped around the insulator body (Figure 2). Insulator leakage current would heat the antifreeze inside the tube. With sufficient internal pressure, a retaining cap would be ejected and a spool of Teflon tape would unroll. The weighted tape would unwind by gravity. This white reflective streamer flapping in the ventilating air would be easily visible to personnel traveling in vehicles. In addition, the antifreeze would remain liquid in areas of the haulage near the portal where temperatures may drop below freezing. But, no easy way could be found to retrofit the tubing on an insulator without losing fluid.

A third possible method featured a polymer disk which would be installed over the top of the insulator (Figure 3). A cartridge containing a Teflon streamer would be mounted on top of the disk. When heated, this disk would deform and a wax seal inside the cartridge would melt. The seal is intended to keep dirt from fouling the streamer. The streamer would unroll by gravity. This simple concept required no external power. However, after careful consideration, it was felt that the wax would not reliably melt as the polymer disk was a poor heat conductor.

A fourth mechanism relied upon the movement of a bimetallic strip and gravity to activate a streamer. For maximum deflection, a spirally-wound strip was needed. An engineering analysis of this design showed that to produce an angular deflection in excess of 90° required a strip so large as to be impractical when mounted on an existing insulator (Crest Manufacturing Company Applications Manual, 1995).

The final concept envisioned, used a cartridge containing a spring-loaded streamer which was brazed to an adjustable hose clamp (Figure 4). The clamp would be installed around the insulator housing. When leakage currents caused the insulator to become elevated in temperature, heat would be transferred via the clamp to the cartridge. Temperature-sensitive wax seals would hold the spooled streamer in place. At the melt temperature specified for the wax, the spring would eject the spooled streamer out of the cartridge. Gravity would pull the nonconductive streamer downward where air currents along the haulage would cause it to flutter noticeably. This design was simple in nature and was easy to install on insulators in service. It had the potential to be inexpensive, while providing a recognizable warning signal to vehicles traveling the haulage. Consequently, it was the design of choice for the project. Reliability would subsequently be evaluated through prototype tests.

**PROTOTYPE CONSTRUCTION**

The assembly of the prototype is summarized here. A hose clamp with a suitable adjustment range was selected for the design. Made of stainless steel to prevent corrosion, this clamp should easily fit around commonly-used insulators. For economy, a 44-magnum brass cartridge was chosen to house the spring-loaded streamer. This cartridge was modified by enlarging the primer opening. Taking care not to deform its circumference, the brass cartridge was brazed to the clamp. A brass rod was then machined as a spool to fit within the cartridge. Teflon tape was carefully wound around the spool. An exterior wax seal excluded dirt from inside the cartridge. The design was fully documented in a patent application (Hudson, 1996).

**LABORATORY TESTS**

The thermal indicator must react before heat generated by leakage currents through resistive paths can ignite nearby combustibles. These paths may be present on the surface of the insulator in the form of moisture and dirt. In the case of a cracked insulator, the resistive path for leakage current may be internal. In addition, heat may be generated in the roof as the current seeks...
Assembled unit

Stainless steel clamp

Figure 4. Hot insulator detector prototype.

Additional tests were planned to gauge the reliability of the design. One hundred wax-sealed cartridges were constructed and mounted on a 1-m by 1.5-m aluminum panel (Figure 6). This panel was inserted into a 2.7-cu m air oven and the temperature in the oven was gradually increased from ambient at the rate of 25 °C per hr. Ninety-seven of the cartridges successfully ejected the Teflon streamer within ±5 °C of the target temperature of the wax. An examination of the three that failed to activate revealed deformities in the brass cartridges that hindered spool ejection. Careful packaging and handling of the device should preclude this damage in storage and transit.

Condensation may form on underground surfaces during the summer months when warm, humid air is drawn into the mine. This moisture may cause sudden arcing across trolley insulators, especially on 600-V systems. Laboratory tests were conducted to determine if the thermal indicator would activate in the presence of an electrical arc and if the indicator would be damaged by the arc. A 600-V direct current supply in PRL's Mine Electrical Laboratory was placed in series with 150 mH of inductance. Consisting of large air-core windings, this inductance simulated the electrical characteristics of a mine trolley/track haulageway. Its presence facilitates electrical arcs on these systems. In the laboratory, the arc was initiated by placing a #18 AWG fuse wire between the insulator outer housing and center threaded stud. Upon energization, the fuse wire quickly melted leaving an ionized path for the electrical arc. This arc was maintained for 4 to 5 sec. During this time there was significant erosion of the insulator stud and housing. The rapidly escalating heat activated the insulator detector nearly instantaneously. In some cases the Teflon streamer remained intact after arc interruption. However, most of the time the arc energy severed the streamer and it fell to the ground. Consequently, the insulator detector cannot be effective in the case of an arcing trolley insulator.

ADDITIONAL TEST RECOMMENDATIONS

It is recommended that the prototype clamp and cartridge assembly undergo additional tests (Trelewicz, 1981) to determine
appropriateness for mine duty. These tests, in accordance with MIL Std 810C (Military Standard 810C, 1984), include high and low temperature which approximate the cyclic temperature extremes (-29 to +38 °C) that may be experienced during storage and operation. In addition, a thermal shock test should be conducted to determine the effect of sudden changes in these temperature extremes. To measure the effect of warm humid air, the indicator should be subjected to 38 °C at 95% humidity. A mechanical shock test would gauge the ability of the device to withstand drops of up to 91.5 cm that may occur during shipment. A vibration test of 1.5 g up to 200 Hz would simulate the motion of common carrier shipping. The device should be exposed to dust concentrations of 10 mg per m³ at both 91.4 and 533.4 m per min and their effects on operation noted. A corrosion test per ASTM Standard B117 (The American Society for Testing and Materials, 1995) with an acidified spray would complete the evaluation of the assembly. Following exposure, the assembly operation should be tested through exposure to heat. Once installed on an insulator, a dielectric strength test (American National Standards Institute (ANSI) C59.48, 1994, "Dielectric Breakdown Voltage and Dielectric Strength of Electrical Insulating Materials at Commercial Power Frequencies," 26 pp.


