IDEA

Innovations Deserving
Exploratory Analysis Programs

Transit IDEA Program

Cleaning Device for Electrified Third Rail Insulators

Final Report for
Transit IDEA Project 36

Prepared by:
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October 2004

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Innovations Deserving Exploratory Analysis (IDEA) Programs Managed by the Transportation Research Board

This Transit IDEA project was funded by the Transit IDEA Program, which fosters development and testing of innovative concepts and methods for advancing transit practice. The Transit IDEA Program is funded by the Federal Transit Administration (FTA) as part of the Transit Cooperative Research Program (TCRP), a cooperative effort of the FTA, the Transportation Research Board (TRB) and the Transit Development Corporation, a nonprofit educational and research organization of the American Public Transportation Association (APTA).

The Transit IDEA Program is one of four IDEA programs managed by TRB. The other IDEA programs are listed below.

- NCHRP Highway IDEA Program, which focuses on advances in the design, construction, safety, and maintenance of highway systems, is part of the National Cooperative Highway Research Program.
- High-Speed Rail IDEA Program, which focuses on innovative methods and technology in support of the Federal Railroad Administration's (FRA) next-generation high-speed rail technology development program.
- Safety IDEA Program, which focuses on innovative approaches for improving railroad safety and intercity bus and truck safety. The Safety IDEA program is funded by the Federal Motor Carrier Safety Administration and the FRA.

Management of the four IDEA programs is coordinated to promote the development and testing of innovative concepts, methods, and technologies.

For information on the IDEA programs, look on the Internet at www.trb.org/idea or contact the IDEA programs office by telephone at (202) 334-3310 or by fax at (202) 334-3471.

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Washington, DC 20001

Dirty Insulator

Burnt Insulator

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CLEANING DEVICE IN ACTION

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Expert Review Panel

This Transit IDEA project has been guided and reviewed by the expert review panel. The purpose of this panel is to provide guidance to the Principal Investigator for the IDEA product development and transfer of results to practice. The panel members' comments and recommendations have been incorporated into the project reports and plans for implementing the results of the Transit IDEA project.

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Executive Summary

The purpose of this Transit IDEA project was to develop cost-effective devices to clean electrified third rail insulators for rail rapid transit systems. A prototype cleaning device was built and field tested on two transit systems.

This project included the development and field testing of a prototype cleaning device on the Washington Metropolitan Area Transit Authority (WMATA) Metrorail system and the Maryland Transit Administration (MTA) Baltimore rail rapid transit systems. This prototype was based on the results of research conducted in Stage I of this project to evaluate the performance of several insulator surface cleaning technologies: (1) pneumatic polishing with rice husks with high silica content; (2) mechanical cleaning with powered rotating brushes; (3) pressure washing with high temperature tap and deionized water.

This report includes information so that other rail rapid transit agencies can consider using such a device for cleaning their third rail insulators. The Bay Area Rapid Transit District in San Francisco (BART), Chicago Transit Authority (CTA), New York City Transit (NYCT), Metropolitan Atlanta Rapid Transit Authority (MARTA) and Southeastern Pennsylvania Transit Authority (SEPTA) have also indicated a need for a third rail insulator cleaning device, and have actively participated in this project. This has been very helpful in making the results of this effort useful for their various transit systems. The insulator cleaning device will improve the safety and security of rail transit systems and will enhance public perception and confidence in the security of such systems.

Rail rapid transit systems use power supplied by a third rail that sits on insulators, which are typically spaced 6 to10 feet apart. Insulators are spaced more closely at the start of the third rail ramp (or end approach) and on curves. Power is conducted to the rail car motors by over-running collector shoes or contactors that slide along the top of the third rail. Some parts of the SEPTA subway system have suspended third rails with under-running pick up contactors. These insulators are covered by a tightly fitted fiberglass cap that makes it very difficult to access the insulator and will need a separate cleaning strategy.

Insulator failure occurs mainly in tunnels. Carbon dust from carbon brushes on the traction motor commutators, rust particles, dirt and grime can short circuit the insulator and cause smoke, explosive breaking of the insulator, or set wood ties on fire, which can shut down the rail transit system. If the insulator is made of fiberglass, it can burn. Porcelain insulators can become red hot and melt.

The problem is that not only are the insulators extremely difficult to clean, but there is no advance warning or diagnostic tool to indicate that an insulator is about to fail and cause a major problem. The third rail cover board, brackets and anchors limit access to the insulators. The voltage can be up to 1,000 volts. Transient voltage spikes of up to 3,500 volts from the electric power substations equipment can initiate an insulator failure event.

The power draw is enormous. A fully loaded train accelerating out of a station can draw over 10,000 amps which can contribute to insulator failure. Insulators are made of porcelain, fiberglass or wood and may have different shapes, diameters and heights. Some rail transit systems have more than one type and size of insulator, which makes it harder to design a standard sized cleaning device. The cleaning device may have to be adjustable to accommodate the different insulators sizes.

Many rail rapid transit systems routinely replace thousands of burnt out insulators every year at considerable cost. Such replacement may require shutting down the rail transit system. Previous and current methods for cleaning insulators are especially difficult and costly inside tunnels, where there is no rain to wash away dust and nowhere for combustible debris and smoke to go. There is very limited space between the insulator and tunnel wall, making it impossible to clean the back side of the insulators. In one agency, for example, about 4000 insulators per year failed and had to be replaced. Tunnels often have constant water drips creating lime and salt deposits and higher humidity. This condition accelerates rusting and corrosion of metal bases, caps and retaining rings on insulators and causes failure.

In Stage I of this project, bench testing of mechanical surface cleaning technologies was conducted in cooperation with cleaning industry leaders and transit agencies. Pressure washing with high temperature tap and deionized water was demonstrated and was found to be the most successful method for cleaning the insulators. Deionized water is an extremely powerful solvent and appears to clean insulators better than tap water. If the insulators have not been cleaned for a long time, deionized water may have to be used. Other alternative methods were also considered in Stage I. These included hydronic polishing (water slurry blasting) with rice hulls, which was not successful with the equipment used. Another method considered in Stage I was pneumatic polishing with rice husks, which was partly successful as the rice husks were too large and needed to be ground to a smaller size. Because of environmental considerations, chemical cleaning agents are generally not allowed.

Although pressure washing with hot water and sodium bicarbonate and light abrasive, cleaned grease and surface deposits from fiberglass, it unfortunately also removed the gel coat, exposing the fiberglass fibers to the touch. Because the protection of the smooth gel coat is gone, dirt can stick to the matrix pores much more easily. On porcelain insulators located in tunnels, hard rust, salt and lime deposits from water drips and other materials attack the glazing and get locked into it. Mechanical cleaning will remove these materials, but the surface glaze is also removed, exposing the porous matrix underneath. Without the glazing, the ability of the surface to shed dirt is greatly reduced. The recommended cleaning method is pressure washing with high temperature water.

A prototype cleaning device using four pressure washing nozzles was developed and mounted on a service vehicle on the tracks, and tested and evaluated at WMATA, Washington DC, and MTA, Baltimore rail rapid transit facilities. Further development of an operational high speed cleaning device would be more useful to rail transit agencies.

IDEA Concept and Product

This Transit IDEA project investigated several insulator cleaning concepts and produced an innovative prototype insulator cleaning method and device. Bench tests were conducted in Stage I of this project, to evaluate cleaning concepts using rotating brushes, hydronic and pneumatic polishing; and pressure washing with high temperature tap and deionized water. Based on the results of Stage I, a prototype cleaning device using pressure washing was developed and attached to a service vehicle and tested on the Washington Metropolitan Area Transit Authority (WMATA) Metrorail system and the Maryland Transit Administration (MTA) Baltimore rail rapid transit systems in Stage II of this project.

The unique design of this device allows insulators to be cleaned all the way around, eliminating the problem of not being able to clean the back of the insulator with a hand held pressure washing gun. An appropriately wide continuous cleaned band on the surface of the insulator is needed to break the electric conduction path and safely run the system. The cleaned band must be kept clean by a regularly scheduled cleaning program. The prototype was designed to offer an easier and faster way to clean insulators. Other transit agencies that participated in this project are BART, CTA, NYCT, MARTA and SEPTA.

A US Patent Application has been filed for this device and process.

Potential Impact on Transportation Practice

Figure 1 WMATA traction motor with contactor shoe

The purpose of this project is to develop a device to clean electrified third rail insulators for rail rapid transit systems to prevent arcing, smoke and system shutdown. This project would include development and proof of concept and prototype testing. There are no automatic devices for cleaning the electrified third rail insulators on rail rapid transportation systems. Most third rail systems carry over 600 volts and sit on ceramic or fiberglass composite insulators. SEPTA and Metro North, New York, have suspended third rails with under-running pick up paddles or contactors. These insulators are covered by a tightly fitted fiberglass cap that makes it very difficult to access the insulator. A separate strategy will be needed for this type of system.

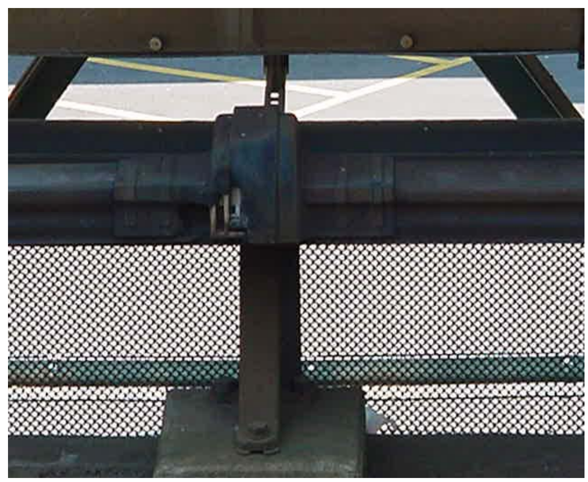


Figure 2 Under running third rail insulator SEPTA 6/03

The third rail usually has a safety cover, brackets and anchors that limit access to the insulators. Cleaning with hand brushes, cleaning pads, or pressure washing with a hand held wand (and blow drying with compressed air to prevent wet surfaces from conducting electricity) is slow, costly, and not fully effective. It is practically impossible to clean the side of the insulator towards the tunnel wall with a hand held pressure washing gun because of the limited space. This project will develop an insulator cleaning device that will be attached to a service vehicle and will be tested on the MTA Baltimore, and the WMATA Metrorail systems.

Insulator failure occurs mainly in tunnels. The problem is that electrically conducting particulates including carbon dust from the carbon brushes on the commutators of the traction motors, rust and dirt adhere to the insulators. Normal maintenance of the tracks includes rail grinding that generates a significant amount of iron particulates that coat the insulators; rust particles and brake shoe particles also coat the insulators. The insulators eventually fail and arc, releasing smoke and flame. If the insulator is made of fiberglass composite, it can burn; porcelain insulators can glow with heat. If the insulator sits on a wood tie, the tie can also burn. The third rail cover guard is also made of fiberglass or wood, and it can also burn. The plastic cable covering on an adjacent electric supply cable can burn releasing possibly lethal toxic fumes. Note that a 10-minute insulator arcing incident delay on one track can tie down much of an entire city rail transit network for much longer. The loss of income to the rail system and lost time for the passengers are substantial.

Rail rapid transit systems routinely replace thousands of burnt out insulators every year at considerable cost. At one agency, when smoke is reported or arcing is seen, the arcing insulator is squirted with a mild cleaning solution containing acid or removed with a sledgehammer and replaced during non-revenue hours. Cleaning insulators is especially difficult and costly inside tunnels where there is no rain to wash away dust and nowhere for combustible debris and smoke to go.

Figure 3. Insulators come in different shapes, sizes and materials. BART 6/03

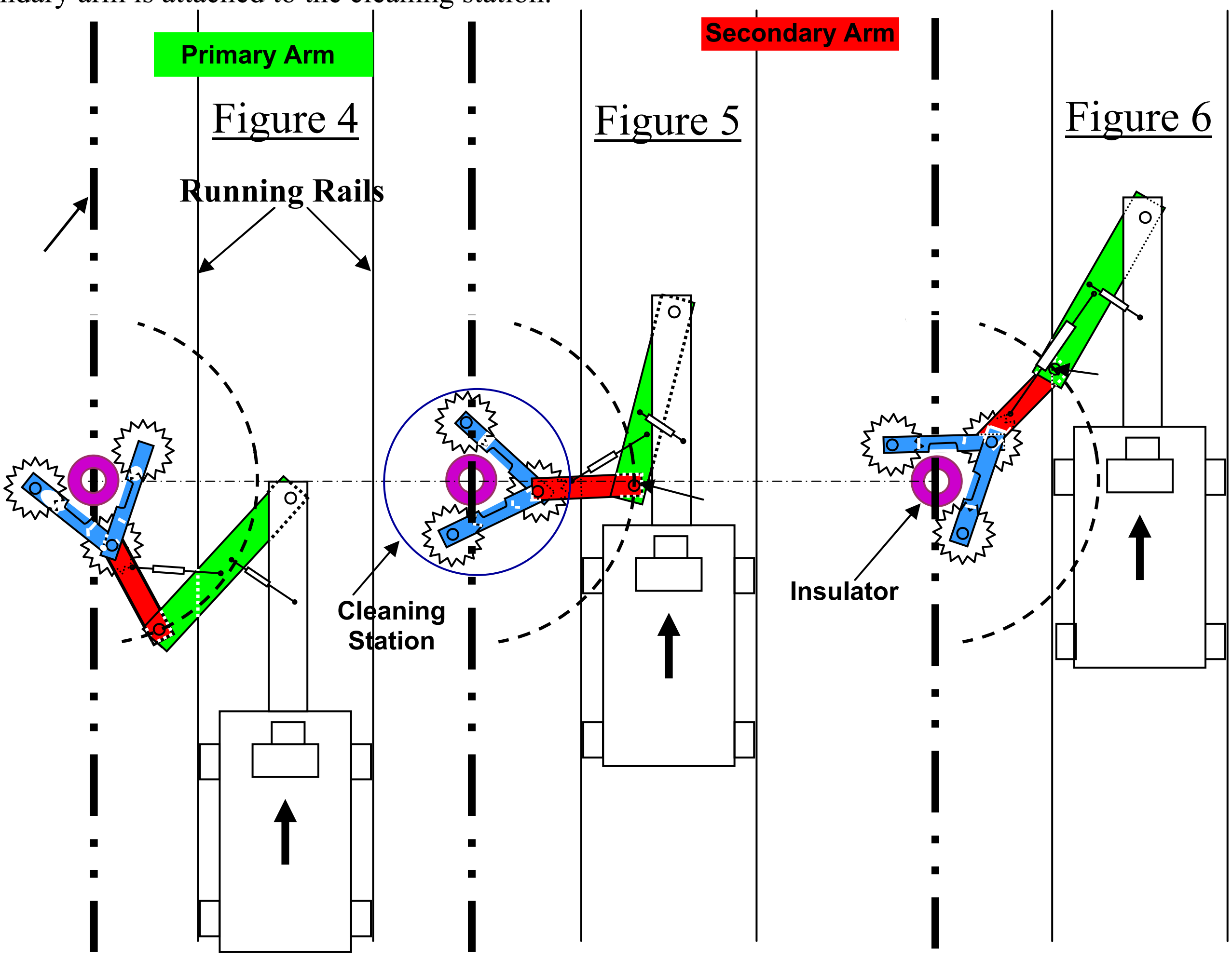
Research and development of a cost-effective insulator cleaning device is a challenge that has not been addressed. It is not easy to focus attention on cleaning insulators, when more visible areas such as station platforms, demand attention. The third rail can be on the right or the left. Insulators come in different materials, shapes and sizes. Manufacturers have not been willing to invest large amounts of money in research and development because of the high risk and the limited number of rail rapid transit agencies with third rail insulators. The level of complexity is increased because some agencies have a seven days a week, 24 hours per day and 365 days per year continuous operation. When the third rail is energized, tap water cannot be used for cleaning the insulators because of the danger of electric shorts or conducting electricity back to the equipment and operator. Also, harsh and abrasive cleaners and cleaning media cannot be used as they may damage the ceramic or fiberglass insulators, or cause corrosion and malfunction of switches, sensors, and metal components. Most jurisdictions ban the use of harsh cleaning chemicals because of environmental and health concerns.

The insulator cleaning device will improve the safety and security of the rail rapid transit systems. After the recent terrorist attacks on the Pentagon and the World Trade Center, people are concerned about their safety. Smoke and electric arcing from dirty insulators and delays in dark tunnels may cause fear and scare people away from using rail rapid transit. Diversion to personal modes of transport will cause traffic jams and delays, and hurt economic development. The cleaning device will enhance the public perception of a safe and secure rail transit system and support economic development.

Concept and Innovation.

The potential performance of high tech cleaning technologies, such as lasers, ultrasonic cleaning, low frequency acoustic vibration, magnetic, vacuum, pneumatic polishing, controlled high pressure washing, and brushing, have been estimated. The most promising cleaning systems researched were powered rotating brushes, pressure washing with high temperature tap or deionized water, and pneumatic polishing (similar to sandblasting) with dry rice husks. Due to the different sizes, shapes and materials of insulators on the same track, it was seen that the most appropriate cleaning tool was pressure washing.

In Stage II, a device for cleaning third rail insulators was developed, comprising a cleaning station with two fingers having cleaning tools. The fingers extend from the cleaning station so as to bring the cleaning tools within operative proximity to an insulator of the adjacent third rail. The cleaning station is mounted on a positioning arm attached to a vehicle that travels on rails so that the fingers of the cleaning station engage, rotate around, and disengage from an insulator of the adjacent third rail as the vehicle passes by the insulator. The positioning arm consists of a primary arm hinged at one end to a service vehicle and hinged at the other end to a secondary arm. The secondary arm is attached to the cleaning station.



The diagrams in Figs. 4, 5 and 6, show a top view of the cleaning device. The cleaning station can have several cleaning tools and technologies such as rotating brushes or pressure washing nozzles. In the above Figures, cleaning tools are represented by gear wheels shown at three locations around the insulator. The cleaning station is attached to the service vehicle by the primary and secondary arms that comprise the articulated arm. The bold arrow represents the direction of travel of the service vehicle. Actuators control the angular movement of the articulated arm and positioning of the cleaning station. The cleaning station is shown in three positions which the device occupies during the course of cleaning the insulator. The running rails carry the service vehicle and the insulator supports the third rail. The rotational path taken by the pivot point where the two members of the articulated arm meet is shown by the dashed circular line.

Investigation

Cleaning Systems Evaluation

The MTA, WMATA, BART, MARTA, CTA, NYCT, SEPTA and MBTA were visited to determine their third rail insulator cleaning procedures and needs. The P.I. worked closely with the MTA and WMATA staff to evaluate the potential performance of three cleaning systems: (1) pneumatic polishing with rice husks with high silica content and push-pull blower/air compressor systems and filter element and housing for conveying and recovering rice hulls; (2) rotating brushes; and (3) pressure washing with tap and deionized water to remove dirt from insulators without causing damage.

This task included holding discussions with the above transit agency staff to solicit their input, and identifying requirements that would impact implementation, and addressing those requirements. Potential issues and solutions were identified. This Task accomplished the following:

- A network of technical contacts was developed with whom to collaborate on the project and form an expert review panel.
- Cleaning system requirements were developed: cleaning performance needed, allowable wear to surface of insulator during cleaning, electrical safety, and health and safety issues.
- Strategies for cleaning insulators by pneumatic polishing with rice husks, rotating brushes and pressure washing with tap water, with and without sodium bicarbonate and light grit, and deionized water were evaluated.
- Bench tests were conducted and preliminary prototypes described to show the participating Transit Agency staff and operating personnel how these systems would work.

After consideration of the research conducted on cleaning technologies in Stage I, it was determined that high pressure water spray nozzles were the most appropriate cleaning system. It would not be possible to use rotating brushes because they are much larger than nozzles and space around the insulator is very small. In the system at MTA Baltimore, the insulator sits in the base of a bracket that supports the third rail cover board. The distance between the bracket and insulator is only a few inches.

In Stage II, an adjustable U-shaped cleaning station was constructed. Four pressure washing nozzles were located at the corners of the cleaning station. The nozzles pointed towards the center of the U-shape. A top view is shown on the right.

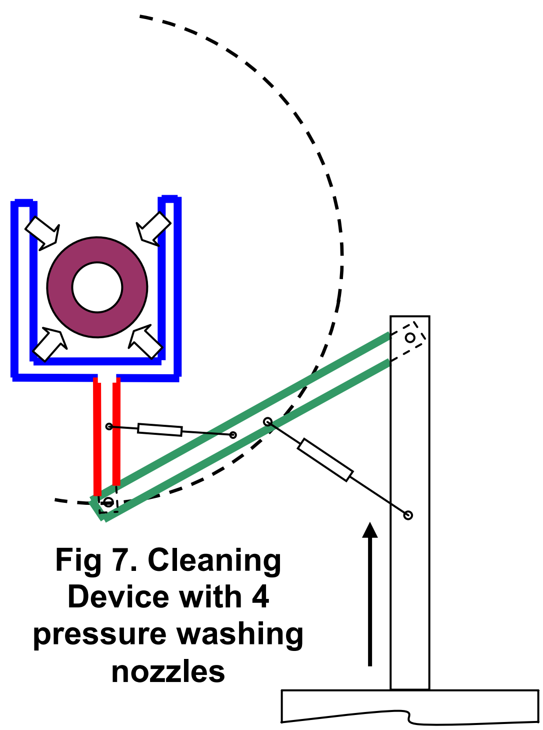


Fig 7. Cleaning Device with 4 pressure washing nozzles

A pressure washer was connected to the 4 pressure washing nozzles. The cleaning station was mounted on a positioning arm attached to a vehicle that traveled on the running rails so that the fingers of the cleaning station engage, rotate around, and disengage from an insulator of the adjacent third rail as the vehicle passed by the insulator. The cleaning station rotates almost 180 degrees counter clockwise around the insulator. As the service vehicle continues moving forward, the cleaning station releases the insulator and is ready to engage the next insulator. The station was connected by the primary and secondary articulated arm members to the service vehicle. The angular movement of the articulated arm and positioning the head was manually controlled.

The prototype was mounted on a service vehicle. The service vehicle was a manually controlled push cart that rolled on the tracks at WMATA Washington, DC and Baltimore MTA rail rapid transit systems.

Description of Third Rail Insulators in Transit Systems

(1) WMATA, Washington, DC

Fig. 8 WMATA hot tap powerwash

The WMATA's metrorail system has 220 miles of track, of which about 100 miles are in tunnels. Porcelain insulators are installed in the tunnels. Fiberglass insulators are used outside the tunnels. Insulators are spaced every 10 feet apart, for a total of about 109,000 insulators. The system uses 750 DC volts. There are about 4 hours available at night for system maintenance. WMATA has to call in the Fire Department when there are smoke and flame incidents.

WMATA started using a hot tap water pressure washing program for insulators on portions of its system about one year ago. However it takes a long time and uses a fair amount of labor to clean the insulators with this method. A four person crew uses a pressure washer carried on a service vehicle. The service vehicle stops about every 50 feet. The crew walk behind the parked service vehicle using a hand held pressure washing gun connected by a length of hose to the pressure washer. About 500 insulators on a 5000 ft section of track are cleaned in one 3-4 hour cleaning shift. This method cleans a significant portion of the surface dirt. The number of train delay incidents due to insulator failure has significantly decreased. However, the back of the insulators, towards the tunnel wall, cannot be cleaned.

If the insulators are extremely dirty with materials baked on and rust encrusted on to the surface, the insulators are removed and shipped to a cleaning contractor who uses powdered limestone media to air blast clean the insulators. Cleaning an insulator with liquid cleaners costs about $20 and blast cleaning costs about $15 per insulator in minimum lot sizes of 5000 insulators. New porcelain insulators cost about $47 each in lots of 5000. In 2002 about 8200 new insulators were installed in tunnels at a material cost of about $390,000. An 8 man night crew cleans and replaces failed insulators on about 200,000 lineal feet of track per year. 60 – 75 insulators are replaced per night. Labor cost is about $100 per insulator. WMATA is conducting ground to earth testing of some insulators.

WMATA tried to use corn cob as a blast cleaning media in the tunnels, but it caused dusty conditions and was discontinued when passengers complained.

Fig 9 Dirty insulator WMATA 8/16/01

As of 2001, about 4,000 failed insulators were replaced annually in the tunnels and about 100 outside the tunnels. The annual material cost of purchasing new insulators alone was about $200,000 (4,000 insulators at $50 each.) The labor cost of installing the new insulators was several times that amount. A 4- or 5-man crew can only replace 10 to 13 insulators per night. If the nuts that hold down the metal collar at the base of the insulator are rusted and frozen, the bolts cast into the concrete tie are cut off and new holes are drilled to installed new bolts to hold down the new insulator. WMATA had a labor cost of $173, 600 for cleaning insulators in 2001.

Fig 10 Dirty insulators WMATA 7/03

Up to 2001, WMATA was plagued with smoke incidents in the tunnels. Based on actual WMATA reports for the period April 20, 2000, to April 20, 2001, there were smoke incidents due to arcing insulators and traction power cable fires that caused service disruptions for a total of 13.83 hours. In *1998 National Transit Database*, WMATA reported 726,130 average weekday unlinked transit trips. The transportation model used in *Public Transportation and the Nation's Economy, Cambridge Systematics, Inc., page 4-4* assigns a value of $10 per hour to the time of transit users. The transit user cost of system backup due to insulator arcing and smoking can be estimated to be in excess of $20,000,000 per year. In 2001, the Manager, Fire and Life Safety at WMATA stated that dirty insulator arcing was the major cause of downtime in the tunnels in the older part of the system. When smoke was reported, 95 percent of the time it was due to arcing.

(2) MTA, Baltimore

The MTA rail rapid transit system in Baltimore has 34 miles of track and 10,847 third rail insulators. It consists of a below ground section, an aerial section and a grade level section. Traction power (750 Volts, DC) is provided to the vehicles through a powered third rail. Trains may operate to a maximum 60 miles per hour at 8-minute headways during rush hour. The fourteen-station trip is scheduled for 29 minutes travel time at maximum speed, one way.

Figure 11. Cable obstruction at insulator. MTA Baltimore

The insulators are placed on the base of a metal bracket that holds the third rail cover guard. The metal bracket is bolted to the rail tie. The third rail is placed on the insulators. Insulators can be removed and replaced by jacking up the third rail. Insulators and the cover guard are made of fiberglass.

Figure 12 Third rail and metal bracket are corroded. MTA Baltimore

Acid cleaning chemicals were sprayed on the insulators and third rail cover, followed by pressure washing using cold water at 1500 pounds per square inch (psi.) The surfaces were successfully cleaned, but there were significant corrosion problems on steel surfaces that the acid contacted. The acid cleaning has been discontinued. There is no present method for testing the insulator performance. There is no fixed replacement schedule per year. The MTA has problems with dirty insulators similar to WMATA, but on a lesser scale since the system is newer and smaller.

Fig 13. Anchor obstruction near insulator. BART 6/6/03

(3) BART, San Francisco Bay Area

The BART rail rapid transit system is very similar to WMATA. BART has 246 miles of track, of which about 62.5 miles are in tunnels. Insulators are spaced every 10 feet apart, for a total of about 130,000 insulators. BART used to clean the insulators by pressure washing with a light grit and sodium bicarbonate solution. The results were satisfactory. It is not known if the sodium bicarbonate causes long or short term metal corrosion. Insulator cleaning has been discontinued because of other priorities.

2 hours are available at night, Sunday thru Thursday, 4 hours on Friday night and 7 hours on Saturday night for track maintenance. BART system voltage is 1000 DC volts. There is about 7 inches of clearance between the third rail cover and the tunnel wall.

Figure 14. Burnt Insulator MARTA

BART has had flashover on elevated sections of track. Bart experience is that when a porcelain insulator flashes over, it can explode and the resulting plasma ball can have temperature of 5000 ^{0}F to 7000 ^{0}F. This plasma ball can vaporize a concrete tie and rebar.

(4) MARTA, Atlanta

MARTA has 104 miles of rail rapid transit track, and 15 miles of yard track of which about 21 miles are in tunnels. Insulators are spaced every 10 feet apart, for a total of about 66,000 insulators. 75% of the insulators are made of porcelain. They are being replaced with fiberglass insulators as they fail. A tunnel washer is used for general tunnel cleaning. In the past, an acid cleaning solution was sprayed on insulators, followed by a medium pressure water wash. The acid caused corrosion and this cleaning process was discontinued.

Figure 15. Cover Board restricts access to insulator . MARTA 6/03

Thermal imaging has been conducted from a geometry car and is very useful. Overheating insulators are clearly identified. Voltage spikes cause a few insulator failures. Rebar can conduct stray currents. MARTA has a major issue with a company that claims that stray currents from MARTA are eroding their nearby jet fuel pipeline at Hartsfield Airport.

(5) SEPTA, Philadelphia

SEPTA's rail rapid transit system has 102 miles of track, of which about 39 miles are in tunnels. Insulators are spaced every 10 feet apart, for a total of about 54,000 insulators. Different parts of SEPTA have different kinds of third rail and third rail insulators, resulting from the different systems that became part of SEPTA. SEPTA has suspended third rails with under-running pick up paddles or contactors. These insulators are covered by a tightly fitted fiberglass cap that makes it very difficult to access the insulator. A separate strategy will be recommended for this type of system.

Figure16. Burnt Insulator, SEPTA

SEPTA professional staff indicated that of the different cleaning systems being considered in this project, deionized water pressure washing is preferred. There is a reluctance to use cleaning brushes on porcelain because of the tendency for pitting, unless the brush material will not scratch or pit porcelain. If the insulator surface gets pitted, it can pick up dirt much faster later on.

Figure 17. Burnt insulator and cap with under running shoe, SEPTA

(6) New York City Transit (NYCT), Metropolitan Transportation Authority (MTA), New York City

The NYCT rail rapid transit system is comprised of 815 miles of track. This includes all mainline and yard track. The tunnel portion is 439 miles and the outdoor section is 376 miles. Insulators can be spaced up to 10 feet apart. There are over 232,000 insulators in the tunnels. The system is in non-stop operation. NYCT has no siding or parking areas between stations and insulator cleaning would have to be done during a general shut down of track section; or with a high speed cleaning device and vehicle that can go at the same speed as the trains.

Some insulators can only last for 6 – 12 months, most last 20 years. Some insulators last 30 – 50 years in dry areas; some are 104 years old. It costs NYCT $5 to $7 to buy a new fiberglass insulator. Porcelain insulators are better in wet areas, where fiberglass insulators develop an encrustation and sometimes fail and melt in 24 hours. Porcelain insulators cost about $30 each and the steel cap is expensive.

Under rail boots prevents arcing with metal cans and other trash. Although the under rail boot program is only a quick fix for the problem, it has proven very effective and delays attributed to insulator failures have reduced somewhat. Stray currents are a problem and corrode gas and water mains in the tunnels.

(7) CTA, Chicago

The CTA rail rapid transit system has 288 miles of track, of which about 22 miles are in tunnels. Porcelain insulators are used in tunnels and on grade adjacent to expressways. On elevated sections of track, wood or fiberglass insulators are used, and a wood rail is placed next to the third rail restricting access to the insulator. Insulators are spaced every 8 feet on straight sections of rail and every 6 feet on curves, for a total of about 200,000 insulators. Some of the insulators have been in service over 20 years. 99 miles of track are in continuous operation. There is a 22-person third rail crew that maintains insulators as well as all associated components involving third rail. They also respond to all third rail emergencies.

Figure 18. CTA Elevated section with insulator hidden by wood protective rail

Chicago has very cold winters and roads are heavily salted. Moving trains entrain a salt mist and/or salt dust cloud as they enter the tunnels from street level. Consequently, insulators face heavier corrosion just inside tunnels, as there is no rain to rinse off the salt. Where the track runs adjacent to a highway, snow plows throw snow and salt on the third rail. Insulators are cleaned by hand using cleaning pads to allow train operation.

At certain locations in the tunnels, there are cooler spots, where during the summer, moving trains pull in hot and humid air. The insulator surface may be below the dew point of the humid air. If so, moisture condenses on the insulator surface and allows conduction of electricity. The wet, dirty insulator surface can flash over. Also, due to seepage and blocked drains, some sections of the tunnel are constantly wet.

Figure 19. Salted snow thrown by highway snow plows deposits salt on insulators, CTA

As the result of an insulator event, CTA is planning to conduct a test to simulate an insulator failure and study the effects. In August 2003, as a train was underway, a porcelain insulator exploded in a tunnel. The noise was amplified by the tunnel walls and the train operator panicked. There was smoke, apparently from the wood half-tie burning. The train operator stopped the train in the tunnel and evacuated the train using the emergency catwalk. Some passengers suffered smoke inhalation.

(8) MBTA, Boston

MBTA has 108 miles of track, of which 14 miles are in tunnels. About 60 miles of track have third rail, the rest use overhead power supply. Insulators are spaced every 10 feet apart, for a total of about 9300 insulators in tunnels and 55,000 insulators outside. Most insulators are about 8 years old and there is no significant failure problem at the present time. Insulators have never been cleaned. Insulator failure on the third rail riser is an issue. Less than 10% of the insulators are made of porcelain, the rest are made of fiberglass. System voltage is 600 DC volts.

Figure 20. MBTA insulator in tunnel

Tests of Insulator Surface cleaning technologies

During Stage I research was conducted to evaluate three surface cleaning technologies as described below.

(1) Pneumatic polishing with rice husks, ground up corn cobs and walnut shells

Rice husks have a high silica content and are abrasive. They are light in weight and have a low saltation point or terminal velocity. Rice husks may be suitable for a low velocity pneumatic polishing application that will not chip or scratch ceramic or fiberglass insulators, yet will be able to blast dirt off the surface. Rice husks do not conduct electricity. This system may be used to clean the third rail insulator while the third rail is electrified. Time and money could be saved since the complicated process of shutting down power is avoided. Rice husks are a processed waste product and are abundantly available.

Rice hulls, ground up corn cobs and walnut shells were evaluated using air blast cleaning. It was seen that high air pressure could cause surface pitting with all three media. The rice hulls used were too big for they did not flow properly with the equipment used. The testing showed that although the rice hulls have good cleaning potential space constraints do not allow placement of a recovery system, leaving loose rice hulls to blow around in the system and cause customer complaints.

Table 1. Results of air blast cleaning with various media

Test #	Insulator	Cleaning media	Air Pressure psi	Surface results
1	MTA, (Baltimore) fiberglass	Corn cob		
2	MTA, fiberglass	Walnut shell	25	
3	WMATA porcelain	Corn cob	50	Cleans, pitting
4	WMATA porcelain	Walnut shell	25	
5	MTA, fiberglass	Rice Hulls	Max (100 psi +)	Cleans, Hulls bridge, pitting
6	WMATA porcelain	Rice Hulls	Max (100 psi +)	Cleans, Hulls bridge, pitting

Fig 21. Blast cleaning equipment

Fig 22. Blast cleaning MTA #2 walnut shell

(2) Surface cleaning using power brushes

Table 2. Cleaning with rotating scotch brite pads, bristle discs and mini cleaning belts Conducted at 3M, St. Paul, MN 8/26/03

Test #	Insulator	Cleaning tool	RPM	Notes	Results	Time (sec)
1	MTA Balto #1	CPD5, 4 in,	5,000	Initial test	Too aggressive	
2	MTA Balto #2	C&F 6x1/2 Disc AFVN on straight shaft	5,000	Initial test	Okay	
3	MTA Balto #3	HS Roloc 3 in disc on soft pad	15,000	Initial test	Okay	
4	MTA Balto #4	Finish Flap Brush 5 AFVN 8x1x3		Initial test	Okay	
5	MTA Balto #5	HS Roloc 3 in disc on soft pad	15,000	Initial test	Ideal	
6	MTA Balto #6	½ x24 SC AFVN Belt on Dynafile I		Initial test Slack of Belt		
7	MTA Balto #7	½ x24 SC AFVN Belt on Dynafile I 5/16 CTW with platen		Initial test		
8	MTA Balto #8	HS Roloc 3 in disc on soft pad	15,000	okay		18
9	MARTA #1	HS Roloc 3 in disc on soft pad	15,000	okay		15
10	MTA Balto #9	CF Disc 6 in AFVN	5,000	5 discs ganged		14
11	MARTA #2	CF Disc 6 in AFVN	5,000	5 discs ganged		13
12	MTA #10	Finishing Flap Brush 8x1x3; 5 in AFVN	3,400			30
13	MARTA #3	Reciprocating				27
14	SEPTA #1	Dynafile				25
15	NYCT #1	CF disc 6 in AFVN	5,000	5 discs ganged		

Angle grinders used: Ingersoll Rand Model AG 230 (9,000 RPM) and Ingersoll Rand Model Cyclone TA 180 (18,000 RPM)

Table 3. Tests with linear and rotating non-metal and metal wire brushes at Schaefer Brush, Waukesha, WI, 8/28-29/03

Test #	**Insulator**	**Material**	**Cleaning tool: Linear Brush (unless noted)**	**Notes**	**Dirt Scale Before cleaning**	**Dirt Scale After cleaning**	**Cleaning Time (sec)**
1	WMATA #1	Porcelain	0.125 stainless steel bristles		6	2	45
2	WMATA #2	Porcelain	TYNEX – A (180 Grit)		7	3	60
3	MARTA #1	Fiberglass	0.125 stainless steel bristles	Pulls off glass fibers from insulator surface	4		
4	MTA #1	Fiberglass	0.125 stainless steel bristles		8	2	35
5	MTA #2	Fiberglass Spot Test	TYNEX – A (180 Grit) Aluminum Oxide	Burnishes existing surface grease	8		
6	MTA #2	Fiberglass	TYNEX – A (180 Grit) Aluminum Oxide	Removes Gel Coat	8		35
7	WMATA #3	Porcelain		Clean a central band on insulator body with one Pass	8		24
8				Clean entire insulator		3	78
9	CTA #2	Porcelain		Clean a central band on insulator body with one Pass	7		21
10				Clean entire insulator		3	79
11	CTA #1	Porcelain Glazing Pitted	0.125 stainless steel bristles		8	2-5	125

Dirt Scale: 1 = Very Clean; 10 = Very Dirty

Notes: (1) Stainless Steel Bristles are not good for ribbed insulators, because the bristles bend excessively, work harden and break off.

(2) The linear brush had a ½ Horsepower motor.

Table 3. (continued) Tests with linear and rotating non-metal and metal wire brushes at Schaefer Brush, Waukesha, WI

Test #	Insulator	Material	Cleaning tool: Linear Brush (unless noted otherwise)	Notes	Dirt Scale Before cleaning	Dirt Scale After cleaning	Cleaning Time (sec)
12	NYCT #1	Fiberglass	0.125 stainless steel bristles		8	4	20
13			Hot water pressure wash		4	2	
14	MTA #3	Fiberglass	0.125 stainless steel bristles		8	3	36
15	MTA #4	Fiberglass	Hot water pressure washed		7	4	
16			0.125 stainless steel bristles		4	2	43
17	MTA #6	Fiberglass	Hot water pressure washed		7	4	
18			0.125 stainless steel bristles		4	2	
19	MTA #7	Fiberglass	Hot water pressure wash only		8	4	
20	CTA #3	Porcelain	0.125 stainless steel bristles	Excellent	6	1	52
21	CTA#4	Porcelain	0.125 stainless steel bristles		7	1	68
22	CTA #1	Porcelain	Stainless steel circular flared end brush	Removes heavy deposits, good job			
23	CTA #1	Porcelain	Stainless steel condenser brush, 1.25 in diameter	Spiral brush – Removes heavy deposits, good job #43536			

Note: Cleaning with rotating brushes is not recommended because of space constraints, the cost of brushes and adjustments needed as the brushes wear and the bristles get shorter. Also, anchor bolts at the base of the insulator could rip up the brushes.

(3) Pressure washing with deionized and tap water

Water at 180 degrees Fahrenheit and 3000 pounds per square inch pressure is not able to remove hard rust deposits, but will remove grease. Deionized water costs about $0.07 to $0.11 per gallon, and appears to perform better than tap water. Hot water pressure washing, with sodium bicarbonate and mild sand abrasive removes grease and dirt stains, but also removes the gel coat from fiberglass. Sodium bicarbonate can not be used because no chemicals can be used because of environmental regulations. Hard rust and lime deposits can be cleaned by increasing the pressure but at 4000 psi, the fiberglass insulators start to lose their gel coat and the surface of the material gets eroded.

Figure 23. Prototype device showing nozzles

Deionized water does not conduct electricity. This system may be used to clean the third rail insulator while the third rail is electrified. Time and money could be saved since the complicated process of shutting down power is avoided. The tests showed that deionized water is a better cleaner than tap water.

Figure 24. Nolan cart with device, WMATA

Further cleaning tests of porcelain and fiberglass insulators by pressure washing with tap water at 180 degrees Fahrenheit and pressures ranging from 3000 to 7000 psi were performed. It was seen that water at 5000 psi cuts fiberglass. The maximum safe pressure for fiberglass is about 4000 psi without cutting the surface. Therefore the maximum water pressure should be limited to 4000 psi.

Pressure washing is the recommended cleaning technology. The prototype device was clamped to

Figure 25. Cleaning device engaging, mid way, and releasing an insulator, WMATA.

a Nolan cart. This type of push cart is available at most transit agencies. As the cart was pushed along the track, the device engaged, rotated around and disengaged the insulator. The spray nozzles cleaned a band all the way around the insulator.

Figure 25. Spray pattern, engaging, mid way, and releasing an insulator, WMATA

The action of the device was smooth and well defined in approaching, the secondary arm rotating the cleaning head around; and releasing the insulator. All four spray nozzles provided cleaning action and cleaned a continuous band around the insulator. The manual control handle allows an operator to precisely allow the U shape head to engage the insulator. The final product would have springs that would cause the cleaning head movement to be automatic with the provision for manual override. The device allows the back side of the insulator to be cleaned

Plans for Implementation.
The results of testing the prototype insulator cleaning device on the MTA, Baltimore and the WMATA Metro rail rapid transit systems will be disseminated by the Principal Investigator via papers presented at professional meetings, conferences and trade shows of rail rapid transit organizations and associations. The insulator cleaning device will be shown to equipment manufacturers for commercialization and manufacture of full-scale models.

Figure 26. Spray action on back of insulator.

Conclusions
After consideration of the research conducted on cleaning technologies in Stage I, it was determined that high pressure water spray nozzles were the most appropriate cleaning system. It would not be possible to use rotating brushes because they are much larger than the nozzles and space around the insulator is very small. Anchor bolts can stick up 2 inches at the base of the insulator and these would rip out the bristles of the brushes if contact were made. At MTA Baltimore, the insulator sits in the base of a

bracket that supports the third rail cover board. The distance between the bracket and insulator is only a few inches and there is no space for brushes and a motor for rotating the brushes. Rotating brushes would also not work because there are insulators of different sizes, shapes and materials on the same track and the brush would not be able to reach the surfaces and the crevices in the complex shapes.

The prototype cleaning device using high pressure water spray would be best way to clean insulators for most transit systems. Higher flows and pressures would provide better cleaning action. Limited cleaning success was achieved because the pressure washing pumps provided were not large enough. New and improved high speed cleaning devices are potentially possible and may be worth investigating if a source of funding is available.

Deionized water is an extremely powerful solvent, but it is expensive and expensive stainless steel pressure washing equipment is needed. Therefore, pressure washing with deionized water may not be cost effective in all cases. However, since deionized water is a non-conductor of electricity, it may be used on an energized system. Note that if pressure washing is used for elevated sections of track, the street below has to be shut off.

Although pressure washing with hot water and sodium bicarbonate and light abrasive, cleaned grease and surface deposits from fiberglass, it unfortunately also removed the gel coat, exposing the fiberglass fibers to the touch. Because the protection of the smooth gel coat is gone, dirt can stick to the matrix pores much more easily. If porcelain insulators have heavy encrustations of rust and lime at the base, it is not possible to remove the encrustation without causing pitting and surface damage. However, it is not essential to clean the entire insulator surface. An appropriately wide continuous cleaned band on the surface of the insulator is needed to break the electric conduction path and safely run the system. However, the cleaned band must be kept clean by a regularly scheduled cleaning program.

A US Patent Application has been filed for this device and process.

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List of Pictures

Pictures of insulators being cleaned are shown in the following 14 pages. Pictures are grouped as follows: