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**Innovations Deserving  
Exploratory Analysis Programs**

***Transit IDEA Program***

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## **Cleaning Device for Electrified Third Rail Insulators – Phase 2**

Final Report for  
Transit IDEA Project 47

Prepared by:  
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Bethesda, MD

***July 2008***

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**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.

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- 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](http://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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Dirty Insulator



Burnt Insulator

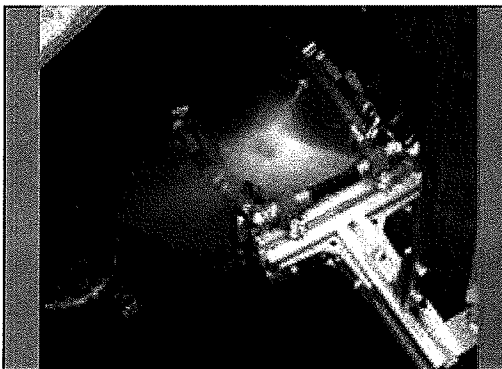
## *Cleaning Device for Electrified Third Rail Insulators – Phase 2*

### Final Report Transit IDEA Project 47

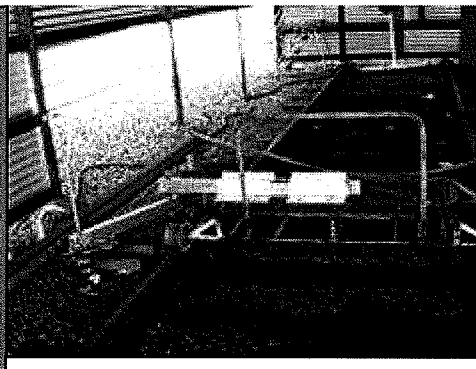
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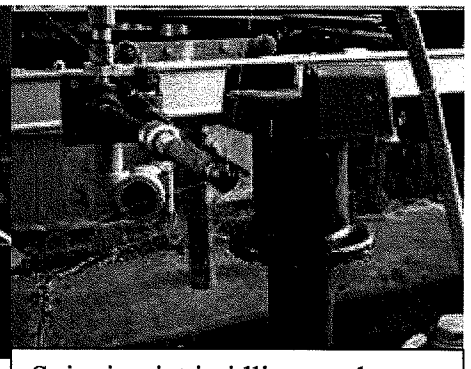
July 2008



Prototype cleaning device in action



Advanced Cleaner at BART



Spinning jet in idling mode on  
NYCT insulator

## Acknowledgements

The participation in this Transit IDEA project and the guidance of the following professional staff of transit agencies and subject matter experts and equipment manufacturers, has been valuable and is appreciated.

### Transit Agencies:

- ♦ Maryland Transit Administration, (MTA), Baltimore: Michael S. Davis, Deputy Director of Metro Operations; Vern Hartsock, Chief, Power and Signals Engineering; Mickey Ross, Principal Engineer Traction Power
- ♦ Washington Metropolitan Area Transit Authority (WMATA): Louis C. Testa, Assistant General Superintendent of Track, Structures and Systems Maintenance; Anthony J. Adams, Superintendent, Special Projects; Allen Riggin, Supervisor; Tony Talley, Manager, Scheduling; Ronald Keele, Chief Safety Officer, Chuck Novick, Fire, Life Safety Liaison; Ron Bodmer, Emergency Management
- ♦ Southeastern Pennsylvania Transportation Authority (SEPTA): John Laforce, Deputy Chief Engineer; Steve Thompson, Assistant Chief Engineer, Track and Civil Engineering; Anthony Bohara, Director, Engineering & Design, Track and Civil Engineering; David Stump, Assistant Director of Track Maintenance
- ♦ Chicago Transit Authority (CTA): Edward Buczkiewicz, Manager of Substation & Power, Maintenance; Rick Straubel, P.E., Senior Power Engineer; Peter Graf, Jr., Foreman, Third Rail Group
- ♦ New York City Transit (NYCT): Richard Curcio, Assistant Chief Electrical Officer; Robert Prasek, General Superintendent, Third Rail Operations
- ♦ Metropolitan Atlanta Rapid Transit Authority (MARTA) : Garry K. Free, Director of Facilities and Structures; Tim Elsberry, Acting Director of Track and Structures; Joseph Flores, Planner
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- ♦ Massachusetts Bay Transportation Authority (MBTA): Thomas A. Tryon, Superintendent, Maintenance of Way; Raul Cuevas, Superintendent of Training
- ♦ Miami Dade Transit (MDT): Lee Emard, General Superintendent

### Subject matter experts and equipment manufacturers:

- ♦ Stoneage Inc, Durango, CO: Doug Wright, Research and Development Manager
- ♦ National Liquid Blasters Wixom, MI: Keith O'Hara, Engineering Manager
- ♦ Schaefer Brush, Madison, WI: Tony Brooks, New Product and Process Manager
- ♦ 3M, St Paul, MN: B. Shawn Peecher, Senior Engineer, Surface Cleaning
- ♦ Jetstream, Houston: Paul Jezek, Research Manager
- ♦ Dwayne Arola, Professor, University of Maryland
- ♦ Ernest Geskin, Professor, New Jersey Institute of Technology
- ♦ Michael T. Gracey, P.E. Houston, water jetting expert
- ♦ Harvey Berlin, Senior Program Officer, Transit IDEA Program, Transportation Research Board

## **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. Key individual members' comments and recommendations have been incorporated into this Final report along with plans for implementing the results of this project.

### **Expert Review Panel members**

Michael S. Davis, Director of Metro Operations  
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**The publication of this report does not necessarily indicate approval or endorsement of the findings, technical opinions, conclusions or recommendations, either inferred or specifically expressed therein, by the National Academy of Sciences or the Transportation Research Board, or the sponsors of the IDEA programs from the United States Government.**

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## Executive Summary

This Phase 2 project builds on the successfully completed Transit IDEA Project 36, *Cleaning Device for Electrified Third Rail Insulators*. The purpose of this project was to test and demonstrate an operational higher speed device for cleaning third rail insulators for rail rapid transit systems. Dirt and grime can short circuit an insulator and cause arcing, burning, and smoke, which can cause the rail system to be shut down.

This project included testing of the prototype advanced cleaning device on the tracks of Metropolitan Atlanta Rapid Transit Authority (MARTA), Washington Metropolitan Area Transit Authority (WMATA), and the San Francisco Bay Area Rapid Transit District (BART).

A robotic arm was used to determine the optimum water pressure, flat jet nozzle fan angle and the standoff distance (distance between the nozzle tip and the surface) for cleaning extremely dirty insulators. This data was used as the basis for the design and development of the advanced insulator cleaner. Since a single flat jet nozzle at an optimum standoff distance cleans a narrow strip at a time, it would take very long to clean an insulator. Furthermore, cleaning a convoluted surface such as a BART or WMATA porcelain insulator is difficult with a flat angle jet. The reason is that the effective range of a flat jet for this application is only half an inch. Making a multiple nozzle array that follows the insulator profile at a standoff distance of half an inch is not practical, because most transit systems have at least two types of insulator materials, fiberglass and porcelain, and the profiles are different. Even insulators of the same materials sometimes have different profiles.

A round jet keeps its efficacy for almost 2 inches. A special nozzle with multiple round jets was designed, fabricated and successfully bench tested for cleaning the groove of a WMATA porcelain insulator with a convoluted surface. However, since this nozzle was too large to use in a multiple nozzle array that cleans several grooves simultaneously, due to the limited space available around the insulator, it was dropped from further consideration. Also, a round jet can cut a fiberglass insulator, unless the dwell time is limited or the pressure is reduced.

Three types of spinning jets with dwell times long enough to remove dirt but not cut the insulator surface, were bench tested. Further research led to the development of a cleaning station with 4 spinning jets at 4 locations on a manifold that rotates around the insulator and cleans all the way round it, eliminating the problem of not being able to clean the back of the insulator with a hand held pressure washing gun. This station was successfully bench tested and had the capability of cleaning extremely dirty insulators that had been discarded because they were deemed to be impossible to clean.

A video of the robotic arm using the flat jet, the multiple jet nozzle and the spinning jets was also shown to MARTA, WMATA, BART, Chicago Transit Authority (CTA), and New York City Transit (NYCT) professional staff and they were pleased with the cleaning efficacy. Many of the agencies felt it would be better if less water was used, and



this could be addressed by fabricating a special type of nozzle. The input from these transit experts has been very helpful in making the results of this effort useful for their systems.

This report shows the demonstrated performance of the higher speed automated cleaner when tested on the MARTA, WMATA and BART systems. The report includes information so that other rail rapid transit agencies can consider using the product for cleaning their third rail insulators. The insulator cleaning device can improve the safety and reliability of rail transit systems and can enhance public perception and confidence in the security of such systems. The automated cleaning device also has the potential to reduce infrastructure corrosion due to stray currents and reduce leakage electricity costs.

## IDEA Concept and Product

In the successfully completed previous Transit IDEA Project 36, a prototype cleaning device using 4 flat jets was developed and attached to a service vehicle and successfully tested on the Washington Metropolitan Area Transit Authority (WMATA) Metrorail system and the Maryland Transit Administration (MTA) Baltimore rail rapid transit systems.

In this Phase 2 project, a robotic arm was used to develop optimum flat jet cleaning criteria. Based on these criteria, a special nozzle with multiple jets shown in Figure 1 was designed, developed and successfully bench tested for cleaning a groove in a porcelain insulator, but it was deemed to be impractical due to geometry variations. Three types and sizes of spinning jets were also bench tested. Figure 2 shows a small, very high speed spinning jet that is designed for cleaning tubes. This spinning jet did not provide sufficient cleaning. A second spinning jet used too much water. The third spinning jet was selected for the high speed cleaner because it used less water than the first two and had the capability of cleaning extremely dirty insulators that had been discarded because they were deemed to be impossible to clean. The advanced higher speed cleaner was successfully tested at MARTA, WMATA and BART.

The unique design of the automated cleaner 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 CTA, MTA Baltimore, NYCT, and SEPTA.

A U.S. patent has been issued and International Patent Applications have been filed for the automated cleaner.



**Fig 1. Specially designed groove cleaning nozzle with multiple jets at WMATA insulator**

**Fig 2. First Spinning Jet with multiple nozzles in the idling mode at WMATA insulator**

## DESCRIPTION OF THIRD RAIL INSULATORS IN TRANSIT SYSTEMS

### (1) WMATA, Washington, DC

The WMATA metrorail system has about 225 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 119,000 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.

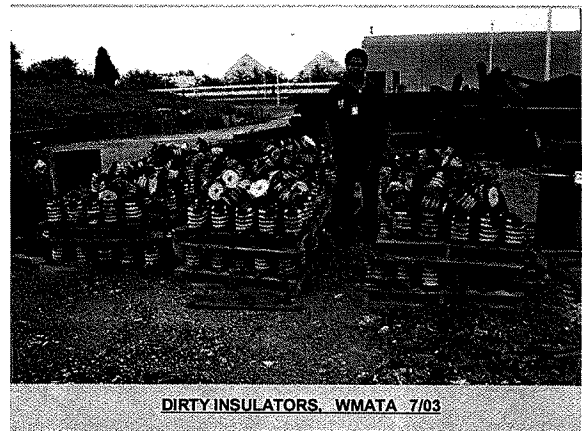


**WMATA HOT TAP WATER POWERWASH**

WMATA uses a hot tap water pressure washing program for insulators on portions of its system. However it takes 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 to 4 hour cleaning shift. This method cleans a significant portion of the surface dirt. However, the back of the insulators, towards the tunnel wall, cannot be cleaned using current methods and could be a path for conduction and flashover. In 2007, 26,410 insulators were cleaned at an estimated labor and equipment cost of \$330,000 or about \$12 to clean an insulator.

WMATA pilot tested using corn cob as a blast cleaning media in the tunnels, but it caused dusty conditions in the stations and was discontinued when passengers complained.

Until very recently, if the insulators were extremely dirty with materials baked on and rust encrusted on to the surface, they were removed and shipped to a cleaning contractor who used powdered limestone media to air blast clean the insulators at a cost of \$28 each. Now, WMATA is replacing porcelain insulators in the tunnels with fiberglass insulators that cost about \$32 each. In 2007 about 5,900 new insulators were installed in tunnels at a material cost of about \$188,000, and a labor cost of \$390,000. An 8 man night crew cleans and replaces failed insulators on about 200,000 lineal feet of track per year.



**DIRTY INSULATORS, WMATA 7/03**

Labor cost to replace an individual insulator is about \$120. 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 has been 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 nearly 14 hours. During January to December, 2007, there were 19 incidents of arcing insulators that caused 12 hours of downtime, up to 1.5 hours in duration each (traction cable fires are not included).

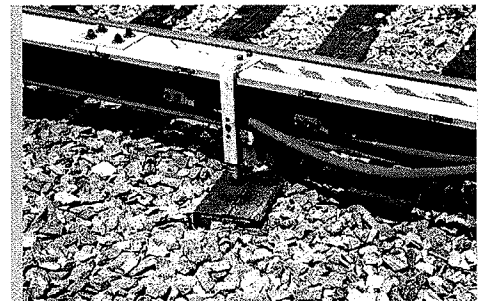


(DIRTY) INSULATOR, WMATA BETHESDA, MD STATION 8/16/2001

In the National Transit Database, WMATA reported 726,130 average weekday unlinked transit trips for 1998 and 932,268 trips for 2006. 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 about \$10,200,000 per year for 1998 and \$11,200,000 for 2006. In 2001, the Manager, Fire and Life Safety at WMATA stated that dirty insulator arcing was a major cause of downtime in the tunnels in the system. When smoke was reported, 95 percent of the time it was due to arcing.

## (2) Maryland Transit Administration (MTA), Baltimore

The MTA rail rapid transit system in Baltimore has 34 miles of track and 11,000 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.



Cable obstruction at insulator MTA Balto 6/26/03

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.

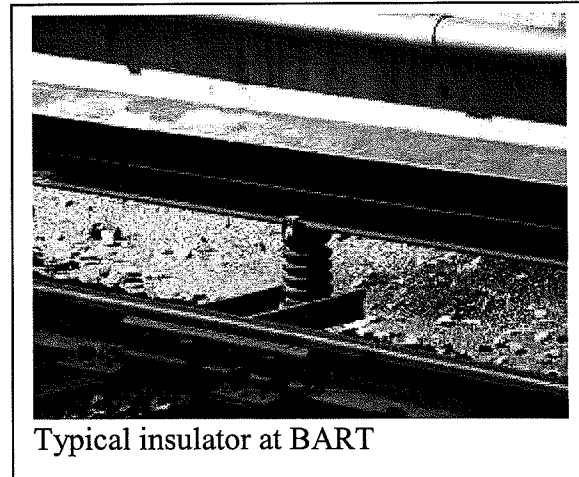
Acid cleaning chemicals were sprayed on the insulators and third rail cover, followed by pressure washing using cold water at 1500 pounds per square inch (psi.) The surfaces were successfully cleaned, but there were significant corrosion problems on steel surfaces that the acid contacted. The acid cleaning 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.



Insulator and metal bracket are corroded . MTA Balto

### (3) BART, San Francisco Bay Area

The BART rail rapid transit system is similar to WMATA, in miles of track and number of insulators. BART has 268 miles of track, of which about 62.5 miles are in tunnels. Insulators are spaced every 10 feet apart, for a total of about 142,000 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.

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 °F to 7000 °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.

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 had an issue with a company that claimed that stray currents from MARTA were eroding their nearby jet fuel pipeline at Hartsfield Airport.

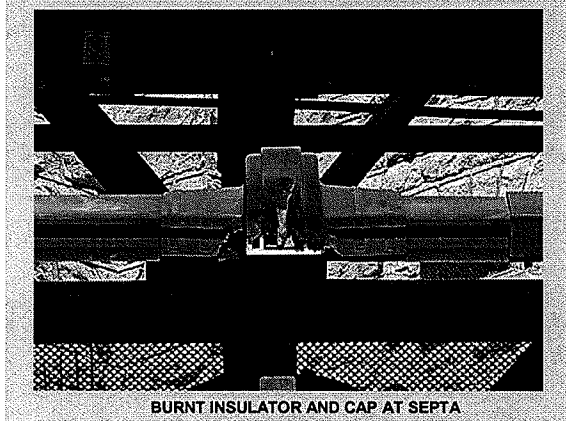


Cover Board restricts access to Insulator MARTA 6/03

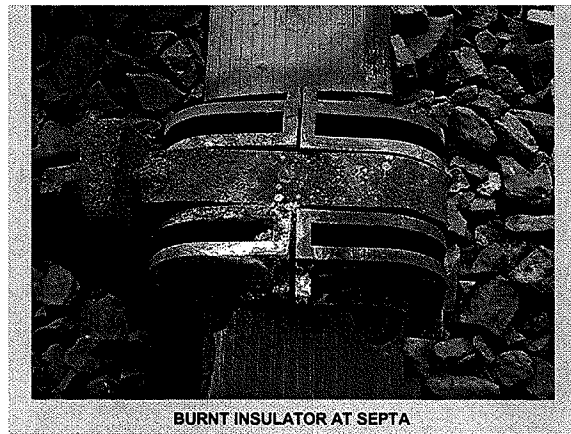


#### (5) SEPTA, Philadelphia

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. A small part of 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. However, this type of insulator generally stays clean as the cap does not allow contaminants to access the insulator surface.



BURNT INSULATOR AND CAP AT SEPTA



BURNT INSULATOR AT SEPTA

SEPTA professional staff indicated that of the different cleaning systems being considered in this project, 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.

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

The NYCT rail rapid transit system is comprised of about 835 miles of track. This includes all mainline and yard track. The tunnel portion is 439 miles and the outdoor section is 396 miles. Insulators can be spaced up to 10 feet apart, for a total of about 441,000 insulators. There are over 232,000 insulators in the tunnels. The system is in 24 hour operation. NYCT has no siding or parking areas between stations and insulator cleaning would have to be done during a shut down of a track section; or with a high speed cleaning device and vehicle that can go at the same speed as the trains.



NYCT third rail and insulator

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 are made of porcelain or fiberglass. The cover board is made of wood or fiberglass.

Some insulators can only last for 6 to 12 months, most last 20 years. Some insulators last 30 to 50 years in dry areas; some are 104 years old. Porcelain insulators are better in wet areas, where fiberglass insulators develop an encrustation and sometimes fail and melt in 24 hours. A new porcelain insulator costs \$50, and a new fiberglass insulator costs \$15.

It costs \$600 (3 persons x \$200 each) in labor to replace a failed insulator. For large scale replacement, the labor cost is \$3000 (6 persons x \$500 per day) to replace 50 insulators per day, or \$60 per insulator. Based on labor costs and cleaning output provided by NYCT staff, it costs \$20 to clean an insulator.

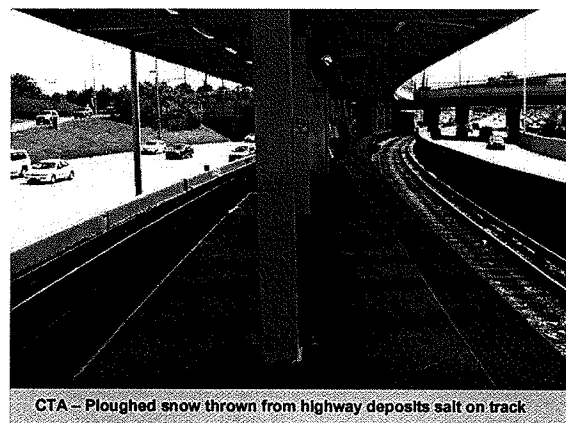
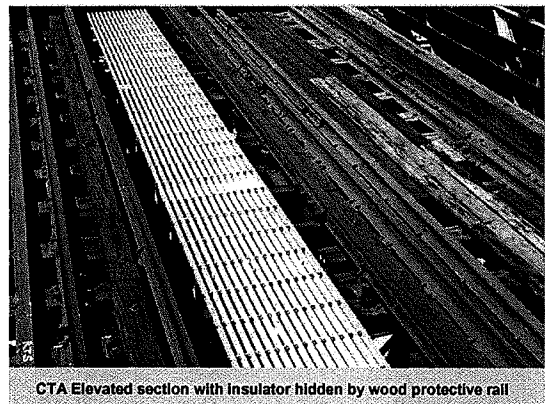
Under rail boots prevents arcing with metal cans and other trash. Although the under-rail boot program is only a quick fix for the problem, it has proven effective, and delays attributed to insulator failures have reduced somewhat.

Salt water runoff and seepage from winter street deicing operations causes the insulators to short out. Stray currents are also 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 on 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.

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.

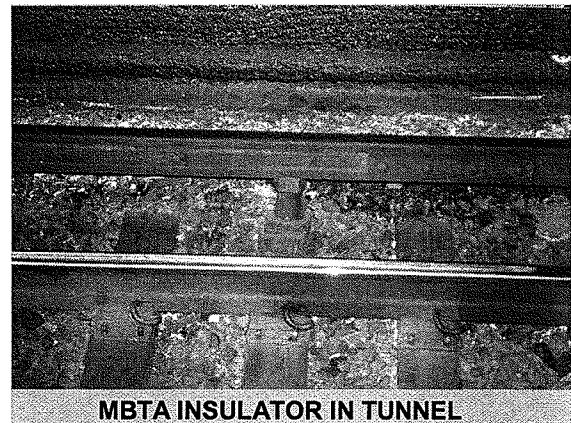


At certain locations in the tunnels, there are cooler spots, where during the summer, moving trains pull in hot and humid air. The insulator surface may be below the dew point of the humid air. If so, moisture condenses on the insulator surface and allows conduction of electricity. The wet, dirty insulator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

As the result of an insulator failure event, CTA conducted 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 left the train on the emergency catwalk. The passengers followed. Some passengers suffered smoke inhalation.

#### (8) MBTA, Boston

The MBTA rail rapid transit system has about 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. About 50 insulators fail due to dirt and arcing per year. Insulators have never been cleaned. Insulator failure on the third rail riser or end approach 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.



MBTA INSULATOR IN TUNNEL

#### **Potential Impact on Transportation Practice**

The WMATA has 225 miles of track, of which about 100 miles are in tunnels. Insulators are spaced every 10 feet apart, for a total of about 119,000 insulators. About 4,000 insulators need to be replaced annually, because of arcing due to baked-on dirt. Most of the failed insulators are located in tunnels. In 2003, the annual material cost of purchasing new insulators alone was about \$200,000 (4,000 insulators at \$50 each.) In 2007 about 5,900 new insulators were installed in tunnels at a material cost of about \$188,000, and a labor cost of \$390,000. A 4- or 5-man crew can only replace 10 to 13 insulators per night. If the nuts that hold down the insulator are rusted and frozen, the bolts may have to be cut off and new ones installed to hold down the new insulator. WMATA had a labor cost of \$173,600 for cleaning insulators in 2003. In 2007, 26,410 insulators were cleaned at an estimated labor and equipment cost of \$330,000 or about \$12 to clean an insulator.

WMATA has been 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 nearly 14 hours. During January to December, 2007, there were 19 incidents of arcing insulators that caused 12 hours of downtime, up to 1.5 hours in duration each (traction cable fires are not included).

In the National Transit Database, WMATA reported 726,130 average weekday unlinked transit trips for 1998 and 932,268 trips for 2006. 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 about \$10,200,000 per year for 1998 and \$11,200,000 for 2006.

A *Washington Post* newspaper article <http://www.washingtonpost.com/wp-dyn/content/article/2007/08/28/AR20> dated August 29, 2007, titled: Metro Blames Mechanical Failures, states: "Metro officials said the unsettling series of smoke and fire incidents that halted train travel throughout much of the system for two nights probably was caused by power and equipment failure ... Some of the fires, for example, were caused by smoldering insulators that heated up because they were damaged by water or coated with grime. The 31 year old system has about 250,000 such insulators, which are attached to the electrified third rail that powers the trains ... For two straight nights, service on the Yellow, Blue and Green lines stopped or was disrupted because of the power, fire and smoke problems. The incidents forced hundreds of disgruntled passengers off crowded trains to look for shuttle buses. ..."

Dirty insulator arcing is a major cause of downtime in the tunnels of the system. When smoke is reported, 95 percent of the time it is due to arcing.

The MTA Baltimore system has 11,000 third rail insulators. MTA recently purchased all new insulators and started to replace the insulators in the tunnels. The insulators had become unreliable because they had no way to clean them. However the insulator replacement was put on hold because the new insulators had structural issues.

The automated high speed cleaner was successfully tested on the MARTA, BART, WMATA and NYCT Metrorail systems. This project included development and product testing. Other transit agencies that participated in this project included CTA, NYCT, and SEPTA.

TRANSIT AGENCY	TRACK MILES	SPACING Feet	# Insulators
MARTA	104	10	66,000
CTA	288	8	190,000
NYCT	835	10	441,000
SEPTA	102	10	54,000
BART	268	10	142,000
WMATA	225	10	119,000
Total	1,822 miles		1,000,800

The above table is based on the FTA National Transit Database. There are more than one million

insulators nationwide, and U.S. track miles total 2,210. The percentage of the total number of U.S. insulators in the transit agencies participating in this project =  $1822/2210 = 82\%$ .

Stray currents caused by partially shorted insulators are another significant issue. Stray currents can cause operational problems with train control circuits, and significantly increase corrosion of metal components and structures in bridges, tunnels and neighboring utilities. MARTA is experiencing excessive rusting of bridges and has an issue with corrosion on an aviation fuel pipeline near their track at Atlanta Airport, but does not have the resources to clean insulators.

The only practical way proven to stop corrosion is cathodic protection. The useful life of metal structures can be reduced to 25% without protection. There are two forms of cathodic protection: impressed current and sacrificial (galvanic) cathodic protection, both of which can be costly. BART spent \$4,000,000 to install an impressed current system on a 4 mile section of tunnel and will spend \$1,000,000 every 5 years to maintain it. It is far better to clean the insulators so there are no stray currents.

Stray currents from dirty insulators run continuously and significantly increase electricity costs. The Principal Investigation on this project also conducted a study, funded by the New York State Energy Research and Development Authority, to estimate the annual cost of leakage electricity due to dirty insulators at the NYCT system. This study showed that the annual cost of leakage electricity from dirty insulators was about \$2,000,000 per year.

The insulator cleaner will improve the safety of rail rapid transit systems. After the recent terrorist attacks on the Pentagon, the World Trade Center, the Madrid and London transit systems, people are concerned about their security. Smoke and electric arcing from dirty insulators and delays in dark tunnels may cause fear and scare some people away from using rail rapid transit. The cleaning device will enhance the public perception of a safe and secure rail transit system. The automated cleaner also has the potential to reduce infrastructure corrosion due to stray currents, reduce leakage electricity costs, and improve the reliability of rail rapid transit systems.

## **Concept and Innovation**

The completed Transit IDEA project 36 *Cleaning Device For Electrified Third Rail Insulators* evaluated 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. 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 determined that the most appropriate cleaning tool was pressure washing.

A prototype 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.

In this Phase II project a higher speed prototype device was developed and tested. It was determined that pressure washing, which is typically limited to about 5000 psi, would require too much water. The same cleaning result can be achieved with lower pressure and higher flow, or higher pressure and lower flow. Since lower water use is desirable, the decision was made to go to the water jetting regime, which is typically 5000 psi to 250,000 psi. Testing showed that a stationary jet would cut a fiberglass insulator surface at about 4000 psi and a porcelain insulator at about 6000 psi. Also, a flat angle water jet loses its power very rapidly with standoff distance (distance between the nozzle tip and the insulator surface). However, a round water jet keeps its power for a standoff distance of about two inches.

A spinning round jet will clean a surface that is 0.5 inches to 2.0 inches away. The rotational speed of the spinning round jet, the pressure of the water, and the standoff distance, can be selected by bench testing so that the jet removes the surface dirt without cutting the insulator surface. Several commercially available spinning nozzles designed to clean the inside of tubes, were tested and one was found to provide adequate cleaning for a porcelain insulator with a convoluted surface. An insulator with a convoluted surface is much more difficult to clean than an insulator with a straight surface. For fiberglass insulators, the water pressure is limited to 5000 psi.

This report describes the development of an operational higher speed cleaning device, with an improved positioning arm and spinning nozzles with round jets that can clean insulators with straight or convoluted surfaces.

## **Investigation**

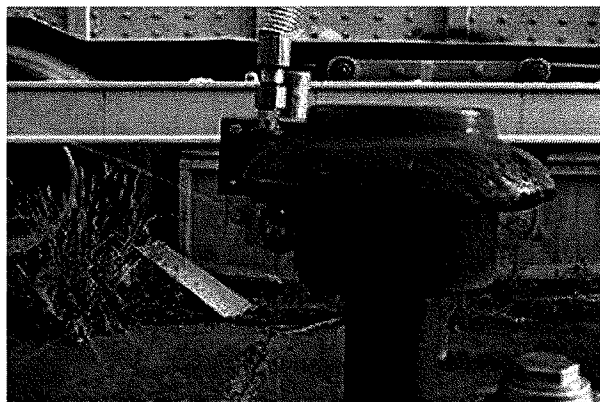
In the completed Transit IDEA Project 36, the MTA, Baltimore, WMATA, BART, MARTA, CTA, NYCT, SEPTA and MBTA were visited to determine their third rail insulator cleaning procedures and needs. The Principal Investigator worked closely with the MTA, Baltimore and WMATA staff to establish that pressure washing with tap water was the most desirable cleaning tool. An adjustable U-shaped prototype cleaning station was constructed. Four pressure washing nozzles were located at the four corners of the cleaning station. Further cleaning tests of porcelain and fiberglass insulators by pressure washing with tap water at pressures ranging from 3000 to 7000 psi were performed. It was seen that water at 5000 psi cuts fiberglass, if the jet is allowed to dwell on the insulator.

For the advanced high speed cleaning device developed and tested in this project, the use of flat jet nozzles was investigated. If flat jet nozzles were to be used, an array of very small flat jet nozzles would be needed to fit into the limited space around the insulator. The Principal Investigator visited all major nozzle manufacturers in the U.S., Switzerland, and Germany to obtain small nozzles, but they are not available off-the-shelf. Moreover, a large number of flat jet nozzles will

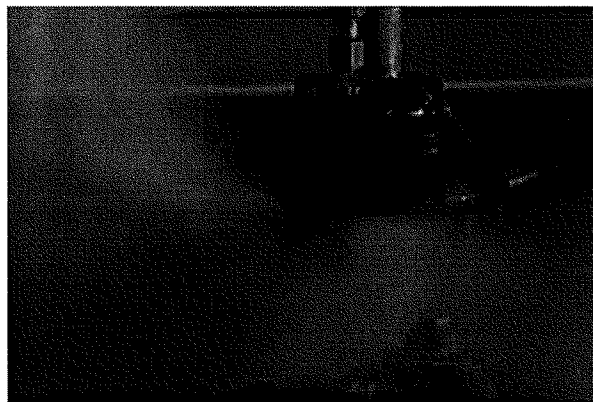
be needed to clean convoluted surfaces such as that of a BART, MARTA, or WMATA porcelain insulator. The standoff distance changes by over one inch and a flat jet has a working range of only half an inch, and can clean a band that is half inch high. For example, at least six nozzles would have to be stacked in a vertical array to clean an insulator height of three inches. Further, the nozzles would have to mirror the insulator profile which is not fixed. Consequently, the flat jet nozzle array could not be used in a cleaner to clean multiple grooves because the locations and dimensions of the grooves are not constant and space around the insulator is limited.

A round jet has a working range of about 2 inches for this application. The Principal Investigator designed, made and bench tested a non-spinning nozzle for cleaning a groove, with multiple round jets arranged in a spiral. This nozzle is shown in Figure 1. This nozzle did an effective job of cleaning the groove. 10,000 psi was used on the porcelain insulators and 4000 psi on the fiberglass insulators. The non-spinning spiral nozzle was more efficient than a spinning nozzle in its use of water, as all the water was directed to the insulator surface. However, this nozzle was difficult to fabricate and several such nozzles would have to be stacked in a vertical array to clean multiple grooves at the same time. This would make the cleaner too large to use in the limited space available around the insulator. Also, this nozzle would not work well on a straight walled fiberglass insulator and a round jet can cut fiberglass, unless the dwell time is limited.

Bench testing showed that a spinning jet can clean a convoluted surface with a dwell time that will remove dirt but not cut the insulator. Two spinning jets with multiple radial jets were evaluated. The first nozzle, shown in Figure 2, rotated at extremely high speed, about 33,000 RPM and 10,000 psi and was good for cleaning a medium level of surface dirt. The second spinning jet, shown in Figures 3 and 4, rotated at about 3500 RPM, had bigger jets and had more cleaning capability. However, the two spinning jets tested did not have the capability of being used at 4 corners of a U shaped cleaner as needed. Moreover, they used too much water. A spinning jet with forward pointing axial nozzles was also evaluated but it would not fit into the tight clearance envelope around insulators.



**Fig 3. Second spin jet with multiple nozzles in idling mode at NYCT insulator**



**Fig 4. Second spin jet with multiple nozzles in operating mode at NYCT insulator**

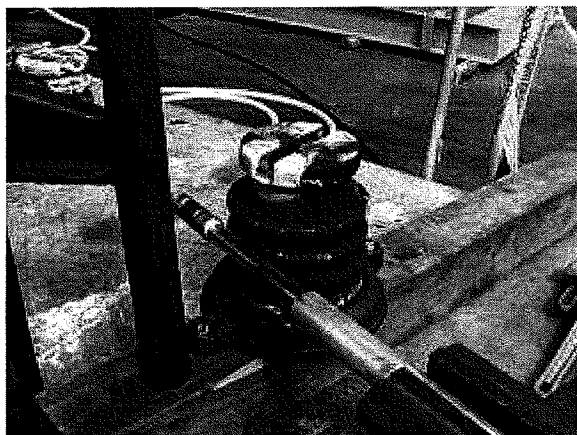


Fig 5. Third Spinning jet with less water use at WMATA insulator



Fig 6. Advanced automated cleaner at BART

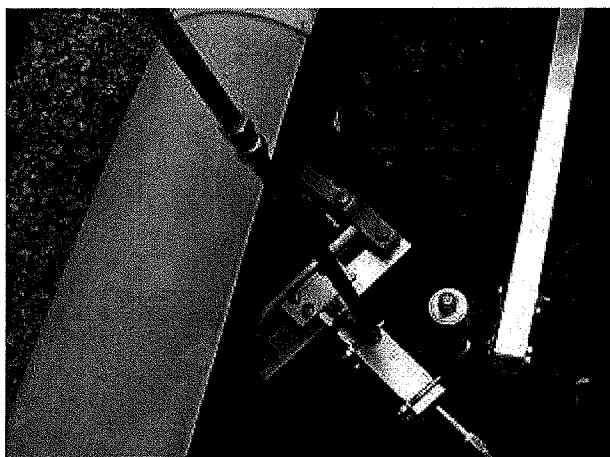


Fig 7. Advanced automated cleaner in start position at MARTA insulator

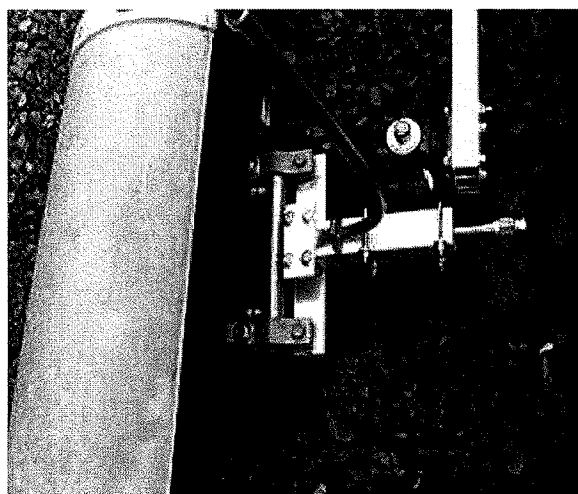


Fig 8. Advanced automated cleaner in midway position at MARTA insulator

A third spinning jet, as shown in Fig. 5, was bench tested and shown to adequately clean a WMATA insulator. The third spinning jet did a better job than the earlier two. Two of these spinning nozzles could be screwed together one behind the other to create a double nozzle. A cleaning station was developed with two double nozzles, attached to the two ends of a supply header, creating a U shaped cleaner. This cleaner, with 4 spinning round jets at 4 locations in a manifold that rotates around the insulator and cleans all the way round it, eliminated the problem of not being able to clean the back of the insulator with a hand held pressure washing gun. This higher speed automated cleaner was successfully tested at MARTA, WMATA, BART and NYCT and successfully cleaned extremely dirty insulators with a convoluted surface that had been discarded because they were deemed impossible to clean.

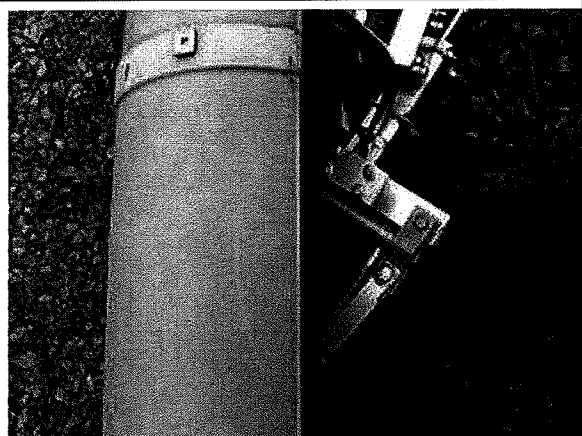


Fig 9. Advanced automated cleaner in finished position at MARTA

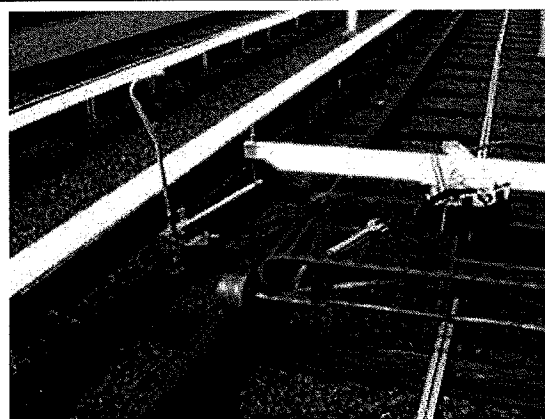


Fig 10. Advanced automated cleaner at WMATA

### Plans for Implementation

The demonstrations of the automated cleaning device for third rail insulators were shown to staffs of the participating transit systems. Videos of the cleaning device demonstrations were also made available to the staff of other transit agencies that expressed interest in this project. The results of demonstrating the higher speed automated cleaning device on the MARTA system were shown at the June 2007 APTA Rail Transit Conference in Toronto as an interactive presentation. Results of the demonstrations at MARTA, BART, and WMATA rail rapid transit systems will also be disseminated by the Principal Investigator via presentations at professional meetings, conferences, and trade shows of transit organizations and associations.

As a result of the success of this Transit IDEA project and the need and interest of transit agencies, a follow-on project was funded for \$100,000 by the Federal Transit Administration via the Department of Transportation's Small Business Innovative Research Program (SBIR). The transit agencies involved in the Transit IDEA project are also participating in the follow-on SBIR project to develop a higher speed second generation automated clean-in-place system called the Spin Wedge. The SBIR Phase I report titled: "High Speed, Low Water Consumption Insulator Cleaner", was funded and has been successfully completed. Phase II SBIR funding is under consideration.

The Principal Investigator also received another \$100,000 in follow-on funding from the New York State Energy Research and Development Authority (NYSERDA) to estimate the annual cost of dirty insulators that leak electricity at NYCT. The study titled: "Reducing Electric Losses from Rail Transit Insulators" estimated that NYCT could save nearly \$2,000,000 per year calculated at an electric rate of 9 cents/Kilowatt-hour.

A cleaning equipment package for third rail insulators consisting of an advanced automated cleaning device, water tank and pump could be acquired by an interested transit agency.

## **Conclusions**

Since insulators on the same track typically are made of fiberglass and/or porcelain and come in a variety of shapes and sizes, it was important to have a cleaner that would work well with all insulators on a particular transit system. It was determined that high pressure water jets were the most appropriate cleaning tool.

Several types of nozzles were tested. They included flat jets, a specially designed nozzle with multiple round jets and spinning round jets. Flat jets were not effective since their working range was less than half an inch for this application. Moreover, very small flat jets needed are not available. Even if small flat jets were available, a nozzle array that would follow the profile of an insulator surface, and be adjustable to match changing insulator profiles, cannot be made.

A special nozzle with multiple round jets in a spiral was also designed and tested by the Principal Investigator. This nozzle was shown to be effective in cleaning a groove of BART, MARTA and WMATA porcelain insulators. However, it could not be used as an array in a cleaner to clean the multiple grooves because the locations and dimensions of the grooves are not constant and space around the insulator is limited.

Three different spinning nozzles with multiple radial round jets were also tested. Round jets do not dissipate their power as rapidly as fan jets and have a working range of about 2 inches. Since the dwell time is short, spinning jets can be tuned to remove dirt and not cut the insulator surface by optimizing the rotational speed, the standoff distance, the flow rate and the supply water pressure. The third spinning nozzle tested used less water than the other two, while still being effective in cleaning dirty insulators.

A cleaning device was made with 4 spinning radial jets at 4 locations in a manifold that rotates around the insulator and cleans all the way round it. This advanced automated cleaner was successfully tested at MARTA, WMATA, BART, and NYCT.

Water consumption is a concern, both to carry the water to the site, and for the inverts to carry away large volumes of water. This could be addressed by designing and fabricating a radically different type of nozzle. Very high speed cleaning is also desired by transit agencies. The Principal Investigator has received direct funding from the U.S. Federal Transit Administration and is developing a higher speed second generation automated clean-in-place system called the Spin Wedge that meets these needs.

A U.S. Patent has been issued and International Patent Applications have been filed for the automated cleaning device and process.

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