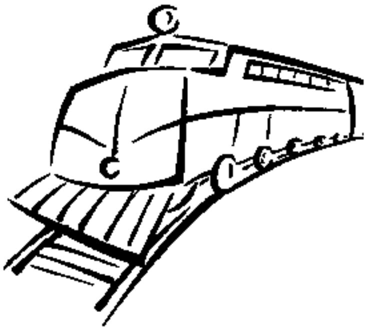
# LMOA

Locomotive Maintenance Officers Association



# Proceedings of the 70th Annual Meeting

## September 21 - 24, 2008

Chicago Hilton & Towers

720 S. Michigan Ave.

Chicago, Illinois

# 2008 ADVERTISERS INDEX

## LOCOMOTIVE MAINTENANCE OFFICERS ASSOCIATION

# LOCOMOTIVE MAINTENANCE OFFICERS APPRECIATES THESE 2008 SUPPORTING ADVERTISERS

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We appreciate the fine financial support these advertisers provide.
We hope to see **these and many more** advertisers' names displayed in this fashion at all of our future **ANNUAL MEETINGS.**
Be sure to read their ads in the Annual Publication.

# INDEX

# 2007 LMOA MVP RECIPIENTS

The executive board of LMOA wishes to congratulate the following individuals who were selected as the Most Valuable People of their respective committees in 2007.

| Name | Company | Committee |
|---|---|---|
| Ian Bradbury | Peaker Services | Diesel Mechanical Maintenance |
| Roger Collen | Simmons Machine Tool | Shop Equipment & Processes |
| Dennis McAndrew | GE Rail Transportation | Fuel, Lubricants & Environmental |
| Todd Nudds | ZTR Control Systems | Diesel Electrical Maintenace |
| Craig Prudian | Electro Motive Diesels | New Technologies |
| Ron Sulewski | Rail Products International | Diesel Material Control |

This honor is bestowed on an annual basis to those individuals who perform meritorious service and make significant contributions to their respective technical committees.

## LMOA EXECUTIVE COMMITTEE

**THE EXECUTIVE COMMITTEE OF LMOA WISHES TO EXPRESS THEIR SINCERE THANKS AND APPRECIATION TO THE AMERICAN SHORTLINE AND RAILROAD REGIONAL ASSOCIATION FOR ALLOWING MEMBERS OF THE LMOA EXECUTIVE COMMITTEE TO ATTEND THEIR ANNUAL MEETING IN SAN ANTONIO ON MAY 4-5, 2008**

**WE ALSO WISH TO THANK THE ASLRRA FOR ALLOWING SIX OF OUR COMMITTEE MEMBERS TO PRESENT TECHNICAL PAPERS BEFORE ATTENDEES AT THE ASLRRA CONVENTION ON MONDAY, MAY 5, 2008.**

**SPECIAL THANKS TO RICHARD TIMMONS, PRESIDENT OF THE SHORTLINE ASSOCIATION AS WELL AS KATHY CASSIDY AND JENNY MCKINNEY FOR GIVING LMOA THE OPPORTUNITY TO ATTEND THE CONVENTION AND TO OUR OWN JACK KUHNS, LMOA 3RD VP, FOR MAKING OUR INVOLVEMENT AT THE SHORTLINE ASSOCIATION ANNUAL MEETING A POSSIBILITY.**

**THE LMOA EXECUTIVE BOARD WOULD LIKE TO EXPRESS THEIR SINCERE APPRECIATION TO JOHN HEDRICK, STEVE FRITZ AND THE ENTIRE STAFF AT THE SOUTHWEST RESEARCH INSTITUTE FOR HOSTING OUR JOINT TECHNICAL COMMITTEE MEETING ON MAY 4 AND MAY 5, 2008 IN SAN ANTONIO, TEXAS AND FOR PROVIDING TOURS OF THEIR CAMPUS AT SOUTHWEST RESEARCH.**

**MANY THANKS FOR JOHN AND STEVE.**

**WE ALSO WISH TO THANK RICK ORTYL OF METRO EAST AND BRIAN MARTY OF HELM FOR HOSTING THE JOINT TECHNICAL COMMITTEE'S LUNCHEONS IN SAN ANTONIO.**

**MANY THANKS TO RICK AND BRIAN AND SPECIAL THANKS TO OUR OWN DENNIS NOTT, LMOA 1ST VP, FOR HIS INVOLVEMENT IN SETTING THE LUNCHEONS UP.**

**LMOA WISHES TO EXPRESS THEIR GRATITUDE AND THANKS TO DWIGHT BEEBE OF TEMPLE ENGINEERING FOR AGAIN HOSTING OUR LUNCHEON ON FRIDAY, SEPTEMBER 14, 2007 DURING THE ANNUAL CONVENTION IN CHICAGO HILTON AND TOWERS.**

**DWIGHT, YOU'RE THE BEST.**

# PAST PRESIDENTS

| | |
|---|---|
| 1939 & 1949 - | F. B. DOWNEY (Deceased) Shop Supt., C & O Ry. |
| 1941 - | J. C. MILLER (Deceased ), MM, N.Y.C. & St. L.R.R. |
| 1942-1946, Inc. - | J. E. GOODWINN (Deceased) Exec. Vice President, C. & N.W. Ry. |
| 1947 - | S. O. RENTSCHILLER (Deceased) Chief Mechanical Officer, Bessemer and Lake Erie R.R. |
| 1948 - | C. D. ALLEN (Deceased) Asst. C.M.O. - Locomotive, C. & O. Ry. & B. & O. R.R. |
| 1949 - | J. W. HAWTHORNE (Deceased) Asst. Vice-Pres.- Equipment, Seaboard Coast Line R.R. |
| 1950 - | G. E. BENNET (Deceased) Vice-Pres.-Gen. Purchasing Agent, C. & E. I. Ry. |
| 1951 - | P. H. VERD (Deceased) Vice-Pres.-Personnel, E. J. & E. Ry. |
| 1952 - | H. H. MAGILL (Deceased) Master Mechanic, C. & N. W. Ry. |
| 1953 - | S. M. HOUSTON (Deceased) Gen. Supt. Mech. Dept. Southern Pacific Co. |
| 1954 & 1955 - | F. D. SINEATH, Retired Chief of Motive Power, Seaboard Coast Line R.R. |
| 1956 - | T. T. BLICKLE (Deceased) General Manager - Mechanical, A .T. & S. F. Ry. |
| 1957 - | J. T. DAILEY (Deceased) Asst. to Pres.-Mech., Alton & Southern R.R. |
| 1958 - | F. E. MOLLOR (Deceased) Supt. Motive Power, Southern Pacific Co. |
| 1958 - | F. R. Denny (Deceased) Mechanical Supt., New Orleans Union Passenger Terminal |
| 1959 - | E. V. MYERS (Deceased) Supt. Mechanical Dept., St. Louis-Southwestern Ry. |
| 1960 - | W. E. LEHR (Deceased) Chief Mechanical Officer, Pennsylvania R.R. |
| 1961 - | O. L. HOPE, (Deceased) Asst. Chief Mechanical Officer, Missouri Pacific R.R., |
| 1962 - | R. E. HARRISON (Deceased) Manager-Maintenance Planning & Control, Southern Pacific Co. |
| 1963 - | C. A. LOVE, (Deceased) Chief Mechancial Officer, Louisville & Nashville R.R. |
| 1964 - | H. N. CHASTAIN, (Deceased) Gen. Manager-Mechanical, A. T. & S. F. Ry. |
| 1965- | J. J. EKIN, JR. (Deceased) Supt. Marine & Pier Maintenance, B. & O. R.R. |
| 1966 - | F. A. UPTON II (Deceased) Asst. Vice-President-Mechanical, C. M. St. P. & P. R.R. |
| 1967 - | G. M. BEISCHER, Retired Chief Mechancial Officer, National Railroad Passenger Corp. Washington, D.C. 20024 |
| 1968 - | G. F. BACHMAN, (Deceased) Chief Mechanical Officer, Elgin Joilet & Eastern Ry. |
| 1968 - | T. W. BELLHOUSE (Deceased) Supt. Mechanical Dept., S. P. Co., - St. L. S.W. Ry. |
| 1970 - | G. R. WEAVER (Deceased) Director Equipment Engineering, Penn Central Co., |
| 1971 - | G. W. NEIMEYER (Deceased) Mechanical Superintendent, Texas & Pacific Railway |
| 1972 - | K. Y. PRUCHNICKI (Deceased) General Supervisor Locomotive Maintenance, Southern Pacific Transportation Company |
| 1973 - | W. F. DADD, (Deceased) Chief Mechanical Officer, Chessie System |
| 1974 - | C. P. STENDAHL, Retired General manager M.P.-Electrical, Burlington Northern Railroad |
| 1975 - | L. H. BOOTH, (Deceased) Retired Assistant C.M.O.-Locomotive, Chessie System, |
| 1976 - | J. D. SCHROEDER, Retired Assistant C.M.O.-Locomotive Burlington Northern Railroad, 244 Carrie Drive, Grass Valley, CA 95942 |
| 1977 - | T. A. TENNYSON (Deceased) Asst. Manager Engineering-Technical, Southern Pacific Transportation Co. |
| 1978 - | E. E. DENT, (Deceased) Superintendent Motive Power, Missouri Pacific Railroad, |
| 1979 - | E. T. HARLEY, Retired Senior Vice President Equipment, Trailer Train Company, 289 Belmont Road, King of Prussia, PA 19406 |

| | |
|---|---|
| 1980 - | J. H. LONG, (Deceased) Manager Locomotive Dept., Chessie System |
| 1981 - | R. G. CLEVENGER, Retired General Electrical Foreman, Atichison, Topeka & Sante Fe Rwy. |
| 1982 - | N.A. BUSKEY (Deceased) Asst. General Manager-Locomotive, Chessie System |
| 1983 - | F. D. BRUNER (Deceased) Asst. Chief Mechanical Officer-R. & D. Union Pacific Railroad |
| 1984 - | R. R. HOLMES, Retired, Director Chemical Labs and Environment, Union Pacific |
| 1985 - | D. M. WALKER, Retired, Asst. Shop Manager, Norfolk Southern Corp., 793 Windsor St., Atlanta, GA 30315 |
| 1986 - | D. H. PROPP, Retired Burlington Northern RR & Vice President, Ontrack, 8913 West 161st St., Overland Park, KS 66085 |
| 1987 - | D. L. WARD, (Deceased) Coord.-Quality Safety & Tech. Trng. Burlington Northern R.R. |
| 1988 - | D.G. GOEHRING, Retired, Supt. Loco. Maint., National RR Passenger Corp., 1408 Monroe, Lewisburg, PA 17837 |
| 1989 - | WILLIAM A. BROWN, Retired, I&M Rail Link, 9047 NE 109th St., Kansas City, MO 64157 |
| 1990 - | P. F. HOERATH, Retired Sr. Mech, Engr. Shops, Conrail, . Box 134, R.R. 4, Hollidaysburg, PA 16648 |
| 1991 - | D. D. HUDGENS, Retired, Sr. Mgr. R & D, Union Pacific, 16711 Pine St., Omaha, NE 68130 |
| 1992 - | K. ALLEN KELLER, Retired, Supt. Loco. Maint., Reading, R.R., 241 E. Chestnut, Cleona, PA 17042 |
| 1993 - | W. R. DOYLE, Project Manager, Sound Transit, Seattle, WA 98104 |
| 1994 - | M.A. COLES, Senior Mgr.-Loco. Engineering & Quality, Union Pacific R.R. 1400 Douglas St., Stop 1050, Omaha, NE 68179 |
| 1995 - | C.A.MILLER, Retired, Mgr.-Loco. Engineering & Quality, Union Pacific RR. 1728 S. 167 Circle, Omaha, NE 68130 |
| 1996 - | G.J. BRUNO, Retired, Supt. - Mechanical, Amtrak, 14142 S.E. 154th Pl., Renton, WA |
| 1997- | D.M. WETMORE, General Supt. - Fuel Opns., NJT Rail Opns. 1148 Newark Turnpike, Kearny, NJ 07032 |
| 1998- | H.H. (MIKE) PENNELL, Ellcon National, 1016 Williamsburg Lane, Keller, TX 76248 |
| 1999- | JAKE VASQUEZ, Retired, Asst. Superintendent-Terminal Services, Amtrak 1130 Walnut Ave., Osawatomie, KS 66067 |
| 2000- | RON LODOWSKI, Asst. Shift Supt., CSX Transportation Selkirk, NY 12158 |
| 2001- | LOU CALA, Consultant, LJC Rail, Duncansville, PA 16635 |
| 2002- | BOB RUNYON, Engineering Consultant, Roanoke, VA 24019 |
| 2003- | BRIAN HATHAWAY, Consultant Port Orange, FL 32129 |
| 2004- | BILL LECHNER, Senior General Foreman-Insourcing-Air Brakes, Governors & Injectors, Norfolk Southern Corp., Altoona, PA 16601 |
| 2005- | TAD VOLKMANN, Director-Mechanical Engineering, Union Pacific RR, Omaha, NE 68179 |
| 2006- | BRUCE KEHE, Mgr.-Maint. Locomotive, EJ & E Rwy. Gary, IN 46402 |
| 2007- | LES WHITE, Technical Sales Rep., Bach-Simpson London, Ontario N4W 2C2 |

## HONORARY LIFE MEMBERS

| | |
|---|---|
| **F. W. BUNCE,** | Retired Chief Mech. Officer, Milwaukee Road. |
| **J. J. BUTLER,** | Retired Chief Mech. Officer, Consolidated Rail Corp., 158 Woodgate Ln., Paoli, PA 19301 |
| **OWEN CLARKE,** | Retired Vice-President, Chesapeake & Ohio Ry., Cleveland, Ohio |
| **B. A. CUMBEA,** | Retired Mgr. Loco. Maint.-Engr., Chessie System, 310 Cherokee Trail, Huntington, WV 25705 |

| | |
|---|---|
| **N. C. ECKERLE,** | Sales Mgr. Specialty Chem., Nalco Chem. Co., 2901 Butterfield Rd., Oak Brook, IL 60521 |
| **W. EWING,** | Retired, Altoona Gear Co., Calbassas, CA |
| **W. T. FARICY,** | Retired Chairman of the Board, A.A.R. |
| **J. G. GERMAN,** | Retired V. Pres.-Engr. Missouri Pacific Railroad Co. |
| **J. J. GREGORY,** | Retired Project Mgr.-Heavy Repair Shop, Consolidated Rail Corp., 603 Ruskin Drive, Altoona PA 16602 |
| **DONALD GRAAB,** | AVP-Mechanical, Norfolk Southern, 1200 Peachtree, Atlanta, GA 30309 |
| **S. GRAHAM HAMILTON,** | President, Global Group, Inc., P.O. Box 2024, Winter Park, FL 32790 |
| **W. J. HARRIS,** | Retired V. Pres., Research & Test Dept., Assn. of American Railroads, Washington, D.C. |
| **H. W. HAYWARD,** | Retired Chief M.P. & R. S., CP Rail, Montreal 101, Quebec, Canada |
| **D. W. HENDERSON,** | V.P.-Technology, Engr. & Maint. Burlington Northern RR, 9401 Indian Creek Pkwy., Overland Park, KS 66210 |
| **JOHN H. HERTOG,** | Retired V. Pres. Operations, Burlington Northern, Inc., St. Paul, MN 55101 |
| **JOHN W. INGRAM,** | Retired Pres. and Chief Executive Officer, Chicago, Rock Island and Pacific Railroad Co. |
| **A. W. JOHNSON,** | Retired, V. Pres. of Opns. and Maint., Assoc. of American RR, Washington, D.C. |
| **JACK L. KUHNS,** | Retired Mgr. Plng. & Maint., CSX Transp., 7015 Bedford Lane, Louisville, KY 40222 |
| **R. M. McDONALD,** | Retired Dir. of Opns., Brd. of Transport, Commissioners for Canada, Ottawa, Ont., Canada |
| **J. F. McDONOUGH,** | Retired Asst. V. P.-Mechanical, Union Pacific RR, 12225 Farnum St., Omaha, NE 68154 |
| **R. G. RAY BURN,** | Retired Executive V.P.-Operations, Chessie System, Baltimore, MD |
| **H.P. RODES,** | Pres., General Motors Institute, Flint, MI 48502 |
| **F. R. RUSSELL,** | Retired Chief Mech. Off., Southern Pacific Co., San Francisco, CA |
| **L. G. SALTS,** | Retired, Asst. Manager-Locomotives AT&SF Rwy., Topeka, KS |
| **H. L. SCOTT, JR.,** | Retired Sr. V.P. and Chief Mech. Off. Norfolk Southern, Corp. |
| **C. M. SMITH,** | Retired Mgr-Mech. Engr.-Passenger and Loco. Consolidated Rail Corp., 3 Princeton Rd., Strafford-Wayne, PA 19087 |
| **R. D. SPENCE,** | Retired Executive V.P.-Operations, Seaboard System RR |
| **J. TAGGART,** | Retired System Mechanical Officer-Motive Power, CN Rail, 655 Richmond Road, Unit 45, Ottawa, Ontario K2A 3Y3 |
| **M. L. VARNS,** | Retired, BN RR, 111 So. Greenfield Rd. #385, Mesa, AZ 85206 |
| **R. W. VITEK,** | VP - Sales and Leasing, Omnitrax, Cicero, IL |

# OUR OFFICERS

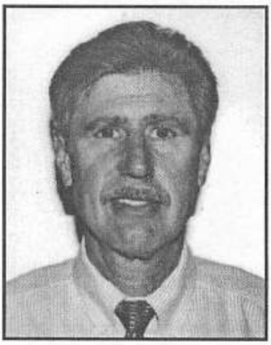
Our President
**MIKE SCARINGE**
**Director-Warranty Enforcement**
Amtrak
Beech Grove, IN 46107

Our Chairman of the Nominating Committee
**MR. LES WHITE**
**Technical Sales Representative**
Bach Simpson
London, Ontario N4W 2C2

# OUR OFFICERS

1st Vice President
**MR. DENNIS NOTT**
**Northwestern Consulting, LLC**
Boise, ID 83703

2nd Vice President
**MR. BOB REYNOLDS**
**Manager - Loco Systems**
Canadian Pacific Railway
Calgary, Alberta T2P 4Z4

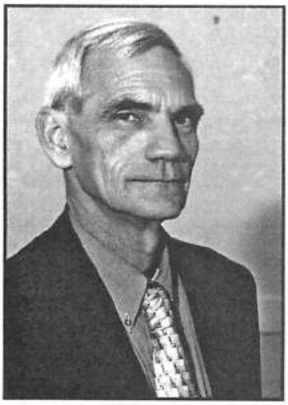


3rd Vice President
**MR. JACK KUHNS**
**Senior Director Business Development and Sales**
Graham White Manufacturing
Jacksonville, FL 32259

# OUR PAST PRESIDENTS

**MR. MARK COLES**
**Senior Manager**
**Engineering & Quality**
Union Pacific Railroad
Omaha, NE 68179

**MR. WEYLIN R. DOYLE**
**Project Manager**
Sound Transit
Seattle, WA 98104



**MR. BRIAN HATHAWAY**
**Consultant**
Port Orange, FL 32129

**MR. BRUCE KEHE**
**Manager-Maintenance**
**Locomotives**
EJ&E Rwy. Co
Gary, IN 46402

# OUR PAST PRESIDENTS

**MR. BILL LECHNER**
**Sr. General Foreman**
**Insourcing-Air Brakes, Governors & Injectors**
Norfolk Southern Corp.
Altoona, PA 16601
Bill also doubles as Regional Executive of the Diesel Material Control Committee

**MR. RONALD R. LODOWSKI**
**Asst. Shift Superintendent**
CSX Transportation
Selkirk, NY 12158

**MR. H.H (MIKE) PENNELL**
Ellcon National
Keller, TX 76248

**MR. ROBERT RUNYON**
(Retired Norfolk Southern Corp.)
Engineering Consultant
Roanoke, VA 24042

# OUR PAST PRESIDENTS

**MR. TAD VOLKMANN**
**Director-Mechanical Engineering**
Union Pacific Railroad
Omaha, NE 68179

**MR. DAVID M. WETMORE**
**General Supt. - Fuel Operations**
NJT Rail Opns
Kearny, NJ 07032

# OUR REGIONAL EXECUTIVES

**MR. RON BARTELS**
**Director Electrical and Engine Sys.**
Via Rail-Canada
Montreal, Quebec

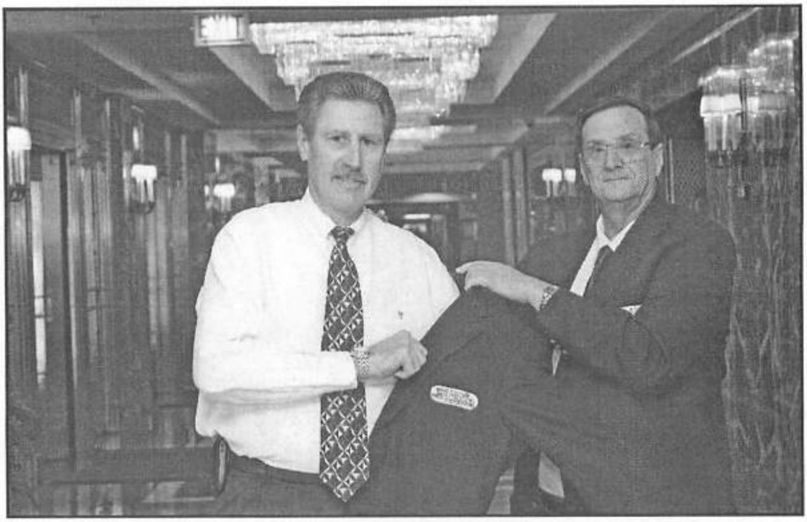
**MR. GLENN BOWEN**
**Director - Lab Services**
BNSF Railway
Topeka, KS

**R. BRAD QUEEN**
**General Foreman-Locomotives**
BNSF Railway
Barstow, CA

Chairman
**DAVE RUTKOWSKI**
**Chief Mechanical Officer**
Providence & Worcester RR
Worcester, MA


Outgoing President Les White, Bach Simpson, presents the President's Gavel to newly elected President, Mike Scaringe, Amtrak.

Past President Tak Volkmann, Union Pacific presents Past President's Pin to outgoing President, Les White, Bach Simpson, as newly elected President Mike Scaringe, Amtrak looks on.



Outgoing President Les White, Bach Simpson, presents the LMOA Blazer to newly elected 3rd Vice President, Jack Kuhns, Graham White Corporation.

Past President, Bob Runyon, Consultant, presents LMOA watch to outgoing President Les White, Bach Simpson. The ceremony was witnessed by Past President Tad Volkmann, Union Pacific.

Dwight Beebe, Temple Engineering, proudly holds the LMOA Most Valuable Person Award. Past President Bruce Kehe, EJ&E (r) and outgoing President Les White, Bach Simpson were present. This award was bestowed on Dwight for his continuing support of the LMOA.

Officers of the LMOA: bottom row - left to right - Secretary Treasurer Ron Pondel, Past President Bob Runyon, Consultant (former NS), newly appointed President Mike Scaringe, Amtrak, Past President Tad Volkmann, Union Pacific, and newly elected 1st Vice President Dennis Nott, Northwestern Consulting. Top row - left to right - newly elected 2nd Vice President Bob Reynolds, Canadian Pacific Rwy., outgoing President Les White, Bach Simpson and Past President Bruce Kehe, EJ&E Rwy.

**STATE OF THE UNION SPEECH**
**President Les White**
**September 13, 2007**

Ladies and gentlemen, the Executive Committee and fellow members. It is my privilege to open the 69th Annual meeting of the Locomotive Maintenance Officers Association.

I wish I could open this State of the Union Speech on a positive note but it is with great sadness that I have to report the passing of one of our former Past Presidents, Mr. Jim Long, Retired Manager Locomotive Dept., Chessie Systems. Jim was a great supporter of the LMOA and for those of you that didn't know he was the gentleman that designed the LMOA Past Presidents Pin. It would be appreciated if we could have a moment of silence in memory of Jim and also for the memory of the U.S., Canadian and British troops that have given the ultimate overseas...Thank You...

We held our joint technical committee meetings April 30 - May 1, 2007 at the Wabtec Railway Electronics facility in Germantown, Maryland. As usual we had an excellent turnout of 60 plus members. I wish to extend the gratitude of the LMOA to Wabtec for their hospitality and tours provided in particular by Bob Bourg and Diane Hopkins. In addition a special thanks to Rick Ortyl for providing a lunch and Mike Scaringe and Amtrak for providing tours of their Ivy City maintenance facility. Mike was kept very busy as tour organizer, guide and driver which was greatly appreciated by all members. I see Mike didn't give up his day job so I guess I will be able to pass on the gavel to you tomorrow. Thanks for your special effort in making our joint meeting a success.

This is a non show year and with the limited support of the RSI in non show years we depend on Table Top presenters and Sponsors to make these proceedings possible. I urge everyone attending to visit our Table Top presenters not only to view their products but also thank them for their support. We have extended our coffee breaks to allow our members more time to view the Table Top presentations.

We have 73 table-top presenters and have collected $12,700.00 towards sponsorship of 2 Continental Breakfasts, 4 Coffee Breaks and a 1 & 1/2 hour beer and wine reception this evening from 5:00 - 6:30. I would like to thank our Table Top Presenters, Food & Beverage Sponsors and RSI Scholarship Sponsors for their support.

Our food and beverage sponsors are:

Bach-Simpson Corporation
MPL Technology Incorporated
National Electrical Carbon Products
New York Aire Brake Company
Norfolk Southern Corporation
PTMW Incorporated
Railpower Technologies
TTCI Incorporated
Union Tank Car Company
Railway Supply
Coordinated Mechanical Assoc.

Our RIS Scholarship Sponsors' are: ($22,470.00)

Amsted Industries
H.K. Burke, LMOA, Australia
Air Brake Assoc. in memory of Henry Christie
Edna A Rice Executive Recruiters
Standard Car Truck Company
Tom Simpson, RSI Washington
Howard & Marilyn Tonn, RSI Chicago
Union Tank Car Company
Railway Supply Association, Inc.

The support of these companies, associations and individuals is greatly appreciated.

On Aug. 13, 2007 there was a news release in railwayage.com concerning the RSI trade show for 2011. I would like to take a moment to share a short excerpt from this release for anyone that may not be aware of the changes coming.

The Railway Supply Institute is taking preliminary steps to address an issue that concerns many in the railway industry: too many trade association exhibits to attend. According to a statement issued by RSI Board Chairman Paul Wilson, the RSI Governing Board "has been discussing the future of the biennial RSI trade show held in conjunction with the Coordinated Mechanical Association meetings in Chicago." He referred to a letter from NACE (North American Chief Engineers) to REMSA (Railway Engineering-Maintenance Suppliers Association) and RSSI (Railway Systems Suppliers, Inc.) that "expresses [NACE members'] concerns regarding the number of trade shows they are asked to "support" and "strongly advocates those two organizations join AREMA (American Railway Engineering Maintenance-Of-Way Association) in a joint trade show as soon as practicably possible." Wilson said that "subsequent conversations between RSI Board members and representatives from NACE and other senior railroad officials resulted in their urging RSI to join RSSI, REMSA, and AREMA in Minneapolis in 2011." Following this, the RSI Board "voted unanimously to support a joint trade show."

I had a conversation with Howard Tonn, Executive Director, RSI-Chicago and he has assured us this decision will not impact the 2008 indoor/outdoor exhibits nor the 2009 table top exhibits both scheduled for Chicago. I also understand from Howard that this change to Minneapolis will be a major undertaking to set up, as it may require the use of three hotels for the associations and shows involved. We can well understand the logistics setting up something of this scale and wish him luck in his endeavors. This will be something to look forward to in 2011.

In closing, I would like to thank my previous employers Canadian National, EMD and my present employer Bach-Simpson for the support they have given me over the years and the continuing support they are giving to the LMOA. I also have to thank my First Lady Lynn and my sons Stephen and Shawn for their unwavering support and understanding through all the years of working in the rail industry. Last but not least a special thank you to the LMOA corner stone Mr. Ron Pondel our Secretary/Treasurer. Ron's devotion to the LMOA goes without saying and he has kept many a president on the straight and narrow. Ron, your help and guidance over the years is greatly appreciated not only by myself but numerous others in our association past and present but above all I am especially proud to be able to call you a friend. Thanks Ron.

# REPORT OF THE COMMITTEE ON FUEL, LUBRICANTS AND ENVIRONMENTAL
# MONDAY, SEPTEMBER 22, 2008 10:15 A.M.

Chairman
**TOM PYZIAK**
Senior Account Executive
Safety-Kleen Systems
Palatine, IL

Vice Chairman
**BOB DITTMEIER**
Customer Technical Service
Afton Chemical Corp.
Richmond, VA

## COMMITTEE MEMBERS

| | | | |
|---|---|---|---|
| D. Beebe | Vice President | Temple Engineering | Liberty, MO |
| K. Bills | VP-RR Operations | Searle Petroleum Co. | Council Bluffs, IA |
| R. Dunn | Consultant | CN | Pierrefonds, Que |
| S. Fritz, P.E. | Mgr. Med. Spd. Dsl. Eng. | Southwest Research Inst. | San Antonio, TX |
| F. Girshick | Technologist | Infineum USA L.P. | Linden, NJ |
| L. Haley, Jr. | Chief Chemist | Norfolk Southern Corp. | Chattanooga, TN |
| D. Koehler | RR Business Mgr. | Predict USA | Cleveland, OH |
| C. Kunkel | Sr. Mgr.-R& D | Union Pacific RR | Omaha, NE |
| G. Lau | Sr. Rel. Specialist | Canadian Nat'l | Edmonton, Alberta |
| R. Lodowski | Asst. Supt. | CSX Transportation | Selkirk, NY |
| M. Maddox | Tech. Support | Industrial Specialty Chem. | Harvey, IL |
| D. Mattey | Key Acct. Manager | Alfa Laval Inc. | Hermitage, PA |
| D. McAndrew | Fuel & Lube Spec. | GE Transportation Rail | Erie, PA |
| J. McDonald | Off. of Trans. & Air Qual. | EPA | Ann Arbor, MI |
| K. Myles | Mech. Engineer | Amtrak | Wilmington, DE |
| W. Strickland | Mgr.-Test & Lab Svcs. | CSX Transportation | Jacksonville, FL |
| D. Tuttle | Mgr.-RR & Marine Sls. | American Refining Group | Roswell, GA |
| P. Van Slyke | | Oronite | Richmond, CA |
| K. Wazney | Chemist/Testing Spec. | Canadian Pacific Rwy. | Winnipeg, MB |
| P. Whallon | Mgr.-Tech. Sales | Clark Filter | Lancaster, PA |

# PERSONAL HISTORY

## *Thomas Pyziak*

Thomas J. Pyziak, Chairman of Fuel, Lubricants and Environmental Committee, was born in Chicago on August 10, 1954. Tom is a graduate of Gordon Technical High School in Chicago. He attended and graduated from St. Norbert in DePere, Wisconsin in 1976 with a Bachelor of Science degree.

Tom began his career as a lab technician with Motor Oils Refining Company in McCook, Illinois which is a re-refiner of petroleum lubricants. He learned all aspects of manufacturing from plant operation to quality control and research and development.

Tom transferred to marketing as a Technical Sales Representative and subsequently became an Industrial Sales Rep. He was given railroad/sales responsibility in 1984, handling product development, marketing/sales and oil waste removal sales. In 1989, this portion of the operation was sold to Breslube which two years later was acquired by Safety-Kleen Systems. Tom's current position is National Account Manager Railroads, handling all aspects of railroad engine oil development, sales/marketing with added technical responsibilities to the OEM's, GM, Ford and Chrysler.

Tom's hobbies include gardening, Chicago softball and auto racing. He is married. His wife's name is Katie and they reside in Palatine, Illinois.

**THE FUEL, LUBRICANTS AND ENVIRONMENTAL COMMITTEE WOULD LIKE TO THANK THE FOLLOWING COMPANIES FOR HOSTING THE COMMITTEE'S MEETING THIS PAST YEAR.**

**DECEMBER, 2007**
**SAFETY-KLEEN SYSTEMS**
**EAST CHICAGO, IN**

**FEBRUARY, 2008**
**ORONITE**
**RICHMOND, CA**

**WE REALLY APPRECIATE THEIR SUPPORT**

## 1. PREVENTION OF FUEL AND FUEL FILTER HEADACHES

*Prepared by*
*Glenn Bowen,*
*BNSF Railway*

### Introduction

At last year's LMOA conference Dennis McAndrew of General Electric presented a paper titled "Diesel Fuel 2007 and Beyond, What Will Be In Your Tank." The paper included results of a fuel survey questionaire which asked railroads what test results their fuel suppliers provided on the fuels they supply and what testing the railroads use to confirm those test results.

As a result of the survey one was left with the feeling that some railroads were not doing enough to ensure their suppliers were providing a quality product and those railroads were susceptible to fuel problems.

This year's paper is a response to that concern and is titled "Prevention of Fuel and Fuel Filter Headaches." The paper describes the quality processes one major railroad has in place to prevent fuel problems and to maximize fuel fulter life.

### Fuel Supplier

Perhaps the most important key in fuel problem prevention is the selection of quality fuel suppliers. The ASTM D-975 Standards Specification for Fuel Oils spells out the specific tests and test results required for a fuel to meet the No. 2-D diesel fuel standard. You have every right and responsibility to ask your fuel suppliers what tests and at what frequency they perform those tests to guarantee their fuel meets the ASTM D-975 specification. The LMOA Fuel, Lubrication, and Environmental committee has recommended that the suppliers provide quality control information on the fuel that they supply in a standard excel format. This standard formatting should enable a quick review and comparison of the quality control procedures performed by each supplier. The user of the fuel can either demand additional quality tests be performed where the supplier's procedures appear inadequate or supplement those procedures with internal quality control analysis.

### Fuel Inspection

The fuel quality process in the field starts with fuel inspection. The inspection of the incoming fuel is one of the **first** and **best** lines of defense against fuel problems.

Fuel inspection involves checking the fuel for excess water, particulate and API gravity (density).

The primary tools used to determine the quality of a fuel are your eyes, some clean glassware and a hydrometer.

You can be pretty confident it is a good quality fuel if the product:

1. has the proper placard (1993) that identifies the contents as diesel fuel (tank car or tank truck)
2. is bright and clear
3. contains no floating or suspended particulate
4. meets API gravity requirments (test performed with a hydrometer)

30-42

Inspection Frequency

1. Pipeline: inspect a sample of the fuel at the start, middle and end of each delivery.
2. Tank Car: inspect each tank car
3. Truck Transport
   a. Locations with delivery to storage tank
      Inspect four (4) random deliveries per month
   b. Locations with DTL (Direct-to-Locomotive) delivery:
      Inspect two (2) random deliveries per month

Sample Collection

1. Pipeline (Figure 1)
   The preferred sampling location is the 1/2 inch valve on the bottom port of the gate valve, which is used for meter proving and which is immediately down stream of the receipt meter.

   Open the sample valve and purge (into a 5-gallon bucket) enough fuel from the line to remove the fuel from previous deliveries. Discard this fuel into a container used to store Reclaim Fuel.

Fill a clean bottle (Figure 2) with fresh fuel. Inspect the fuel for clarity, particulate and API gravity. Record date, time, appearance (bright and clear or other) and API gravity in record book. Discard this fuel into a container used to store Reclaim fuel.

2. Tank Car
   a. Proper placard
      Tank car must have the proper placard (1993) identifying the contents as diesel fuel. (Figure 3)
   b. Determining the amount of free water
      Prior to sampling for inspec tion, the tank car should be tested for the presence of free water with Kolor Kut (follow directions on the tube for use of the paste).

      The Kolor Kut is easiest applied to a long stick which is lowered into the fuel. The paste will turn red in the presence of free water. If free water is found over 1" deep, Fuel Management should be notified immediately.
   c. Tank car sampling procedure
      Samples from tank cars for inspection are taken from the top of the tank car with a "bomb type" sampler.
      The bomb sampler should be slowly lowered until the plunger at the end of the sampler is approximately 4 inches above any free water that was detected in the tank car. (Figure 4) Pull the secondary string to open the plunger at the end of the sampler body. Release the string after thirty seconds (this will allow a representative sample of the fuel to enter and stabilize within the sampler body). Pull the sampler to the surface and depress the plunger to empty the contents into a

clean glass bottle. Inspect the fuel for clarity, particulate and API gravity. Record date, car number, appearance (bright and clear or other) API gravity and placard (number) in record book. Discard this fuel into a container used to store Reclaim Fuel.

3. Truck Transport
   a. Proper placard
      Truck transports must have the proper placard (1993) identifying the contents as diesel fuel. (Figure 5)
   b. Truck transport sampling procedure
      All truck transports should have a valve connected to the header at the bottom of the tank. Open the sample valve and purge (into a clean 5-gallon bucket) enough fuel from the line to remove the fuel from previous deliveries. Discard this fuel into a container used to store Reclaim Fuel. Fill a clean bottle with fresh fuel. Inspect the fuel for clarity, particulate and API gravity. Record date, transport number, appearance (bright and clear or other), API gravity and placard (number) in a record book.

Fuel Inspection Procedures

1. Clarity and Particulate
   In 1995 the federal government began requiring refineries to identify Off-road diesel fuel with the addition of red dye. Depending on the source of the crude, this tint can produce a variety of colors in the finished product. It is not unusual to see a red, pink or straw colored diesel fuel. Because these dyed fuels are generally darker than in the past, visual examination for clarity and particulate is more difficult. To examine the fuel, hold the sample at eye level in a glass bottle and shine a flashlight through it from the opposite side. The fuel should be clear and bright and contain no suspended particulate. If the fuel is hazy, it may contain water or finely dispersed particulate. Either condition should be immediately reported to supervision and Fuel Management.
2. API Gravity
   Place the hydrometer in the bottle and read the value on the stem of the hydrometer at the meniscus of the fluid. (Figure 6) The API gravity of diesel fuel should be between 30 and 42. A hydrometer reading below 30 may indicate the presence of water. A hydrometer reading above 42 may indicate the fuel is contaminated with a lighter material such as gasoline. If the API gravity is not between 30 and 42, it should immediately be reported to supervision and Fuel Management.

Product Rejection

If the fuel has any of the following conditions, do not take receipt/unload the product. Immediately report conditions to supervision and Fuel Management.

1. The product does not have the proper placard (1993) identifying the contents as diesel fuel (tank car or tank truck).
2. The fuel is not clear and bright
3. The fuel contains floating or suspended particulate
4. The fuel API gravity is not between 30 and 42

**Vendor Fuel Samples for Quality Control**

Vendor fuel samples are necessary in order to monitor the quality of fuel being delivered to each facility. Samples are to be forwarded to the laboratory as soon as possible after the sample is taken.

A. Sample Frequency
1. Pipeline: A minimum of one sample per month
2. Tank Car: A minimum of one sample from each supplier per month
3. Truck Tansport:
   a. Locations with delivery to storage tank. A minimum of one sample from each supplier per month
   b. Locations with DTL (Direct-to-Locomotive) delivery. A minimum of one sample from each supplier per month

B. Sample Collection
Sampling procedures are the same as given in the section on taking samples for inspection

C. Sample Containers and Labeling Requirements
Sample container and labeling requirements vary by facility and state. Samples should **never** be shipped by air.

**Storage Tank Samples**

Storage tank samples provide a measure of the fuel quality at a facility and the condition of storage tank maintenance.

A. Sample Frequency
A sample of fuel should be taken from the bottom of each storage tank once a month *after* the removal of any water and "rag layer" of fuel and sludge which may have collected in the bottom of such tank.

B. Sample Collection
Draw off all free water and sludge until a representative sample of the fuel is available (Figure 7). Inspect the fuel for clarity and particulate in a clear glass bottle. When satisfied that the fuel sample is representative of the fuel in the tank, transfer the sample to an appropriate can or bottle for shipment.

C. Sample Containers and Labeling Requirements
Sample container and labeling requirements vary by facility and state. Samples should **never** be shipped by air.

**Fuel Hose Samples**

If tank samples show the quality of fuel to be poor (high particulate or water in the fuel) hose samples should be taken to check the quality of the fuel being delivered to the locomotives. Procedures for taking and inspecting hose samples are as follows:

The hose samples should be taken immediately after the fueling of a locomotive. Do not take a sample from fuel that has been sitting in a hose or in a dead line. Transfer the sample to a clean glass bottle. Be on the lookout for any haze or suspended particulate in the fuel. These are indicators of storage tank or wayside filter maintenance problems. Good fuel should appear clear and bright. Notify Fuel Management if the fuel being delivered to the locomotives is not bright and clear. Change wayside fuel filters and see if the condition clears up.

**Storage Tank Maintenance and Record Keeping**

The warming and cooling of the fuel within the storage tank promotes formation of condensation which collects on the bottom of the storage tank. Bacteria grow in this water and feed on the fuel at the water/fuel barrier and produce a "rag layer" of fuel and sludge at the bottom of the tank. This water and sludge can significantly reduce the life of wayside and locomotive fuel filters.

The best means of controlling sludge development is through periodic removal of the free water and "rag layer" of fuel from the bottom of the storage tanks.

A. Water Drain Frequency

The free water and "rag layer" of fuel from the bottom of the storage tank should be drained at least twice a month.

B. Water Drain Procedure

All fuel storage tanks should be eqiupped with operating water draws. The water draw should be piped to a fuel reclamation system. If it is not, the waste fuel and water must be collected and disposed of through a waste oil reclamation system. All waste and fuel must be disposed of in an environmentally acceptable manner. Personnel responsible for removing water from the storage tanks should be cautioned that after all of the water has been removed from the bottom of the tank, good diesel fuel will remain in the water draw lines. The next time water is to be drawn off, this good fuel will have to be purged from the lines before the water can be removed. Water and sludge and emulsified fuel are drained from the water until the effluent (collected and inspected in a clear glass bottle) is clear and bright.

C. Inspection of Storage Tank Bottom for Sludge

At a minimum of once every quarter, the storage tank should be climbed and the bottom of the tank sampled with a "bomb type" sampler. The sampler should be slowly lowered until the plunger at the end of the sampler makes contact with the bottom of the tank and is fully depressed. The sampler body should be held vertical in that position for one minute in order for the fuel and sludge to stabilize. Withdraw the sampler and transfer the contents to a clean glass bottle. A small layer of free water will typically be found in the bottom of the tank. Above this water there may be a layer of sludge and hazy fuel (fuel emulsified with water) present. On top of this layer the fuel should be bright and clear. Estimate the amount of free water (inches), sludge or hazy fuel (inches) and the distance of clean fuel from the bottom of the tank. Make a written record of these values. Determine the height of the fuel pickup line in the tank. If the sludge and hazy fuel is allowed to build up to the height of the fuel pickup line, the wayside and locomotive fuel filters may become plugged. If the sludge or hazy fuel is approaching the height of the fuel pick up lines, this condition should be reported to Fuel Management.

D. Record Keeping

The following format is to be used for recording results of quarterly storage tank inspections:

Date
Storage Tank Number
Inches of Water
Inches of Sludge and Hazy Fuel

**Wayside Fuel Filter Maintenance and Record Keeping**

Each diesel fuel dispensing facility shall be equipped with a filtration system capable of filtering all fuel dispensed to locomotives, fuel tenders, and trucks used to transload fuel to locomotives.

***All Fuel Dispensed to Locomotives Must Be Filtered.***

The wayside fuel filters are the last line of defense against putting bad fuel in the locomotives. If the wayside fuel filters are not carefully watched and changed as needed, the filters can bypass and release poor quality fuel to the locomotives.

A filter maintenance log must be kept for each filtration system at a site, to record the date and gallons at the time of the last filter element replacement. The upstream and downstream fuel pressures should be recorded at least once a month. It should also be recorded before and after each fuel filter change. This data will prove helpful in developing site-specific filter change-out requirements. Fuel filters must not be bypassed during the filter change-outs. Redirect fuel to a backup filter or schedule the change-out during a slack fueling period when dispensing activity can be shut down until change-out is complete. The standard replacement filter elements must be 10-13 micron porosity.

A. Filter Change Criteria and Procedures

The waysisde fuel filters should be changed on the following criteria:

1. Whenever fueling rate through the nozzles is notably slowed.
2. Whenever the pressure drop across the filters exceeds 10 psi.

3. At least once every six months.
4. A total of ten million gallons have passed through the filter housing.

B. Monitoring of Wayside Fuel Filter Life

A good reference for evaluating wayside filter life is if the filter plugs before an individual 10" filter has passed 125,000 gallons of fuel, or before an individual 6" filter has passed 43,000 gallons of fuel. If the filter plugs in less than the indicated gallons, immediately contact Fuel Management.

C. Record Keeping

A filter maintenance log must be kept for each filtration system, at a fueling facility, to record the date and gallons at the time of the last filter element replacement. The upstream and downstream fuel pressures should be recorded before and after each filter change. This data will prove helpful in developing site specific filter change-out requirements. Last but not least, the wayside fuel filter life on a per filter basis should be calculated and recorded for each filter system. For example, if 900,000 gallons passed through the 6-filter housing before it became plugged, the average filter life was 900,000/6=150,000 gallons per filter.

The following fomat should be used for recording wayside fuel filter change-outs:

Date: 1/21/96

Location: Belen-East M/L

Number of Filters in Filter Housing: 8

Gallons of Fuel Gallons/Filter: 1,695,000

Filter Life Gallons/Filter 211,875

The following format is to be used for recording wayside fuel filter pressures:

Date

Location

Upstream Fuel Pressure (psi)

Downstream Fuel Pressure (psi)

**Wayside Fuel Filter Samples**

The analysis of wayside fuel filter residue has been found to be extremely useful in the investigation of locomotive fuel filter plugging. By comparing the residues on the wayside fuel filters with those on the locomotive filters, we have been able to identify problem fueling locations. This information is also useful in understanding changes in fuel quality at a given facility.

A. Wayside Fuel Filter Sampling Frequency

Wayside fuel filter samples and storage tank samples are to be submitted for analysis:

1. Whenever the fuel filter life is reduced significantly (50% or more) from normal.

2. Annually. The laboratory will contact each facility when this sampling is to occur.

B. Filter Sampling Packaging Instructions

1. Remove one filter from the filter housing and remove the outer paper wrap. (Figure 8). Immediately cut a 12" x 12" section of paper from the outer pleat. (Figure 9) Do not allow the filter to dry out.
2. Wrap the section of filter paper in heavy plastic bags (3 or more) so the fuel does not leak out in shipment.
3. Tag the filter sample indicating the location, date removed and the estimated gallons of fuel which had passed the filter since it had last been changed (total gallons of fuel through the filter housing divided by the number of individual filters in the filter housing). Indicate the diameter of the filter; whether a 6", 10" or other.

C. Sample Shipment

Sample container and labeling requirements vary by facility and state. Samples should **never** be shipped by air.

**Laboratory Analysis**

Analysis performed:

A. New fuel supplier or fuel supplier with a history of problem fuel.
Complete ASTM D975 fuel analysis plus fuel stability (ASTM D6468-99).

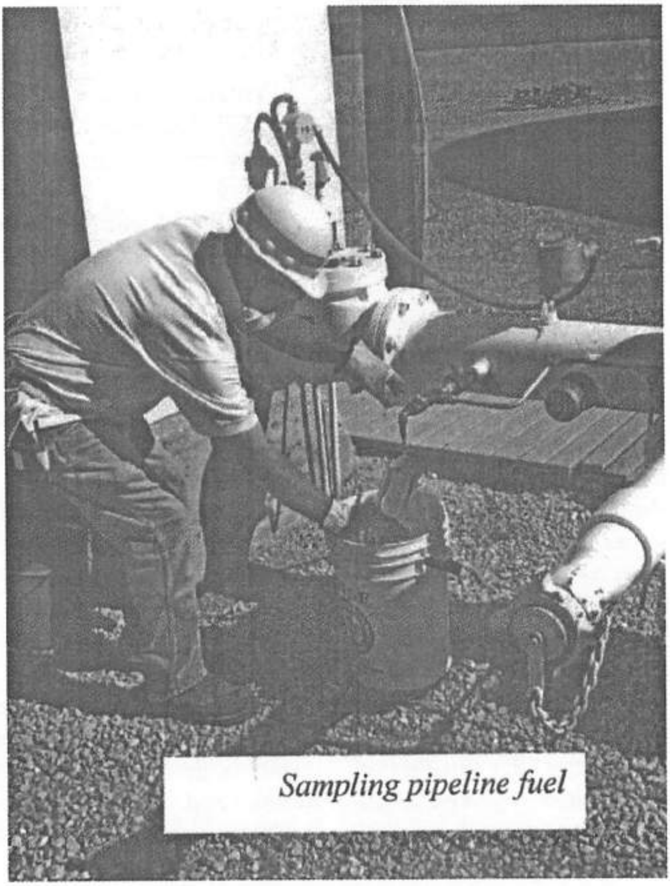
B. Vendor and storage tank samples

1. Bright and clear, particulate, API gravity and fuel stability.
2. Quarterly run sulfur content on all fuel.
3. Winter months run pour point and cloud point.
4. Monthly run lubricity on all fuels less than 500 ppm sulfur.

C. Wayside and locomotive filter samples
Infrared analysis and X-Ray diffraction of ash.

**Conclusion**

To summarize, several simple steps a railroad can perform to ensure the quality of their diesel fuel have been summarized. By adopting these, or similar steps, the railroad can go a long way toward preventing fuel quality issues and maximizing fuel filter life.



*Sampling pipeline fuel*

**Figure 1**

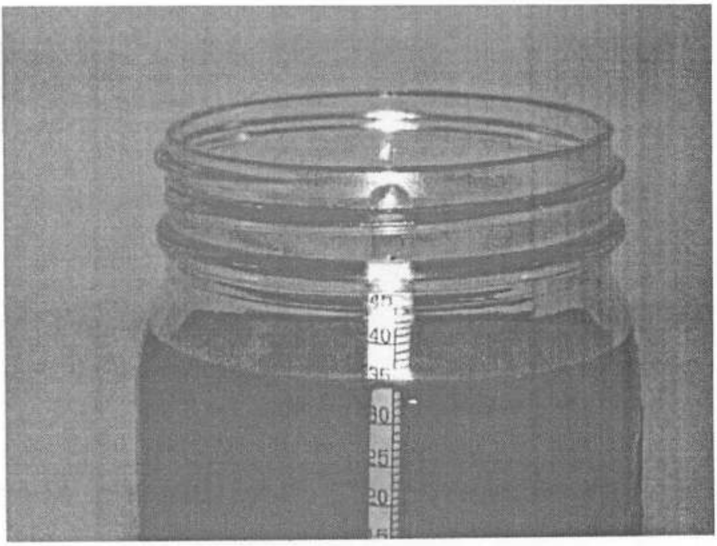



Figure 2


Figure 3

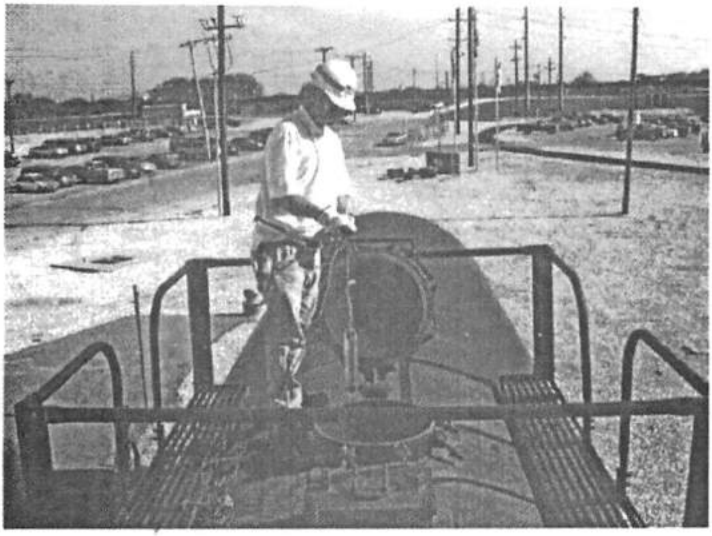
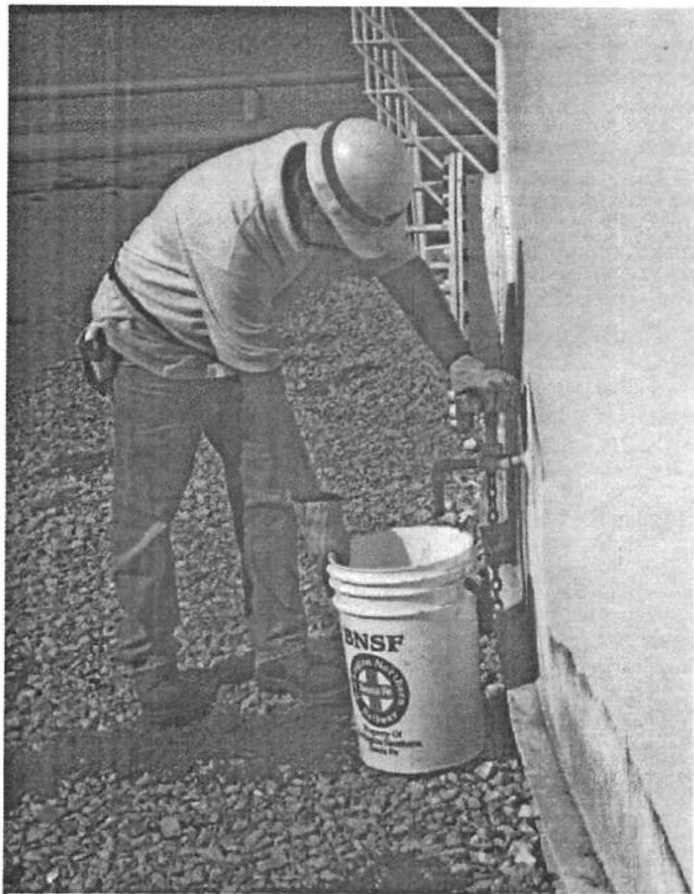


Figure 4


Figure 5

Figure 6




*Drawing off water from bottom of storage tank*

**Figure 7**

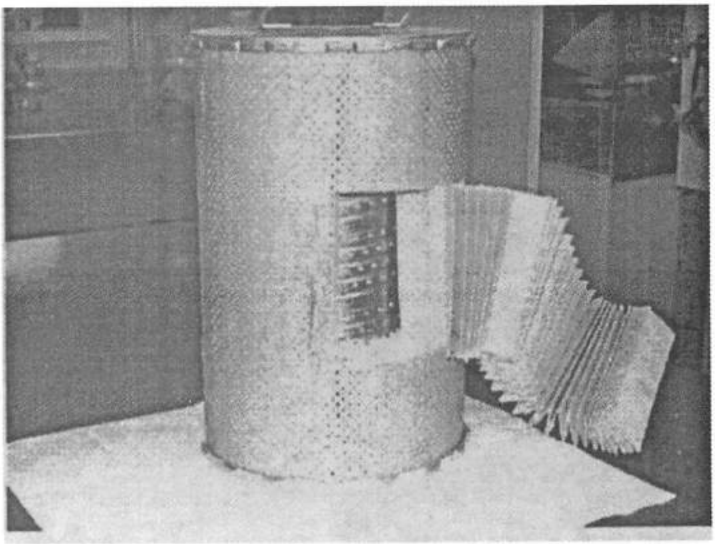


Figure 8 - Cutaway of outside pleat of Fuel Filter sample.

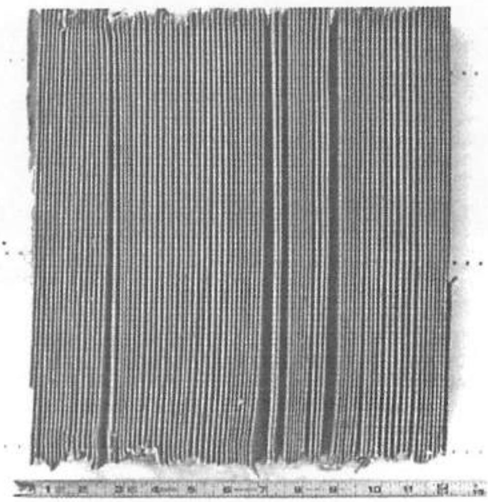


Figure 9 - 12" x 12" Filter Paper

## II. LOCOMOTIVE IDLE AND START-UP EXHAUST EMISSIONS TESTING

*Prepared by*
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*Southwest Research Institute*

*Steven G. Fritz, P.E.,*
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**Abstract**

The objective of this project was to quantify locomotive idle and start-up emissions, and to answer the question: "At what point is it preferable from an emissions standpoint to idle a locomotive engine rather than shut down the engine and restart it when needed?" Idle and restart emissions tests were performed on two Tier 0 emission locomotives; a 1,120 kW EMD MP15-DC Switcher (UPY1378) and a 3,280 kW line-haul GE Dash9-44CW (BNSF4373).

The results of the testing showed that continuous idling emissions of NOx and PM were greater than the start up emissions from the two test locomotives. The only exception ws the 15-minute restart on the line haul locomotive BNSF4373, but this was envisioned to be due to a non-typical operational cycle of the GE AESS.

The results of the extended idle tests showed that the older locomotive (UPY1378) operates at a relatively consistent idle emissions output through the four hours of extended idle. However, idle emissions from BNSF4373 varied over the idle period as the engine speed changes in response to on-board computer controls to accomplish engine warm-up and a series of other locomotive functions.

**Introduction**

Historically, diesel locomotives spend a lot of time at idle [1,2]. This is reflected in the EPA locomotive duty cycles for emissions which have a weighting factor for idle of 59.8% for the switch cycle and 38.0% for the line-haul cycle[3].

Recently, the railroad industry has begun purchasing new locomotives with automatic engine start-stop systems to reduce emissions and save fuel by limiting the amount of time spent at idle. The railroads are also retrofitting existing locomotives with these automatic start stop systems. Additional reductions in unnecessary diesel engine idling will reduce fuel consumption and emissions.

The objective of this paper is to quantify idle and start-up emissions, to answer the question: "At what point is it preferable from an emissions standpoint to idle a locomotive engine rather than shut down the engine and restart it when needed?"

**Nomenclature**

AESS - Automatic Engine Start-Stop System
BNSF - BNSF Railway Company
CARB - California Air Resources Board
EMD - Electro-Motive Diesel
EPA - United States Environmental Protection Agency
FTP - Federal Test Procedure
GE - General Electric
kW - kilo Watt
SCAQMD - South Coast Air Quality Management District
UP - Union Pacific Railroad Corporation

## Technical Approach

The task to quantify locomotive engine start-up emissions, in a meaningful manner, was technically challenging. There are no standardized test procedures for measing locomotive start-up emissions. In addition, locomotive engine restart emissions are dependent on many factors, such as ambient air temperature, engine jacket water and lubricating oil temperatures, the engine operating history preceding engine shut down, the engine starting procedure, and the engine's mechanical and starting system conditions (locomotive starting batteries, starters, etc.). Boundaries for some of these variables were defined in the simplest of terms, understanding that all start-up scenarios could not be covered.

## Test Locomotives

The first locomotive tested was UPY1378 (Figure 1), which is an EMD MP15DC locomotive, and was equipped with a 12-cylinder 645E engine rated at 1,120 kW. This locomotive is known as a shunter or yard switcher and is not typically used for line haul applications. The locomotive was rebuilt the year before the start of the project and was fitted with a ZTR automatic engine start stop system at the time of overhaul.

The second locomotive tested was BNSF4373, a GE Dash9-44CW that was originally manufactured in March 1999 and was rebuilt in January 2004 to meet the EPA Tier-0 emissions standard. This locomotive has a 16 cylinder GE-FDL engine that produces 4,400 horsepower and is considered a line-haul locomotive. This was equipped with a GE Automatic Engine Start Stop (AESS) System. Figure 2 shows the front view of BNSF4373.

## Test Sequence

Testing of both the UPY1378 and BNSF4373 studied the effect of restarting the locomotive engine on emissions. The restart testing sequence is shown in Figure 3. The test sequence allowed for emissions sampling during the initial start and warm up of the engine, which overall resulted in a 12 hour test day. As shown in Figure 3, the shutdown and start-up sequence for each of the scenarios was conducted consecutively. There was no warming of the locomotive between each test. For example, the engine was shutdown for 60 minutes, restarted and idled for the test, the engine was shutdown for 120 minutes and restarted and idled for testing, and the engine was shutdown for 240 minutes and restarted and idled again. The engine was never loaded after the baseline emissions test was started.

## Instrumentation

Data that was acquired for each test included:

- Jacket water temperature
- Oil Sump temperature
- Fuel flow rate (Average over the test point)
- Engine speed
- Ambient temperature at the start of the test
- Barometer
- Relative humidity or wet bulb temperature

- Rack position (EMD)

Emissions that were acquired for each of the test points included:

- Oxides of nitrogen (NOx) (PPM)
- Carbon monoxide (CO) (PPM)
- Carbon dioxide ($CO_2$) (%)
- Oxygen (02) (%)
- Hydrocarbons (HC) ($PPM_C$)
- Particulate (mg)

Gaseous emissions from the multi-stack EMD locomotive were sampled within an exhaust manifold collection system installed above the roof of the locomotive, as shown in Figure 4 for the roots blown engine in UPY1378. A heated line transferred the raw exhaust sample to the emission instruments for analysis. Hydrocarbon concentrations in the raw exhaust were determined using a heated flame ionization detector (HFID), calibrated on propane. $NO_x$ concentrations in the exhaust were measured with a chemiluminescence analyzer. $NO_x$ correction factors for ambient air humidity are applied as specified by EPA in 40 CFR 92. Concentrations of CO and $CO_2$ in the raw exhaust were determined by non-dispersive (NDIR) instruments.

Particulate emissions were measured at each test point using a "split then dilute" technique, in which a portion of the raw locomotive exhaust is "split" from the total flow and mixed with filtered air in a 254 mm diameter dilution tunnel. The split sample is transferred to the dilution tunnel through a 51 mm diamter stainles steel tube that is insulated and electrically heated to 191°C.

A particulate sample was extracted from the dilute exhaust stream within the dilution tunnel. Particulates were accumulated on 90 mm fluorocarbon-coated glass fiber filters (Pallflex T60A20) at a target filter face velocity of 70 cm/s. The filters were mounted in stainless steel filter holders and connected to the dilution tunnel. Particulate filters were preconditioned and weighed before and after testing, following the FTP.

**UPY1378 Results**

Test "T2" utilized a standard FTP warm up, performance and emissions test at the idle condition. This test provided the baseline for comparision for subsequent tests on this locomotive. The results of this test are:

- NOX (corrected) = 605.4 g/hr
- CO = 138.8 g/hr
- HC = 130.8 g/hr
- PM = 6.7 g/hr

For the restart tests (tests T3 through T6), the measured exhaust emission were post processed to calculate mass emissions flow rates. The results can be seen in Figure 5 through 8, for tests T3 through T6 respectfully.

The instantaneous emissions mass flow rates, from test T3 through T6, were then integrated over the test cycle. The outcomes of these results were compared to the baseline emissions test, assuming that baseline emissions rate would be constant while the engine was idling. The results of this work for $NO_X$ emissions are shown in Figure 9. In general, restarting the engine does not produce unusually high $NO_X$ emissions due to the starting event. Figures 10 and 11 shows the trends for HC and CO emissons are the same as the $NO_X$ emissions.

PM emissions were also measured for each of the restarts. Some of the tests taken had multiple PM samples taken and were labeled Filters A, B and C. Each PM emission sample was taken for 300 seconds, so the filter weights are an average over the 300 second sample period. The test description, test code, PM filter weight gain, and the PM emissions rate are all shown in Table 2.

These tests show that the PM emission rate increased during the start-up of the engine compared to the standard idle PM emssion rate. However, the additional filters taken on Test 4 and Test 5 shows that the PM emission rates returns to a level close to the baseline PMS emissions rates after the initial filter is completed. This suggests that the start-up event PM emissions are somewhat higher than baseline, but quickly drops to a lower level shortly after the restart of the engine.

**BNSF4347 Results**

Test "T-21" utilized a standard FTP warm up followed by a combined performance and emissions test at the idle condition. This test provided the baseline for comparison for subsequent tests on BNSF4373. The results of this test are:

- $NO_X$ (corrected) = 296.6 g/hr
- CO = 29.1 g/hr
- HC = 30.6 g/hr
- PM = 10.6 g/hr

For the restart tests (tests T-22 through T-26), the measured exhaust emission were post processed to calculate mass emissions flow rates. the results can be seen in Figures 12 through 16, for tests T22 through T26 respectfully. These graphs show that the emissions out of the engine varies over the test period due to the changes in engine speed and various auxiliary loads of the locomotive are on and off. These are primarily the air compressor and various cooling fans.

The emissions profile from the BNSF4373 locomotive was significantly different than that of the UPY1378 locomotive. These two locomotives are different in many ways. They include, but are not limited to; manufacturer, control system of the engines and the locomotive in general, engine types and power rating. The one fact that became obvious during these tests was when the UPY1378 was started, the engine speed was held constant by the mechanical governor, except for minor (and short lived) decreases in engine speed as the air compressor turned on shortly after the engine was started. BNSF4373 is computer controlled and equipped with electronic fuel injection and electronic speed governing. the GE locomotive computers manage various engine and locomotive parameters, including engine speed up for high and low jacket water oil sump temperatures and low air pressure. These locomotive control issues, which drove the variable emissions traces seen in Figures 12 through 16 can also be seen in the engine speeds of the BNSF4373 locomotive over these same tests. The engine speed over the tests can be seen in Figure 17.

Because of the variable emissions profile from BNSF4373, the cumulative emissions rates are also more unpredictable, as shown in Figures 18 through 20. These emissions rates shows that the higher engine speeds and auxiliary loads of the locomotive when the restart takes place causes the cumulative rate to be very steep and in T-22 actually crosses the baseline test line. For many of these tests the cumulative emissions rates are starting to drop somewhat and have less steep slope, after about five minutes of operation, depending on the test.

The PM emssions from this series of restart tests are shown in Table 3. By comparing the PM results in Table 3 to the PM results of the UPY1378 in Table 2, one can see that the PM emissions from BNSF4373 are higher than that of the UPY1378. Additionally if one compares the results shown in Table 3 to the engine speeds that the engine exhibited during the restart tests, as shown in Figure 17, one can see that the engine produces higher PM emissions as the engine is allowed longer engine shutdown periods and as the locomotive drives the engine to higher speeds, for a longer duration, after the restart of the engine.

### Conclusions

The first and main conclusion that can be drawn from this testing is that continuous idling emissions of $NO_X$ and PM were greater than start-up emissions following shut-down period for both locomotives. The only exception is the 15 minute restart test on the BNSF4373, but this is envisioned to be a non-typical operating cycle for the AESS system.

The second conclusion is that restarting the EMD 12-645E engine does not dramatically increase the emissions rate. Figure 9 shows that by shutting down the engine for four hours could reduce the $NO_X$ emissions by nearly 2,450 grams compared to continuously idling the engine during the same period. Additionally, there does not appear to be a significant increase in any of the other emissions emitted by the engine at the start-up.

The third conclusion is that the GE Tier 0 engine in locomotive BNSF4373 operated at higher than nominal idle speed for a number of the restart tests (see Figure 17). After restart, the engine operated at engine speeds of 580 RPM and some times as high as 980 RPM to accommodate the locomotive system demands. These high engine operating speeds increase the emissions rate from the GE engine when compared to the baseline condition.

A fourth conclusion is that during any future tests to characterize idle or restart emissions, the pre-shutdown engine conditioning should better reflect actual locomotive operation, especially for 120 and 240 minute equivalent shutdowns where a typical cold starting occurred.

The final conclusion from this project concerns the GE AESS system tested. When BNSF4373 was first delivered to SwRI for testing, the system only allowed the engine to be shutdown for a maximum of approximately 90 minutes at a time and had an extended idle of about 9.45 hours until finally shutting down again. These operating characteristics of the AESS system highlight the importance of balancing exhaust emissions and fuel consumption with the necessary engine protection system and locomotive readiness.

### Acknowledgements

This work was performed under contract with the South Coast Air Quality Management District, AQMD Contact #06001 [6] under the direction of Mr. Mike Bogdanoff. The BNSF Railway and the Union Pacific Railroad Corporation provided the locomotives used for these tests.

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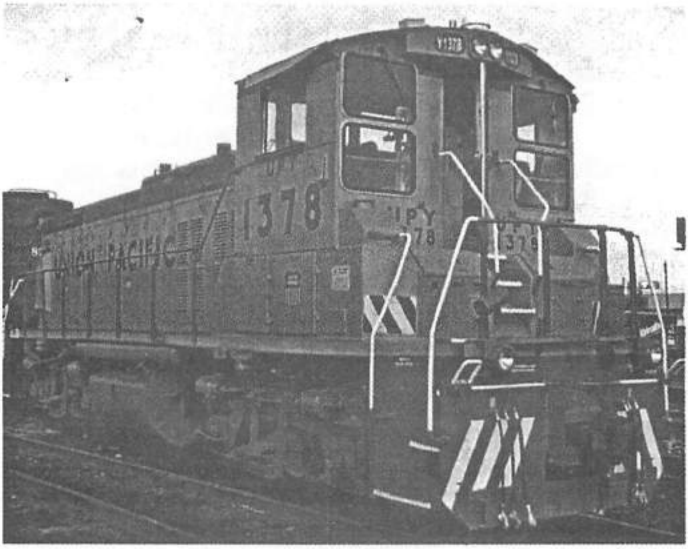


**Figure 1**
**UPY1378**


**Figure 2**
**BNSF4373**

| |
|---|
| ⊟ Baseline Emissions Test |
| Engine Warm Up |
| Fuel stabilization at Idle |
| Low Idle Test |
| Idle Test |
| AESS timed shut down |
| ⊟ 30 Minute Shutdown Test |
| Engine off period |
| Idle emissions test - Post 30 minute shut off |
| AESS timed shut down |
| ⊟ 60 Minute Shutdown Test |
| Engine off period |
| Idle emissions test - Post 60 minute shut off |
| AESS timed shut down |
| ⊟ 120 Minute Shutdown Test |
| Engine off period |
| Idle emissions test - Post 120 minute shut off |
| AESS timed shut down |
| ⊟ 240 Minute Shutdown Test |
| Engine off period |
| Idle emissions test - Post 240 minute shut off |
| AESS timed shut down - End of Test |

**Figure 3**
**Day 1 Test Time Line**

**The test sequence and test number used to track the emissions test in Table 1**

| Test Condition | UPY1378 Test Number | BNSF4373 Test Number |
|---|---|---|
| Initial Start | T1 | T-20 |
| Baseline test simulating FTP | T2 | T-21 |
| Restart post 15 minute shutdown | (A) | T-22 |
| Restart post 30 minute shutdown | T3 | T-23 |
| Restart post 60 minute shutdown | T4 | T-24 |
| Restart post 120 minute shutdown | T5 | T-25 |
| Restart post 240 minute shutdown | T6 | T-26 |
| (A) - Not part of the original test plan. This test point was added to the matrix for the second locomotive. | | |

**Table 1**
**Test Sequence**

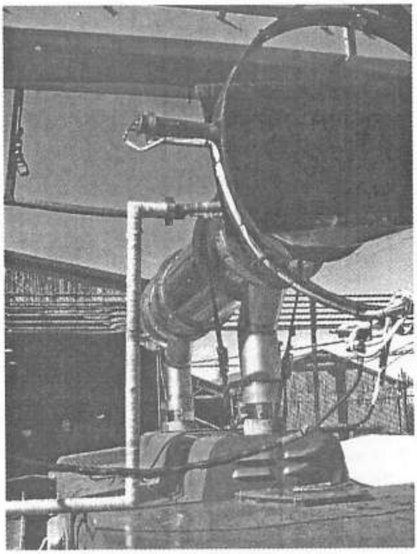

Figure 4
Exhaust Manifold Collection System for Emissions Sampling on UPY1378

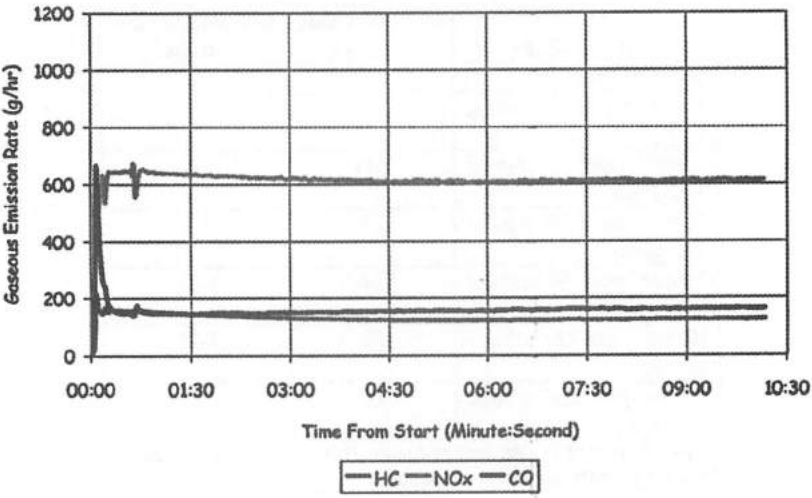


Figure 5
Test 3 Emissions Mass Flow Rates for UPY1378

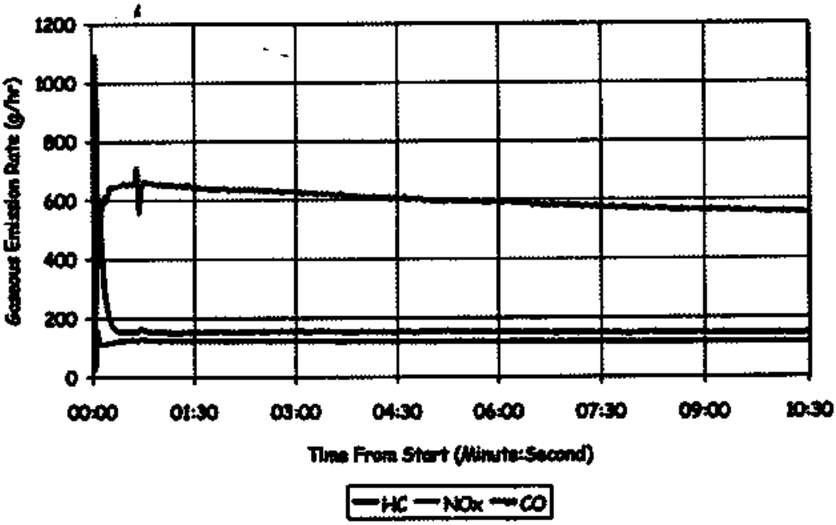


**Figure 6**
**Test 4 Emissions Mass Flow Rates for UPY1378**

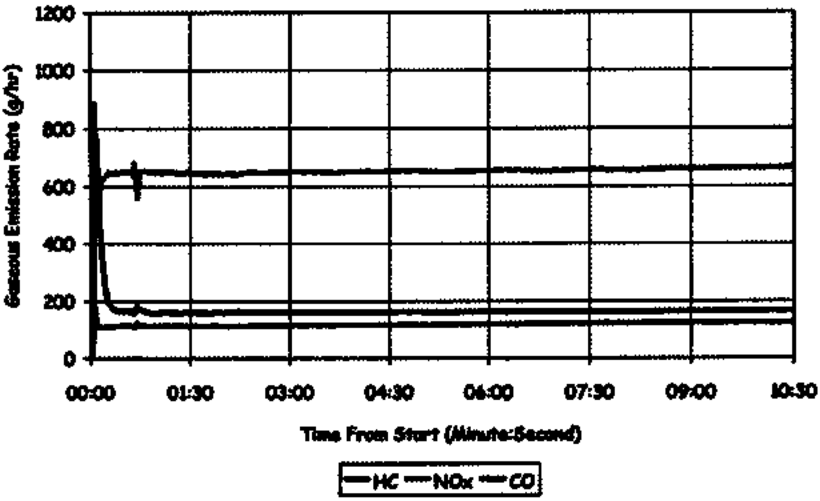


**Figure 7**
**Test 5 Emissions Mass Flow Rates for UPY1378**

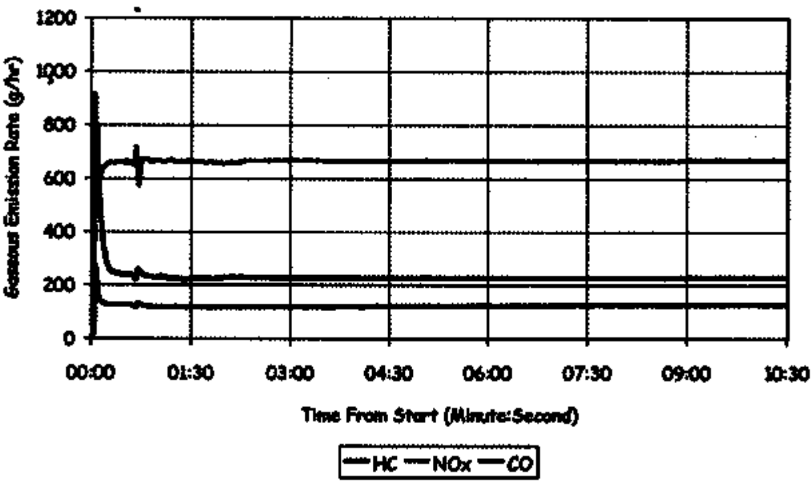


**Figure 8**
**Test 6 Emissions Mass Flow Rates for UPY1378**

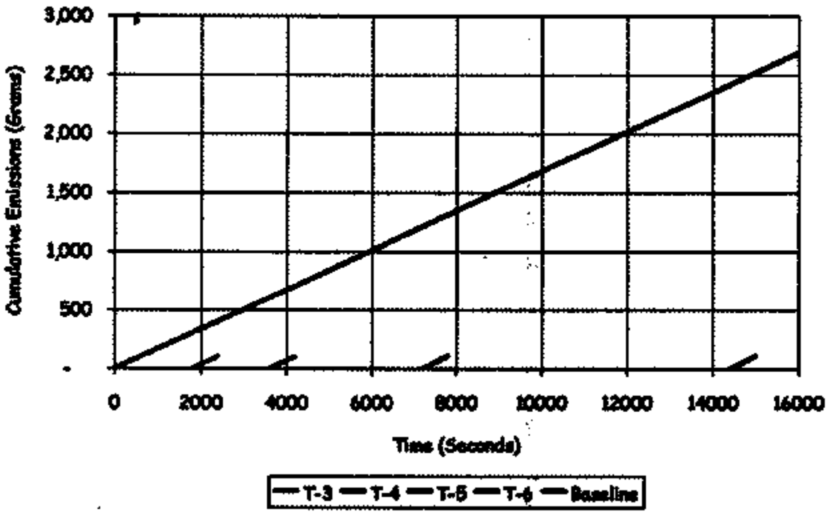


**Figure 9**
**UPY1378 Cumulative $NO_x$ Emissions for UPY1378**

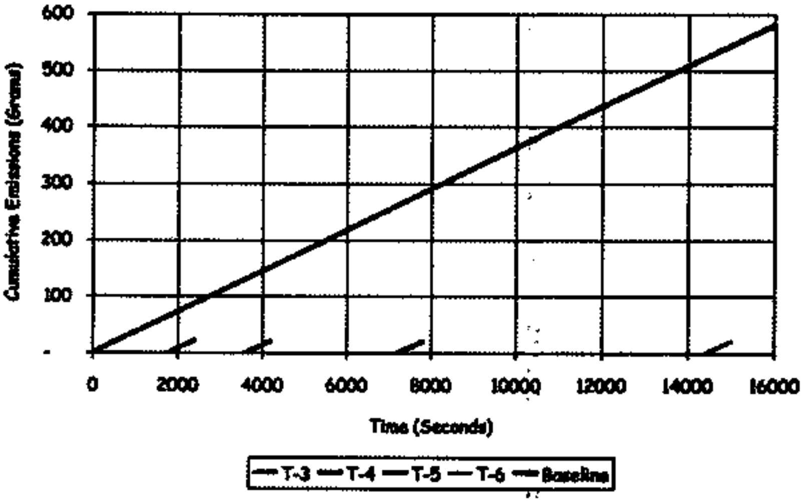


**Figure 10**
**UPY1378 Cumulative HC Emission for UPY1378**

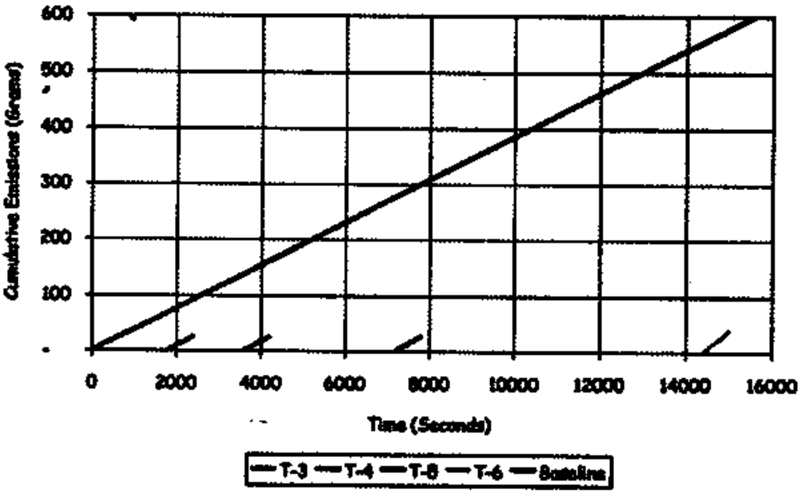


**Figure 11**
**UPY1378 Cumulative CO Emissions for UPY1378**

| Condition of Test | Test Code | Filter A (g/hr) | Filter B (g/hr) | Filter C (g/hr) |
|---|---|---|---|---|
| Baseline =, FTP conditions | T-2 | 6.7 | (A) | (A) |
| Start-up post 30 minute shutdown | T-3 | 13.1 | (A) | (A) |
| Start-up post 60 minute shutdown | T-4 | 13.2 | 7.8 | (A) |
| Start-up post 120 minute shutdown | T-5 | 17.6 | 7.8 | 7.2 |
| Start-up post 240 minute shutdown | T-6 | 19.3 | 7.1 | 8.0 |
| A = PM emissions not measured | | | | |

**Table 2**
**PM Emission Results For Restart Tests on UPY1378**

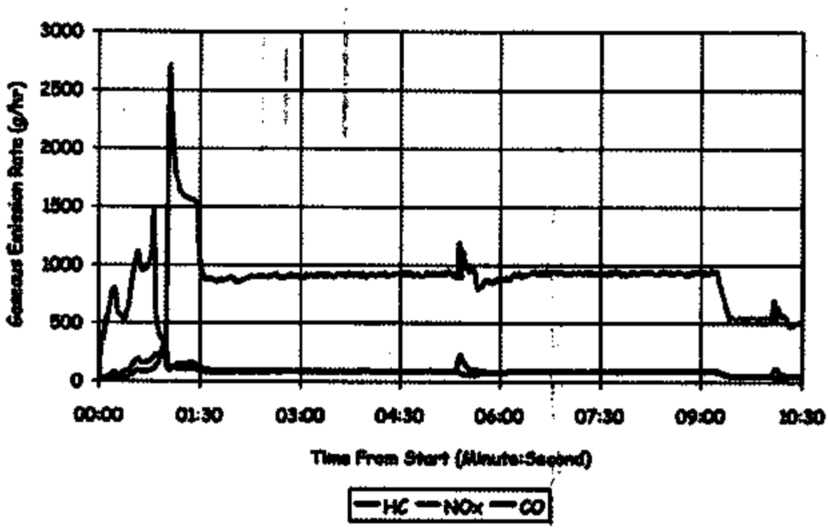


**Figure 12**
**Test 22 Emissions Mass Flow Rates for BNSF4373**

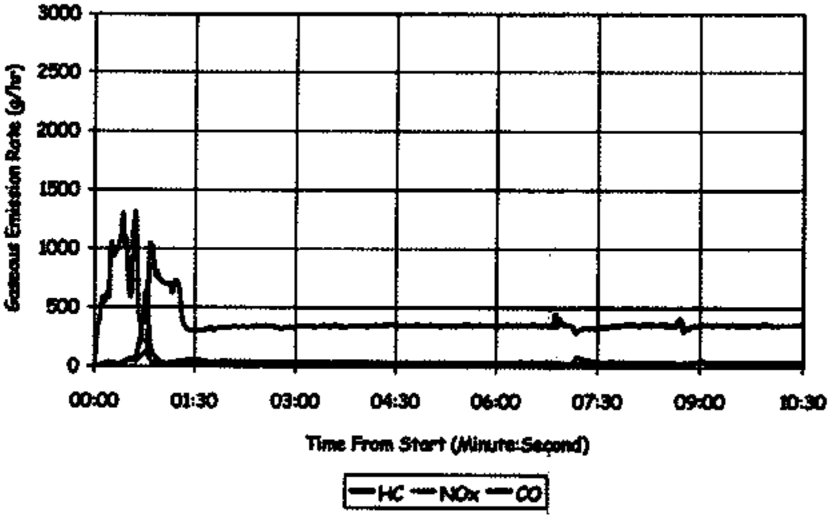


**Figure 13**
**Test 23 Emissions Mass Flow Rates for BNSF4373**

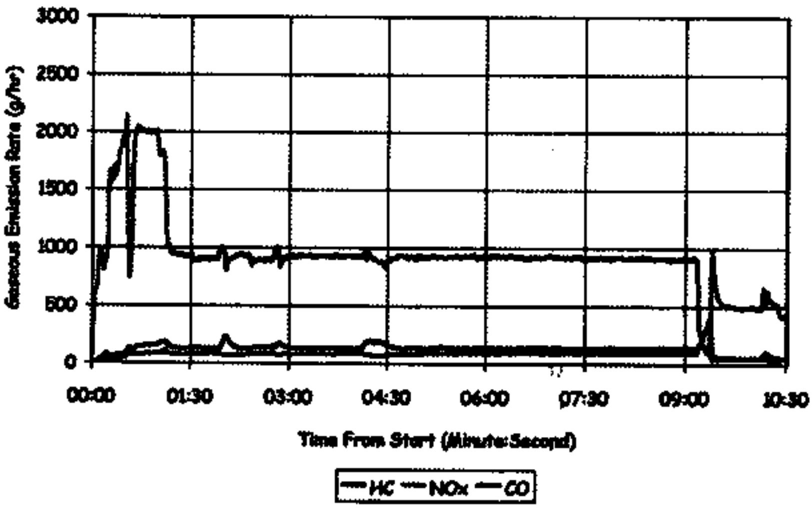


**Figure 14**
**Test 24 Emissions Mass Flow Rates for BNSF4373**

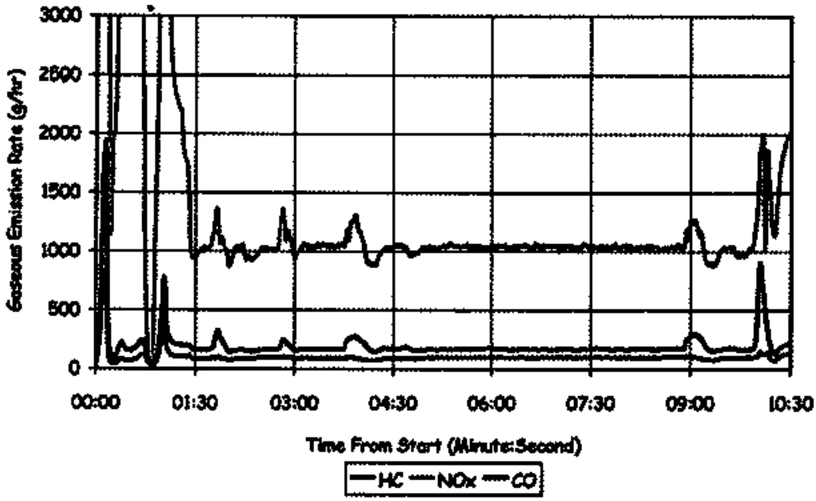


**Figure 15**
**Test 25 Emissions Mass Flow Rates for BNSF4373**

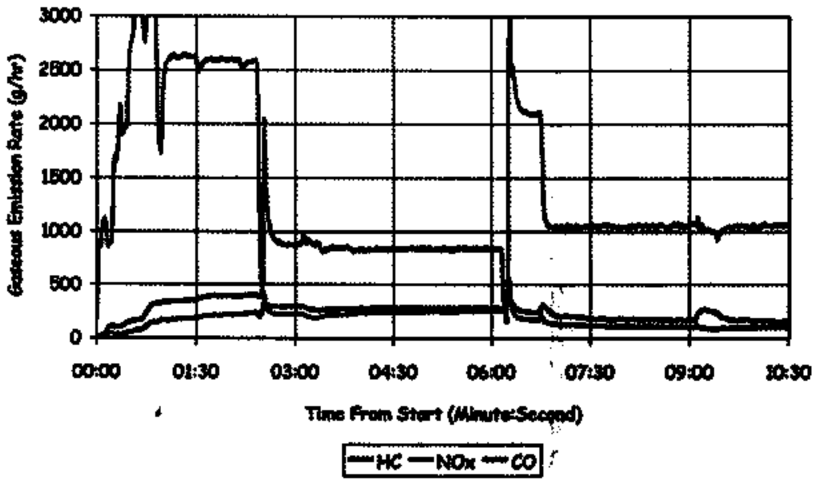


**Figure 16**
**Test 26 Emissions Mass Flow Rates for BNSF4373**

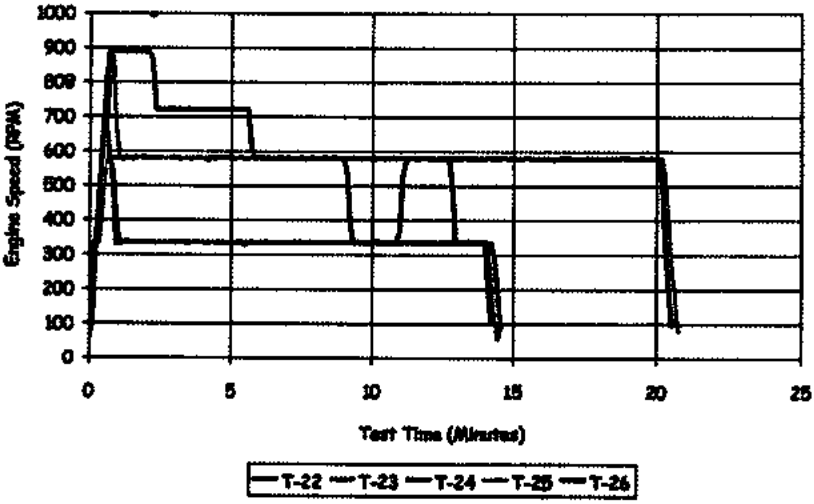


**Figure 17**
**Engine Speeds During the Restart Tests on BNSF 4373**

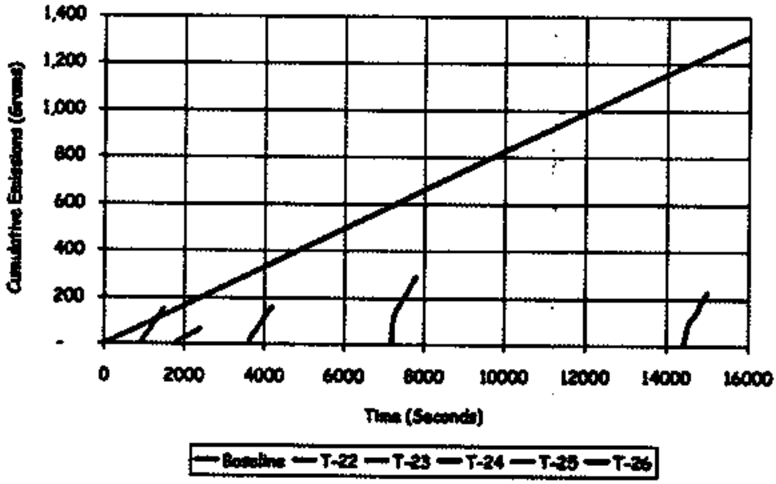


**Figure 18**
**Cumulative NOx Emissions From BNSF4373**

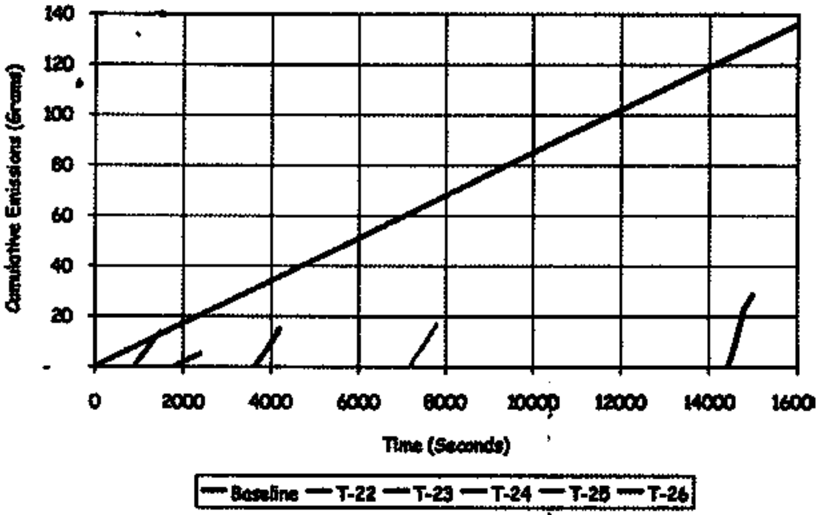


**Figure 19**
**Cumulative HC Emissions From BNSF4373**

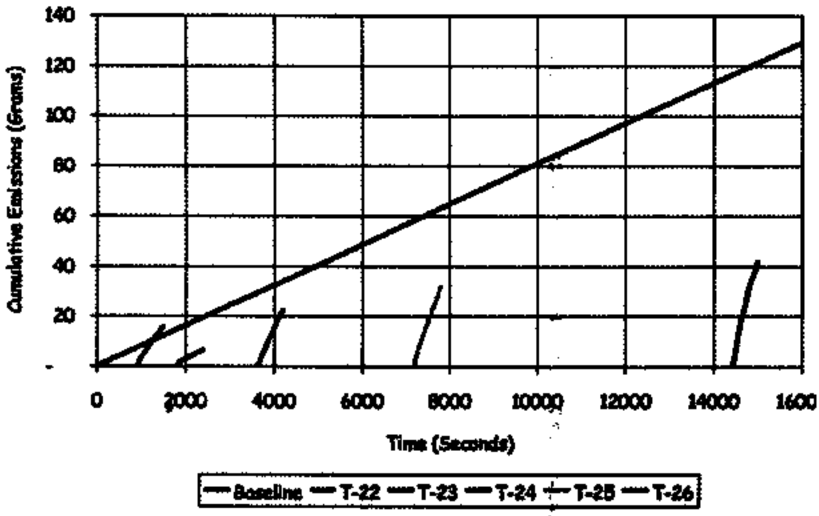


**Figure 20**
**Cumulative CO Emissions From BNSF4373**

| Condition of Test | Test Code | PM Emissions Filter A (g/hr) | PM Emissions Filter B (g/hr) | PM Emissions Filter C (g.hr) |
|---|---|---|---|---|
| Baseline = FTP Conditions | T-21 | 10.6 | (A) | (A) |
| Start-up post 15 minute shutdown | T-22 | 11.0 | 9.8 | (A) |
| Start-up post 30 minute shutdown | T-23 | 10.7 | 10.1 | (A) |
| Start-up post 60 minute shutdown | T-24 | 36.3 | 32.3 | (A) |
| Start-up post 120 minute shutdown | T-25 | 46.1 | 51.6 | 48.4 |
| Start-up post 240 minute shutdown | T-26 | 106.3 | 50.6 | 45.2 |
| (A) PM emissions not measured | | | | |

**Table 3**
**PM Emissions Results for Restart Tests on BNSF4373**

## III. OPERATIONAL EFFECTS OF LOW SULFUR DIESEL FUEL IN LOCOMOTIVES

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### Abstract

This paper will examine the current and future United States locomotive engine emissions regulations, briefly discuss possible engine technologies that may be used to achieve them, and present the role of lower sulfur diesel fuels in helping to achieve these emissions standards. Experiences, both good and bad, with lower sulfur diesel fuels will be illustrated, and potential remedies for the problems will be presented.

### Motivation

It is said the three most important things in Real Estate are Location, Location, and Location. Clearly, then, the three most important things in Diesel Engines are Emissions, Emissions, and Emissions. Diesel engines, whether used for passenger cars and pickup trucks, on-highway trucks, tugboats, ships at sea, or railroads, are subject to emissions regulations, and those regulations are getting increasingly stringent. New types of engine designs are being introduced to improve combustion, reduce oil consumption or reduce pollutants formed during the combustion process (exhaust after-treatment). Some of these hardware changes benefit from the use of diesel fuel with lower sulfur content; some hardware changes require it. This reduction of fuel sulfur has occurred, and continues to occur, in segments other than railroad and in regions other than North America. The experiences gathered in those applications may serve as an object lesson to American railroads to help anticipate, or bypass, any potential problems or required adjustments.

### Locomotive Emissions Standards

In 2000, the United States Congress enacted laws to regulate the amount of pollutants in the exhaust emissions of non-road diesel engines, including railroad locomotives. Three levels of emissions were defined as Tier 0, Tier 1, and Tier 2, effective for model years 1973 (retroactive), 2002, and 2005 respectively. In 2008, these were supplemented with Tier 3 and Tier 4, to go in effect 2012 and 2015, respectively. The relevant limit applies to either the year an engine is built, or the year of a re-build or major overhaul. There are different limits for linehaul and switcher service. The tiers and limits are shown in Table 1.

If a picture is worth a thousand words, then a graph is worth a thousand numbers; the emissions Tiers are shown in graphical form in Fig. 1.

For diesel engines, Nitrogen Oxides, (NOX), and Particulate Matter, (PM), are the most difficult emissions to meet and often trade-off against each other. Typically, improvements - decreases - in one cause increases in the other. For that reason, plotting PM against NOX emphasizes such trade-off. For

example, retarding injection timing reduces NOX but increases PM, as shown in Figure 1. To reduce both requires new technologies, as discussed later.

Another way to view increasing reduction in both NOX and PM is to graph them against time, in Figure 2. NOX is shown above the zero line on the Y-axis and PM is shown below the zero line; this format emphasizes the "squeezing" of emissions limits with time.

The timeline for "Trucks" is shown superimposed on the timeline for "Trains" (linehaul locomotives). In terms of grams per brake horsepower-hour, locomotives were required to meet, starting in 2005, roughly the same emissions levels as on-highway trucks did in 1992. The Tier 4 locomotive limits, effective 2015, are roughly the same as the on-highway truck limits for 2007. Due to higher hauling efficiency, emissions *per* revenue ton-mile are approximately 1/3 as much for trains as for trucks (Iden). Given the much larger size of the aggregate truck fleet compared to the aggregate locomotive fleet, trucks in total emit over two times as much NOX and eight times as much particulates as railroads (EPA).

However, the EPA sets the standards in units of brake specific emissions (g/bHP-hr) and considers them achievable based on both theoretical grounds and the demonstrated performance of on-highway, high-speed diesel engines.

One option for future locomotives is the use of high-speed diesel engines, similar or identical to those developed to meet on-highway emissions standards, in a configuration with multiple generator sets (multiple gen-sets). A single engine of this type would not be available in the power range required for typical railroad line-haul service. In addition to lower specific emissions, the multiple engine configuration would allow computer control to shut down one or more engines if the power demand is low. This technology has been and is being tested in switcher service. The latest information about multiple gen-set locomotive operations is being presented at this meeting by Volkmann and by Slomski.

High-speed, on-highway type diesel engines may be used in a hybrid configuration to reduce emissions. This system works because, for many situations, the average power demand on a locomotive is much lower than the maximum power capacity of a large railroad diesel engine. In a hybrid, the (smaller) diesel engine charges batteries which are then used to meet peak power demand. This technology has also been tested and is being used in switcher service.

An update of emissions regulations as related to railroad operations is being presented at this meeting by Hedrick.

### Technologies and Strategies to Meet Emissions Standards

In Figure 1, the largest box represents the EPA estimate of emissions for the aggregate United States locomotive fleet before any standards were introduced. The initial limit, Tier 0, was supposed to be a mild introduction, with subsequent tiers triggering substantial decreases.

Tiers 0 and 1

North American locomotive engine manufacturers met Tiers 0 and 1 by fine-tuning existing engine designs. Some engine designs or configurations already met these limits and needed no change. Others required various degree of modification, for example higher pressure fuel injectors and revised electronic injection timing.

Tier 2

Tier 2 was not, in general, achievable with engines designed before that time, and both North American engine manufacturers introduced new engine designs. These featured improved and more efficient combustion, higher pressure injection, more sophisticated electronics, and lower oil consumption. Oil consumed by leakage past the piston rings merges with the exhaust and will be measured as particulate emissions.

The engine design strategies to meet Tiers 3 and 4 are not yet known, but it may be instructive to examine how the on-highway segment met the equivalent limits and what that experience has been.

Tier 3

The equivalent of Tier 3 was met by on-highway, high-speed diesel engines by more fine-tuning, higher pressure injectors, revised electronics, and Exhaust Gas Recirculation (EGR). The on-highway segment did not have time to develop new engine designs to meet this equivalent limit, due to imposition of that tier ahead of the original schedule. In the view of some, EGR was a "fix" that could be deployed quickly and may not have been the preferred solution had more time been available. It is not clear whether locomotive engine manufacturers will choose EGR, given a) the increased time available to develop other solutions, and b) some of the trade-offs required by the use of EGR.

Exhaust Gas Recirculation, EGR, is a system that takes a portion of the exhaust gas and "recirculates" it back into the intake air stream. This dilutes the air-fuel mixture, lowers its temperature, and effectively reduces its combustion efficiency, leading to lower nitrogen oxide emissions. The exhaust gas is approximately inert to combustion, having already been combusted. The introduction of any inert gas - for example, carbon dioxide or argon - into the air-fuel mixture will dilute the combustion event and reduce nitrogen oxide emissions. Unfortunately, the burnt air-fuel mixture, comprising carbon dioxide, water, carbon monoxide, nitrogen oxide, particulate matter, and other combustion products is not perfectly inert and does, in fact, get incorporated into the combustion event, causing new undesirable by-products.

Combustion with EGR tends to cause higher acid levels than combustion without EGR. One reason is that any sulfur in the fuel gets "reburned," forming more sulfur acids. These acids must be neutralized by the engine oil to avoid severe engine damage. The extra amount of acids reduces engine oil life, as illustrated in Figure 6. The same engine was operated with the same engine oil under the same speed and load with and without EGR. With EGR, the oil shows a typical decreasing BN curve, from its starting value to the approximate range of typical railroad condemning limits for four-stroke engines. Without EGR, the same engine was operated with the same oil at the same speed and load for the same duration, at which time it had not approached the range of condemning limits. Comparing the two conditions at the ending BN depletion without EGR, the effect of EGR is to reduce oil life approximately in half. Of course, the amount of reduction will depend on engine design, the degree of EGR, the fuel sulfur content, and the engine oil.

Another effect of EGR is to change the chemical nature of the soot produced. This new form of "EGR-soot" does not respond to traditional dispersant chemistries and new additive technology had to be developed to allow engine oils compatible with EGR. These chemistries are now well-known and available for use in the railroad engine oils.

Tier 4

The emissions limits required by Tier 4 can only be met with one or more catalytic after-treatment devices, probably accompanied by engine re-design - *for example Miller Cycle combustion* - to take maximum advantage of them. The three most popular after-treatments are Diesel Particulate Filters (DPF), Diesel Oxidation Catalysts (DOC), and Selective Catalytic Reduction (SCR). A Diesel Particulate Filter (DPF) is exactly what it sounds like: a filter that removes particles from the exhaust stream, lowering the amount of PM in the exhaust gas. Like any filter, these must be replaced or regenerated periodically. DPF was the subject of an LMOA presentation in 2006 by Fritz.

A Diesel Oxidation Catalyst (DOC) oxidizes unwanted emissions to form less harmful species. Hydrocarbons are oxidized to carbon dioxide and water; carbon monoxide is converted to carbon dioxide; and nitrogen is converted into nitrogen dioxide, which must be dealt with separately.

Selective Catalytic Reduction (SCR) uses a reducing agent, usually urea, to convert nitrogen oxides into ammonia and water. The urea must be carried on-board, is consumed in the reaction, and must be replaced periodically.

A more comprehensive review of diesel after-treatment devices for emission control may be found in Stewart.

## Introduction of Lower Sulfur Levels

Coincident with introduction of more stringent emission tiers. low- and ultra-low sulfur diesel fuel was mandated for the on-highway segment, and the locomotive segment will follow suit.

Prior to 2007, railroads were allowed to use "high" sulfur fuel, defined as less than 5000 *per* million, (0.5%), meeting ASTM D975, Standard Specification for Diesel Fuels. Typical fuels in-service were about 4000 ppm sulfur.

Beginning 1992 for on-highway diesels and 2007 for off-highway diesels (including railroads), fuel sulfur was constrained to a maximum of 500 ppm (0.05%), referenced in this paper as "low sulfur diesel" fuel, or LSD.

Beginning 2005 for on-highway diesels and 2012 for off-highway diesels (including railroads), fuel sulfur was and will be constrained to a maximum of 15 ppm (0.0015%), referenced in this paper as "ultra-low sulfur diesel" fuel or ULSD.

These limits are illustrated in Figure 3. For both on-highway and off-highway, there are exceptions to the strict introduction of limits, known as "80-20" rules, which will not be discussed in detail here.

The transition of the United States diesel fuel market to ULSD is shown in Figure 4, compiled using data from the US Energy Information Agency, a branch of the Department of Energy, www.eia.doe.gov. The US refineries changed production essentially immediately following the requirements of ULSD, with an estimated investment of $6 billion. The small peak around 2004 probably represents trials of the new refinery configurations to produce ULSD.

Although railroads and other off-highway diesel engines may use LSD until 2012, it is not clear these fuels will be readily available; it is possible ULSD will dominate the marketplace. Although the aggregate North American railroad fleet uses a lot of diesel, it is a small fraction - about 7% - of the total. Figure 5 shows this by combining data from the US EIA on total production of diesel fuels and data from the AAR on fuel used by North American railroads.

Although LSD is less expensive to refine than ULSD, it would require a refinery or distributor to maintain separate storage tanks and clean transfer pipes between shipments, *etc.* This might not be worthwhile and refineries may opt to produce only one grade. A survey of fuel usage by North American railroads was reported by McAndrew, *et. al.* in 2007.

After 2012, both on-highway and off-highway will use ULSD. Between now and then, railroads may receive one type on one day (or place) and the other type another day (or place). This uncertainty makes optimizing the engine-fuel-oil system more difficult.

## Reasons For Lower Sulfur Fuels

The reasons to reduce fuel sulfur fall into three general categories: 1) Direct Effects: mechanisms by which fuel sulfur contributes to emissions, 2) Facilitation Effects: emissions technologies which work <u>better</u> with lower sulfur fuels, and 3) Enabling Effects: emissions technologies which <u>require</u> lower sulfur fuels.

<u>Direct Effects</u>

Sulfur in fuel is converted in the combustion process to sulfur oxides, (SOX), which combine with water vapor from combustion to form sulfurous and sulfuric acids. These in turn can react with other species to form sulfates, which are measured in the exhaust as particulates. Lowering fuel sulfur reduces the amount of Particulate Matter (PM) emissions.

Facilitation Effects

Exhaust Gas recirculation (EGR), as mentioned above, caused "extra" oxidation of fuel sulfur, leading to increased acid production, decreased oil life, and greater engine corrosion. Reducing the amount of sulfur in fuel reduces the amount of "extra" acid formed by EGR, increasing oil and engine life.

Diesel Particulate Filters (DPF) will trap the sulfates that would otherwise become particulate emissions. Lowering fuel sulfur reduces the amount of extra particulates to be trapped, increasing the efficiency and life of the DPF.

Enabling Technologies

Any catalyst - DOC, SCR, or other- will be poisoned by sulfur. These exhaust devices require ultra-low sulfur diesel fuel to work. Emissions standards that require catalyst technologies also require ultra-low sulfur fuels.

## Operational Experiences with Lower Sulfur Fuels

North American railroads are not the only segment to reduce diesel fuel sulfur. North American and European on-highway diesel engines reduced fuel sulfur, as noted above. Ships at sea reduced fuel sulfur, although from extremely high levels (~4.5%) to levels still well above those tolerated by truck or railroad engines. However, this is *still* a reduction of sulfur content and may be instructive to consider. This section combines data from railroad, on-highway, and marine experiences in several geographic regions to determine the effects of reduced sulfur diesel fuel, whether patterns exist, and what strategies were used to effect the transitions.

The benefits of lower sulfur diesel fuel, discussed above, are:

1) Reduces particulate matter in exhaust
2) Extends life of Diesel Particulate Filters
3) Permits use of catalytic exhaust after-treatments
4) Forms less acid in engine oil

An example of lower acid formation is shown in Figure 7, where the same engine and engine oils were run at the same conditions for the same duration with high (<5000 ppm) and low (<500 ppm) sulfur fuels. The Base Number (BN, ASTM D4739) retention is greater with low sulfur fuel. That is, the lower sulfur fuel depletes the engine oil slower, and may be assumed to allow increased oil drain intervals (if base number loss is the critical parameter, rather than insolubles or oxidation, or another property). There are not enough points to establish a general rule of how much more base number is retained; it may depend on details of the oil chemistry.

The problems experienced with lower sulfur fuels are divided into Direct and Indirect Effects:

Direct Effects

1) Lower fuel economy
2) Injector wear (Lubricity)

Lower fuel economy is a consequence of sulfur being contained in aromatic molecules, which are denser. (See the references by Girshick, Leffler, and Speight for discussions of refinery processes and crude oil chemistry.) Removing the sulfur-containing molecules reduces the density of the fuel. There is less energy per unit volume. There is no known additive or technological solution to this. The only remedy would be to change the units of efficiency, from volumetric - megawatt-hours per gallon - to mass - megawatt-hours per pound or, even better, to true thermal efficiency - megawatt hours per BTU. Perhaps railroads can even enter fuel purchase contracts tying the sale price to energy content.

Injector wear is due to the sulfur compounds in fuel being surface-active and providing boundary lubrication to maintain the moving parts within fuel injectors. Removing the sulfur removes the lubricants. There are other natural lubricity agents, oxygen and nitrogen compounds, that are removed during the process of removing sulfur. The lower lubricity of ULSD fuel can be rectified by adding lubricity additives; this is a common practice.

Indirect Effects

1) Combustion chamber deposits
2) Liner varnish (lacquer)
3) Bore polishing (liner wear)
4) Oil consumption increase
5) Black smoke

These effects have all been observed in various times and places, and are quite variable. Some operations changing to low or ultra-low sulfur fuel experience no problems whatsoever. The extreme variability in experiences makes it difficult to formulate a hypothesis or chemical theory about their causes.

Probably these effects are related. It is known that liner varnish - thin yellow-orange deposits that fill in the normal hone marks - will lead to loss of oil consumption control and black smoke. Whatever causes combustion chamber deposits is likely also to form deposits on the piston top land, leading to bore polishing (liner wear). Once the liner has been worn smooth, loss of oil consumption control and black smoke will result.

One common assumption is that, with high sulfur fuel, the amount of Base Number - or detergent or ash - in the oil was exactly sufficient to balance the amount of acid produced by the fuel sulfur. When the fuel sulfur is reduced, all other things being equal, the excess ash forms combustion chamber deposits and liner lacquer. This can be refuted by noting that the amount of base number in engine oil varies over its life. Even with high sulfur fuel, base number started very high and decreased over the oil drain interval (for four-stroke designs) or during the cycle of top-up and depletion (for two-stroke designs).

Whatever the mechanism, it is known that remedies exist and others are certain to be developed between now and the implementation of Tiers 3 and 4. Many of these will be subjects of future papers by the Fuels, Lubricants, and Environmental Committee of LMOA. A more detailed discussion of the impact of ULSD on maintenance is being presented by Standish.

**Biodiesel Fuel**

Another form of low-sulfur is biofuel. These fuels were the subject of an LMOA paper in 2005 by Bowen, et. *al.*

Although not directly related to the subject of lower sulfur diesel fuels, results of a recent field test are available and of interest to this audience. As discussed in Bowen and McAndrew, biodiesel blends could be used by railroads in the foreseeable future, either by mandate, economic incentive, or choice.

Figure 8 shows the viscosity increase for two oils of differing quality using ULSD, a 50% blend with biodiesel (B50), and straight biodiesel (B100). There is a difference in oil quality, even with pure ULSD fuel and the difference increases as the biodiesel content is increased. The low quality oil does not meet typical railroad condmening limits with any fuel blend. The high quality oil would meet typical railroad viscosity increase condemning limits up to about 40% biodiesel (B40).

Figure 9 shows the increase in lead corrosion for biodiesel blends compared to the corresponding result with ULSD (B0). Engines from two manufacturers showed different sensitivities to biodiesel , with the same engine oil. A series of commercial oils were run in the more sever engine and showed a variety of results (diamonds).

The effect of biodiesel source is shown in Figure 10. Fatty acid methyl ester (FAME) biodiesels were manufactured from three biosources: soybean, canola, and palm oil. The amount of lead corrosion increase correlated with the degree of saturates in the source molecule. See also Girshick (2005) for the relation between saturates and oxidative stability.

**Possible Remedies**

The holistic system of engine, fuel, lubricants, coolants, and operational strategies for North American railroads has evolved to a stable equilibrium. The introduction of new emissions standards is causing revolutionary changes that upset that equilibrium, at least temporarily. The ultimate answer will be a new equilibrium comprising new engine designs, new exhaust after-treatment devices, new fuels, and perhaps new fluids or operations tactics. LMOA is watching these changes very closely and participating in understanding, facilitating, and easing the required new technologies. Each LMOA Committee shares their knowledge through presentations and publication, so a complete solution may be reached.

During the transitional period between one equilibrium and another, one of the strategies to remedy the negative operational effects of low sulfur fuels is the use of fuel additives. A general review of fuel additives was presented to LMOA by

Bowen in 2001. Kunkel presented a review of fuel economy fuel additives in 2006.

A new class of fuel additves, designed to ameliorate the problems experienced with low sulfur fuels are being deployed in worldwide markets - wherever and whenever lower fuel sulfur is being mandated, resulting in the problems listed above. The benefits of fuel additives include a) the ability to restore properties to the fuel, such as lubricity, and b) the ability to target the affected engine areas, such as combustion chambers, piston top lands and liners. The types include traditional fuel additives, such as wax crystal modifiers, combustion improvers, and lubricity agents; new fuel additives, to deal with changing fuel compositions by increasing stability and compatibility; and additives similar in functionality to lubricants, such as cleanliness and acid neurtralization addtives. Obviously, none of these additives can contain sulfur because that would likely violate the very sulfur limit mandating use of the fuel.

An example of liner varnish reduction is shown in Figure 11. The photograph on the left shows a heavily varnished liner following a transition to lower sulfur fuel. The photograph on the right shows the same liner after a period of incorporating a cleanliness additve into the lower sulfur fuel.

The photograph in Figure 12 shows removal of valve deposits from the same engine as Figure 11.

Figure 13 shows oil consumption control by a fuel additive. In this case, the dependent variable (oil consumption) is a continuous parameter and can be measured more easily as a function of time, unlike deposits. For the first five months of the test, the engine was operated with fuel additive and oil consumption slowly reduced. Then the use of fuel additive was discontinued, and oil consumption began to increase. In The final stage, the fuel additive was again used, and oil consumption decreased. This type of testing gives increased confidence that the treatment is really the cause of the observed effect and is consistent with the revised fuel additive testing protocol being developed by the FL&E Committee, as communicated by Lau (2007).

Another example of fuel additive testing protocol is shown in Figure 14. Although possibly not directly relevant to North American railroad operations, it illustrates "best practice" with respect to fuel additive testing. Fuel consumption was measured in marine service following deployment of a combustion improver fuel additive. Brake specific fuel consumption decreased by over 10% over seven weeks. At this point, test could have been terminated and the results published. However, to prove a point, and to understand the mechanism, the use of additive was discontinued and the brake specific fuel consumption increased, but not as high as the initial value. Again, the additive was used for another stage and the fuel consumption decreased, this time to the same level as before; this value was declared the equilibrium fuel consumption with additive. The additive was discontinued for another stage and fuel consumption increased, this time to the same point as the second stage and this was delcared the equilibrium value without additive. The difference between equilibrium values with and without additive was 4.9% and this is the supportable claim. The results, augmented by laboratory testing and chemical analysis, suggest the mechanism is improvement in combustion of the "heavy" end of a poor quality fuel. For high quality fuels, typical of those in North American railroad service, there might not be any room for improvement with such a fuel additive.

**Acknowledgements**

The author thanks the Fuels, Lubricants, and Environmental Committee for their help and guidance in preparing this paper, and for their review and corrections. In particular, I would like to thank the FL&E Chairman, Tom Pyziak, for his encouragement and support, and the LMOA Secretary-Treasurer, Ron Pondel, for his help preparing the manuscript for publication.

**Glossary of Acronyms**

AAR - Association of American Railroads
ASTM - American Society of Testing and Materials
BN - Base Number, ASTM D2896 or D4739
Bxx - Biodiesel blend with xx% biodiesel ULSD fuel
CO - Carbon Monoxide
DPF - Diesel Particulate Filter
DOC - Diesel Oxidation Catalyst
DOE - Department of Energy
EGR - Exhaust Gas Recirculation
EIA - Engergy Information Agency
EPA - Environmental Protection Agency
FAME - Fatty Acid Methyl Ester
FRA- Federal Railroad Administration
g/BHp-hr - Grams *per* brake horsepower hour
HC - HydroCarbons
LMOA - Locomotive Maintenance Officer's Association
LSD - Low Sulfur Diesel (fuel)
NOX - Nitrogen Oxides
PM - Particulate Matter
ppm - parts *per* million
SCR - Selective Catalytic Reduction
ULSD - Ultra-Low Sulfur Diesel (fuel)

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**Table 1**
**US EPA Locomotive Emissions Standards**

| Tier: | Tier 0[1] | Tier 1[1] | Tier 2[1] | Tier 3[2] | Tier 4[2] |
|---|---|---|---|---|---|
| Model Year: | 1973 | 2002 | 2005 | 2012 | 2015 |
| Parameter | | | | | |
| Nitrogen Oxides (NOX), g/bHp-hr[3] | | | | | |
| Linehaul | 8.0 | 7.4 | 5.5 | 5.5 | 1.3 |
| Switcher | 11.8 | 11.0 | 8.1 | 5.0 | 1.3 |
| Particulates (PM), g/bHp-hr[3] | | | | | |
| Linehaul | 0.22 | 0.22 | 0.20 | 0.10 | 0.03 |
| Switcher | 0.26 | 0.26 | 0.24 | 0.10 | 0.03 |
| Hydrocarbon (HC), g/bHp-hr[3] | | | | | |
| Linehaul | 1.00 | 0.55 | 0.30 | 0.30 | 0.14 |
| Switcher | 2.10 | 1.20 | 0.60 | 0.60 | 0.14 |
| Carbon Monoxide (CO), g/bHp-hr[3] | | | | | |
| Linehaul | 5.0 | 2.2 | 1.5 | 1.5 | 1.5 |
| Switcher | 8.0 | 2.5 | 2.4 | 2.4 | 2.4 |
| Smoke Opacity, percent | | | | | |
| Steady-State | 30% | 25% | 20% | 20% | 20% |
| 30-second peak | 40% | 40% | 40% | 40% | 40% |
| 3-second peak | 50% | 50% | 50% | 50% | 50% |

[1]40CFR Parts 85, 89, and 92 (2000)
[2]40CFR Part 1033.925 (signed 14 March 2008)
[3]bHp-hr = grams *per* brake horsepower-hour

US EPA Locomotive Emissions Standards

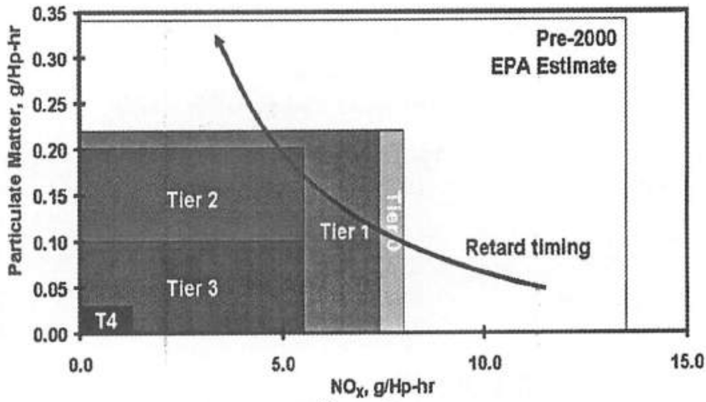



Figure 1

US EPA Locomotive Emissions Standards – Timeline

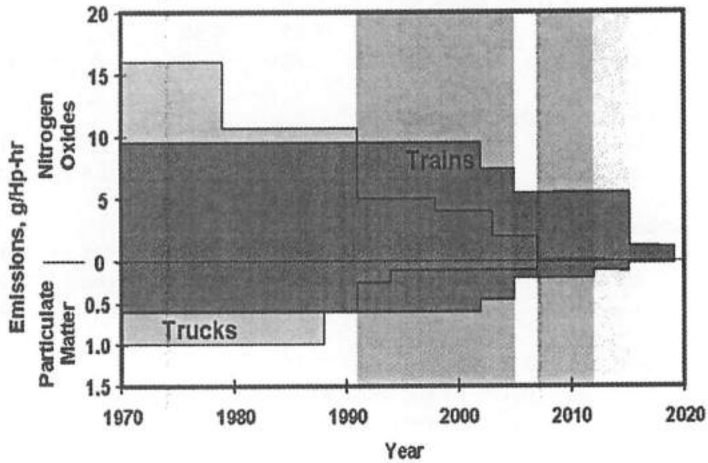



Figure 2

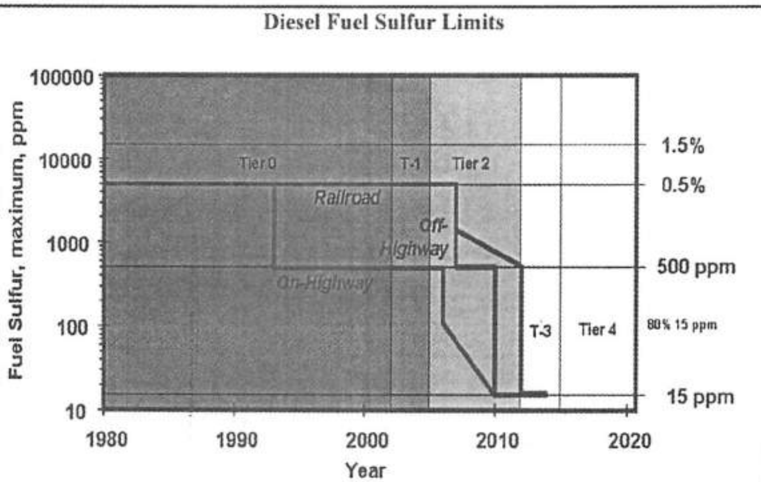



Figure 3

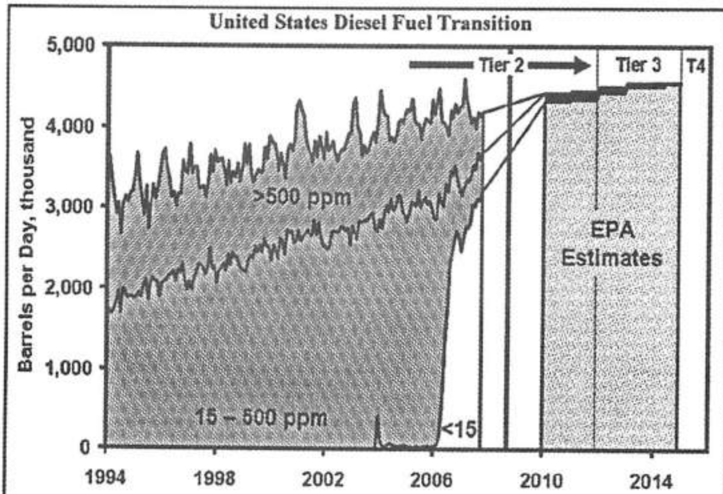



Figure 4

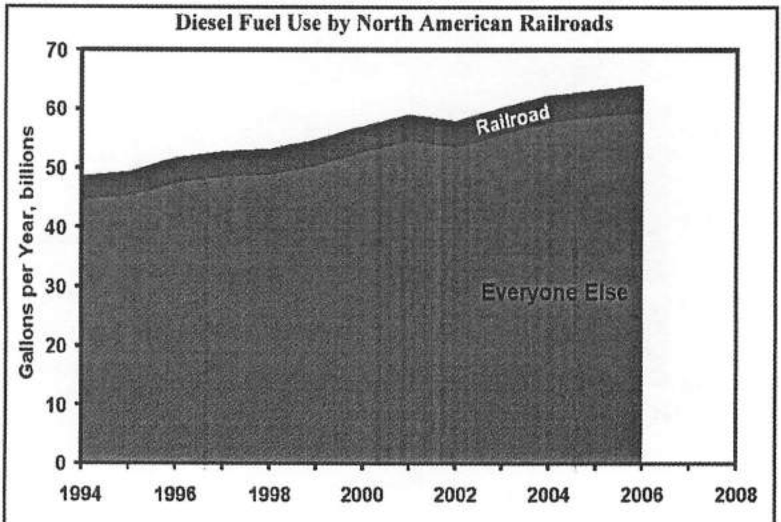



Figure 5

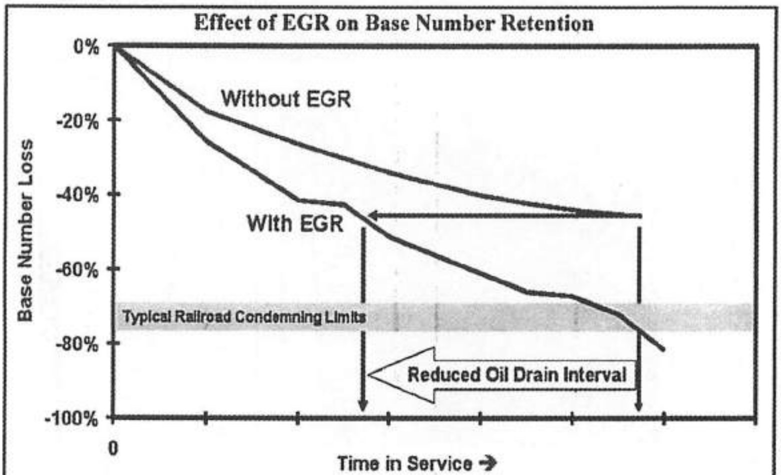



Figure 6

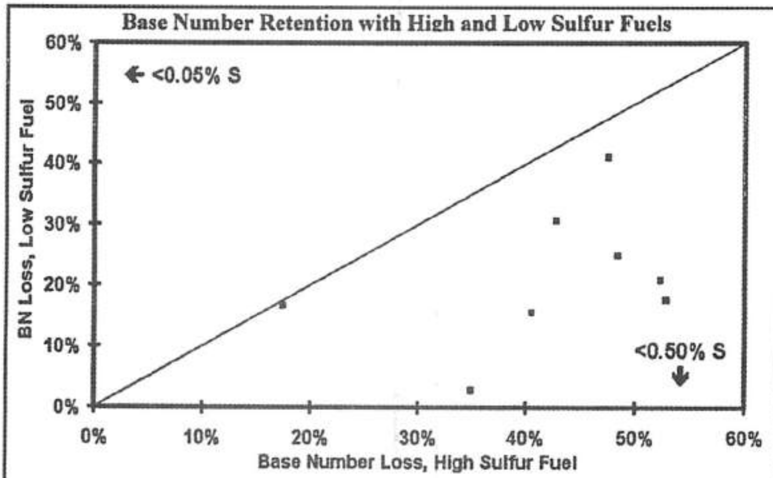



Figure 7

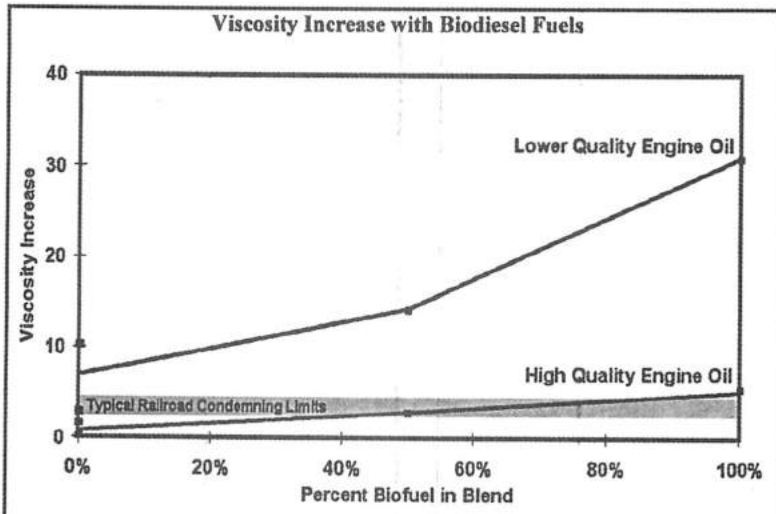



Figure 8

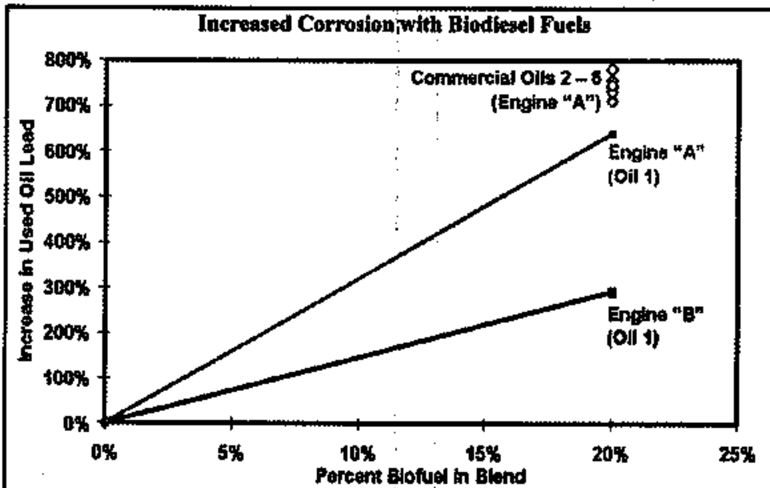



Figure 9

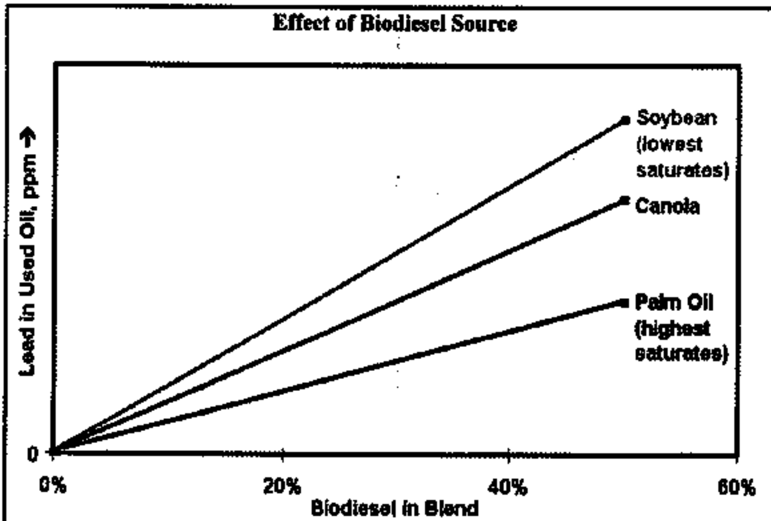



Figure 10

**Liner Varnish Removal**

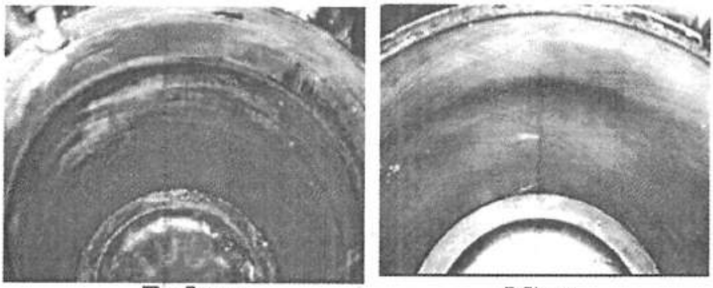



Figure 11

**Exhaust Valve Clean-Up**

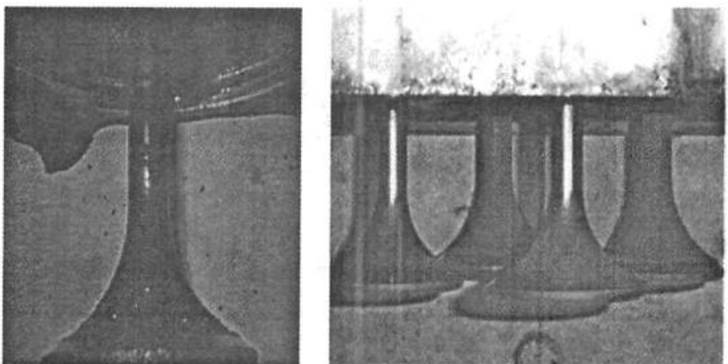



Figure 12

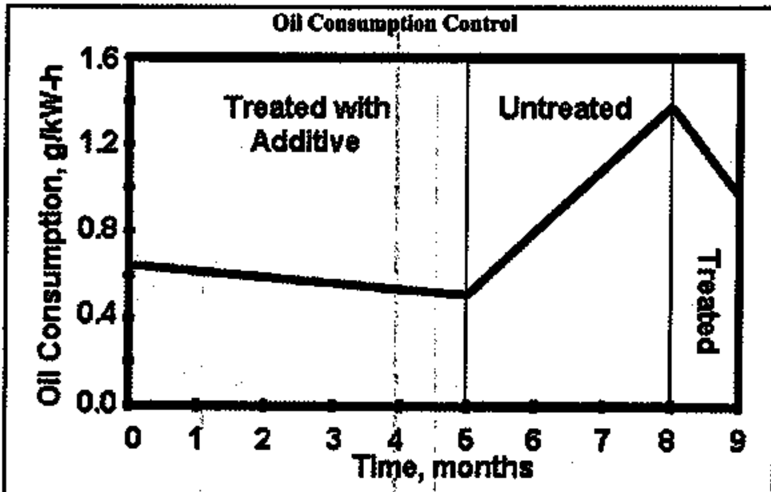



Figure 13

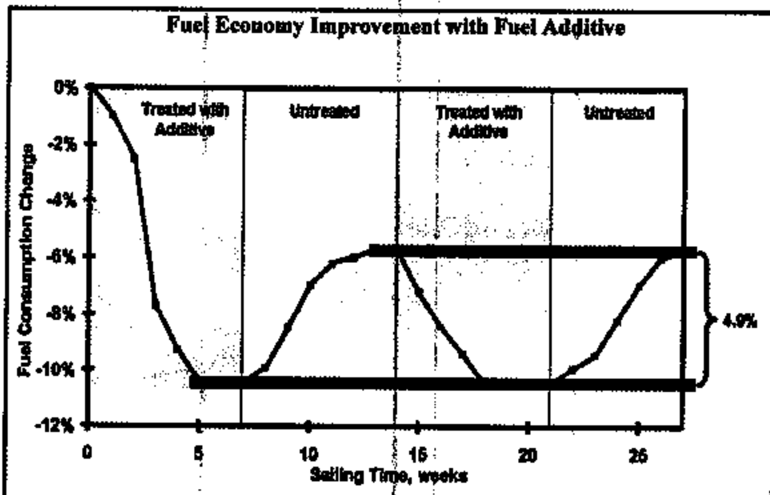
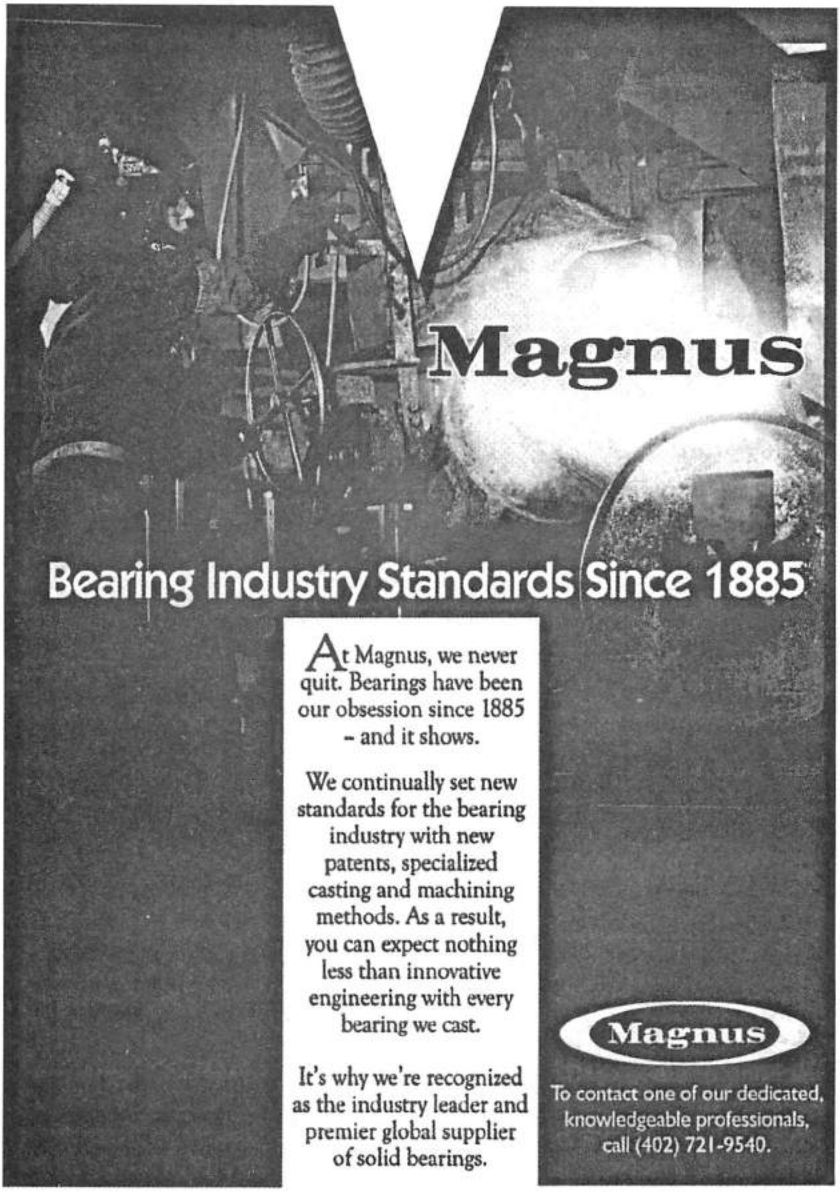



Figure 14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# REPORT OF THE COMMITTEE ON NEW TECHNOLOGIES

# MONDAY, SEPTEMBER 22, 2008
# 2:00 P.M.

Chairman
**JIM CHRISTOFF**
Business Mgr.-Traction Segment
Morgan AM&T/National
Cicero, NY

Vice Chairman
**ROGER DALTON**
Director-Project Management
Wabtec Motive Power, Inc.
Boise, ID

## COMMITTEE MEMBERS

| | | | |
|---|---|---|---|
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| B. Kehe | Mgr-Maintenance-Locos | EJ&E Rwy. | Gary, IN |
| A. Miller | President | Vehicle Projects LLC | Denver, Co |
| C. Nordhues | Dir. Acct. Services | Railpower Tech. | Omaha, NE |
| C. Prudian | Senior Systems Engineer | Electro Motive Diesels | LaGrange, IL |
| D. Sweatt | Elect. Systems Engineer | CSX Transportation | Jacksonville, FL |
| T. Volkmann | Dir.-Mech. Engrg. | Union Pacific RR | Omaha, NE |
| J. Whitmer | Loco. Rel. Specialist | CN RR | Homewood, IL |

# PERSONAL HISTORY

*Jim Christoff*
*Business Manager, Traction Segment*
*Morgan AM&T/National*
*Cicero, NY*

Jim who was raised in Western Pennsylvania now finds himself living in Cicero, NY. His 25 plus years in the carbon business have given him a broad knowledge of DC rotating equipment and an understanding of the operating conditions and environments that are present in railroad freight and passenger service.

Jim has worked for Morgan Crucible plc (parent company of Morgan AM&T/National) for 18 years. From 1989 thru 2001 he handled the East Coast Transit, Industrial, and Consumer Business. In 2002 he started working exclusively on Transit, Traction business and in 2005 he was promoted to Business Manager of Traction in the Americas.

Jim and his wife Diane have 2 children and 2 grandchildren. When work is done they enjoy boating, golfing, and visiting their children.

**THE NEW TECHNOLOGIES COMMITTEE WOULD LIKE TO EXTEND THEIR SINCERE APPRECIATION TO MORGAN AM&T/NATIONAL FOR HOSTING THEIR COMMITTEE MEETING IN GREENVILLE, SOUTH CAROLINA ON NOVEMBER 15, 2007**

**THE COMMITTEE ALSO WISHES TO THANK CSX TRANSPORTATION AND THE FLORIDA EAST COAST FOR HOSTING THEIR WINTER COMMITTEE MEETING IN JACKSONVILLE, FLORIDA ON MARCH 3 AND 4, 2008**

## I. MAINTENANCE EXPERIENCE WITH GEN SET SWITCHER LOCOMOTIVES TO DATE

*Prepared by*
*Tad Volkmann,*
*Union Pacific Railroad*

UPY 2005, a National Railway Equipment Company model GS14B, was the first modern gen set switcher locomotive. This locomotive has been in service in the LA Basin for nearly three years and has been successful in service. (Figure 1)

Railroads or other entitties that are considering the acquisition of gen set switcher locomotives via purchase or lease face several challenges in comparison with traditional types of diesel electric locomotives.

The new, non-rail technology and suppliers pose a challenge in determining maintenance strategy and parts stocking.

- Do you want on-site OEM technical assistance during the warranty period and after the warranty expires?
- Does it make business sense to pursue a Maintenance Service Agreement with the OEM or other party, or maintain the locomotives yourself, or a hybrid of both?
- Internal maintenance will entail extensive training on components/systems with which your mechanics are not familiar.
- If you maintain the locomotives yourself, be aware that parts identification and stocking will be a challenge.
- Lube oil, compressor oil, and coolant may vary from your existing fleet, and even between different types of gen sets, making servicing at already existing service tracks challenging.

One major railroad has chosen a hybrid maintenance strategy, in which basic oil/filters maintenance is performed in-house, with more involved maintenance to be performed by another party. (Figure 2)

Several railroads have found that obtaining spare and repair parts for gen set locomotives is more difficult than anticipated.

Factors that have made parts an issue early in the service lives of gen set locomotives are:

- Obtaining a comprehensive parts catalog from the OEM has been very difficult, although that situation is improving as time goes forward.
- One railroad cannot identify part numbers or sources for common commodities such as cab glazing, wiper arms/motors and light bulbs after nearly a year of effort.
- In some cases, the OEM may not know the source and ordering references for parts in subassemblies fabricated by subcontractors.
- Depending on how your purchase contract is written, you may be forced to buy all parts and supplies from the OEM at a mark-up to maintain the new locomotive warranty.

All gen set switcher locomotives and hybrids operating in mid-2008 share the same control strategy. The gen sets, or batteries, or fuel cells feed power to a common bus. The power is then processed by inverters and choppers for precise single axle control to DC traction motors. (Figure 3)

This paper will detail the features and problems experienced to date in two types of gen set locomotives that have accumulated sufficient service for a meaningful report, the Railpower RP20GE and the National Railway Equipment Company 3GS21B.

**Railpower RP20GE (Figure 4)**

**Features**

- Three Deutz Gen Sets with duty cycle equalization and 1,000 hour basic maintenance interval.
  Note: Railpower will soon offer gen sets with expanded sump capacity to extend oil changes to 2,000 hours.
- Water cooled inverters and choppers.
- Good functional computer display. (Figures 5, 6, 7 & 8)

**Problems Experienced to Date**

- Inverter fires - generator excitation cards were not robust enough for railroad service and failures caused voltage spikes. Cards were replaced with a more robust version.
- Insufficient chopper cooling - shortened water line fittings have helped. Cooler weather in autumn and winter seem to help.
- Transition power cut was initially simultaneous versus sequential, resolved by a software revision.
- Runaway incident on BNSF in Stockton, CA - resolved by retrofitting burden board with diode protection.
- Multiple quality issues with loose terminal board connections and improper bus bar material have caused several incidents and may be linked to the runaway incident.
- Schematics provided by Railpower were sometimes inaccurate, in early experience.
- All problems have been addressed and most are related to infancy failures on a new product.

**National Railway Equipment Company 3GS21B (Figure 9)**

**Features**

- Three Cummins gen sets with duty cycle equalization and 750 hour basic maintenance interval.
- Air cooled inverters and choppers
- N-Force computer (Figures 10, 11, 12 & 13)

**Problems Experienced to Date**

- Improper shutdowns were draining batteries so gen sets could not restart - resolved with battery saving software.
- Multiple chopper failures early - resolved with N-Force computer software upgrades and modifications.

- Cab Screen Modification - will replace original "fail light" display and provide much more information, including when 750 hour maintenance is due.
- "Kicking Car Software" - eliminated early crew complaints that units were "slow to load."
- Exhaust manifolds breaking around the bracket studs causing exhaust leaks. NRE has designed an improved exhaust manifold and will retrofit the BNSF fleet.
- Oil migration into traction motors - some locomotives did not have ballast secured in the frame during manufacture, allowing ballast to rub through traction motor air cooling plenum.
- BNSF has experienced premature fuel filter plugging, not lasting 92 days.

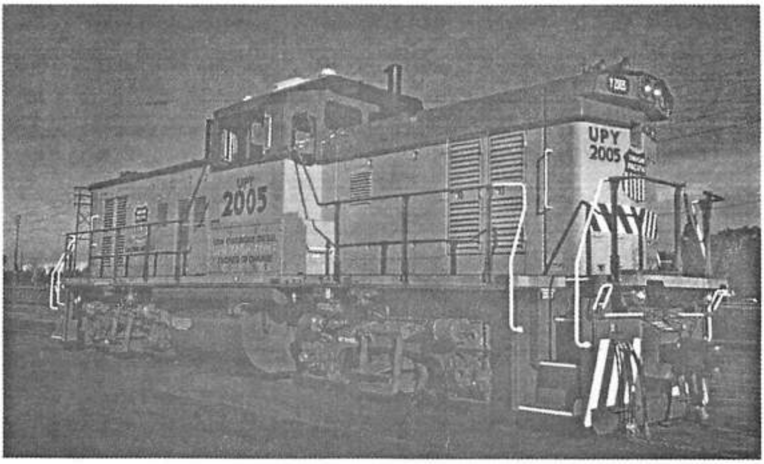
## Conclusion

Both types of gen set locomotives that have sufficient field experience to report on have good features, promise improved fuel economy and lower emissions, and have experienced problems in service. It is important to note that most of the problems experienced by both types of locomotives are common to "bugs' that can be expected in a new product containing a large amount of non-rail parts/systems content. All problems are being addressed by the OEM's, and maintenance experience will undoubtedly improve going forward.

## Acknowledgements

Thanks to Jase Geary, Daniel Hecht, Bob Smisek, and Jim Brix of Union Pacific Railroad. Thanks to Brad Queen of BNSF Railway. (Figure 14)

# Genset Yard Locomotives




**Fiugre 1**

Union Pacific Has Chosen a Hybrid Maintenance Strategy


**Figure 2**

## Common Bus / Inverter / Chopper Control -

Ability to efficiently control multiple power sources on one common platform (Experience on tracks since year 2000)

Design enables very precise individual control of each axle providing maximum adhesion level for track conditions

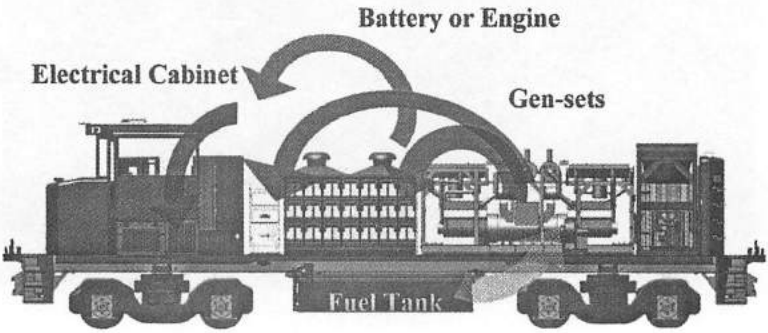



Figure 3

# Railpower RP20GE Highlights

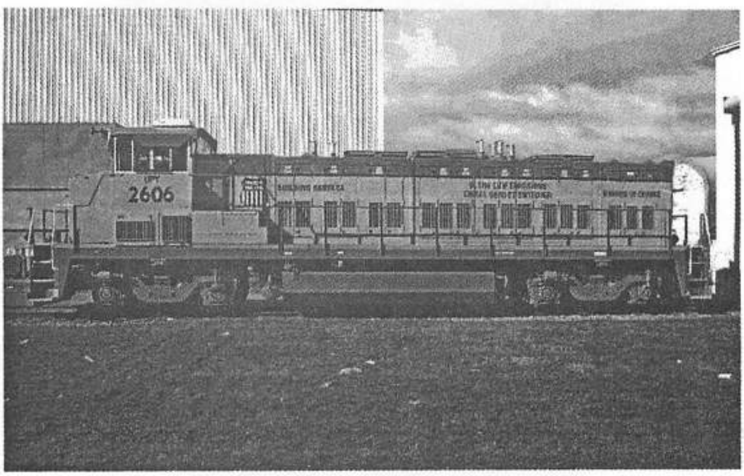



Figure 4

## Deutz Gen Set – 1,000 Hr. Basic Maintenance Interval

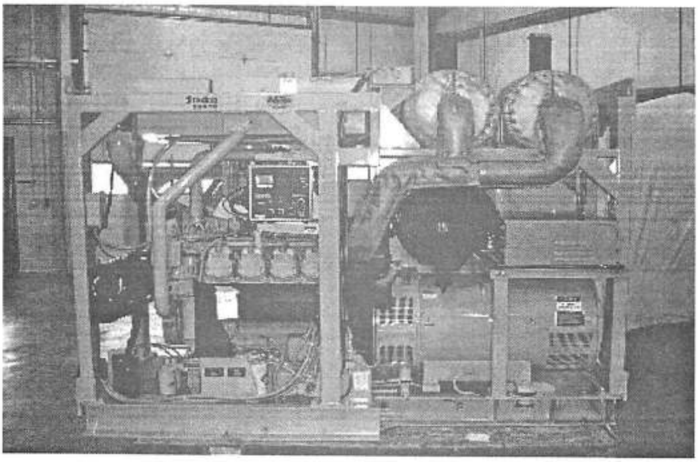


Figure 5

## Water Cooled Inverters

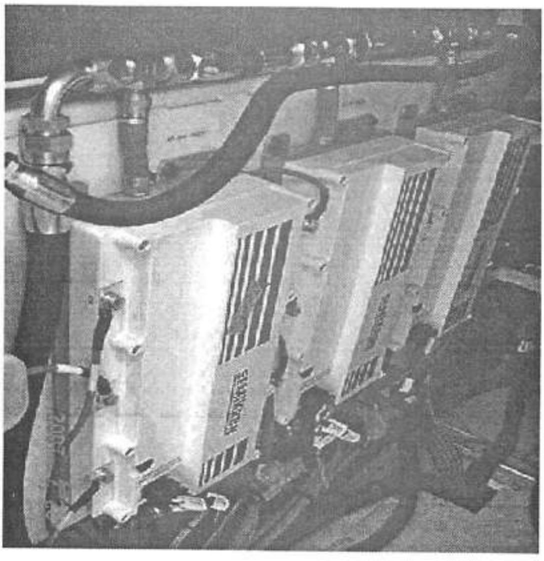


Figure 6

## Water Cooled Choppers

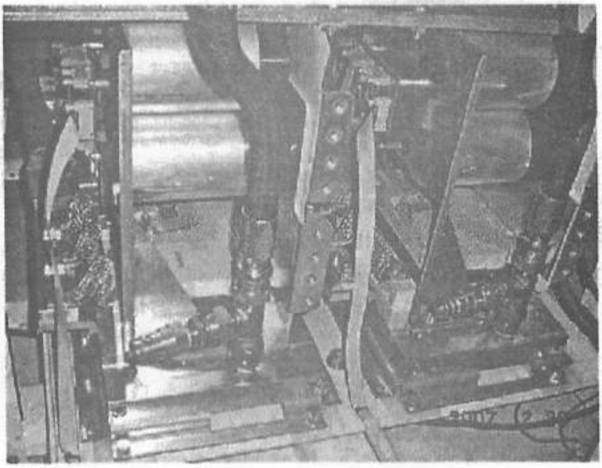


Figure 7

## Computer Display

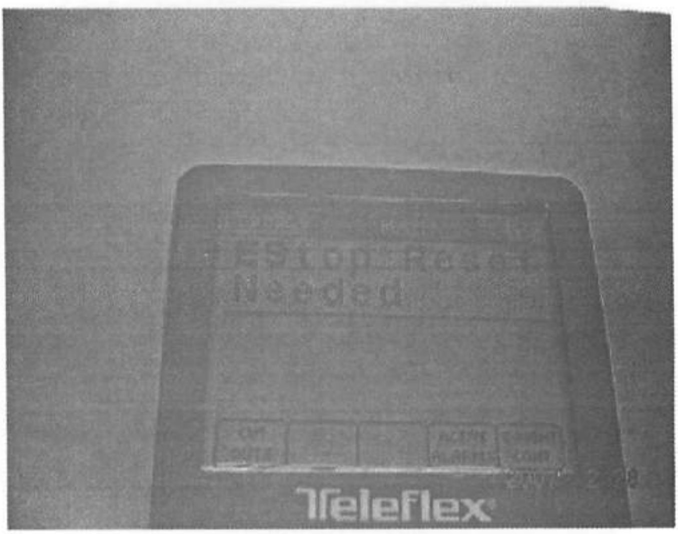



Figure 8

## National Railway 3GS21B Highlights

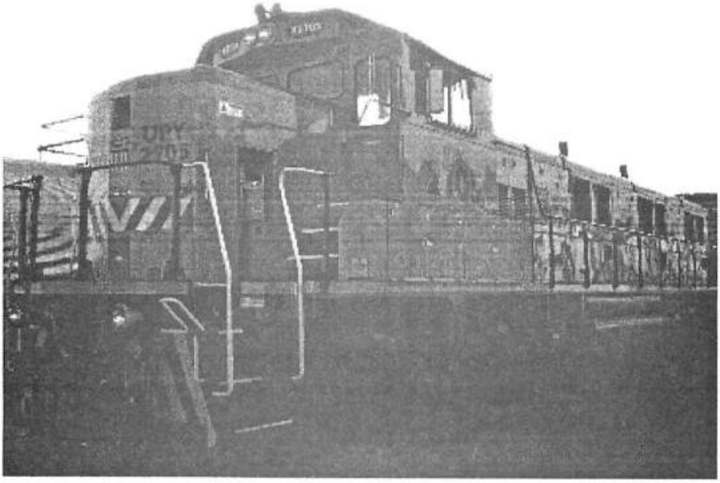


Figure 9

## Cummins Gen Set – 750 Hr. Basic Maintenance Interval

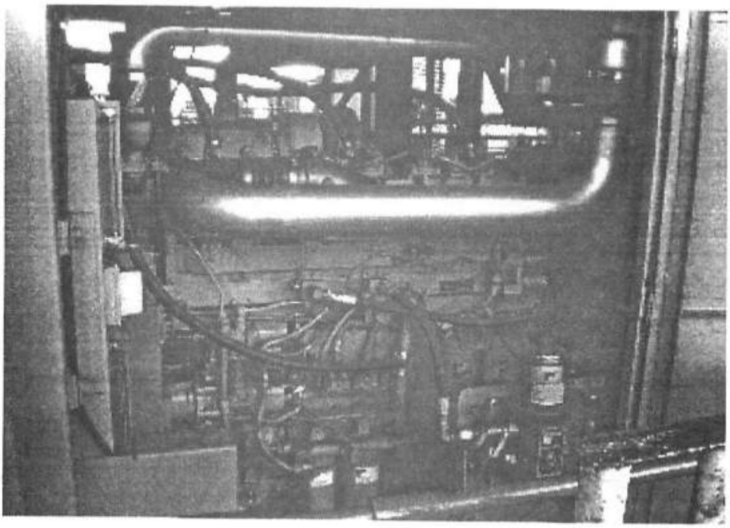


Figure 10

## Air Cooled Inverters and Choppers

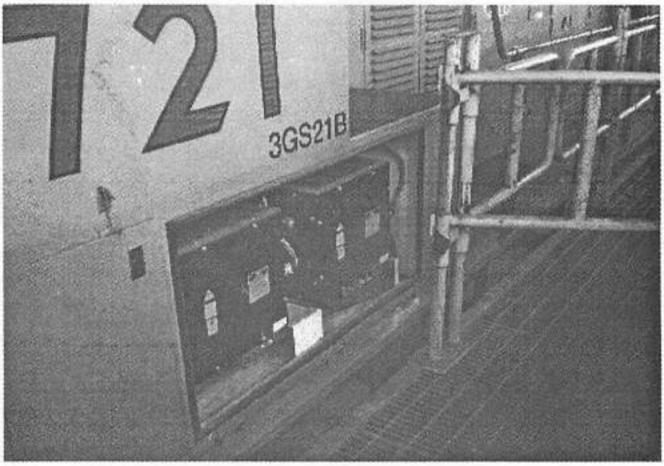



Figure 11

## NForce Computer

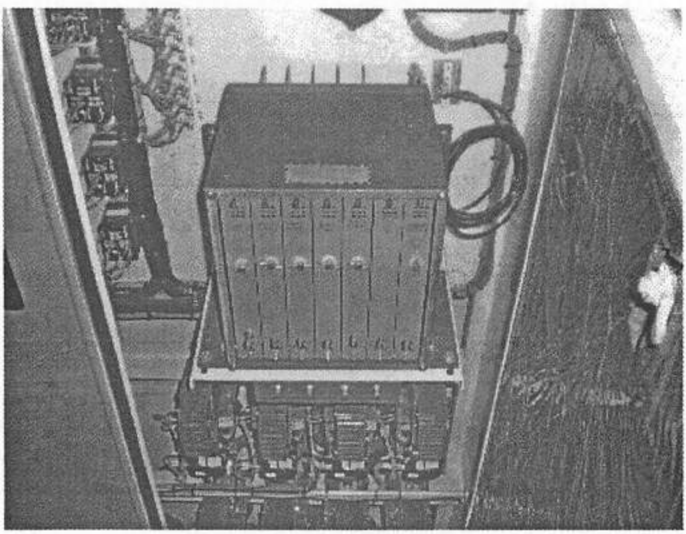


Figure 12

## Original "Fail Light" Display on Engineer's Control Console

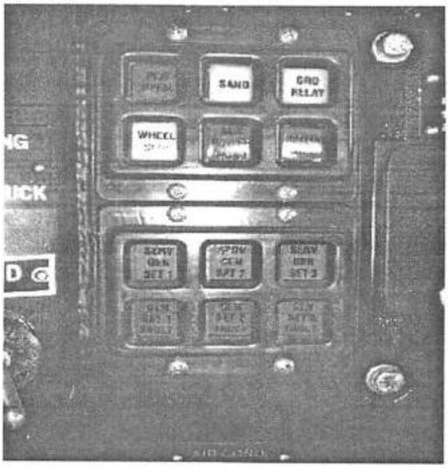



Figure 13

## Thanks to Jase Geary, Daniel Hecht, Bob Smisek, and Jim Brix

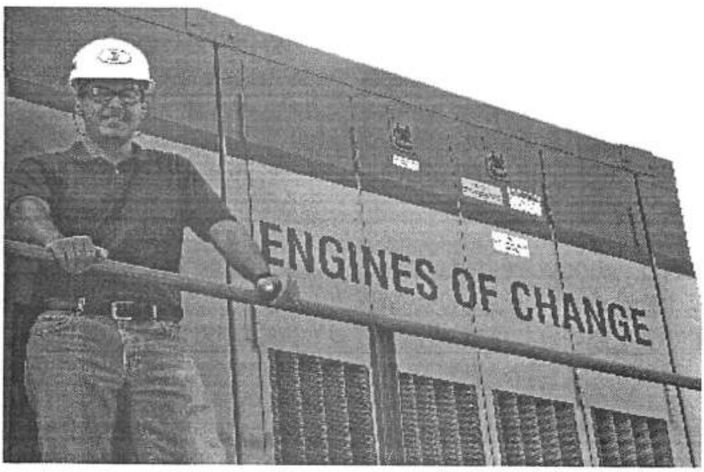



Figure 14

## II. MAINTENANCE OF THE BNSF FUELCELL-HYBRID SWITCH LOCOMOTIVE

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**Abstract**

A North American consortium, a public-private partnership, is developing a prototype hydrogen-fueled fuelcell-battery hybrid switch locomotive for urban and military-base rail applications. At 127 tonne, continuous net power of 220-250 kW from its fuelcell prime mover, and transient power well in excess of 1MW, the hybrid locomotive will be the heaviest and most powerful fuelcell land vehicle yet built. At the time of this writing, engineering design and fabrication of all major components of the hydrogen and fuelcell systems are complete, and the vehicle as a whole is scheduled for testing near the end of 2008. Hydrogen-fuelcell locomotives potentially can contribute to the solution of two major problems facing the world today: the end of oil and global climate change. This project has thus been led by the prospect of commercialization, ultimately culminating in fuelcell freight locomotives. The change from a diesel powerplant to a hydrogen-fuelcell powerplant has substantial implications to the overall maintenance and service requirements of a locomotive. As future fleets of fuelcell locomotives are developed, a sound maintenance plan must consider the unique requirements for safety, training, and facility needs. This paper focuses specifically on the BNSF Railway Company's prototype fuelcell-hybrid switch locomotive and its maintenance requirements.

**Introduction**

A North American consortium, a project partnership among BNSF Railway, the US Department of Defense, and Vehicle Projects LLC, is developing a prototype hydrogen-fueled fuelcell-battery hybrid switch locomotive for urban and military-base rail applications. The platform vehicle prior to installing the fuelcell powerplant and traction battery is shown in Figure 1. At 127 tonne (280,000 lb), continuous net power of 220-250 kW (290-330 hp) from its proton exchange membrane fuelcell prime mover, and transient power well in excess of 1MW, the hybrid locomotive will be the heaviest and most powerful fuelcell land vehicle yet built. Previous papers have discussed the theory [Miller, 2005; Miller, et al, 2006 A; Miller and Peters, 2006 B; Miller, 2006 C] and engineering design [Miller, et al, 2007; Miller, 2007] of the hybrid locomotive. While the BNSF locomotive is the largest and most sophisticated fuelcell land vehicle to-date, it is not the first fuelcell locomotive. The first fuelcell-powered locomotive was an underground mine locomotive successfully completed and demonstrated in a working gold mine by Vehicle Projects LLC in 2002 [Miller, 2000; Miller and Barnes, 2002].

Because the terminology of a fuelcell vehicle may be unfamiliar to the reader, the following terms comprise a glossary that will be referenced in the remainder of the paper.

**Glossary**

*Fuelcell stack module (FSM singular) FSMs plural)*: A box with dimensions 105 x 76 x 54 cm (L x W x H) containing the fuelcell stacks and ancillaries directly serving the stacks, including stack water management, humidification, cell cooling channels, and hydrogen purge hardware. The FSM, analogous to an engine "short block," is the heart of the fuelcell powerplant, and like a short block, many ancillary systems must exist to make it function as an engine or powerplant. These are described in the list below. The powerplant employs two FSMs, each rated at 150 kW gross continuous electrical power.

*Air system:* Two-stage, inter-cooled air compression system, including a high-speed turbo-centrifugal compressor (turbocharger) as the second stage, along with various internal and inlet air filters and silencers, that provide clean air (oxygen) at about 2 barg (30 psig) to the FSMs.

*Lube oil system:* Oil pump system that provides lubrication and cooling to air system components, mainly the second-stage centrifugal turbocompressor rotor bearings and the gears in the first-stage positive-displacement compressor.

*Primary cooling system:* Coolant pump, motor, and related hardware that provide coolant to the FSMs and air and lube oil systems.

*Secondary cooling system:* Coolant pump, motor and related hardware that provide coolant to the power electronics and FSM water-recovery system.

*Radiator module:* Two thermally efficient radiators in parallel air streams that reject heat from the FSMs and the lube oil system via the primary coolant system, and one radiator whose air stream is in series with one of the primary-coolant radiators that rejects heat via the secondary coolant system. The radiator module includes two three-phase induction fan motors with a dedicated inverter.

*Power electronics module:* DC-to-DC converters, plus associated liquid coolant and control systems, that provide the high-voltage DC output from the FSMs to the traction battery and traction motors on demand (650 VDC nominal), as well as provide lower voltage to subsystem components (350 VDC nominal).

*Electrical cabinets:* Separate high - and low-voltage cabinets providing control and power distribution to system hardware and sensors.

*Hydrogen storage system:* Fourteen

carbon-fiber composite storage tanks, partitioned into two modules of seven tanks each, along with ancillaries such as safety hardware, valves, and piping, which provide hydrogen fuel to the FSM. Each seven-tank module stores 35 kg of hydrogen at 350 bar (5100 psi).

*Fuelcell powerplant:* This term is reserved for the union of all of the above except the hydrogen storage system and radiator module. That is, the *fuelcell powerplant* = FSMs + air system + lube oil system + primary and secondary cooling systems + power electronics module + electrical cabinets. The fuelcell powerplant is often referred to as the *prime mover* in a hybrid vehicle. Collectively, all the components of the fuelcell powerplant, aside from the fuelcell stacks themselves (which are only part of the FSM), are termed the *balance of plant* (BOP). Net power of the fuelcell powerplant, in the range of 220-250 kW, consists of the gross power of the FSMs minus the parasitic losses of the BOP.

With the exception of the FSMs and power electronics module, all the major components of the powerplant were designed as detailed three-dimensional CAD models, based on engineering-design principles, by Vehicle Projects LLC. The FSMs, as used in the Citaro™ transit buses, which have logged more than 1.5 million kilometers of fare-paying passenger service in Europe and other parts of the world, were purchased from Ballard, and the design of the power electronics module was outsourced. Engineering drawings were derived from our CAD models and sent to the BNSF Topeka Rail Shop, which has fabricated most of the components, or in a few instances (e.g., fabrication of the electrical cabinets), the fabrications were outsourced. The hydrogen storage modules were built by Dynetek Industries. The two hydrogen storage modules, each with seven carbon-fiber composite tanks, located above the traction battery, store a total of 70 kg of hydrogen at 350 bar (5100 psi). These are also used in the Citaro buses.

Most of the subsystems listed in the glossary have already been tested as modules either in whole or part. Minor work remains in executing the following for the locomotive: modifying the sheet-metal hood over the powerplant and hydrogen storage, adding nine thousand kilograms of ballast [Miller, 2007], hydrogen plumbing, and some electrical wiring in the locomotive itself. The separately tested modules are scheduled to be assembled into the locomotive near the end of the year, which will then be tested as a complete vehicle at the Transportation Technology Center, Inc., in Pueblo, Colorado.

A schematic layout of the complete hydrogen-fuelcell system in the locomotive is shown in Figure 2 as a two-dimensional diagram and Figure 3 as a three-dimensional CAD model. Figure 3 shows the lightweight carbon-fiber hydrogen tanks at the roofline, a location also utilized by the Citaro buses. While keeping the tanks out of harm's way and allowing buoyant hydrogen to

harmlessly dissipate upward, the light weight of the carbon-fiber tanks does not adversely affect the vehicle's center of gravity. The rear compartment of the locomotive houses the 220-250 kW (net) fuelcell powerplant, and Figure 4 provides details of the rear compartment.

Hydrogen-fuelcell locomotives potentially can contribute to the solution of two related, major problems facing the world today: the end of oil and global climate change. This project has thus been led by the prospect of commercialization, ultimately culminating in fuelcell freight locomotives. The change from a diesel powerplant to a hydrogen-fuelcell powerplant has unique implications to the overall maintenance and service requirements of a locomotive. As future fleets of fuelcell locomotives are developed, a sound maintenance plan must consider the unique requirements for safety, training, and facility needs. This paper focuses specifically on the BNSF Railway Company's prototype fuelcell-hybrid switch locomotive and its maintenance requiements.

The ability to maintain and service the fuelcell powerplant and auxiliary systems was a significant influence in the overall design of the hydrogen fuelcell system. Focus was placed on access to areas where scheduled service or re-build is expected. Subsystems were designed as modular units to facilitate off-board service or quick replacement. Although intense focus was placed on serviceability, by the nature of a demonstration vehicle, some compromises were made where the existing locomotive platform, off-the-shelf hardware, or time constraints outweighed the cost versus benefit of a more serviceable solution.

## Maintenance

### Strategy

Service points of the powerplant system strongly influenced the overall component layout in the rear compartment. Each of these service and access points - de-ionized water fill and filter, electrical cabinets, power electronics, etc. - can be accessed from the locomotive walkway. Longer service-interval components, such as air pre-filter, air compressor belt, and air system lubricant, can be accessed from within the rear compartment. Because the power electronics requires minimal access, it is located at the bottom of the powerplant; this allowed the fuelcell stack modules to be mounted at the top of the powerplant, oriented symmetrically opposite on the same plane, thus allowing access to the FSM top covers or ready removal of the entire FSM. This layout also allows symmetric piping of air and coolant to both fuelcell stack modules and results in closely balanced flow for the air and coolant systems, which are driven by a single (two-stage) compressor and pump, respectively.

Access and removal of fuelcell system modules is facilitated by a modular rear hood. The hood is designed such that the sides and tops can be removed independently, allowing quick access to the cooling module with an overhead crane or access to the powerplant with a lift truck or overhead crane.

The following pages provide greater detail on the maintenance of each of the subsystems listed in the glossary of the Introduction, as well as the associated service schedules. Because the BNSF fuelcell-hybrid locomotive is a demonstration prototype, exact service intervals have not been fully determined for all aspects of service. For purposes of discussion, some service intervals will be described as "daily" or "intermediate" (meaning in the range of 2-4 months). This paper is not intended to be a service manual but to educate the reader on what type of service can be expected for hydrogen-fueled fuelcell locomotives and the associated skills and facilities needed to execute maintenance.

**Subsystems**

*Fuelcell Stack Module:* each of the two FSMs, a 105 x 76 x 54 cm box (L x W x H), bolts to the powerplant frame with four bolts and has all interface fittings on one end of the module. Air, coolant, and hydrogen interface with and flow through the modules. This configuration leads to efficient installation and removal if necessary. Additionally, the fuelcell stack module side and top covers can be removed to access items that require frequent service. The fuelcell stack modules, as well as their input process piping are sensitive to contamination, including particulate contamination (dirt, dust, and metal particles), chemical, and gaseous contamination. All cleaning agents, process fluids, and replacement hardware must be approved for use with the powerplant.

Some critical hardware components must be replaced or rebuilt periodically due to wear, aging, or possibly failure. The internal gears of the spray water gear-pump, which humidifies the inlet air, must be replaced every 640 hours of operation (there is no inherent reason for this short life and we believe newer versions of the FSM have longer-lived pump gears). The spray water pump can be accessed through the top cover with the module in place. Within each FSM is a hydrogen ejector pump that requires a rebuild every 1000 hours of operation to replace a diaphragm that is prone to wear. The FSM must be removed to perform this service operation. In this demonstration vehicle, it is expected that the fuelcell stacks will require replacement every 6000 hours of operation. Old stacks are easily replaced, but the FSM must be removed from the locomotive to perform the replacement. These re-build or replacement operations should be performed by a qualified service technician. Depending on the nature of the work, the fuelcell stack modules can be serviced in the field, railway repair shop, or an FSM box can be returned to the manufacturer for rebuilding.

Routine maintenance, such as replenishing fluids and changing filters, should be executed on a scheduled or routine basis. The water management system requires de-ionized water for the humidification of air and hydrogen. A de-ionizing filter, which maintains the water at a low electrical conductivity and can be accessed by removing the top cover of the FSM in situ, should be replaced every 320 hours of vehicle operation. A particulate filter to capture any debris that may enter through the fill opening or come from internal components should be replaced at the same time. The FSM uses a condenser to remove de-ionized water from the fuelcell-stack exhaust air, and normally the condenser will replenish the de-ionized water tank. However, if a low-level alarm is triggered, the de-ionized water tank can be refilled through the capped opening on the top of each FSM. Scheduled service items can be performed by local service people with basic technical training, and in most cases the maintenance can be performed in the field.

*Air System:* The mass flow and pressure of the air deilvered to the fuelcell stacks, by the two-stage, inter-cooled air system, determines the power output of the fuelcell stacks. In addition to providing air at the correct mass flow and pressure, the air system must provide clean, humidified air at the correct temperature. Air is drawn from the top of the locomotive hood through air filters, compressed, and then humidified within the FSM. After passing through the stacks, water is condensed and separated from the air, and the air then drives the turbocharger while exiting to the atmosphere. The turbocharger is used to regulate the system back pressure, provide additional compression, and recover some compression energy from the first-stage compressor. Note that the air system is only pressurized when the fuelcell powerplant is operating. The air system, along with the lube oil system that supports it, is constructed as a unit that may be removed from the powerplant in one piece for the purpose of testing or repair. Figure 5 shows the air and lube oil unit both inside and outside the powerplant.

The air system process tubing also incorporates multiple pressure and temperature transducers, as well as drain valves and tubing that remove water from the exhaust stream. Due to the constantly wet exhaust stream, 316 alloy stainless-steel tubing and stainless-steel and/or aluminum components are used to minimize corrosion. Materials that do not contaminate the air stream, and subsequently the fuelcell stack, must be employed. In general, stainless steel and aluminum are desired for their corrosion resistance and odorless rubbers and plastics are critical. If a rubber or plastic has an odor, this indicates off-gassing that could cause damage over time to the fuelcell stacks. Even more than in an internal combustion engine, cleanliness is paramount to maintain the operation and longevity of the fuelcell powerplant. During maintenance operations, special care must be taken to keep all "wetted" surfaces of the process stream free of any contamination. In the case of the air system, any internal surfaces of the air stream process tubing and associated components are considered wetted surfaces. If at any time the process stream is opened for service, the opened locations must be physically capped or taped off.

Additionally, when replacing components, the wetted surfaces must be cleaned with a neutral cleaner that will not contaminate the fuelcell stacks. Also, de-ionized water, rather than tap water, should be used for any rinsing or dilution of cleaners. Attention to these details will ensure maximum performance and fuelcell stack life.

Some air system hardware will require an inspection and/or rebuild based on the length of use in service and/or performance degradation. In the air system, this includes the air compressor and the turbocharger. The powerplant control system will log usage and provide the operator an inspection notice. These components must be sent to a qualified facility if re-build is required. Larger components may require removal of the air system sub-assembly as shown in Figure 5 and/or removal of the complete powerplant.

The intake filters are similar to an internal combustion engine air filter that removes particulate contamination, and also include active-carbon filtration that removes hydrocarbons, carbon monoxide, and other ambient-air contamination. A pre-filter is located between the air compression devices and the fuelcell stacks. The primay purpose of the pre-filter is to capture any oil contamination if there is a seal-leak or failure of the air compressors. This prevents potentially costly damage to the fuelcell stacks. The first-stage air compressor is belt driven by an electric motor. This drive belt and belt tension assembly require inspection and periodic replacement during the intermediate maintenance checks. The belt and tension assembly can be accessed with the powerplant in situ by removing a safety guard. Air intake and exhaust should be checked daily for obstructions. Intermediate service checks should include visual inspection of flexible couplings to identify tears that may allow dirt into the system or kinks that could reduce air pressure, as well as inspection of water drain lines to identify kinks or leaks.

*Lube Oil System:* The lube oil system consists of an oil pump, oil filter, oil reservoir, oil thermostat, oil cooler, pressure sensor, and temperature sensor. It provides lubricating oil to the air compressor and the turbo compressor. Oil temperature is controlled with a thermostat and oil cooler: when oil is below 82 C (180 F), the oil cooler is bypassed; when above 82 C (180 F), the oil circulates through the oil cooler. The primary cooling system provides coolant to the lube oil cooler.

The lube oil system uses standard automotive style hardware. Service of the system will require basic technical training of local service personnel. The lube oil should be replaced based on hours of operation as logged by the control system or once a year if the maximum hours of operation are not reached. The system uses approximately 4 L of fully synthetic SAE 5W40 motor oil. The in-line oil filter should also be changed at the time of each oil change. Both the oil and filter change can be performed from inside the rear hood while all equipment is in place. Intermediate service checks should include an oil-level check using the visual sight glass on the oil reservoir.

*Primary Cooling System:* The primary cooling system cools the FSMs and lube oil system by pumping coolant through the radiator module. It consists of a centrifugal pump, swirl pot (to remove air from the system), two motor-controlled valves, various pressure and temperature sensors, plus two radiators and radiator fans that are part of the radiator module. Coolant is pumped through the two fuelcell stack modules in a parallel piping configuration to provide equal-flow and equal-temperature coolant to each FSM. Coolant is also supplied to the air intercooler and de-ionizing filter loops. The speed of the pump is controlled by an inverter and is set to maintain a specific temperature differential between the stack coolant inlet and outlet. The radiator bypass valve is used to control the fuelcell stack module inlet temperature. The locomotive does require a "block heater" to maintain the fuelcell stack coolant temperature above freezing. A smaller heater and pump are plumbed into the primary coolant loop and must be plugged into off-board power when the locomotive is not in service (for a period of hours) or is in long term storage when temperatures are below freezing.

Cleanliness of the coolant is critical to maintain performance and stack life because the primary coolant is in contact with the internals of the fuelcell stacks and could become a possible electrical path between stack cells and chassis. Unlike coolant in a typical internal combustion engine, the coolant, a 50-50 mixture of de-ionized water and pure ethylene glycol, contains no corrosion inhibitors. With the absence of corrosion inhibitors, it is critical that the hardware in the primary coolant system be corrosion resistant.

Coolant should be replaced at the earliest occurrence of the following: (1) when the hours of operation as logged by the control system reach a designated value, (2) when two calendar years have been reached, or (3) if the ion concentration exceeds the ability of the de-ionizing filter to maintain control. High conductivity levels will be detected by the ground fault system and can be physically tested using a handheld tester. Coolant conductivity should be tested at each regular service interval. The primary coolant system fill cap is below an access panel located on the roof of the rear hood. The system volume of 50-50 mixture of de-ionized water and pure ethylene glycol is approximately 100 L (25 gal). To completely fill the system, the primary coolant pump should be run for several minutes to remove entrapped air before topping off the coolant.

The coolant system utilizes two filters. The first is located just upstream of the radiator inlet and is part of the cooling module assembly. It can be accessed through a roof access panel. A partial system drain is required to bring the coolant level below the particulate filter. The filter should be emptied during each coolant refill or inspected if the controller identifies a high coolant pressure upstream of the filter. The second filter is a de-ionizing filter that removes any carbon or metal ions from the coolant. Ion contamination can come from metal components in the system or dissolved gases from the air. This filter removes the ion contamination and ensures that the coolant conductivity is kept at an acceptable level. Coolant level at the fill tank should be checked on a weekly basis. A visual inspection of the system for any leaks should be performed during each intermediate service. Cooling system hardware within the powerplant frame can be accessed by removal of the rear hood door side frame and removal of the high voltage cabinet from the powerplant frame.

*Secondary cooling system:* The secondary cooling system provides a lower temperature (10 C below the primary coolant system) coolant to the FSM water condensers, the power electronics module, and the air compressor drive motor and controller by pumping coolant through the radiator module. Because the secondary coolant system does not come into contact with the fuelcell stacks, a de-ionization filter to keep coolant conductivity low is not needed. Segregation also allows the use of standard automotive type engine coolant, which includes corrosion inibitors. Although care should be taken during service operations, standard best practices as used on internal combustion engine cooling systems is all that is required.

Coolant should be replaced based on hours of operation as logged by the control system or once every two years. The secondary coolant system fill cap is below an access panel located on the roof of the rear hood. As with the primary coolant system, the secondary system can be gravity drained using a quick-connect hose fitting. Intermediate service checks should also include a visual inspection of all hoses for wear or chafing. Coolant level at the fill tank should be checked on a weekly basis. A visual inspection of the system for any leaks should be performed during each intermediate service. All secondary cooling hardware can be accessed while the powerplant is installed in the locomotive, either from the walkway or from inside the rear hood. Access to some components may require the removal of the high voltage cabinet located along the locomotive walkway.

*Radiator module:* The primary and secondary cooling systems feed the two primary radiators and single secondary radiator that reject the heat of the fuelcell powerplant through the roof of the locomotive. The radiator module is mounted above the powerplant and interfaces to the power module using flexible lines to allow relative movement between the two modules. The speed of the radiator fans, driven by three-phase industrial motors, is controlled by a singe inverter and is controlled to maintain a specific temperature at the radiator outlet.

Service checks should also include a visual inspection of all hoses for wear or chafing. The radiator module uses standard industrial hardware, and service of the system will require only basic technical training.

*Power Electronics Module:* The voltage produced by the FSMs drops as additional current is drawn. However, the high voltage bus on the locomotive requires a specific voltage profile depending on the state of charge of the traction battery, while the BOP components require a constant voltage. The power electronics module regulates the voltage produced by the FSMs to provide the required voltage in each case. The locomotive controller specifies a power demand to the powerplant controller, which then commands the power electronics module to deliver the required electrical current to the high voltage bus at the voltage of the high voltage bus. A constant voltage is provided to the medium voltage bus to power BOP components. During start up, power is drawn from the large locomotive traction battery in order to power BOP components until the FSMs are self-sustaining. Physically, the power electronics module is located directly below the powerplant.

All service to the power electronics module should be performed by qualified specialists that are trained for high-voltage, high-power systems. Interaction with the control system to troubleshoot issues will require a trained fuelcell powerplant engineer or technician. Service to the system is minimal. However, it is expected that there will be the occasional failure of some electrical devices, such as fuses and relays. To replace the coolant pump inverter, the locomotive chassis air compressor must be removed. To replace the cooling module inverter the rear hood roof must be removed.

*Electrical Cabinets:* The high voltage output of the fuelcell stacks is distributed to the other high voltage systems from a high voltage cabinet that is mounted to the powerplant frame. Also mounted to the frame and accessible from the locomotive walkway is the low voltage cabinet that holds the system controller and all 120 VAC, 24 VDC, 12 VDC, and 5 VDC power supplies, relays, terminal blocks, etc. The low-voltage cabinet uses multiple quick-disconnect electrical connectors to allow easy removal of the entire cabinet for service access to components behind or for service work to the panel. Both the high and low voltage cabinets are rated NEMA 4 for protection from the environment.

All service to the electrical system should be performed by qualified electricians that are trained for high voltage systems. Local service people can perform assembly, disassembly, and troubleshooting after basic training. Service to the electrical system is minimal; however, it is expected that there will be periodic failure of some electrical devices, such as fuses and relays. These components can be easily accessed from the locomotive walkway by accessing the high or low voltage cabinets.

*Hyrdrogen Storage System:* Hydrogen fuel storage uses readily available hardware and proven safety design measures. Two modules are mounted above the traction battery (see Figure 3), each consisting of seven carbon fiber/aluminum tanks, with a combined storage of 70 kg compressed hydrogen at 350 bar (5100 psi). This storage system provides fuel for a rigorous 8-10 hour switcher duty cycle. The hydrogen fuel system incorporates multiple redundant safety devices to ensure that in the event of line ruptures or failed components only a negligible amount of hydrogen is allowed to escape the system. The system plumbing includes excess flow valves, normally closed solenoid valves, pressure regulators, and pressure relief devices. Additionally, tanks are fitted with redundant pressure relief devices that safely vent the contents in event of a fire.

A re-fueling panel is located on both sides of the locomotive for fueling and de-fueling operations. As with diesel locomotives, an emergency shutoff button is located on each panel to allow non-operators or refueling personnel to shut down the fuel system and locomotive. On -site operators and technicians will undergo basic training for daily and intermediate service leak checks. Service work beyond this should be performed by personnel trained specifically for this storage system.

Hydrogen fuel is the most unique system of the fuelcell-hybrid locomotive and demands the most training and learning for unfamiliar personnel. There are three critical attributes that must be considered when interacting with the hydrogen fuel system. First, hydrogen is odorless, and odorants cannot be added since they will contaminate the fuelcell stacks. Second, hydrogen is very buoyant, and it will gather in the top of hoods or buildings. Third, hydrogen flames often burn invisibly, posing a danger to both immediate unaware personnel, as well as emergency response personnel. On the other hand, hydrogen is the only fuel that is completely physiologically inert, although suffocation in a high concentration of hydrogen can occur.

The odorless characteristic of hydrogen can be dealt with using a handheld or permanently installed (in vehicle or buildings) hydrogen detector. Detectors can identify hydrogen at levels far below dangerous flammability limits and provide adequate time for response. The buoyancy of hydrogen is an advantage, as hydrogen will very quickly dissipate upward and be reduced below its lower flammability level. However, care must be taken in design and service not to allow hydrogen fuel to accumulate in areas lacking adequate ventilation or dispersion volume because of the potential of detonation. It is a requirement for all those who work with hydrogen equipment and are first responders for emergencies to be educated about and be aware of the invisibility of hydrogen flames. In addition to the hydrogen itself, the high pressure of 350 bar (5100 psi) of the hydrogen fuel storage system demands proper training and procedures for safe interaction. Whether high gas pressure poses a risk depends on the strength of the container and the carbon-fiber containers are exceptionally strong.

Commonplace compressed natural-gas vehicles use the same tanks that the locomotive uses.

An inspection of the cylinders and surrounding enclosures should be done daily. Any abnormal damage or residues should be investigated to ensure no damage has been done to the cylinder physically or from chemical exposure. Additionally, outlet caps of the pressure relief device vent lines should be confirmed to be intact and capped. The hydrogen storage tanks used on the BNSF fuel-cell-hybrid locomotive are certified for 20 years of service.

Occasional plumbing leaks may occur. These leaks can be detected and repaired by local service people after basic training. In-tank valves and hardware within refueling panels will require more extensive local training or a trained field service technician. If necessary, tank modules can be removed after first de-fueling and purging with an inert gas such as argon. Refueling panels can also be individually removed after a de-fueling and purge operation. Operation of all hydrogen leak detectors in the rear hood and within power modules should be periodically tested.

### Training

The Maintenance section outlined the specific needs of each system as well as the associated skill set. In summary, all daily inspection and most intermediate service items specific to the fuelcell-hybrid locomotive can be done after a 2-3 day on-site training program for those that will operate or service the unit. Personnel would also be required to have previous training for all normal locomotive service operations as well as high-voltage systems. Given the unique properties of hydrogen, the facility's emergency response must include hydrogen specific training.

### Facilities

Maintenance of a hydrogen-fueled locomotive will require some unique facility preparations. Any buildings where the locomotive may be serviced or stored while fueled with hydrogen must be analyzed. There are several acceptable methods to allow the locomotive within a building. If the building volume is sufficiently large when compared to the hydrogen volume onboard the locomotive, there may be no additional requirements for the building. If the building to hydrogen volume ratio is too small, the passive or active building air ventilation exchange rate may safely allow the locomotive indoors. Alternatively, procedures for temporary vent lines from the locomotive pressure relief lines to outside the building can eliminate concerns of the full system volume escaping into the building. This would allow a safety analysis of the building to consider a smaller volume of hydrogen escape. A hydrogen detection device within buildings where the vehicle is serviced is also important to alert personnel if a hydrogen leak occurs. It is useful to bear in mind that the risk of hyrdrogen as a flammable gas (except notably its lack of odorant) is not significantly different from that of natural gas, which is used as a vehicle fuel using identical tanks to the ones used in the locomotive. If hydrogen did have an odor, the facility requirements for housing a hydrogen-fueled vehicle should be the same as those for a CNG-fueled vehicle.

Most fuelcell systems use typical combustion engine or industrial type hardware. Because of this, very few specialty tools are required to maintain the locomotive. The most notable addition to a service person's toolbox would be a handheld hydrogen detector because fuelcell hydrogen, unlike natural gas, lacks an odorant. This detector can be carried or worn by the service person if working in proximity to a hydrogen-fueled locomotive. Some specialty test equipment is required for detailed leak checks and service of some of the internals of the fuelcell stack module and hydrogen valves. However, these specialty tools would accompany a qualified field service technician if they are required for an intermediate service check, scheduled re-build, or non-scheduled maintenance. To completely service the fuelcell locomotive (when all equipment modules are removed), an overhead crane (3 ton minimum) and lift truck (3 ton minimum) are required. Specialized lifting devices are required for the fuelcell stack modules and hydrogen storage modules. Facilities will also need specialized cleaners, specific coolant, and de-ionized water onsite. An increased level of vigilance will be required to prevent system contamination from the surroundings. This requirement may also necessitate new facility procedures for work conditions or limitation on allowable surrounding equipment (such as grinders, saws, etc.).

## Conclusion

Although the BNSF fuelcell-hybrid locomotive is a proof-of-concept vehicle, great care has been taken to consider short- and long-term maintenance operations; specifically, access to commonly serviced areas and modularity of systems to allow easy removal for off-board service or replacement. Most routine service operations can be performed by local service personnel, but some basic training beyond typical training for locomotive and high-voltage systems will be required. Most service work closely resembles typical industrial service work but generally with an increased need for attention to cleanliness. For this demonstration vehicle, some specialized field support will be required for significant service tasks to the fuelcelll stack modules, control system modifications, and some hydrogen system non-scheduled service.

Aside from the lack of an odorant, the risk of hydrogen as a flammable gas is not significantly different from that of natural gas. Nonetheless, lack of odor has the consequence of requiring a building approved for hydrogen service work, including hydrogen detection within the building. Additionally, handheld hydrogen detection for personnel, some specialized lift equipment, and unique fluids will be required to perform service.

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### Author's Biographies

**Arnold R. Miller**

Until founding Vehicle Projects LLC in 1998, Dr. Miller was a research professor at research universities, including the University of Illinois. From 1994 to 1998, he was founding Director of the Joint Center for Fuel-Cell Vehicles at Colorado School of Mines. As an academician, Prof. Miller published numerous papers in refereed journals such as the Journal of the American Chemical Society. As President of Vehicle Projects, besides leading the company, he frequently presents its work at leading international conferences. He founded the indpendent company Supersonic Tube Vehicle LLC in 2007 whose mission is basic scientific and engineering analytic work on vehicles operating in a hydrogen atmosphere on aerostatic gas bearings. Dr. Miller received his PhD degree in chemistry from the University of Illinois, Urbana-Champaign.

**Kris S. Hess**

Prior to joining the Vehicle Projects team in 2006, Mr. Hess worked at the General Motors Technical Center from 1998 in various postions in advanced vehicle development. These included subsystem design engineer, concept-vehicle lead engineer, and concept-vehicle program manager. This diverse background has provided the experience to successfully execute projects at both the technical level and total vehicle integration level. As a Design Engineer at Vehicle Projects, Mr. Hess is responsible for engineering design, CAD modeling, and engineering integration with project partners. He received his BS degree in mechanical engineering from the University of Michigan-Ann Arbor and MS degree from Purdue University.

**Timothy L. Erickson**

Prior to joining Vehicle Projects, Mr. Erickson spent 10 years working as a software engineer designing intelligent process control systems, utilizing impedance sensing technology. Prior positions include working as a control systems engineer for a system-integration company as well as six years as a submarine officer in the United States Nuclear Navy. As Controls Engineer at Vehicle Projects, Mr. Erickson is responsible for working closely with the Design Engineer and implementing the control systems that run fuelcell vehicles. He received his B.S. degree in electrical engineering with a computer science minor from the Colorado School of Mines.


**Figure 1**
**Fuelcell-hybrid switcher platform vehicle. As shown, the diesel fuel tank, genset, and battery of a commerically available diesel-hybrid switcher have been removed in preparation for retrofitting the fuelcell power plant and hydrogen storage.**

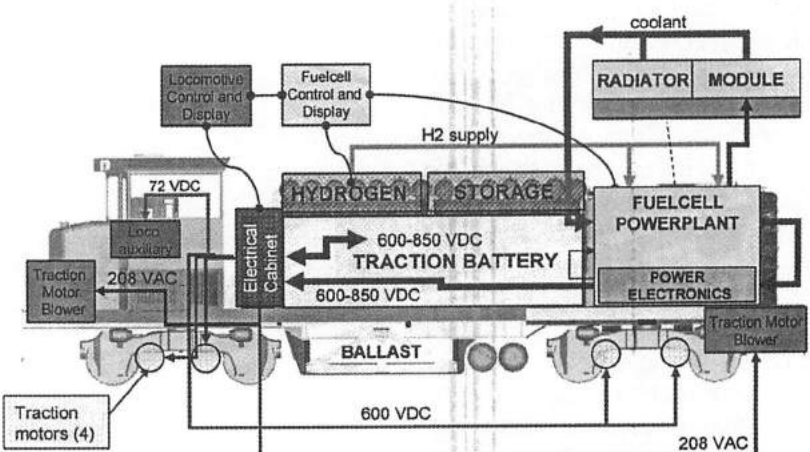


**Figure 2**
**System layout of the fuelcell hybrid locomotive, including the 220-250 kW continuous net power powerplant, power electronics, hydrogen storage, and control interface**

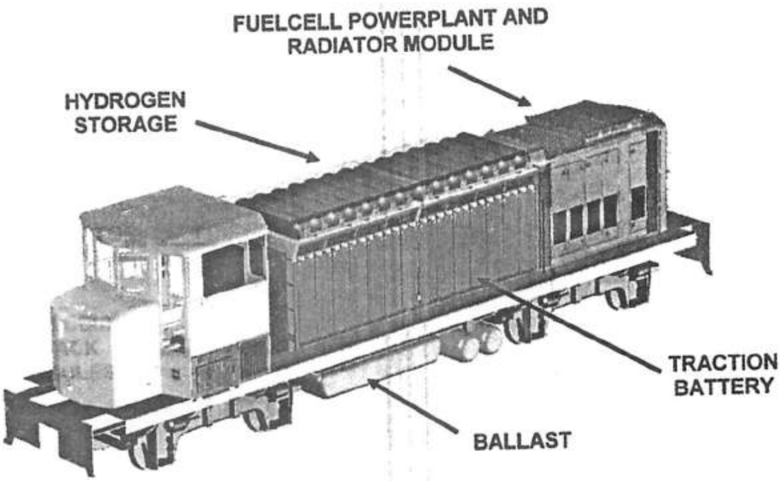


**Figure 3**

**The locomotive's fuelcell prime mover provides 220-250 kW of continuous net power for traction or power-to-grid, and the auxilary traction battery allows transient power in excess of 1 MW. Lightwieght carbon-fiber composite compressed-hydrogen storage tanks reside at the roofline analogously to the Citaro™ fuelcell transit buses**

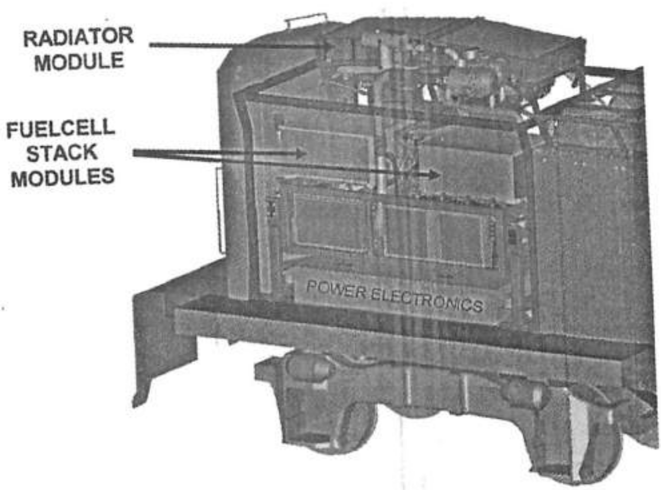


**Figure 4**

**Rear compartment layout. Systems were designed as bolt-in modules, requiring minimal modifications to the locomotive platform. This allows for off-line fabrication and testing of modules prior to vehicle installation.**

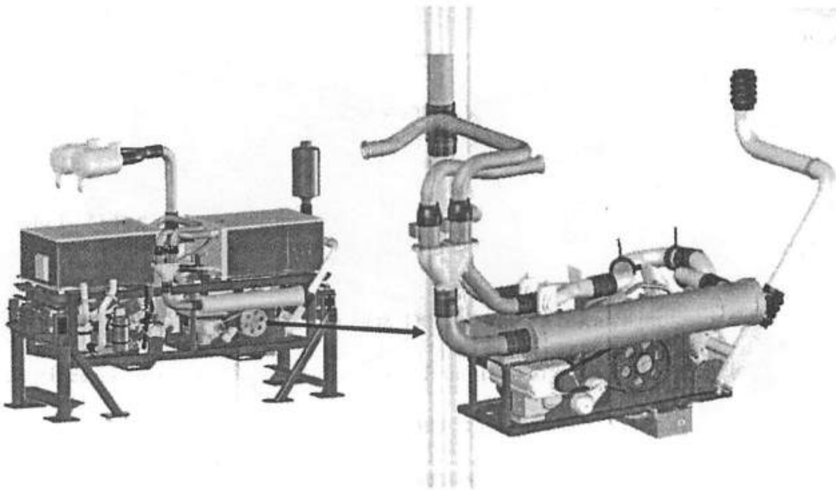

Figure 5
**Air and lube oil subsystems are mounted to a single sub-frame and can be removed as one assembly for service.**

# REPORT OF THE COMMITTEE ON DIESEL MECHANICAL MAINTENANCE

# MONDAY, SEPTEMBER 22, 2008 3:30 P.M.

Chairman
**JEFF CUTRIGHT**
Senior General Foreman
Norfolk Southern Corp.
Roanoke, VA

Vice Chairman
**GEORGE KING, II**
Chief Mechanical Officer
NYS&W RR
Cooperstown, NY

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| R. Svoboda | Mech. Compl. Off | METROLINK | Los Angeles, CA |
| G. Winsel | Asst. Manager | Canadian National | Edmonton, Alberta |

# PERSONAL HISTORY

## *Jeff Cutright*

Jeff was born in West Virginia and attended WVU earning a BSME in 1979. He joined Norfolk Southern Corp. in 1980 as a management trainee after a year and a half with Weirton Steel. Jeff has held many positions in the NS Mechanical Department, including staff and shop supervision. His work experience includes all aspects of Locomotive Maintenance, including running repair and back shops that specialize in both GE and EMD overhaul and components. Jeff has been active with LMOA since 1994 and earned an MBA from Averett University in 2004. Jeff and his wife Leonita have two teenage daughters Sarah and Haley that are very active in sports.

**THE LMOA DIESEL
MECHANICAL MAINTENANCE
COMMITTEE WOULD LIKE
TO THANK THE
TRANSPORATION TEST CENTER
IN PUEBLO, COLORADO
FOR HOSTING THE
COMMITTEE'S WINTER
MEETING ON
MARCH 10, 2008**

## I. ULTRA-LOW SULFUR DIESEL FUEL: IMPACT ON LOCOMOTIVE MAINTENANCE

*Prepared by*
*Tim Standish,*
*Electro-Motive Diesel, Inc.*

Ultra low sulfur fuel (ULSD) is now more readily available and, in some locations, it is the only diesel fuel available as some refineries only produce ULSD. There have been many questions as to the impact of ULSD on locomotive engines including maintenance, performance, and engine reliability. The latest on-highway trucks are now required to run on ULSD, which also increases the availability and potential of receiving ultra low sulfur diesel fuel in the railroad supply system much sooner than the required June 2012 implementation date. In response to the importance of this subject, the LMOA Fuel, Lube and Environmental Committee is covering this topic this year from their perspective. The focus of this paper is to review some of the potential mechanical issues with ULSD and to familiarize mechanical departments with what to look for as their fleet converts to ULSD.

Before going over the potential impact of ULSD on locomotive maintenance, a quick explanation of ULSD is needed. Over the years, the amount of sulfur allowed in diesel fuel had been regulated by the EPA, and will continue to be reduced at future dates based on engine application (see Figure 1).

Traditional #2 diesel contains 2000 - 3000 parts per million (ppm) of sulfur. Low Sulfur Diesel (LSD) is 500 ppm or less, and ULSD is 15 ppm or less. ASTM identifies LSD as S500 (0.05% sulfur) and ULSD as S15 (0.0015% sulfur). Why the change to ULSD? This low level of sulfur is needed to enable aftertreatment control devices to reduce post-combustion chamber emissions and meet lower limits established by EPA. ULSD enables efficient use of exhaust aftertreatment devices since sulfur "poisons" the catalyst and will dramatically reduce its efficiency. ULSD also lowers sulfate PMS and sulfur dioxide emissions.

Sulfur is inherent in crude oil and the amount of sulfur varies based upon the crude oil supply. However, the amount of sulfur in crude must be refined to bring sulfur down to regulated levels and is accomplished mainly by two processes, hydrocracking or hydrotreating. The most common process is hydrotreating, which is a refining process that separates sulfur from hydrocarbon molecules. This process also reduces aromatics and density of the fuel, which very slightly lowers the energy content. This refining process also removes some of the lubricity compounds in diesel fuel along with changing its stability and electrical conductivity. It is because of these changes, that mechanical departments are concerned and should pay close attention to the potential impact on locomotive performance and maintenance. The issues that will be touched upon include lubricity, energy content, combustion, and fuel leaks, and are brought up to help identify potential issues for mechanical departments to consider and to watch for as ULSD enters into the fuel supply system.

### Lubricity

Lubricity is the quality of liquid that prevents wear when two moving metal parts come in contact with each other. As sulfur is removed, other chemical compounds are impacted including those that give diesel fuel its inherent lubricity and separate additives are needed to protect critical engine components. Therefore, ASTM has added a lubricity requirement (D6079) to its diesel fuel specification (ASTM D975), and EMD has added this lubricity requirement to their diesel fuel requirement. The initial lubricity specification was established by the on-highway engine and fuel injection equipment manufacturers to prevent premature wear of rotary pump fuel injection systems used by many in the industry. Locomotive fuel injection systems, which are not based on a rotary pump design, are more tolerant of lower lubricity fuels but require the lubricity specification to assure trouble free operation and to be harmonized with the on-highway lubricity requirement so that fuel treated at the distribution terminals can be used in both markets.

A controlled ULSD test was conducted on an EMD engine by Interstate Diesel to review potential impact on injectors. The ULSD fuel used met the lubricity specification. Injectors were removed and analyzed after 2000 and 6000 hours of running time and lab analysis of the plunger and bushing assemblies at both time intervals show that both were in good condition with no visible signs of excessive abrasion or wear. Helices and nozzle body seating area were also in good condition with no indication of chipping, erosion or abrasion (see Figure 2). Needles were likewise in good condition and showed no signs of scuffing or scoring on the quill bearing surfaces. Spray holes appeared to be well formed (round and symmetrical) and did not exhibit any unusual wear patterns. Remaining internal components all indicate normal wear patterns - no abnormalities were detected under visual examination. Injectors continued to successfully run up to recommended change interval with no impact on reliability of performance. Many other engines have been running since this testing was conducted and no injector issues have been noted. As long as the lubricity specification is met, OEM injector performance will most likely not be impacted.

### Energy Content

Locomotives are designed to provide constant power under varying environmental and track conditions. Fuel consumption is dependent on these same conditions as well as energy content of diesel fuel. Energy content is directly related to the hydrocarbon composition of the fuel. Heavier (more dense) components provide higher energy content on a per gallon basis. Sulfur in fuel is usually associated with these heavier components. Energy content decreases with decreasing specific gravity and in a simplistic sense, locomotive fuel efficiency can be viewed as linear with the energy content of the fuel (see Figure 3) regardless of locomotive model. Lower energy content = fewer ton-miles per gallon. It has been estimated that the resulting ULSD S15 fuel will lose from about 0.7% to as much as 4.5% energy content on a per gallon basis depending on the level and type of processing required at the fuel refinery. This results in increased fuel flow rates to supply the same load thus shortened racks (or longer pulse width for electronic engines) for engines to make equivalent power. It is believed that the fuel injection system has adequate capacity to make rated power under most environmental conditions. However, in ambient temperatures above 95F and assuming worst case energy content reduction, there may be noticeable loss of power. Therefore, transportation departments need to watch locomotive range and hp/ton margins as ULSD is implemented.

**Fuel System Leaks**

Based upon the type of process to remove sulfur, and the extent of processing needed upon the amount of sulfur in the crude oil supply, the aromatic content of the fuel may be altered. Lower aromatics may cause seals to shrink and may or may not be an issue depending on the age of the seals, seal material, and temperatures the seals are exposed to. Buna N seals may be impacted by lower aromatics and cause seal leaks, whereas Viton seals will most likely maintain their elasticity and not be subject to leaks due to shrinkage. Actual shrinkage is not known since aromatic content before and after change to ULSD is not known. EMD changed its fuel system seals to Viton ten years ago and it is not anticipated that ULSD will cause fuel leaks. There have also been no issues noted on EMD test engines and other applications already running on ULSD. Maintenance departments need to pay attention to fuel system leaks on older locomotives in which seals have not been maintained to determine if a proactive seal change is needed.

**Combustion Issues**

Combustion issues are complex and are related to a large number of variables that may or may not be impacted by the usage of ULSD, including the type of lube oil used. As mentioned earlier, the LMOA Fuel, Lube and Environmental Committee is also investigating ULSD usage including possible combustion issues based upon ULSD/lube oil interactions. Mechanical departments will need to work with their lube/fuel suppliers to minimize these possible issues.

Recent experiences indicates that in light road applications, there is some build up of ash during combustion due to high TBN lube oil. These lube oils have additive packages to interact with sulfuric acid produced from the combustion process and sulfur in the fuel. As sulfur is removed, there is a potential of ash build up from the undepleted additive package, therefore, there may be a need to rebalance additives and TBN.

Ash buildup can cause valve failures, turbo screen plugging, ring sticking, and bore streaking/scuffing. Operation of engines at typical duty cycles will help burn off ash before it becomes a problem, but if engines are operated consistently at low combustion temps (light loads) ash has a good probability of building up. There have been a couple of reports of valve failures due to combustion deposits (see Figure 4) upon switching to ULSD (and in one case a Biodiesel/ULSD blend) in which all cases were all on lightly loaded engines. Exhaust manifold, turbo screens, turbine nozzle and blades may also be subject to ash buildup in rare conditions (see Figure 5 and 6).

Because of the variability of operating conditions, maintenance of engines, type and quality of fuel and lube, and quality of parts; all aspects have to be considered upon discovering combustion related issues. Mechanical departments need to work with lube/fuel suppliers along with OEM's for solutions to such issues. Options may include using engine oils specifically developed for ULSD, utilization of power assembly upgrades such as low oil consumption assemblies, hardened valve seats, and valve rotators. Raising combustion temperatures through changes in injection timing is not an option if engines are certified to any EPA Tier levels.

### Oxidative/Thermal Stability

The natural oxidative and thermal stability of diesel fuel is expected to decrease as sulfur is removed during the refining process used to produce these fuels. This could have an adverse impact on long-term storage in wayside tanks and in locomotive fuel tanks. The customer may need to be more vigilant in tank maintenance as the risk from poor stability fuel is one of filter plugging. There is currently consideration of adding oxidative and thermal stability standards into fuel specifications.

### Electrical Conductivity

This property is related to the safe handling of diesel fuel to control static electricity build up in the fuel. It has been reported that ULSD may have lower electrical conductivity levels as a consequence of removing sulfur. Customers should check with their fuel suppliers to determine if ULSD shipments will have adequate electrical conductivity levels to provide for safe handling and establish an internal fuel specification for this property to assure consistent quality from all potential suppliers.

### Summary

As ULSD makes its way into rail fuel supply systems, mechanical and transportation departments need to be aware of the potential issues covered above and other issues that may arise. Close monitoring of units (perhaps on a captive fleet) during ULSD transition can help railroads understand what impact it will have on them and develop a strategy to mitigate any problems.

### Acknowledgements

I would like to thank my coworker, Dan Meyerkord, for his contributions and review of this paper. I also thank Jerry Jones of Interstate Diesel for the detailed test and lab analysis of injectors. Thanks to the LMOA Mechanical Committee for their review and thanks to the LMOA Fuel, Lube and Environmental Committee for background information.

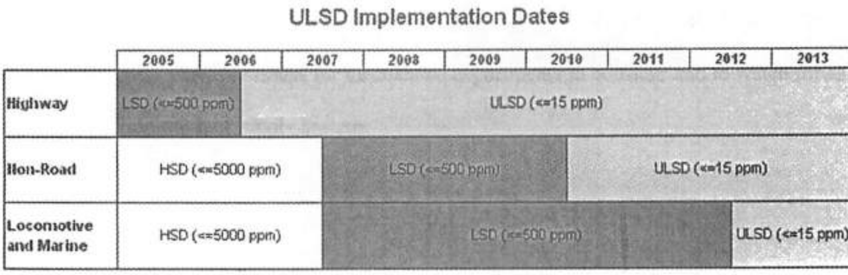



**Figure 1: ULSD Implementation Dates**

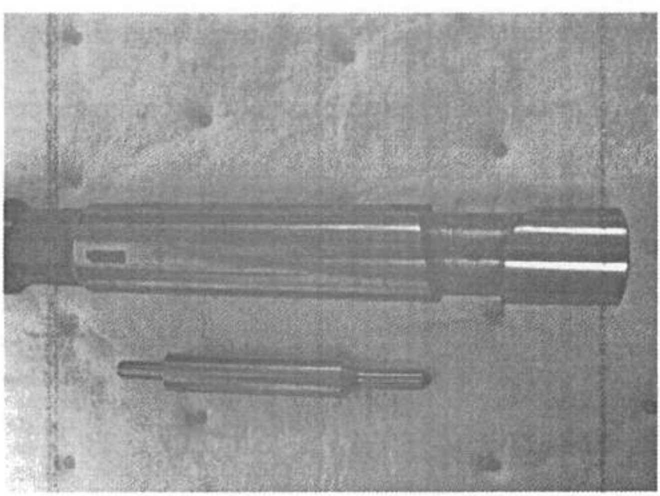


**Figure 2: Injector and Needle in good condition after 6000 hrs**

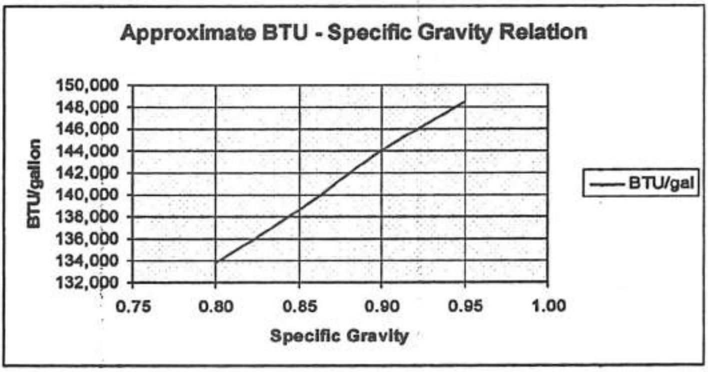



Figure 3: BTU/Specific Gravity Relation

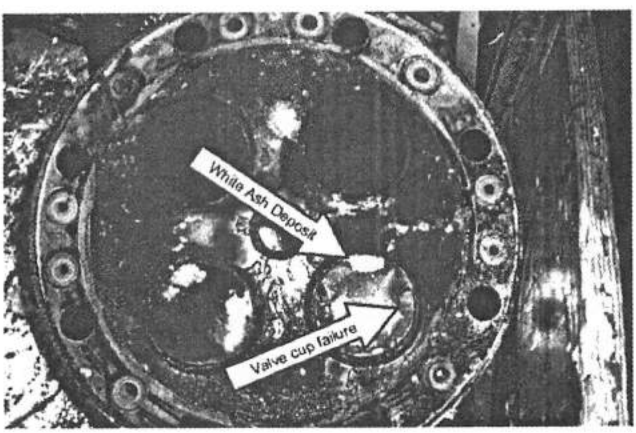



Figure 4: Ash deposits and valve cup failure

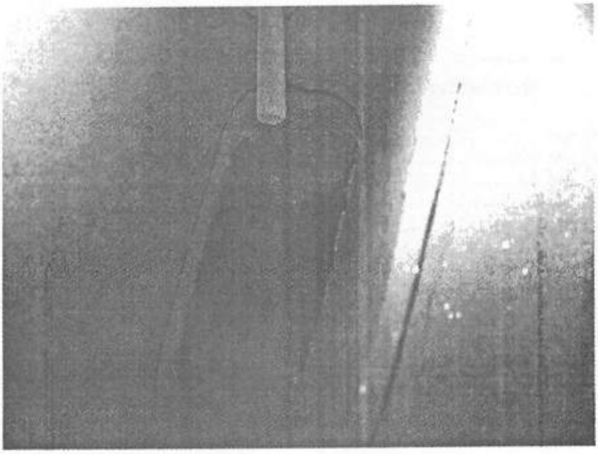


Figure 5: Ash buildup in exhaust leg

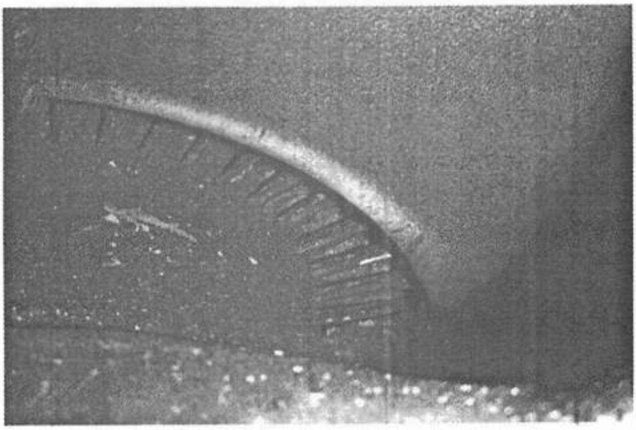
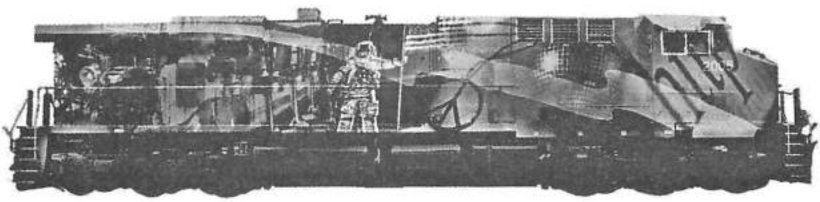


Figure 6: Ash buildup on turbine nozzle and turbine wheel



## II. EXHAUST AFTERTREATMENT TECHNOLOGIES DEFINITIONS AND MAINTENANCE

*Prepared By*
*Ted E. Stewart P.E.*
*Advanced Global Engineering*

This presentation is a continuation of the technological information first presented by Mr. John Hedrick, Principal Engineer for the Medium Speed Diesel Engine Group at the Southwest Research Institute's Locomotive Technology Center in San Antonio, Texas. His 2007 Mechanical Committee paper was titled: Locomotive Particulate Matter Reduction Through Application of Exhaust Aftertreatment Systems.

The purpose of this presentation is to describe some of the current exhaust aftertreatment technologies with a clear definition of what it is and the maintenance issues associated with these add-on systems. The second purpose is to provide a reference document that can be regularly updated as these technologies are being introduced into the rail industry.

The technologies to be discussed are as follows:
Diesel Particulate Filter, (DPF)
Diesel Oxidation Catalyst, (DOC)
Selective Catalytic Reduction, (SCR)
Exhaust Gas Recirculation, (EGR)
Closed Crankcase Ventilation, (CCV)

### Diesel Particulate Filter, (DPF)

A diesel particulate filter (Figure 1) is a mechanical filtering system, device or apparatus that contains many channels or passageways through a catalyst medium or substrate material that physically captures the particulate matter as it comes in contact with the walls of the passageways. The advantages of a DPF are its relatively high PM reduction efficiency and reduction of exhaust noise. The disadvantages of this system are its plugging due to high ash lube oil and the resultant fuel penalty associated with increased back pressure.

There are two types of diesel particulate filters; a "wall flow" system in which the exhaust must flow through the walls of alternating blocked channels of the filter medium and the "through flow" system in which the exhaust must flow through very small filter passageways thus forcing the exhaust to make contact with the medium wall surfaces. (Figure 2)

The soot is gradually trapped and stored inside the filter until the exhaust backpressure increases to a certain level and then the filter element is either replaced with a clean element or the filtering system is designed to clean itself by oxidizing or burning off the trapped material to "regenerate" itself and start again. Both systems have the same maintenance issue in which the filter at some point in its service life must be removed and cleaned. This periodic maintenance schedule will be primarily based on a) the exhaust back pressure and engine operation, b) the ash content level of the lube oil being used and c) the DPF's capacity to store the ash, and d) the oil consumption level of the power assembly.

### DPF Maintenance Issues

Actual in-use service data does not currently exist at this time, in order to provide accurate schedules for conducting regular maintenance. However, some assumptions can be presented that may be helpful in understanding what may be required. Potentially every 92 days, the DPF will need the system's control device down loaded or queried to make sure everything is operating correctly and that there are no system errors or faults logged. The heat source for regeneration of the filter, (if equipped), must be inspected for proper operation. Possibly once a year, or perhaps longer, the DPF elements must be removed and cleaned or reconditioned. The timing of this maintenance issue could be based on a) calendar days to coincide with the locomotive shoppings, b) fuel and/or lube oil consumption quantities and c) the system's increase in exhaust back pressure that may set off a warning. Any or all of these intervals will be determined with input from the OEM, the kit supplier and the DPF manufacturer.

There is a potential safety issue that must be carefully considered. This trapped soot material inside the filter structure will most likely be considered "hazardous" and will need to be addressed with training and specialized handling. It may be beneficial to establish service contracts with the OEM or kit supplier in order to handle the cleaning and/or reconditioning of the elements.

### Diesel Oxidation Catalyst , (DOC)

A diesel oxidation catalyst is a flow-through honeycomb arrangement with large amounts of interior wall surfaces that chemically oxidizes hydrocarbons, carbon monoxide and particulate matter in the exhaust stream. The interior walls of the catalyst substrate are coated with catalytic metals such as platinum and palladium that induce the chemical reaction to convert the pollutants into harmless gases. The DOC system can either be placed in the exhaust manifold itself, (pre-turbo), or in the exhaust stack, (post-turbo). (Figure 3)

The advantages of the DOC are that it's highly efficient, relatively easy to retrofit on the engine and if used as a post-turbo application it also helps to provide a noise reduction. The disadvantage of this system is that it is highly susceptible to the sulfur content of the diesel fuel and the ash content of the lube oil as discussed in the following maintenance issues. (Figure 4)

### DOC Maintenance Issues

A DOC element must be removed and replaced with a new one if it becomes "poisoned" with the use of diesel fuel containing high levels of sulfur. The sulfur reacts with the precious metal coating creating a "sulfate" layer thus preventing any further oxidation to occur. The higher the sulfur content, the faster this "poisoning" occurs and the element's service life is dramatically reduced. The recommended sulfur content is 15 ppm to insure an acceptable service life. Higher sulfur levels shorten the life of the catalyst. The elements must also be removed and physically cleaned at periodic service intervals in order to remove the lube oil ash contaminant that builds up on the catalyst surfaces. This interval could be as short as 6 months or as long as every two or three years and is dependent on the ash content of the lube oil and the power assembly's oil consumption rate. Another maintenance consideration for the pre-turbo systems is that the elements must be easily removed and replaced with no resultant exhaust leaks.

There is also a potential safety issue with the DOC systems that must be carefully considered. The residual materials that have been deposited on the substrate layers will also most likely be considered "hazardous" and will need to be addressed with training and specialized handling. It may be beneficial to establish service contracts with the OEM or kit supplier in order to handle the cleaning and/or reconditioning of the elements.

### Selective Catalytic Reduction, (SCR)

Selective catalytic reduction (Figure 5) is a process to primarily reduce NOx emissions by introducing a "reductant" such as urea into the exhaust stream where it chemically reacts with the NOx to form $N_2$, $CO_2$ and $H_2O$. The SCR system also involves a catalytic substrate arrangement that provides the necessary reaction surfaces for the urea to break down into water and ammonia and then react with the nitrogen oxides in the exhaust stream. The rate at which urea is injected and the operating exhaust temperatures are two very critical components of this system. The advantages of this system are its very high conversion of NOx, it is not fuel sulfur or lubricating oil ash content sensitive and can be readily combined with other systems to efficiently reduce all pollutants. The disadvantage of this system is that it requires a complete and separate infrastructure that must be maintained on both the locomotive and at the maintenance facility.

### SCR Maintenance Issues

Other maintenance considerations are <u>extensive</u>. A separate locomotive and facility infrastructure containing the urea storage units must be carefully maintained. The urea containers will require special storage and handling and therefore training must be conducted in both the locomotive shops and on-board the locomotive. The locomotive urea storage canisters, (estimated to be about 200-300 gallons), and facility storage containers must be maintained in secured locations with temperature limits. They cannot be subject to freezing conditions, (-32 deg F) or temperatures that are too hot, (+100 deg F). The urea and water solution must be maintained such that the correct injection ratio is continuously available. The urea injection nozzles on the engine must be maintained to ensure proper flow and mixing. A hot shutdown of the engine may cause urea salts to form and the injectors to plug. The urea injection system must be routinely inspected and checked to ensure the injection is occurring at the proper times in the proper amount.

If either of these parameters is not functioning properly, ammonia slip, (a term meaning raw ammonia is being expelled into the atmosphere), can now occur which represents a serious safety issue. As stated earlier, "ammonia slip" is a term meaning raw ammonia has escaped without interacting with the exhausts and may find its way into the operator's cab. An SCR system will most likely require that a Diesel Oxidation Catalyst will accompany the SCR system to clean up any potential amount of ammonia that happens to "slip" out.

**Exhaust Gas Recirculation, (EGR)**

Exhaust gas recirculation, EGR, is a flow control device or valve that channels or re-circulates a certain percentage of exhaust gas back into the air intake to lower the NOx levels. Cooling this re-circulated exhaust gas which now contains less oxygen than the ambient intake air helps to lower the peak combustion temperatures thus further inhibiting the production of NOx. A diesel oxidation catalyst or particulate filter is normally used to clean up the exhaust before introducing any of it back into the engine's intake air system. The primary advantage of an EGR system is a cost effective means of obtaining a significant NOx reduction. The disadvantage is the resultant fuel penalty that is usually associated with these systems.

**EGR Maintenance Issues**

The maintenance issues with EGR systems are primarily associated with the control valves. Plugging with carbon and soot can frequently occur and therefore the valves must be periodically checked and cleaned. Chemical corrosion and heat stress can cause the valves to prematurely fail. EGR valves require an actuator for proper operation which also must be routinely inspected. All piping and valves must be periodically checked for leaks that will occur inside the car body. The heat exchangers used to cool the exhaust will require inspection and maintenance to ensure proper operation.

**Closed Crankcase Ventilation, (CCV)**

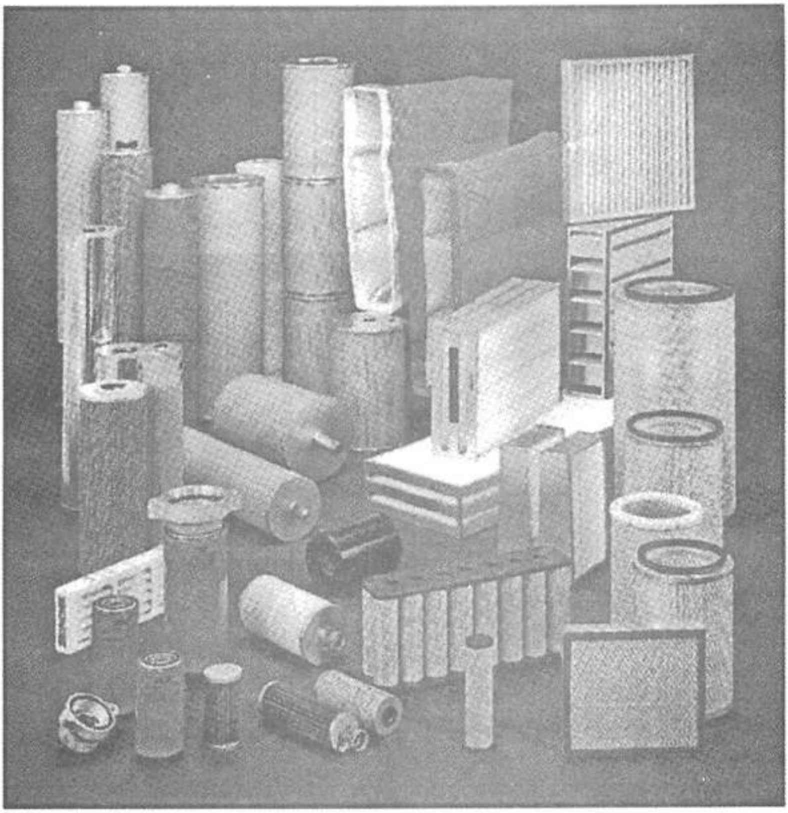
Closed crankcase ventilation, CCV, although not directly associated with the exhaust gases, will become an important contributor to the overall reduction of the particulate matter levels. CCV is a system or device that captures, cleans and returns the crankcase blowby gases either to the atmosphere or potentially back to the engine through the air intake system for re-combustion. Generally, the oil mist is either filtered or coalesced from the crankcase air that is being drawn out and is then returned to the engine's sump. The resultant cleaned blowby gases are then re-directed to the atmosphere or potentially mixed into the engine's air intake where the residual fuel and oil hydrocarbons are burned in the combustion process. The advantage of this system is that it offers a somewhat significant reduction of PM and it reduces the overall lube oil consumption of the engine. The disadvantages of this system are that if it fails to operate properly, the engine could shutdown due to crankcase overpressure alarm or engine lube oil could be potentially supplied into the intake system which could lead to the inability to shut the engine down or worse yet, an engine runaway.

### CCV Maintenance Issues

The maintenance issues related to this system are that the device and any associated valves need to be inspected and checked routinely for proper operation. There are devices or systems that are available that require no routine maintenance but there are others that require filter changes on a scheduled basis to prevent the engine from a crankcase overpressure shutdown.

### Conclusion

As the EPA locomotive exhaust emission regulations continue to become more stringent, (especially in 2015), the implementation of an exhaust aftertreatment system in some combination or function will be required. The railroads will then be responsible for the proper maintenance of these systems to ensure first and foremost, the safety of the craftsmen, the continuous EPA compliance for each locomotive and the cost effective means of performing the maintenance requirements.



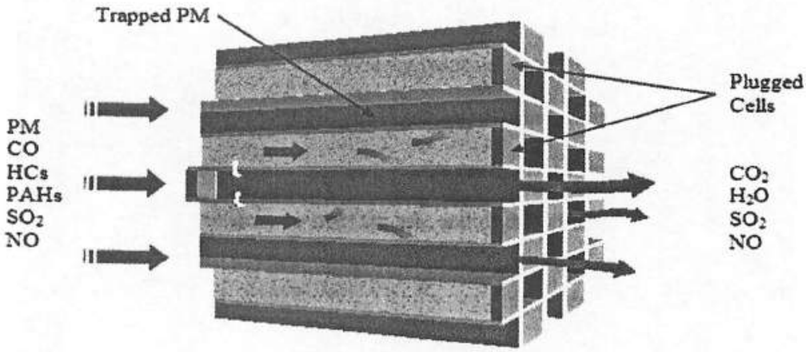



**Figure 1: Diesel Particulate Filter**

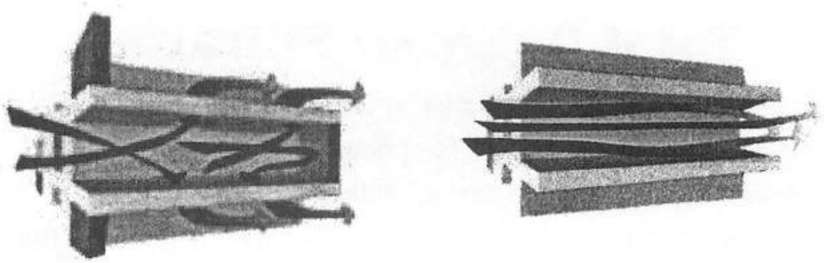


**Figure 2: Wall Flow and Through Flow Filtering Systems**

Pre-Turbo Concept, courtesy of Miratech, Corp.

Post-Turbo Concept, courtesy of MotivePower

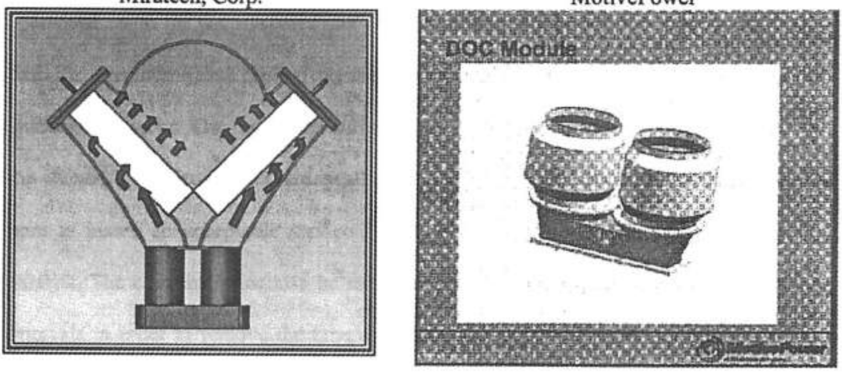



**Figure 3: Pre-Turbo vs. Post-Turbo Diesel Oxidation Catalyst Arrangements**

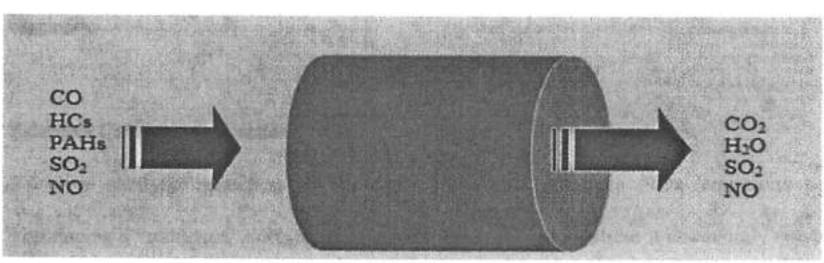



**Figure 4: Diesel Oxidation Catalyst**

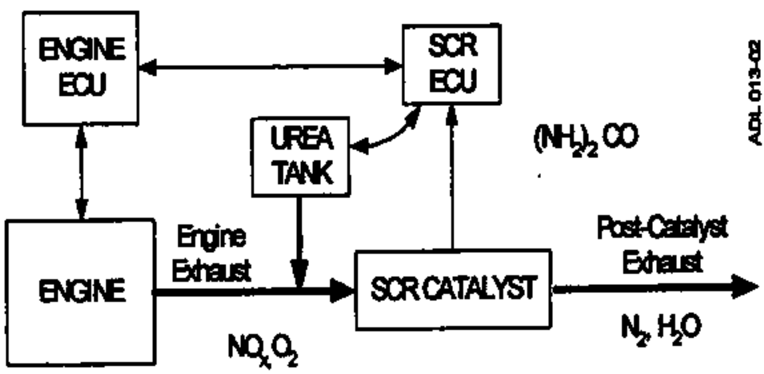



**Figure 5: Selective Catalytic Reduction Schematic**

## III. EPA EMISSION REQUIREMENTS FOR LOCOMOTIVES

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### Introduction

This presentation is being provided by the US Environmental Protection Agency as a Rail Industry update for the New Locomotive Exhaust Emission Regulations. This overview provides additional information on the following three topics: a) Background on the existing program, b) the New Standards and c) Other New Requirements.

As an introduction to this presentation, several locomotive regulatory definitions have been improved upon to provide clarification of previous explanations, see also Part 1033.901 Definitions.

**Remanufacture:** replacing all of an engine's power assemblies, whether all at once or in several steps.
**Useful Life:** the interval between the times of remanufacturing.
**Tier:** the set of standards based on the year that the locomotive was originally manufactured.
**Refurbish:** overhauling a locomotive using 50-75% new parts.

### Previous Emission Standards

- The previous locomotive emission regulations (Figure1) required existing locomotives ordinally manufactured from 1/1/1973 to 12/31/2001, (with some exceptions), to reduce the level of the Oxides of Nitrogen, (NOx), emissions to 9.5 gms/bhp-hr when remanufactured, with no particulate, (PM), emission required.
- The primary NOx control technologies for these Tier 0 engines were delaying the start of ignition, (injection timing retard) and/or the incorporation of improved engine intake air cooling.
- The newly manufactured locomotives that fell under the Tier 1 and Tier 2 timeframes were required to meet much tighter standards.

### Remanufacturing Program

- The remanufacturing program was based on the requirement to use EPA Certified Kit designs whenever the remanufacturing of the locomotive engine occurred.
- Clean emission reduction kit designs are approved by the USEPA based on prototype test data and can be certified by any of the following: a) the OEMs, b) the Railroads and c) the aftermarket suppliers.
- The Certificate Holder is

responsible for the effectiveness of the emissions reduction kit design.

- The Railroads can then choose from any certified emissions reduction kit design on the market or certify its own design.
- The Railroads/Rebuilders are then required to follow the Certificate Holder's instructions for emission related parts and adjustments when remanufacturing the locomotives and locomotive engines.

**Maintenance Requirements**

- The Locomotive Owners/ Operators are responsible for the proper maintenance of those locomotives and engines that were remanufactured with a certified emissions reduction kit.
- The Locomotive Owners /Operators are generally required to follow the Certificate Holder's mainenance instructions and were also permitted to use OEM equivalent parts.
- The Locomotive Owners /Operators were required to keep basic maintenance records for every certified locomotive and engine, Section 92.1004.

**New Emission Standards**

• The EPA has recently set new exhaust emission standards for the locomotives: (Figure 2).

- The New Standards are being phased in from 2008 through 2013.
- In 2015, the first exhaust aftertreatment *catalyst-based* standards for future Tier 4 locomotives will take affect.
- The New Standards leave most of the existing program structure unchanged.

**Phase in of the New Tier 0, Tier 1 and Tier 2 Standards**

- New Tier 0 and Tier 1 Standards will take effect as soon as the new emission reduction kit designs can be certified for each engine family.
- The Railroads would be required to meet the new standards in 2008 and 2009 if a new kit design has been certified, otherwise the previous standards would apply until 1/1/2010 when these new standards become mandatory.
- The New Tier 2 Standards become mandatory on 1/1/2013.

**How will these New Standards affect the Tier 0 and Tier 1 locomotives?**

- The new NOx standards for the Tier 0 engines will require the application of previous Tier 1 technologies.
- The new PM standards for Tier 0 engines will require better control of lube oil consumption, both in the cylinder's chamber and the crankcase blowby.
- Both Tier 0 and Tier 1 may require the addition of Electronic Fuel injection and recalibration.

**How will these New Standards affect future locomotives?**

- Tier 4 standards will start in 2015 but are applicable to locomotives originally manufactured in earlier years.
- Tier 4 locomotives will include catalytic exhaust aftertreatment systems, such as particulate filters for the remediation of soot and oil in the engine's exhaust.
- Tier 4 locomotives will also require an on-board supply of Urea (Ammonia) for the Selective Catalytic Reduction, SCR, system required for ultra low NOx control.

**Other New Regulations**

- Simplified Railroad Certification see Part 1033.240.
  a. Railroads can already certify their own engine families. This new provision makes it easier.
  b. This provision allows the use of parts from aftermarket suppliers instead of OEM as well as reconditioned parts instead of new.
  c. This provision gives the rail roads additional control of the process.
- Aftermarket Parts Certification, see Part 1033.645.
  a. Voluntary part certification allows the component parts manufacturer to voluntarily certify its component part based on engineering analysis showing complete equivalency.
  b. The OEM (or other Certificate Holders) is not allowed to restrict the use of a certified part during remanufacturing.
  c. The part manufacturer agrees to accept specific liability for emission performance of its "certified" part.
- Refurbished Locomotives, see Part 1033.640.
  a. Standards apply based on the value of the parts that are replaced.
     i. 0-50% new parts=> "remanufacutured"
     ii. 50-75% new parts=> "refurbished"
     iii. 75-100% new parts=> "freshly manufactured"
  b. Refurbished Switch locomotives:
     i. Must meet Tier 0 through 2014
     ii. Must meet Tier 3 in 2015 and later
  c. Refurbished LineHaul locomotives:
     i. Must meet same standards as freshly manufactured locomotives
     ii. Special allowances for locomotives below 3000 hp prior to 2015
- Small Railroad Definition, see Part 1033.901 Definitions.
  a. The new explanation limits the definition of "small railroad" to Class III railroads that classify as small business.
- Revised In-Use Testing Requirements, see Part 1033 Subpart E.
  a. The new requirements provide a reduced testing rate and a more flexible program for rail

roads compared with the existing in-use testing program.

- Special Provisions for "gen-set" Switchers, see Part 1033.625.
  a. Special provisions have been provided to allow the manufacture of new Switchers using non-road certified gen-set engines.

**Fore more information:**

General EPA Information: www.epa.gov

Locomotive Specific Information: www.epa.gov/otaq/locomotv.htm

# Previous Emission Standards

## LineHaul

PREVIOUS REGULATIONS
40 CFR Part 92
(effective 1/1/2002)
hp > 2350, kW > 1750

| | Tier 0<br>existing | Tier 1<br>new | Tier 2<br>new |
|---|---|---|---|
| Model year | 1973-2001 | 2002-2004 | 2005-2011 |
| Emissions, gms/bhp-hr | | | |
| NOx | 9.50 | 7.40 | 5.50 |
| PM | 0.60 | 0.45 | 0.20 |
| CO | 5.00 | 2.20 | 1.50 |
| THC | 1.00 | 0.55 | 0.30 |
| Smoke, percent opacity | | | |
| Steady | 30 | 25 | 20 |
| 30 sec | 40 | 40 | 40 |
| 3 sec | 50 | 50 | 50 |

## Switcher

PREVIOUS REGULATIONS
40 CFR Part 92
(effective 1/1/2002)
1006 < hp < 2350,
750 < kW > 1750

| | Tier 0<br>existing | Tier 1<br>new | Tier 2<br>new |
|---|---|---|---|
| Model year | 1973-2001 | 2002-2004 | 2005-2011 |
| Emissions, gms/bhp-hr | | | |
| NOx | 14.00 | 11.00 | 8.10 |
| PM | 0.72 | 0.54 | 0.24 |
| CO | 8.00 | 2.50 | 2.40 |
| THC | 2.10 | 1.20 | 0.60 |
| Smoke, percent opacity | | | |
| Steady | 30 | 25 | 20 |
| 30 sec | 40 | 40 | 40 |
| 3 sec | 50 | 50 | 50 |

Figure 1

## New Emissions Standards

### LineHaul

**40CFR Part 1033 (effective 6/6/2008)**
**hp > 2350, kW > 1750**

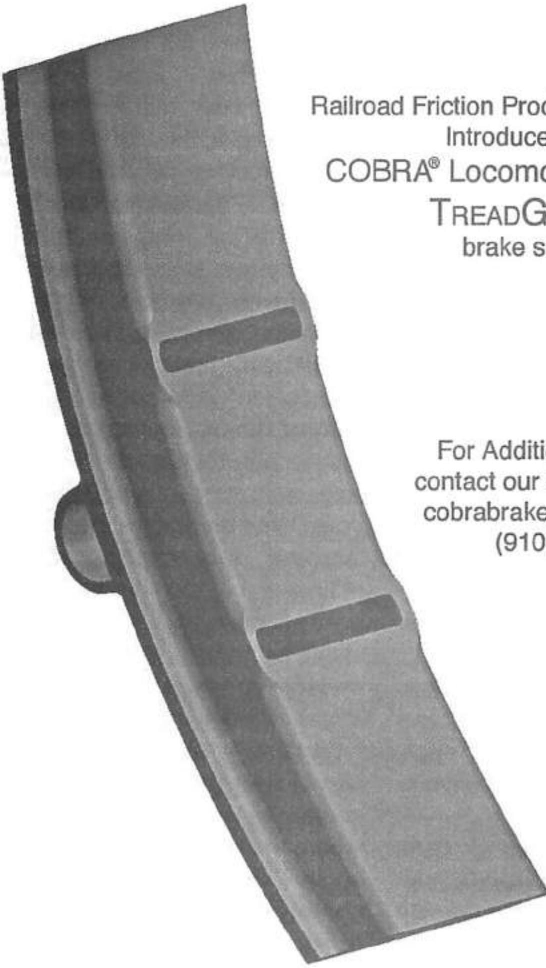
| | Tier 0+[a] existing 1973-1992[f] | Tier 1+[a] existing 1993[f]-2004 | Tier 2+[a] existing/new 2005-2011 | Tier 3[b] new 2012-2014 | Tier 4 new 2015-later |
|---|---|---|---|---|---|
| **Emissions, gms/bhp-hr** | | | | | |
| **NOx** | 8.00 | 7.40 | 5.50 | 5.50 | 1.30[e] |
| **PM** | 0.22 | 0.22 | 0.10[d] | 0.10 | 0.03 |
| **CO** | 5.00 | 2.20 | 1.50 | 1.50 | 1.50 |
| **THC** | 1.00 | 0.55 | 0.30 | 0.30 | 0.14[e] |
| **Smoke, percent opacity** | | | | | |
| | 30 | 25 | 20 | 20 | 20 |
| | 40 | 40 | 40 | 40 | 40 |
| | 50 | 50 | 50 | 50 | 50 |

### Switcher

**40CFR Part 1033 (effective 6/6/2008)**
**1006 < hp < 2350, 750 < kW > 1750**

| | Tier 0+[a] existing 1973-2001 | Tier 1+[a] existing 2002-2004 | Tier 2+[a] existing/new 2005-2010 | Tier 3 new 2011-2014 | Tier 4 new 2015-later |
|---|---|---|---|---|---|
| **Emissions, gms/bhp-hr** | | | | | |
| **NOx** | 11.80 | 11.00 | 8.10 | 5.00 | 1.30[c] |
| **PM** | 0.26 | 0.26 | 0.13[b] | 0.10 | 0.03 |
| **CO** | 8.00 | 2.50 | 2.40 | 2.40 | 2.40 |
| **THC** | 2.10 | 1.20 | 0.60 | 0.60 | 0.14[c] |
| **Smoke, percent opacity** | | | | | |
| | 30 | 25 | 20 | 20 | 20 |
| | 40 | 40 | 40 | 40 | 40 |
| | 50 | 50 | 50 | 50 | 50 |

**Figure 2**



## IV. AIR COMPRESSORS BEST PRACTICES IDENTIFICATION AND MAINTENANCE, PART I

*Prepared by*
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*LOCODOCS, Inc.*

### Introduction

A clean, dry, reliable source of compressed air is essential to a healthy locomotive. Air allows each locomotive's electrical control, auxiliary equipment and braking systems to function. Without air, the locomotive's ability to operate and stop will be hindered. This paper will provide an overview of air compressor types, air compressor drives, suggested preventative maintenance practices and maintenance strategies.

### Air Compressor Types

Two general types of locomotive compressors are currently in use in a variety of configurations and applications: reciprocating and rotary screw.

Reciprocating two stage air compressors are positive displacement machines; reciprocating meaning that the air compressor increases the pressure of the air by reducing its volume (Engineering/M.I. 1110). Locomotive reciprocating two stage air compressors can be broken down into two main categories: air cooled and water cooled (GP15-1). Air cooled compressors can be identified visibly by their finned cylinder heads. Water cooled air compressors cylinder heads are smooth. Air and water cooled air compressors come in two , three, four and six cylinder models with low, medium and high base configurations. Reciprocating compressors have low pressure and high pressure cylinder heads, each with intake and exhaust valves; they have either single end or double end crankshafts. Each compressor has its own oil pump and pressure lubricating system (GP38-2). Internal oil pumps are either of a strap plunger style or a gear crankshaft driven style.

A rotary screw style air compressor is being introduced on modern and "green" locomotives. Rotary air compressors are positive displacement compressors in either single stage helical or spiral lobe configurations. With current industry trends to increase duty cycle and reduce maintenance, the rotary screw compressor may prove itself to be a viable alternative. Rotary screw compressors consist of two rotors within a casing. The rotors compress air internally without valves. Rotary compressors are oil cooled (with air cooled or water cooled oil coolers) where the oil seals the internal clearances. Cooling takes place inside the compressor minimizing extreme operating temperatures; therefore, rotary compressors are a continuous duty compressor (Engineering).

Reciprocating two stage air compressors have been installed on most diesel locomotives over the past 60 years. The concentration of this paper will deal with reciprocating air compressors.

### Air Compressor Drives

Air compressors are driven by the diesel engine directly or independently by an alternating current (AC) - single phase single speed (Triangle) or three phase two speed (S00049EP) motors. Directly driven compressors are mechanically connected to the diesel engine through a series of shafts, couplings and/or v-belts, or air released compressor clutches (S00049EP), either from the engine crankshaft or off the main generator (M.I. 1110). Other appurtenances, such as traction motor blowers or cooling fans, may also be powered by the compressor. Directly driven compressors add drag to the diesel engine decreasing horsepower. AC - single phase motor driven compressors are not mechanically connected to the diesel engine. Power is provided from a companion alternator that is physically connected to but is electrically independent of the traction alternator (S00049EP). As a self contained system, AC - single phase motor driven compressors neither add diesel engine drag nor decrease horsepower.

Air compressors are controlled by a variety of different means from simplistic systems with air regulating governors to computer based systems controlling the compressor control logic: switches, contactors, magnet valves and solenoids. Such control logic devices include: compressor control switches (CCS) (S00049EP), compressor control magnet valve (CMV on Electro-Motive Diesels (EMD) or MV-CC on General Electrics (GE) (M.I. 1144 / S00049EP), compressor governor switch (CGS) (GEMS 6), compressor load request relay (CRL) (S00049EP), clutch magnet valve (CLU) (2L-95), and main reservoir pressure transducer (MRPT) (S00049EP).

Older style compressor systems are simplistic and controlled solely by an air compressor air governor and safety relief valves. The governor is connected to the main reservoir. When main reservoir pressure reaches 130 psi, the governor actuates the unloader. The unloader holds the intake valves open in the compressor, preventing it from pumping air. When main reservoir pressure falls below 120 psi, the governor cuts off the air supply to the unloader and the compressor resumes delivering air (SW1).

Compressor control systems have grown building off the simplistic air valve controlled. An upgrade added a compressor control switch (CCS) to the system. From there, additional sensors, transducers, electrically operated air control magnet valves and computer interfacing was added to modernize compressor control systems.

EMD's SD70MAC uses a computer control system, EM2000, to regulate operation of the AC motor driven compressor by adding a main reservoir pressure transducer to the compressor control switch circuit. Three phase, 230 volt (V) AC compressor motors are controlled through the air compressor slow speed (ACSS) contactor allowing the motor to come up to speed before the compressor is placed under load. The two speed motor capability is controlled through the use of two additional contactors (S00049EP).

General Electric AC Evolution

Series locomotive also uses an AC electric motor to drive the air compressor. Motor speed and compressor loading are controlled through a computer system called Smart Display Panels (SDIS). The SDIS controls the compressor drive contactor energization through an air reservoir pressure sensor (ARPS) to start he AC motor. The SDIS then de-energizes the compressor magnet valve (CMV), which allows the compressor to load. The SDIS also monitors and regulates motor speed (GEJ-6845).

### Suggested Preventative Maintenance Practices

Preventative maintenance practices vary from Class I, IA, II, III, Regional and Short Line railroads and by regulatory status. For successful locomotive operation, the locomotive owner must:

1. Provide knowledgeable, supervised work force.
2. Provide adequate maintenance facilities, specialty tools, repair supplies and appropriate renewal parts.
3. Provide air compressor consumable supplies: filter elements, oil and coolant treatment (if water cooled).
4. Perform inspection and maintenance according to an appropriate schedule, while retaining records of maintenance performed (GEK-76716).

Captive locomotives fall into a category of their own since United States Department of Transportation (DOT) Federal Railroad Administration (FRA) Code of Federal Regulations (CFR) Railroad Locomotive Safety Standards - Part 229 do not apply. Captive locomotives do not leave private property. Regardless of a locomotive's regulatory status, FRA or non-FRA governed, a consensus of necessary preventative maintenance practices can be divided into two categories: basic maintenance and storage.

### Maintenance Supplies

Basic air compressor maintenance can be performed on a calendar day (FRA governed) or a per hour usage (non-FRA governed) plan. Assuming a locomotive is used daily, a calendar day plan is easiest to implement. Calendar day scheduled inspections include: daily, monthly, 92 day, semiannual, annual, biannual and triennial. Maintenance differs at each interval.

Before performing basic air compressor maintenance, a general guideline should be followed:

1. Never mix crankcase oil or lubricants of different grades or brands (M.I. 1752).
2. NEVER OVERFILL - too much lubricant can be as harmful as too little.
3. Clean grease fittings before adding grease.
4. Clean equipment covers if removed during servicing.
5. Always use clean containers to transport bulk oil and lubricants (GEK-76716).
6. Always service the air compressor with the locomotive SHUT

DOWN, reverser centered, unless otherwise specified. Apply the locomotive handbrake. Cut off all power to the compressor. Apply wheel chocks to the locomotive to prevent potential movement. Apply "WARNING" placards about the locomotive indicating that work is to be performed (M.I. 1300).

**Basic Maintenance**

For peak air compressor efficiency, a maintenance program such as detailed below should be implemented:

**I. Daily:**

1. Check the oil level.

Compressor oil level can be determined at any time with the compressor running or stopped. If the compressor has a float gauge, the needle must be kept within the green "RUN" range (M.I. 1100). If checked while running, center the reverser, apply the brakes and set the throttle at IDLE (RAILS-302). Verify the fill mark (air compressor crankcase dipstick, sight glass or gauge). If the level is low, add appropriate oil until within the "SAFE" range on the dipstick. Ensure the dipstick has been wiped clean and is fully seated when taking readings (GEK-76313). Do not overfill.

2. Drain condensate.

Drain the compressed air system daily. The manual main reservoir filter drain valves should be opened daily to ensure proper operation (S00049EP/GP38-2).

**II. Every month (30 days) or 15,000 miles:**

The air filter dryer system should have the following main tenance performed monthly:

1. Check humidity indicator condition.
2. Cycle towers.
3. Test function of precoalescer drain and sump purge valves (S00049EP).

**III. Every 92 days or 45,000 miles:**

1. Sample compressor crankcase oil and send for analysis (M.I. 1144).
2. Verify that mechanical gauges function properly (49CFR229.25).
3. Visually inspect lines, connections and equipment for leaks: oil, water and air (M.I. 1777A).
4. Visually inspect direct drive components including coupling grommets, fasteners, Fast or Falk members. If the direct drive system is equipped with an air compressor clutch, routine is limited to periodic inspections and functional tests of the clutch and its air control system during normal shutdown periods for service (M.I. 1145). Note any unusual noises during operation. Record the friction wear plate measurement (M.I. 1777A). Under normal locomotive and air compressor operating conditions, the friction plate gap change rate is 0.003 to 0.005 inches or less per month (2L-95). Visually inspect mechanical drive couplings for

wear. If grease type, inspect for leaks. If leak is evident, clean grease fitting and reapply appropriate long term grease (LTG) (Falk 438-110).

5. Visually inspect and manually test the MV-CC (S00049EP).
6. AC motor driven - inspect electrical connections, verify contact tips are clean.
7. Test air compressor operating parameters (see normal operating conditions below).
8. Test safety valves (see intercooler safety valve section below).

**IV. Every six months (184 days) or 90,000 miles:**

1. Change air compressor oil, oil filter and air filter.

Air compressor oil filter/s should be changed out at least once every six months and every time the oil is changed. Air compressor air filter element/s should be changed every 180 days. Air compressor crankcase oil should be changed at least once every six months or as oil analysis trending dictates (GEMS 7). The six month inspection should include visually inspecting the air compressor for unusual damage or operation (GEK-76313). The crankcase interior should be thoroughly cleaned by flushing the crankcase with a petroleum solvent then wiping the interior clean with lint free, bound edge towels before adding new oil (M.I. 1100).

When installing a new air filter, be sure to completely remove the old filter. Clean the housing of any and all dirt, oil and debris. Properly seat the new filter within the housing. Close and latch the housing to prevent unfiltered air from entering the compressor. Unfiltered air will wear the compressor out more quickly (GEMS 7). If equipped with early model air intake screens instead of air intake filters, clean screens and reapply oil (M.I. 1724).

2. Inspect operation of unloaders. Inspect intercooler exterior and clean. If so equipped, inspect and clean aftercooler exterior (M.I. 1300).
3. If the direct drive compressor turns additional accessories (traction motor blowers and cooling fans in EMD switching locomotives) through sheaves and v-belts, visually inspect v-belts. Tighten if loose. Replace if worn. (M.I. 1203/M.I. 1724).

**V. Annually (365 days) or 180,000 miles:**

1. Clean main reservoir filtering devices of dirt collectors. Repair and replace as required (49CFR229.27a1).

2. Clean and test safety valves (49CFR229.27a2).

3. Perform compressor orifice testing as a means to measure its condition, as outlined in the DOT rulings (M.I. 1144/49CFR230.71).

4. Change air dryer system filter (S4000EP).

5. Open water cooled compressor liner access covers and flush sediment.

Flush sediment from cylinder liner water passages on WLN, formerly WBO, and WLG, formerly WBG, air compressors. If not equipped with low sludge cylinders or deflector

kits, water should be directed into the lower liner area through the water inlet passages and inspection ports to flush the accumulated materials. WLN and WLG compressors are equipped with gear driven style oil pumps and low sludge cylinders (M.I. 1805-1). If the WBO or WBG is not equipped with a sediment removal water jacket system, conversion kits can be ordered. Use part number 8498379 for WBO compressors and 9083385 for WBG compressors (14L74).

6. Clean oil pump strainer, and if necessary replace (M.I. 1300).

7. Check the operation of the purge valve heater, if so equipped (M.I. 1300).

8. Clean magnet valves and replace the "O" ring and seats (M.I. 1740). It is not necessary to completely disassemble the solenoid valve and replace the coil. Test for proper operation (M.I. 4707).

9. Inspect and clean all air compressor switch gear contact tips. Replace as required (M.I. 1738/M.I. 5511).

10. Replace AC motor brushes (M.I. 1739).

11. Verify air compressor alignment and torque mounting bolts.

For general reference, bolt torque values for 1" - 8 threads per inch medium carbon Society of Automotive Engineers (SAE) (grade five noted by three radial lines embossed on the bolt head) bolts range between 440 to 490 foot pounds (Lb.-Ft.). 1" - 12 threads per inch alloy steel (SAE grade eight noted by an embossed "X" or six radial lines embossed on the bolt head, socket head bolts are also grade eight) bolt torque values range between 685 to 735 Lb.-Ft. (LSM-1987). When a torque wrench is unavailable, a service technician can exert a pull of around 125 Lb.-Ft. on a wrench handle which, when multiplied by the wrench length in feet, results in the approximate torque produced in Lb.-Ft. (SMI-00013D).

For compressors installed in EMD locomotives, the compressor mounting bolt torque range is between 300 to 330 Lb.-Ft. for 7/8" - 9 mounting bolts (7/8" - 9 x 3-1/4" grade five bolts) (No. 90). If equipped with 3/4" - 10 mounting bolts, the torque value is 165 Lb.-Ft. (LSM-1987).

For compressors installed in GE locomotives, the compressor mounting bolt torque range is between 400 to 500 Lb.-Ft. for standard mounting bolts (1" - 8 x 4-1/2" grade five bolts) (LSM-1987).

Direct drive compressors are connected to the locomotives diesel engine by a shaft and coupling arrangement. Couplings have no radial flexibility but some angular flexibility. Although a coupling can withstand some misalignment, the shafts must still be aligned as accurately as possible. Precise alignment reduces coupling and shaft stress, thereby minimizing vibration. Although rotating system alignment is usually performed on coupling surfaces, the real concern is shaft alignment. It is often more convenient to attach dial indicators to coupling faces than to the machine shaft (M.I. 1753). Alignment of the compressor to the diesel engine is accomplished by ensuring the diesel engine is first properly torqued down to the locomotive frame (M.I. 1776).

Verify that the air compressor drive shaft couplings are installed (Falk, Fast or rubber grommet type) with coupling bolts torqued to 100 Lb.-Ft. Verify alignment of air compressor and diesel engine couplings twice. The first verification should measure length and distance between the coupling and shaft. The second should check radial and angular misalignment. The radial dimension is measured outward from the center of the shaft in a plane perpendicular to the shaft's main axis. Radial misalignment means a difference in the position of the rotating axis of one shaft from a reference point. The angular dimension is measured from a reference axial centerline (Axial is measured back and forth along the rotating axis of the shaft). Axial misalignment means the position of the whole shaft must be shifted in the direction of its length.) to the actual shaft or coupling rotational axis. Angular misalignment refers to the angle one shaft makes with another shaft at their coupling interface (M.I. 1753).

To verify air compressor coupling angular alignment, two dial indicators (EMD#8255423) will be necessary. Attach a dial indicator on each coupling flange against the face of the mating flange within the same plane. Mount the indicators on brackets and set the dial to zero at the 12 o'clock position. During shaft rotation, record indicator readings every 90º. All readings must be within 0.020 inches. This measurement must not be exceeded (M.I. 1753). Verify measurements by taking a second set of readings. If readings still exceed 0.020 inches, refer to the appropriate OEM instructions for removal and reinstallation of air compressors. Alignment of the compressor will be required as if installing a replacement compressor. In EMD switching locomotives, any maintenance requiring the movement of the air compressor will also require an alignment verification of the cooling fan and pedestal assembly (M.I. 1753).

After alignment verification, torque the compressor mounting bolts to the locomotive frame by the following torque values:

For EMD switching locomotives equipped with front end cooling fans, the air compressor has a drive sheave that connects to the cooling fan through a series of v-belts. The three sheaves from the air compressor, fan drive and idler must be aligned so that the finished faces of the three sheaves are in the same plane within 0.060 inches (M.I. 1203). The air compressor drive sheave retaining nut should be torqued to 500 Lb.-Ft. (M.I. 1753). The cooling fan driveshaft angular alignment must not exceed 0.020" (M.I. 1765).

Mechanical drive couplings should be visually inspected for alignment and wear. If equipped with Falk or Fast couplings, LTG should be reapplied. Disassemble coupling. Check for wear. Replace worn parts. Clean grease from coupling and repack with new LTG. Install new gasket. Tighten all fasteners to proper torque values (Falk 438-110).

12. Note air system cleaning and testing on the Blue Card Form FRA F6180-49A (49CFR229.27a3).

### VI. Biennial (736 days) or 360,000 miles:

1. Brake valve change out:

For locomotives equipped with 24RL, 6BL and 14EL or equivalent brake systems, all of the locomotive's brake system pneumatic components that contain moving parts and are sealed against air leaks must be removed from the locomotive, disassembled, cleaned, lubricated and the parts that can deteriorate with age must be replaced (49CFR238.309).

2. Test the main reservoirs per 49CFR229.31.

3. Inspect inlet and discharge valves (GEK-76313).

WABCO recommends replacement or overhaul of all discharge valves on its compressors biannually (M.I. 1300).

4. Clean and inspect the unloader mechanism (M.I. 1300).

5. Replace the crankcase breather valve (M.I. 1300).

6. Note brake valve change out on the Blue Card Form FRA F6180-49A (49CFR238).

### VII. Triennial (1,104 days) or 540,000 miles add:

1. Brake valve change out:

For locomotives equipped with 26L or equivalent brake systems, all of the locomotive's brake system pneumatic components that contain moving parts and are sealed against air leaks must be removed from the locomotive, disassembled, cleaned, lubricated and the parts that can deteriorate with age must be replaced (49CFR238.309).

2. Overhaul entire air dryer system including:

A. Replace all seals, gaskets and seats.
B. Renew desiccant canisters.
C. Renew tower purge valves.
D. Renew precoalescer drain valve.
E. Renew inlet and outlet check valves.
F. Renew solenoid valve.
G. Replace regenerating orifice.
H. Renew desiccant compactor.
I. Perform control circuit operation. Replace the circuit board if a malfunction occurs.
J. Renew filters (S00049EP).

3. Clean and inspect the unloader mechanism (M.I. 1300).

4. Verify intercooler pressure relief valve functions. Replace if valve malfunctions (M.I. 177A).

5. Renew all air compressor valves (M.I. 1300/M.I. 1144).

6. Note brake valve change out on the Blue Card Form FRA F6180-49A (49CFR238).

### VIII. Every six years or 1,080,000 miles:

EMD suggest to overhaul air compressors, as well as all direct drive coupling components every six years or 1,080,000 miles (M.I. 1724/M.I. 1776).

GE suggest to overhaul air compressors every eight years. The intercooler should be replaced every 26,000 motoring watt hours (MWHrs) of operation. It is suggested by the OEM to overhaul the air compressor AC motor on an eight year schedule. Air compressor contactors should be rebuilt every 12 years (GEK-76716).

*Notation: Actual time periods between overhauls must be established by the user based on user conditions and experience (M.I. 1300)

**Storage**

Locomotive storage preparation procedures for air compressors is determined by the length of time the locomotive will be stored and locomotive storage location related to inclement weather (GEK-61240E).

Short term storage will be defined as storing a locomotive for six months or less. To prepare the air compressor, spray compressor lubricating oil into each intake pipe for a period of three minutes while the compressor is rotating and loading. DO NOT rotate or restart the air compressor after applying lubricating oil into the intake pipes. Drain all air lines of water. If the air compressor is a water cooled compressor, also drain the coolant system. It is strongly recommended that each locomotive in storage is inspected monthly during the early portion of storage to evaluate preparation, determine the lasting qualities of the preparations and make corrections where necessary (GEK-61240E).

Long term storage will be defined as storing a locomotive for more than six months. To prepare the air compressor for long term storage, drain the crankcase oil. Spray the crankcase interior, including any exposed machined surfaces (cylinder walls, pistons and rods) with a petroleum based anti-rust solution. Remove the air compressor inlet valves. Spray the pistons and cylinder walls with a petroleum based anti-rust solution. Reinstall the inlet valves. Tape over the air filter inlet openings with a pressure sensitive tape (GEK-61240E). Apply a "DO NOT START" tag to the crankcase dipstick.

Apply a light coat of petroleum jelly on contact tips. Wrap compressor control contactors, relays and magnet valves with MIL-B-131 barrier material and seal with a pressure sensitive tape. Cover compressor related switch boxes and electrical receptacles with MIL-B-121 barrier material and seal with a pressure sensitive tape (M.I. 1726).

If the compressor is directly driven with v-belts, remove the v-belts and store in a flat position. Coat all sheaves with a corrosion preventive compound. Coat metal portions of all compressor couplings with a corrosion preventive compound, wrap with VPI-B and seal with a pressure sensitive tape (M.I. 1726).

Inspect long term storage preparation methods after three months. Inspect compressor and related components for corrosion; corrosion should not be found. If found, reapply long term storage methods implemented previously. Replace all disturbed sealing materials and repeat inspection every six months thereafter (M.I. 1726). For storage periods beyond one year, each locomotive should be reactivated and the short term or long term storage process repeated (GEK-61240E).

When removing a locomotive from storage, air compressors should be removed of all protective wrappings, seals and covers applied for storage. Reinstall any and all external air hoses that may have been removed. Verify filters are in place. DO NOT change the oil filters at this time. Fill the air compressor crankcase with the appropriate oil. Visually inspect drives. Add appropriate lubricant if required. Remove the "DO NOT START" tag from the air compressor dipstick (GEK-61241G).

If reactivating a water cooled air compressor, fill the cooling system with an alkaline based cleaning solution (1 oz. of cleaner per gallon of water). A cleaner, such as one used for washing the exterior of the locomotive carbody, is recommended. When the locomotive is operable, warm up and run the locomotive for one hour ensuring the water travels through the entire coolant system. Store the engine and drain the cooling system. Further flushing is NOT required. Refill the cooling system with treated water (GEK-61241G).

Before returning the locomotive to service, further air compressor maintenance is required. Replace all air filter elements. For air cooled air compressors, run the compressor for approximately one hour to cycle the crankcase oil removing storage preservatives. It is not necessary to cycle the crankcase oil for water cooled compressors, as crankcase oil was cycled during coolant system preparation. Drain cycled air compressor crankcase oil. Change oil filters. Refill the air compressor crankcase with new appropriate oil (GEK-61241G). For Federally Regulated locomotives, notate on the Blue Card (Form FRA F6189-49A) the number of out-of-use days. A carrier supervisory employee responsible for the locomotive must attest to the notation and sign the Blue Card (49CFR229.33).

After installation of new parts, general overhaul or compressor replacement, the following steps should be taken:

1. Inspect the air compressor for visible damage during transport, repair or remanufacture.
2. Renew filters.
3. Fill crankcase oil with appropriate oil to within the "SAFE" mark on the dipstick.
4. Turn the compressor over by hand to ensure everything is free and in working condition.
5. Install and align the air compressor driveshaft per the proper OEM installation and alignment publication.
6. Connect the unloader air supply, inlet filter and discharge air piping (GEK-76313).

When storing remanufactured compressors in inventory in highly damp or coastal climates, it is recommended that each compressor be test run under load for one hour for each 20 to 90 days of storage to prevent minute rust areas from forming in cylinders and on valves. For indefinite storage, compressors should be protected against rust. A petroleum based anti-rust solution should be applied internally. The breather cap, all safety valves and connection openings should be sealed with a pressure sensitive tape

(M.I. 1100).

In conclusion, a clean dry reliable source of compressed air is essential to a healthy locomotive. Air allows each locomotive's electrical control, auxiliary equipment and braking system to function. Without air, the locomotive's ability to operate and stop is hindered. With the integration of computerized technology, trending towards AC motor drive versus direct drive compressor application and increasing duty cycles while reducing maintenance, a consistent, documented, easy to follow maintenance and storage plan must be outlined for all facets of the railroad industry's maintenance personnel to follow in order to help ensure reliable motive power.

**Resources**

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6/10/08

Reciprocating Two Stage Air Compressors

| Source | Compressor Make | Model | Type | # Cylinders |
|---|---|---|---|---|
| GEK-76313 | Ingersoll-Rand (IR) | YHE | air cooled | 2 |
| SMI-00002B/LSM-1987 | Westinghouse (WABCO) | 3CMDCB8L | air cooled | 3 |
| SMI-00013D | WABCO | 3CDCLA | air cooled | 3 |
| M.I. 1300 and M.I. 1756 | WABCO | 3CD | air cooled | 3 |
| GEJ-6693 and M.I. 1756 | Gardner Denver (GD) | WLN /WBO | water cooled | 3 |
| M.I. 1144 and M.I. 1756 | GD | WLG /WBG | water cooled | 6 |
| M.I. 1110 and M.I. 1756 | GD | WLO /WXO | air cooled | 3 |
| M.I. 1110 and M.I. 1756 | GD | WLE /WXE (upgraded to WXO) | air cooled | 3 |
| M.I. 1110 and M.I. 1756 | GD | WHL / WXG | air cooled | 6 |
| M.I. 1110 and M.I. 1756 | GD | WLP / ABO | water cooled | 2 |

| Source | Compressor Make | Model | Type | # Cylinders |
|---|---|---|---|---|
| M.I. 1110 and M.I. 1756 | GD | WLQ / ADJ | air cooled | 2 |
| M.I. 1110 and M.I. 1756 | GD | ADX (upgraded to ADJ) | air cooled | 2 |
| S00049EP | GD | WLA | air cooled | 4 |

<u>OEM Suggested Compressor Overhaul Schedule</u>

| Source | Model Compressor | Overhaul Every |
|---|---|---|
| M.I. 1300 | 3CD - direct drive models | Four years |
| M.I. 1300 | 3CM - motor driven models | Six years |
| M.I. 1724 / GEJ-6693 | All EMD applied | Six years |
| GEK-76716 | All GE applied | Eight years |

# REPORT OF THE COMMITTEE ON DIESEL ELECTRICAL MAINTENANCE

# TUESDAY, SEPTEMBER 23, 2008

# 9:00 A.M.

Chairman
**STUART OLSON**
Regional Sales Manager
Wabtec Corporation
Alpharetta, GA

Vice Chairman
**MIKE DRYLIE**
Electrical Systems Engineer
CSX Transportation
Jacksonville, FL

## COMMITTEE MEMBERS

| | | | |
|---|---|---|---|
| D. Becker | Design Engineer | Electro Motive Diesels | LaGrange, IL |
| J. Boggess | Sr. Mgr.-Motive Pwr. | Alaska RR | Anchorage, AK |
| D. Bruss | Engr. New Cap. Equip. | Amtrak | Philadelphia, PA |
| M. Fitzpatrick | Sales Manager | Cattron | Lyndhurst, OH |
| F. Fraga | | CSX Transportation | Jacksonville, FL |
| B. Hathaway | Consultant | | Port Orange, FL |
| B. Kirdeikis | Sr. Rel. Specialist-Elec. | CN RR | Edmonton, Alberta |
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| D. Maryott | Mgr.-Locos. | BNSF Railway | Fort Worth, TX |
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| V. Trout | Mgr.-Mech. Engrg. | Union Pacific RR | Omaha, NE |
| L. White | Tech. Sales Rep. | Bach-Simpson | St. Hubert, Quebec |

Note: Brian Hathaway and Les White are Past Presidents of LMOA.
Also, Ron Bartels, Regional Executive is also a very active member of this committee

# PERSONAL HISTORY

## *T. Stuart Olson*

Stuart was born in Jacksonville, FL and received a Bachelor of Science degree from the University of Central Florida. In 1974, following a six-year tour of duty as a US Navy nuclear submariner, he began his railroad career with a relatively new company, Auto-Train in Sanford, FL. While at Auto-Train he advanced from locomotive junior machinist to Draftsman, Project Engineer, Director of Facility Maintenance, and finally Director of Operations.

In 1979 he began serving the industry from the other side of the track as Field Representative for New York Air Brake. In 1983 he took the position of Sales Engineer for Aeroquip Corporation in Chicago, IL, where he advanced to Account Executive. In 1987 he was promoted and transferred to Wytheville, VA as Aeroquip Railroad Products Manager.

After a brief stint with Republic Locomotive Works as Director of Sales, and Bach-Simpson as Regional Sales Manager he continued to broaden his knowledge by accepting a position at Q-Tron as Manager of Business Development.

The railroad industry was changing at a fast pace. Railroad supply companies were merging and in acquisition mode. Q-Tron was purchased by Motive Power Inc., where Stuart transitioned to the position of Regional Sales Manager.

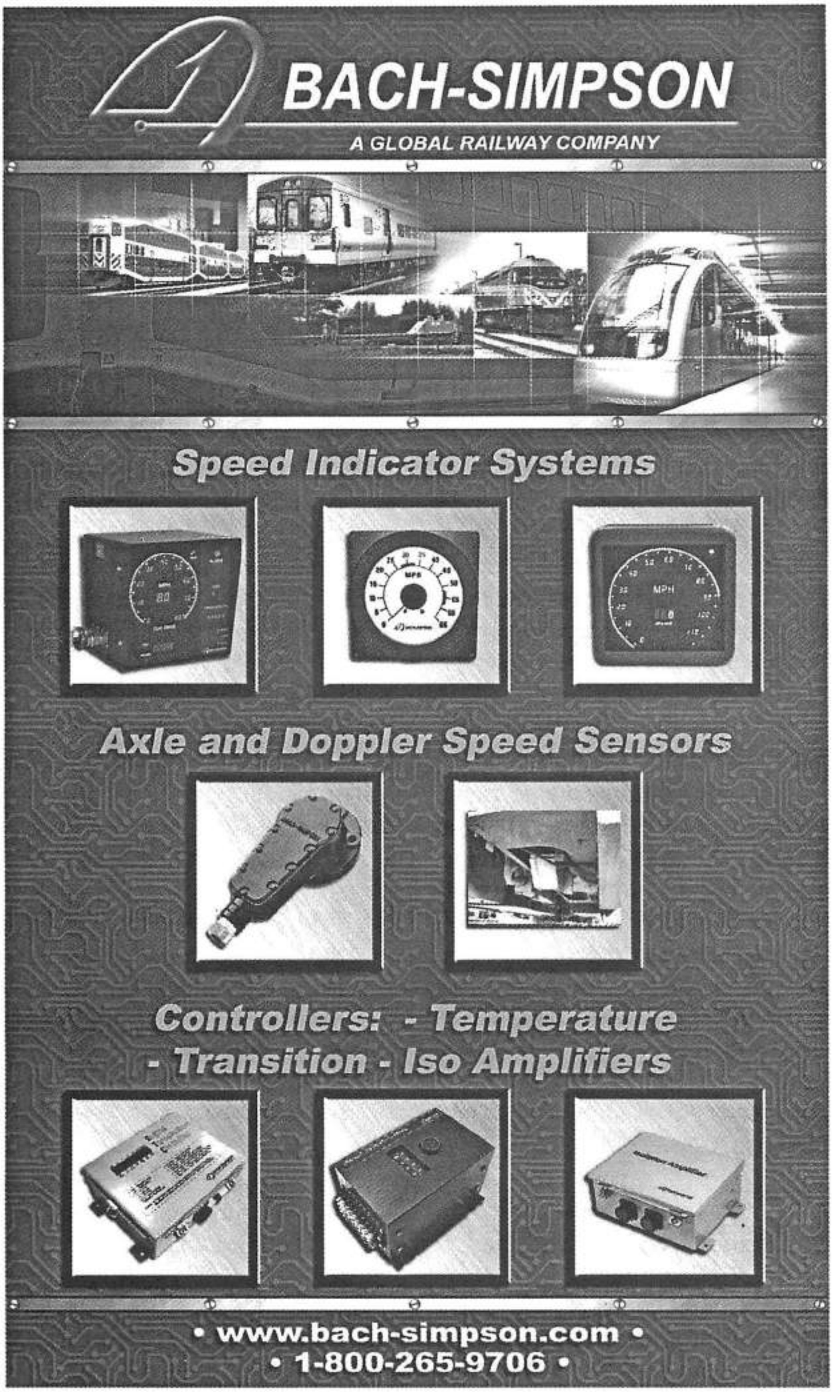
A short time later Westinghouse Air Brake Co. merged with Motive Power forming Wabtec Corporation. He is the Regional Sales Manager for Wabtec servicing Class 1, Short Line and regional railroads in the Southeastern US.

Stuart is a long time member of the LMOA Diesel Electrical Maintenance Committee serving as committee member and vice chair, as well as presenting technical papers. He is a past recipient of the Committee MVP.

Currently living in Atlanta, GA with his wife Winky, they have two children and five grandchildren.

**THE DIESEL ELECTRICAL MAINTENANCE COMMITTEE WOULD LIKE TO EXPRESS THEIR SINCERE APPRECIATION TO TTCI FOR HOSTING THEIR WINTER MEETING IN PUEBLO, COLORADO ON FEBRUARY 4 AND 5, 2008**

**THE COMMITTEE WOULD ALSO LIKE TO THANK PEAKER SERVICES, INC. FOR HOSTING THEIR SUMMER MEETING IN BRIGHTON, MICHIGAN ON JULY 21 AND 22, 2008**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## I. CHALLENGES WITH RETROFITTING NEW SYSTEMS TO OLD LOCOMOTIVES

*Prepared by*
*Charles Taylor,*
*Bach-Simpson Corporation*

### Introduction

With the average life expectancy of equipment on a locomotive being approximately 20 years; this has caused the need to retrofit existing systems which have become either beyond economic repair and/or obsolete due to other regulations. Bach-Simpson Corp. has been involved with a number of event recorder/speed indicator retrofits on both passenger and freight applications. The reasoning for the need to do a retrofit will be discussed as well as challenges and actions involved in a typical equipment retrofit.

### Why the retrofit requirement? FRA Requirements

49 CFR 229.135 states that all locomotives manufactured before October 1, 2006, and equipped with an event recorder that uses magnetic tape as its recording medium shall have the recorder removed from service on or before October 1, 2009, and replaced with an event recorder with a certified crashworthy event recorder memory module. (Figures 1 & 2).

### Major Rebuilt (Obsolete/Non-serviceable Equipment)

49 CFR 238.103 (a) (2) states that materials introduced in passenger car or a locomotive cab as part of a rebuild, refurbishment or overhaul of the car or cab, shall meet the flammability and smoke emission characteristics as specified. This requires the use of compliant material in the new cabling and equipment design. e.g. Exane®-cross linked polyolefin insulation (Figure 3). 49 CFR229.135 (b) (5) states that "a locomotive equipped with an event recorder that is remanufactured, as defined in this part, on or after October 1, 2007, shall be equipped with an event recorder with a certified crashworthy event recorder memory module that meets the requirements of Appendix D to this part and is capable of recording, at a minimum, the same data as the recorder that was on the locomotive before it was remanufactured." (Figure 4)

### Fleet Standardization

With many large fleets, the potential of having different generations of equipment is quite common. Below are some advantages of retrofitting to standardize a fleet's equipment.

- Add features that may assist in monitoring "new" parameters that can reduce maintenance, monitor train handling, reduce operating costs.
- Reduce the number of spare parts being procured and stocked.
- Ease troubleshooting, routine maintenance and training due to the commonality of the systems.

### Challenges Maintainability & Life Cycle Cost

As part of the planning and reviewing of a potential system retrofit, the equipment should be assessed on ease of maintainability and the associated life cycle cost. When assessing the equipment the following areas should be reviewed:

- Tools required for routine maintenance (e.g. test jigs, gauges).
- Labor required for maintenance, calibration (if applicable).
- Ability to upgrade, add options or consolidate features.
- Requirements for preventative maintenance.

### EMI (Electromagnetic Interface) Considerations

Where equipment is being installed in a new application/environment, the affects of EMI should be reviewed. The equipment mounting location and cable routing should be analyzed for possible sources of EMI. Areas to avoid when routing cables are radio antenna coaxial cable and high current cable as these all emit unwanted EMI which could or may affect the equipments functionality. To reduce EMI affects, shielded cables and proper shield terminations should be used for low level and noise sensitive signals.

### Enviromental Considerations

After the removal of the obsolete equipment, proper material disposal procedures should also be followed to reduce the environmental impact caused by contaminants in land fills. Examples of potential contaminants are cadmium which is a plating used on many existing cable connectors as a protective plating and PVC which is an insulator used on many existing wire harnesses; also proper disposal of internal batteries used with random access memory (RAM) devices as these may contain environmentally harmful chemicals. E.g. lithium mercury.

### Actions - Typical Equipment Installation

When retrofitting old equipment or installing new equipment the following are general action areas which should be reviewed:

### Functionality

A functional review and comparison study of the equipment being installed with previous equipment being replaced should be performed. This will ensure all preferred features and options are not excluded and that the functionality is correct. This is also an area where improvements can be incorporated into the new system's functionality and design. One example is an event recorder system design with integral or external pressure switches/transducers. While integral switches/transducers compared to external switches/transducers may be a cost savings during initial installation, a future failure of an integral switch or transducer would require the complete event recorder to be removed and replaced. In addition to the labor to remove and install the replacement event recorder, a complete test of the event recorder system is required. The replacement of a defective external pressure switch or transducer is less labor intensive and would only require testing of the pressure transducer aspect of the system. This test could be done easily on the dispatch track which would reduce out of service time. Another advantage of external pressure switches/transducers is in cold weather climates such as northern states and Canada as they are generally installed in the control stand which is a high point in the air system. This reduces the chances of water migration and freezing compared to the integral switches/transducers in the event recorder which are normally mounted under cab floor. With installations under the cab floor and water accumulation due to being a low point in the air system, pressure switches/transducers are more prone to freeze up when exposed to cold weather conditions. This causes the pressure switches/transducers to become non-functional or inaccurate. It should also be noted that the cab is heated in normal operation and with the pressure switches/transducers in the control stand there is virtually no possibility of a freeze up issue in cold climates.

The retrofit should be also reviewed to determine if it affects or requires changes as per 49 CFR 238.105. E.g. modification to the Train Control software or hardware. "The railroad shall develop and maintain a written hardware and software safety program to guide the design, development, testing, integration, and verification of software and hardware that controls or monitors equipment safety functions."

**Labor & Downtime Analysis**

A review of the labor and downtime required in performing the installation/retrofit should be completed. This will ensure proper work force loading is achieved which in turn will avoid longer downtimes and unexpected delays.

**Procuring Equipment**

Once the functionality of the new equipment has been reviewed, the lead time to procure the equipment should be also confirmed. Many custom parts are not generally a stock item at the manufacturer or distributor; therefore these items may have longer lead time compared to ordering standard items.

**Cable/Wiring Interface**

Interfacing with the existing cable wiring and/or routing of new replacement cables should be done in compliance with 49 CFR 229.135 (b) (5). The use of CFR compliant material in the new cabling and equipment must be followed. An example of compliant cable material is Exane®-cross linked polyolefin insulation; this material meets the flammability and smoke emission characteristics detailed in 49 CFR 229.135 (b) (5).

When applicable, as part of the retrofit, the existing wires/cabling should be inspected for insulation fatigue caused by vibration, chafing and rubbing. This extra effort will help in avoiding future problems which could cause intermittent connections and/or ground faults. When possible, pending cabling condition, the reuse of existing cables should be encouraged as this is a major area for installation labor cost savings.

**Mating Connectors & Contacts**

If part of the system retrofit or installation involves interfacing to existing connectors, a detailed review of the connectors should be done to ensure connector compatibility and avoid possible problems, such as, galvanic reactions caused by dissimilar metals. The following are examples of connector details which should be checked:

- Manufacturer of connectors (ensure proper part numbers are used)
- Correct contact plating
  E.g.: gold 15u/30u, silver and phosphorous bronze
- Service rating of connector
- Plug connector
  E.g.: Cadmium, Black Zinc Cobalt, and Nickel

**Mounting Location**

During the review of the equipment's mounting location the following areas should be checked.

For retrofits, compare the new equipment's physical size to the old equipment being replaced. Verify mounting configuration to determine if additional adapter plates, hardware or modifications are required. The mounting location space should be checked to ensure adequate space to provide proper air flow and ventilation of the equipment. Where equipment is mounted near doors or removable panels, proper connector and cable clearances should be achieved to avoid possible wire chafing or pinching of cable insulation. When new equipment is being installed and interfacing to other systems (E.g. pneumatic system) is required, a central location should be determined. This will ease and reduce the amount of additional piping and cable wiring required. The ease of accessibility for maintenance and service should be also confirmed during this review.

**Tools**

Some equipment retrofits may require the use of specialty tools; some will be one time use during installation (E.g. hole punches, fixtures for mounting) and other will be required for maintenance repairs (E.g. crimping tools, connector pin insertion tools).

**Workmanship/Safety**

As with all work activities, the proper guidance of shop safety procedures, manufacturer instructions, and tool safety procedures should be followed. This will ensure workmanship/good quality and personal safety is not compromised.

**Equipment Testing**

After the completion of the retrofit installation, a full system test should be performed. This will ensure the new system has been properly installed and that all existing and new features are functioning correctly.

### Configuration Management

With all equipment retrofits the updating of manuals, instructions and schematics are crucial to ensure proper testing and routine maintenance is followed and performed. These documentation efforts will also ease in troubleshooting and downtime should a failure be detected. Proper training is also a key component to a smooth retrofit transition. The revision tracking of both the new hardware and software should also be updated and maintained in a master log. Where applicable all PC/Lap Top computers which are needed to interface with the new equipment should have the interface software installed or updated.

### Summary

With aging equipment and changing technology changing the need for upgrades, rebuilds and retrofits will continue. Proper planning, and the reviewing of the equipment being retrofitted from start to finish, will insure the replacement system will out perform in maintainability and reliability to the previous system being retrofitted.

### References

49 CFR 229.135 (b) (2)
49 CFR 229.135 (b) (5)
49 CFR 238.103 (a) (2)

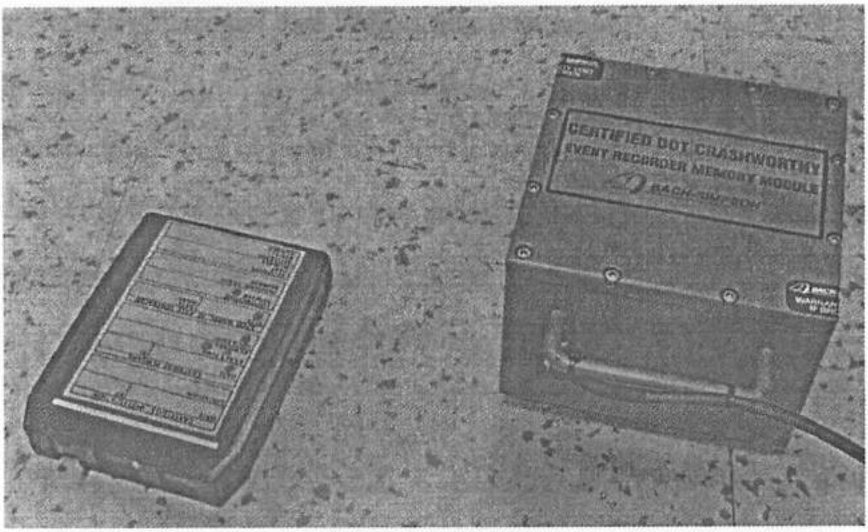


**Figure 1: Magnetic Tape & Certified Hardened Memory Module (CHMM)**

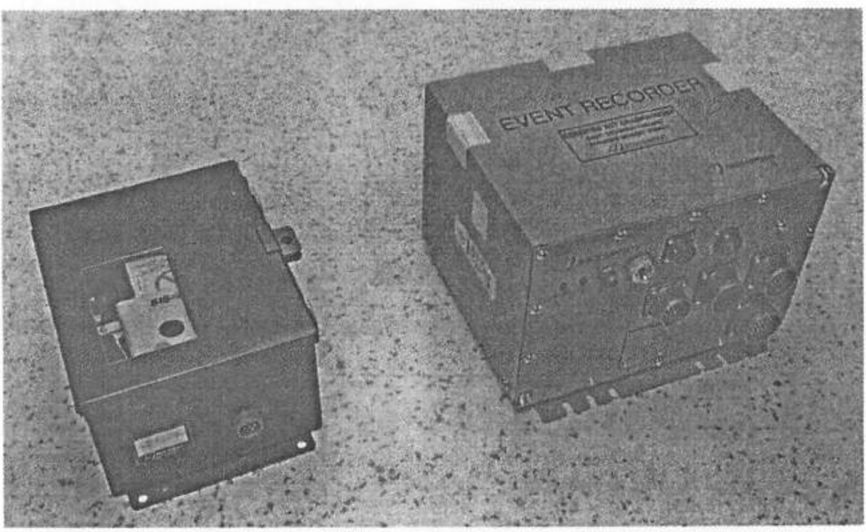


**Figure 2: Magnetic Tape Event Recorder/Replacement Event Recorder with CHMM**

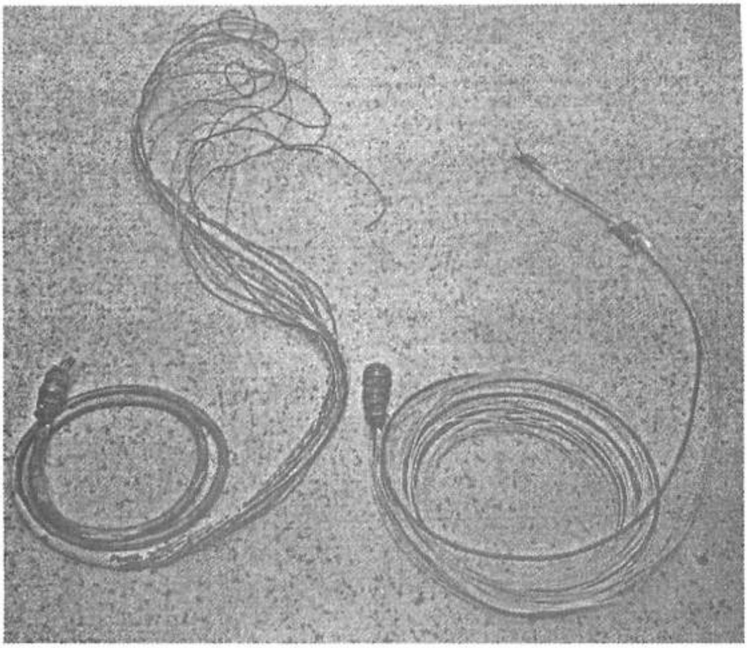

**Figure 3: Typical PVC Cable/Replacement Exane Cable**

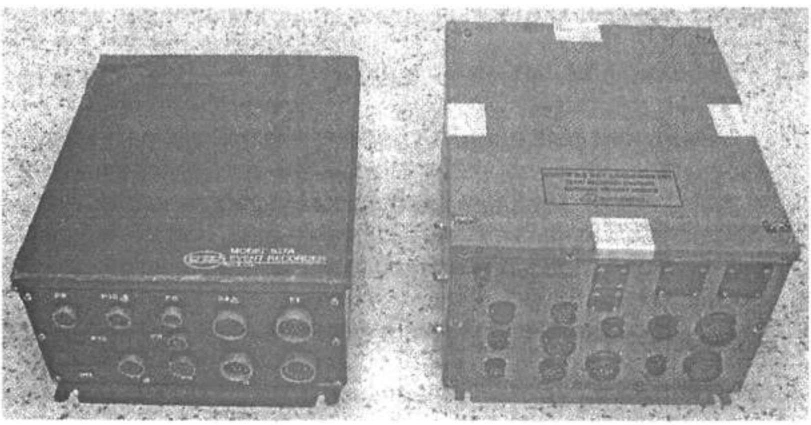

**Figure 4: Existing Event Recorder/New Event Recorder for Rebuild Application**

## II. LOCOMOTIVE MAINTENANCE, CONVENTIONAL VS GENSET

*Prepared by*
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*Account Executive*
*Railpower Hybrid Technologies Corp.*

### Introduction

New technology...

Genset locomotive technology is quickly becoming "the" answer for railroads. Genset technology allows them to meet the latest emissions requirements, maintenance reductions and fuel economy improvements on their aging, diesel electric, four and six axle switcher fleets.

For maintenance operations these new technology locomotives present some new learning opportunities. This paper will compare and contrast some of the maintenance points of conventional diesel electric locomotives and new "Genset" locomotives.

First some definitions as will be used in this paper:

**Engine** - This word has several meanings. For this paper we will define it as the component of a locomotive that is the prime mover, the diesel engine.

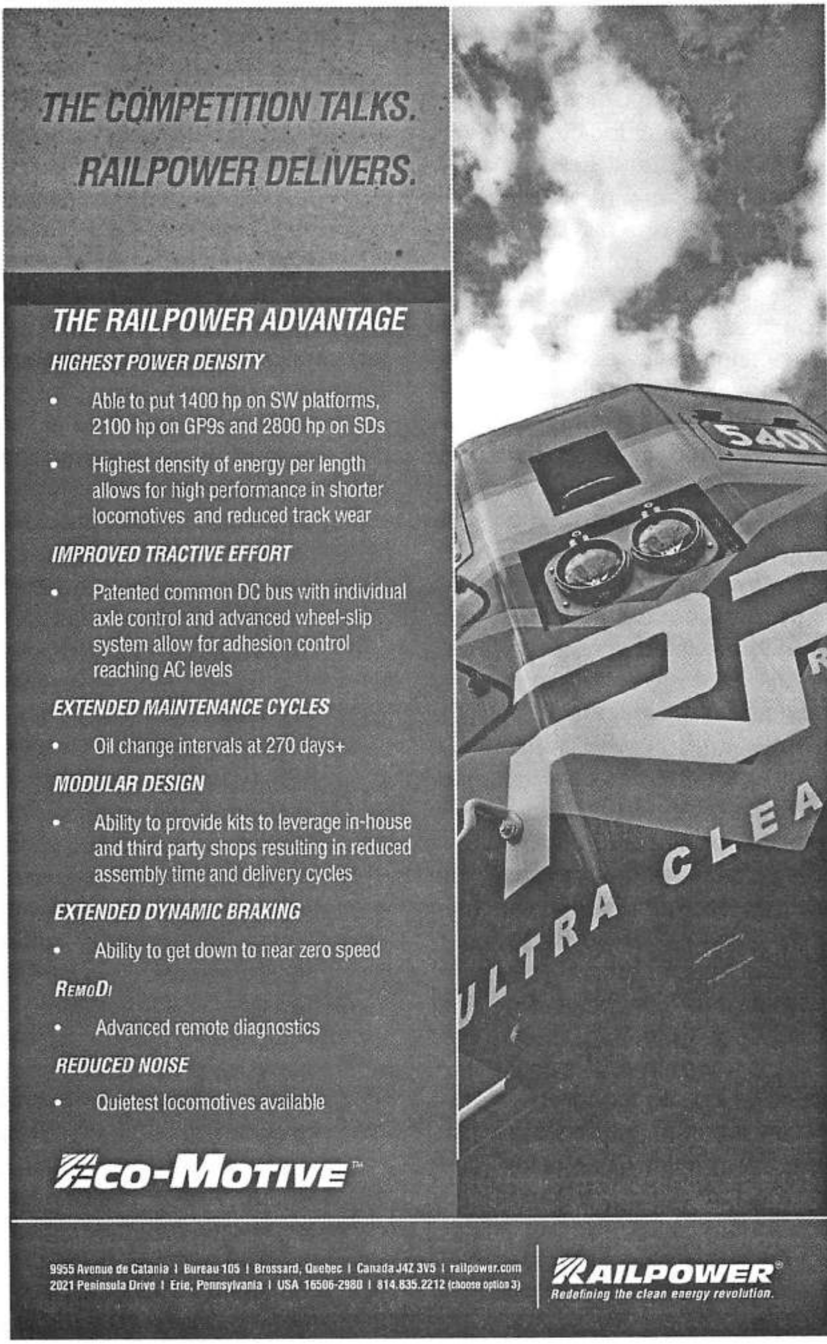
In conventional locomotives, this is typically a single 12 to 16 cylinder, low speed (900 rpm), two stroke (EMD typical) or four stroke (GE typical) diesel engine capable of producing 1,000 to 4,000 gross horsepower. When these engines were originally designed and built (40 to 50 years ago), there were no emissions regulations, so they are called "unregulated." Some may have been overhauled/upgraded over the years to meet Tier 0 emissions compliance.

In genset locomotives the engine is again a diesel engine, however it is now smaller (700 HP typically), higher speed (1,900 rpm typical), four stroke, Tier 3 emissions compliant and will typically be used in some multiple combination on a single locomotive to develop the required horsepower.

**Generator** - The generators on early conventional diesel electric locomotives were large DC generators sized appropriately for the rated traction HP of the diesel engine. In addition, many conventional locomotives utilized an additional auxiliary generator to drive auxiliary loads such as control electronics and smaller electric motors for fans and the air compressor. Later generators were switched to AC alternator that were more efficient and required less maintenance. These alternators could also be fitted with internal auxiliary windings for the auxiliary function.

The genset locomotive typically utilizes the AC alternator also. This machine is sized to the smaller diesel engine and, because it has no brushes or slip rings, requires little maintenance.

**Genset** - A genset, although a common term to the mobile or stationary power generation was not common to the rail industry until the commercial introduction of the first hybrid yard switcher the "Green Goat®" by Railpower in 2000. A genset is the combination of an engine and generator "set" on a sin-


THE COMPETITION TALKS.
RAILPOWER DELIVERS.
THE RAILPOWER ADVANTAGE
HIGHEST POWER DENSITY
• Able to put 1400 hp on SW platforms, 2100 hp on GP9s and 2800 hp on SDs
• Highest density of energy per length allows for high performance in shorter locomotives and reduced track wear
IMPROVED TRACTIVE EFFORT
• Patented common DC bus with individual axle control and advanced wheel-slip system allow for adhesion control reaching AC levels
EXTENDED MAINTENANCE CYCLES
• Oil change intervals at 270 days+
MODULAR DESIGN
• Ability to provide kits to leverage in-house and third party shops resulting in reduced assembly time and delivery cycles
EXTENDED DYNAMIC BRAKING
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gle skid, thus a "genset."

Conventional diesel electric locomotives have the engine/generator, cooling system, air filter system and oil filter system all mounted to the deck in separate locations due to their large sizes and need for maintenance access. On older models some of these systems, such as radiator fans and air compressors, were mechanically linked to the engine through drive shafts. This created many maintenance points.

The relatively small size of the genset in a genset locomotive allows all of the components related to that genset to be conveniently mounted on a single skid. This would typically include the diesel engine, the alternator, the oil filter system, the air filter system and the cooling system. The skid mounted genset is typically modular in design and can be lifted off and onto the locomotive with the use of a small mobile crane should major repairs be necessary. Another genset module can be immediately replaced and the locomotive can be back in service in one shift. The defective genset module can then be repaired or overhauled off-line.

**Genset Locomotive** - A genset locomotive is any locomotive that utilizes at least one genset module as the prime mover. A genset locomotive is typically a conversion of an existing locomotive. The main platform and running gear below deck are retained, while the above deck components such as the engine, generator, control system and air compressor are replaced with new modules.

Examples of genset locomotive configurations are:

1) A hybrid yard switcher such as the Green Goat® as mentioned above. This is a battery dominant hybrid that has a single genset and a large storage battery.
2) An engine dominant hybrid switcher such as the Railpower RP20BH which utilizes two 700 HP gensets and a smaller storage battery.
3) Straight diesel genset locomotives utilize one to four genset modules based on the size and HP requirements of the locomotive.
   - Older EMD "SW" type platforms can be converted to utilize one or two gensets to provide up to 1,400 HP. These would be Railpower Model RP7BD or RP14BD genset locomotives.
   - Four axle EMD "GP" and GE "B" type platforms can be converted with up to three genset modules to provide up to 2,000 HP. These would be Railpower Model RP14BD to RP20BD genset locomotives.
   - Six axle EMD "SD" and GE "C" type platforms can be converted with up to four genset modules to provide up to 2,700 HP. These would be Railpower Model RP20CD to RP27CD genset locomotives.

### Maintenance Differences

*Disclaimer...This paper is intended as an overview of some of the mainte-*

*nance differences between conventional locomotives and multi-genset and is not intended to replace any maintenance manual defined practices. Please, always follow the instructions in the maintenance manual for your specific model.*

**Engine** - Conventional locomotive diesel engines employ a host of mechanical items that require maintenance. Some items such as power assemblies, governors and mechanical fuel injectors can be adjusted, rebuilt or replaced on board the locomotive. If kept on a maintenance schedule, the engines should be rebuilt approximately every seven years.

Genset locomotives utilize new four stroke engines and electronic fuel injection. Adjustments related to mechanical governors and mechanical fuel injectors are eliminated. The overhaul cycle for these engines is at about 29,000 hours of engine time. With multiple gensets and automatic engine shutdown functionality inherent in the design, this 29,000 hours equates to about ten years between overhauls with a typical road switcher duty cycle.

**Engine Oil** - Both conventional and genset engines employ dipsticks to check the level and sample ports to check for quality, but there are some major differences that need to be noted here.

- With conventional engines, the oil level is checked while the engine is running. With the new genset the oil level is checked when the engine is shut down. This is a critical difference that maintenance personnel need to be made aware of. Overfilling the oil reservoir can cause engine damage.
- Conventional two stroke engines can consume as much as a gallon per cylinder per day and need to be sweetened regularly during fueling. The new four stroke genset engine will consume only about a quart a day per locomotive in typical road switcher service.
- If sweetening does not correct oil quality conventional engines need to have the oil changed on a 92 day basis. This is an additional approximately 400 gallons of oil. The genset engine oil change cycle is 184 days for heavy usage and can be as much as 457 days for lighter duty cycles. Additionally an engine oil change requires only 37 gallons of oil per genset.
- The last difference is that the genset engine requires a synthetic oil, so standard locomotive engine oil will not work in these engines.

**Engine Oil Filters** - Conventional locomotive engines typically utilize an externally mounted oil filter that hold about 27 paper filter elements inside a large filter housing. The new genset oil filters are individual canister filters located in a service location and over a drip pan on the genset skid. There are two primary filter canisters and four bypass filters per genset.

**Engine Oil Drains** - Conventional locomotive engines have large oil drain ports to accommodate the large volumes of oil that need to be pumped out every 92 days. The genset engines have the same type of drain lines, but they are much smaller and there are typically two per genset (engine sump and auxiliary tank drains). Further, they may have an additional shut off cock in line to prevent accidental drainage.

**Fuel Filter** - Conventional locomotives typically employ canister type fuel filters. This is the same for the genset locomotive however it has two levels of canister filters, primary and secondary, located on the inlets to each individual engine. In addition the genset locomotives employ a main fuel filter that is located on the main fuel loop that supplies all the gensets on the locomotive. This filter has paper elements contained in a larger tank mounted between the genset skids. The filter module is also equipped with a drip pan piped to the ecology tank to prevent unwanted spills.

**Genset Cooling System** - A major maintenance difference with genset locomotives is the fact that the genset utilizes a closed-loop, antifreeze based coolant rather than the water type systems used in conventional locomotives. This antifreeze based system allows the genset engines to be shutdown even in freezing weather. There is no conventional dump valve or water filling "carrot." The system uses 50/50 glycol based antifreeze solution and is filled using an integrated fill pump mounted on the genset skid. Drain valves and drain piping are routed to the side of the locomotive for easy draining, when necessary.

**Genset Air Filter** - Conventional locomotives utilize spin, baggie or "furnace" type filters for the engine inlet air. The genset locomotive utilizes a large dual stage paper cartridge filter that is genset mounted. This filter uses quick snap closures and is easily accessible from the walkway.

**Genset Start Station** - Conventional locomotives need to be started from an engine start station. However, for normal operation the genset never needs to be started manually. The locomotive control system will complete all the start-up and shut downs necessary for proper and efficient operation. The genset module is equipped with an engine start station that is to be used only when locomotive control system is not operational and troubleshooting or diagnostics is required on an individual genset. The particular genset in question is switched from "Locomotive Control" to "Local Operation" mode and is then started locally. A diagnostic display provides details on the engine performance with displays such as RPM, voltages, various pressures and other diagnostics for that genset. The display can be accessed in either local or locomotive control modes.

**Alternator** - The conventional generator is typically a DC generator that requires regular maintenance on the brushes. The genset utilizes an AC alternator that has no brushes nor slip rings that need to be maintained. Periodic greasing may be required.

**Air Compressor** - Conventional locomotives utilize either shaft driven or electric motor driven piston compressors. The genset locomotive utilizes a rotary screw type compressor that is skid mounted with its own AC motor, compressor, cooling radiator, air filter, oil filter, oil separator filter and compressor oil heater. The intake filter is a cartridge filter located on the top of the intake. The oil and oil separator filters are canister type filters and are located on the side of the compressor skid for easy access. The compressor oil level is easily viewed though a site gauge on the side of the compressor.

**Control System** - Conventional locomotives utilize a number of low tech electronic controls that typically require little to no maintenance other than replacing fuses and/or failed devices. However, these systems offer limited feedback and control capabilities. The genset locomotive utilizes a state of the art, hardened microcompressor that monitors voltages, currents, temperatures and pressures. These added monitoring points provide a wealth of data for optimizing control of the engines and traction system and also provide data for monitoring the locomotive performance. The data can even be transmitted for remote monitoring and diagnostic needs. Railpower provides RemoDi (pronounced like "remedy"), a remote monitoring function, on its locomotives. This allows engineers and technicians to remotely monitor the health of the locomotive and provide maintenance suggestions sometimes prior to an actual failure.

Some of the power switching devices in the genset locomotives are the same as in a conventional locomotive. The power contactors and reversers are similar to those found in conventional locomotives. Where the genset locomotive is different is that it utilizes a common DC buss architecture that allows multiple power sources on the common buss. The genset architecture utilizes chopper controls to individually regulate the current flowing to each traction motor. Combined with an advanced wheel slip control algorithm, the genset locomotive is able to obtain adhesion levels nearing that of AC traction motors. From a maintenance standpoint, this also allows individual traction motors to be cut out should a failure occur on one traction motor. In theory, a multi-genset locomotive could have both a failed engine and a failed traction motor and it could still complete its mission, though with reduced capability.

Another aspect of the common DC buss architecture is that all auxiliary loads are run off of the common DC buss through the use of inverters. This eliminates the need and maintenance of an auxiliary generator.

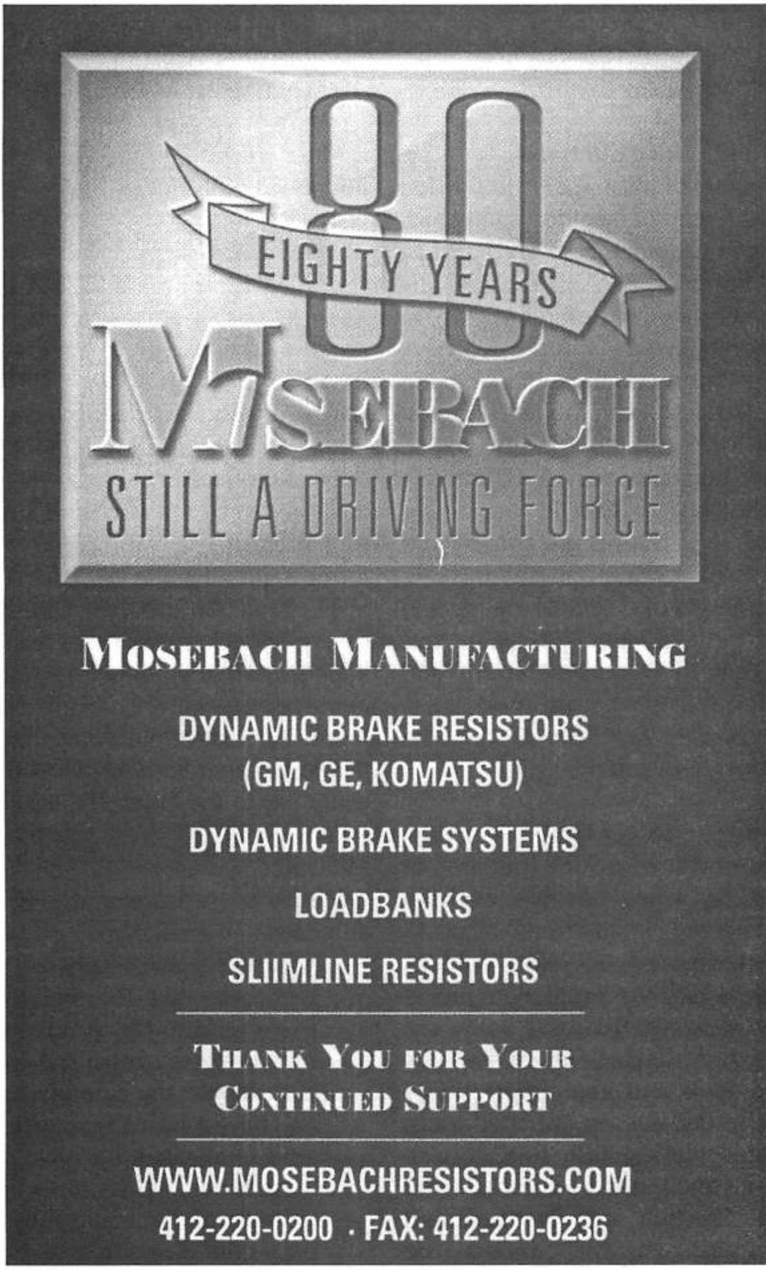
Both the choppers and the inverters are water cooled. This is a new maintenance item on the genset locomotive, but the benefits are significantly increased pulling capacity especially at low speeds. The system is filled with a premixed ethylene glycol solution for optimum system performance.

The genset locomotive employs a battery knife switch that is similar to the conventional locomotive knife switch. The difference is that operators should not open this knife switch when they leave the locomotive for short periods of time. The control system design includes an automatic engine stop and start function that controls all of the gensets as needed. For servicing the locomotive the knife switch can be opened though. An additional safety feature built into the genset locomotive is a separate Lock-Out Tag-Out (LOTO) feature located directly on each genset module. This allows one genset to be locked out of operation separately from the others.

**Lighting** - The genset design incorporates LED lighting in many of the traditional incandescent lighting locations with the exception of the head and ditch lights. The LED bulbs feature a long life, estimated at ten years before they start to fade, thus eliminating the need for routine light bulb change-outs.

## Summary

Although there are many new items on genset locomotives, the basics are not that different from conventional, single engine locomotives. With a handy maintenance/service manual to reference and a little reading, any technician can be up to speed on most or all mechanical items. However, the new electronic control system may require that the technician attend some specific training on servicing this system.


80
EIGHTY YEARS
MOSEBACH
STILL A DRIVING FORCE
MOSEBACH MANUFACTURING
DYNAMIC BRAKE RESISTORS
(GM, GE, KOMATSU)
DYNAMIC BRAKE SYSTEMS
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## III. USING TEST INSTRUMENTATION SAFELY

*Prepared by*
*Keith Mellin,*
*Technical Sales Engineer*
*Peaker Services*

### Introduction

The goal of this paper is to provide an awareness of electrical safety hazards and to minimize these hazards. It is not intended to replace any existing safety procedures in place at your organization; it is an overview. Many improvements have been made in test instruments, some of which will be covered in this paper. Higher horsepower and AC traction locomotives, as well as the newer Genset locomotives are coming into our shops. These all incorporate higher levels of electrical energy and higher voltage supply systems. This can lead to increased hazard and risk for those who maintain these systems. Safe practices need to be foremost in our minds.

### Safety First

Safe practices include (but are not limited to): when possible, work on de-energized circuits. Verify all possible sources of powered circuits. Follow approved protection procedures. If possible, visually verify disconnected devices. Use well-maintained tools and appropriate safety gear, (safety glasses, insulated tools, insulated gloves, flash suits, insulating mats etc.). It is best not to work alone. Practice safe measurement techniques. Always connect the grounded lead first, hot second. Use the three point test method - measuring both phase to phase and phase to ground if applicable. The three point test method is:

- Test a known circuit.
- Measure target circuit.
- Then retest the known circuit.

One hazard that has been addressed with newer meters is Arc Flash.

### What is an arc flash?

An arc flash is a phase to phase, or phase to ground short circuit. It can be through the air. Ionized air (plasma) is a good conductor generally lasting a very short duration, less than a second. Arc fault current is initially limited by the resistance (ohms) in the upstream wiring and transformers, less than an ohm on a 480 VAC circuit. An arc flash can cause severe burns in many cases resulting in personal injury, sometimes fatal. In almost all cases it will damage equipment. An industry estimate is that five to ten arch flash incidents occur every day in the United States.

MISUSE:

Misuse of measurement tools can also cause an arc flash:

- Measuring across phases with the meter set to read as an inline amp meter. Amps mode on a meter is almost a short circuit. While the voltage terminals have a high impedance, the amp terminals have a very low impedance. This is why a meter's amp circuit must be protected with fuses. Using meters that come with high energy fuses can further protect against damage.

- Measuring continuity on a live circuit with a meter that cannot withstand full voltage. Some older meters cannot handle the full AC or DC voltage on the ohms setting. These measurements should be made only on circuits that are not energized. Using a meter that is equipped with "overload protection" functions, are self protected to the meters rated voltage.
- Shock from accidental contact with live components. Use test leads that are double insulated, recessed and shrouded, with finger guards as an effective precaution. See Figure 1. Verify that the test leads are rated higher than the voltage being tested. Always replace these leads when damaged. When it comes to your personal protection don't let the test leads be the weak link.
- The wrong fuse could damage the meter and its user. Only use the fuse specified by the manufacturer of the test equipment.
- Using a meter or meter leads above their rated voltage. This will also damage the meter and its user.

DESIRABLE METER SAFETY FEATURES:

Verify that your meter has these features:

- Fused current inputs (high energy fuses).
- Overload protection on the ohms function.
- Test leads that have shrouded connectors and finger guards.
- Recessed input jacks.
- Test equipment meets the latest safety standards (refer to your local/company safety standards) and are independently certified by the manufacturer or a local certification company.

METER SAFETY OPERATION:

To perform accurately and safely, test tools must be regularly inspected and maintained.

- Does the case have cracks or is it oily?
- Are the input jacks broken or damaged?
- Test instruments and all associated test leads, cables, power cords, probes and connectors should be inspected for external defects and damage before use.
- Visual inspection alone may not detect all possible problems. One procedure for testing leads is to use the meter's ohm function. Short the leads and move the wire around the input connectors and lead grips. If the meter reads <0.3 ohms leads should be OK, if >0.5 ohms the leads may need to be replaced. These specifications are based on using a calibrated meter. Some technicians are now using a fused lead. You may only need to change a fuse.
- Hang or rest the meter if possible. Try to avoid holding it in your hands to minimize personal exposure to the effects of transients or misuse.
- Use the old electrician's trick of keeping one hand in your pocket. This lessens the chance of a

closed circuit across your chest and through your heart. But common sense must rule. Conditions at the test location may make it impractical to use this technique.

- After taking a measurement, remove the leads from the meter and then store in a protective case. This provides added protection for the leads. By not removing the leads, the technician may take a measurement with the leads in the wrong jacks. Also by installing the leads when taking the next measurement, the technician will know that he is putting the leads into the correct jacks for the measurement he is taking.
- Putting the meter in its protective case backwards will protect the display when carrying it in your tool box or bag.
  See Figure 2

## Conclusion

The more you follow safe practices the better your chances are for avoiding test instrument damage or injury. Knowledge is the key-know what you are working with and read the instructions provided with your test equipment.

## Acknowledgements

The Fluke Corporation "Electrical Measurement Safety" Electrical Safety Education Program.

Ideal Industries "Meter Safety" Safety presentation.

## References

Many instrumentation companies have safety presentations available for your companies' use in promoting safety awareness.

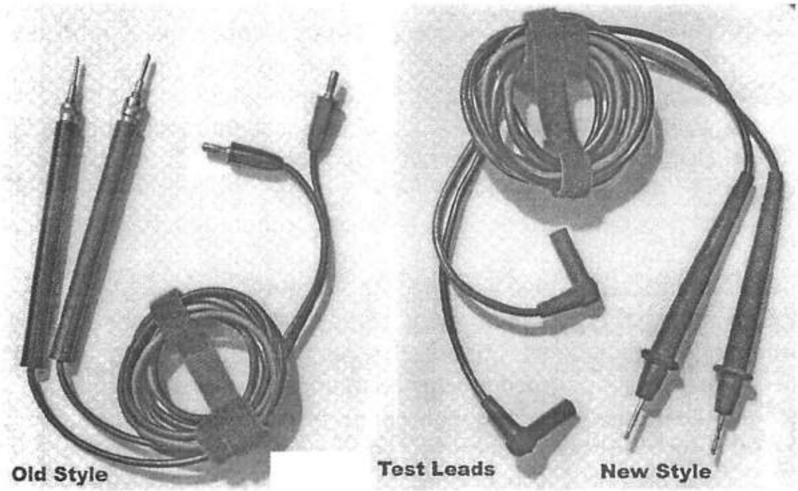


Figure 1

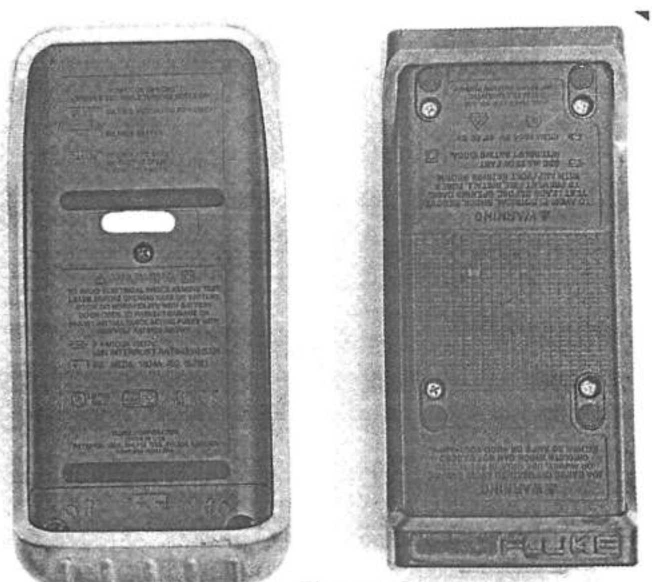

Figure 2

## ELECTRIC MOTOR PREVENTATIVE MAINTENANCE

*Prepared by*
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*Division of Morgan AM&T*

Successful long term operation of DC motors and generators, like any piece of industrial equipment, need maintenance. Scheduled periodic inspections to replace brushes also need a visual inspection of the commutator, brush holder and brush springs along with the brushes being replaced. It is really a team effort of all these parts for the motor to deliver it's expected performance. It takes proper mechanical adjustment of these parts to ensure good electrical operation. Proper and uniform brush holder settings are very important. Electrical settings like neutral and interpole strength also need to be correct for good operation of DC motors & generators. Before we get too far into discussions of settings or adjustments, let's understand just what brushes do, what is commutation, what are acceptable commutator conditions and then what is proper maintenance for brushes and commutators, Most times if we understand how something works, we can maintain it better.

Brushes carry load current from the stationary parts of the machine to the rotating section of the machine. Brushes assist in the commutation process for DC motors and generators, and they act as a window to the motor since analyzing brush and commutator conditions can often determine other motor, control, mechanical or environmental problems.

**Commutation** is not the amount of sparking under the brush. Brush sparking may be caused from "poor commutation" but it may also have many other mechanical causes. Commutation is simply the reversal of current in the armature coils as they pass between the main field poles. Another way to understand commutation is to visualize the current in each armature coil reversing every time it approaches and goes past a brush. In a 4 pole machine there are four commutation processes occurring at the same time. This current must stop, then go in the opposite direction. A typical 4 pole motor running at 2000 RPM has only .0004 seconds to complete this commutation cycle. See Figure 1. This is no small accomplishment, especially to reverse full load or overload currents without sparking.

Sparking is current going through air and if intense enough will cause brushes and commutators to wear much faster. During this commutation process, when the current flow is stopped, the collapsing magnetic field induces a high voltage across those armature coils that are short circuited by the brush. This causes a circulating current to flow between the adjacent commutator bars that are ultimately connected to the armature coils. If this circulating current is not minimized, sparking will result. The resistivity of the carbon and the voltage contact drop on the commutator film are factors in

reducing the circulating current. There is always some uncompensated reactance voltage $V_R$ in the armature coils. Figure 2 shows how higher resistivity of the brush $R_B$, being in the denominator, will reduce the circulating current $i_C$. The brush resistance cannot be too high though since load current also passes through the brush which may cause brush temperatures to exceed their limits. Figure 4 shows another way to limit circulating current in the brush face without raising the resistivity of the carbon, which is to use a multi-wafer brush construction. The added resistance of the extra wafers $R_W$, further reduces the circulating current. The multiple wafer brush will also ride irregular commutator surfaces better. The number of brush wafers in a brush assembly is limited by the ability to attach a shunt wire to a thin wafer that will survive traction service. This is approximately .200" thick. Two wafer brushes add sufficient resistance for most applications, but three are also common.

Figure 4 should also show the importance of having the brush stay in intimate contact with each commutator segment that passes under it so current can be conducted without arcing. The commutator needs to be reasonably round for this to happen. In general, once the comm. exceeds .004" TIR, it starts to become an impossible task. Brush construction has many options too, but brushes with rubber hard tops or pads seem to dampen brush movement in the case of a rough commutator surface, better than a clip construction. Brush holder style can be either RADIAL or REACTION. Radial brushes (Fig. 5 & 6) are perpendicular to the commutator. Radial brush can rock back and forth as the direction of rotating changes and the brush moves within the normal .002 to .010" clearance between the brush and brush holder. Reaction brushes (Fig. 7 & 8) are at an angle to the comm. Reaction style brush holders, when designed properly, have the advantage of better brush stability in reversing applications. The long side of the brush always stays in contact with the brush holder no matter what direction the commutator is turning.

Long brush life requires a good **commutator film**. Rapid comm-utator wear is certainly undesirable and proper film formation is also necessary to protect the copper commutator bars. One must keep in mind that the film on the commutator forms through an electro-chemical reaction.(Fig 9) The **electro** portion means there must be current flow. The film will not form if the machine is running at no load, light load or a load that is below the range where film can begin and continue to form. The **chemical** portion of this process is a function of the ***copper*** comm. bars, the ***carbon*** brush, the treatments in the brush and the environment it operates in. The environment includes things like; humidity, temperature, friction between the brush and comm., amount of force pushing the brush toward the comm., oil or chemical vapor considerations and/or abrasive dirt in the cooling air. This film takes a few hours to a few days to fully develop. It also requires the commutator to be warm or even hot with a maximum of approx. 125º C. Special treatments in the brush can help the commutator film form in the absence of humidity or in lower temperature environments. The ***chemical*** portion of this film forming is a significant part of the whole process. Temperature, humidity and treatments Impreg-nated into the carbon brush play a big role in total brush performance which includes brush life. Chemical or oil vapors usually affect the copper oxide portion of the commutator film in a negative manner. Chemical contaminants can sometimes create a voltage contact drop between brush and commutator that is too high, it may even develop a non-conductive film which will cause excessive sparking. The concentration of some chemical vapors may only be a few PPM to cause problems with obtaining a visually desirable commutator film. Silicone vapors from sealants or greases typically produce a very light film along with extremely fast brush wear. Some oils and greases have "copper corrosion inhibitors" or "anti-oxidizing additives" which interfere with the normal film formation on commutators.

The overall quality of the of the cooling air that is forced thru the motor needs to be considered. A blower rated at 10,000 CFM pushes over 14 million cubic feet of air thru the ventilating system each day. It is because of this large volume of air that even small concentrations of contaminants can negatively affect film formation and brush life. Blowers in unfiltered dusty environments need to be considered "mini-sandblasters" when you take into account the large air volume and the high velocity of this cooling air. DC motors and generators generally perform best if they are in the same kind of environment that a person could work in, 24 hrs per day. Typical film on an EMD commutator is shown in Fig.10 and typical film on a GE commutator with spiral grooves is shown in Fig. 11.

Spiral grooves or helical grooves can be machined in commutators or slip rings. These grooves some-times appear straight but there is a definite lead to them. They help prevent selectivity of the brush path by forcing the current to be conducted in different places across the brush as the groove wipes or travels across the face of the brush. These grooves also help cool the brush. Figure 12 shows a bronze EMD slip ring assembly. Figure 13 shows a steel GE slip ring. Notice that both have spiral grooves machined in them.

### Commutator Conditions

A properly designed and adjusted motor operating within its nameplate rating in a good environment will have good commutation and a good looking commutator film as depicted in Fig. 14. This is very good looking film and could be a little lighter or darker but what is exceptional is its uniformity. Some comm films that are not quite as pleasing are streaking, mottled film or slot bar pattern, however, they are still considered normal. Figure 15 shows a commutator with a very **streaky** film which is not damaging as long as the streaks are only in the film and are not into the copper. This can be proved by taking a pencil eraser or large Pink Pearl eraser and actually erasing the film on the comm. If the copper underneath that film is also in good condition, then your good operation will continue.

Figure 16 shows a **mottled** film which is also only in the film – not in the copper. This may be the more common film as small contaminants get on the comm. and get smeared around as it rotates. The **Slot Bar** Pattern in Figure 17 occurs naturally in some motors because of the number of armature coils per slot in the armature core. Again no reason for concern as long as the pattern is limited to the commutator film.

The following commutator conditions are destructive and measures should be taken to eliminate the cause. The **treading** condition shown in Figure 18 is somewhat like streaking except that concentric grooves are etched or machined into the copper. The most common cause is long term operation at very light loads. Brush current density lower than 35 amps per square inch produces threading. Normal current density is in the 70 to 100 APSI range. **Bar Burning** ( Fig 19 ) is caused by sparking under or more typically at the edge of the brush. It can have many causes like an improper brush ( 2 wafer vs 3 wafer ), the neutral or interpole adjustment could cause the motor to be out of electrical adjustment or there could be locomotive control problems. You can see the edges of the copper bars are eroded away and sparking can be evident on the brush edge.

**Copper Drag** also has sparking occurring that destroys the comm film and melts copper and deposits it into the brush face, which then drags more into the slots between the commutator bars, see figure 20. An oily environment or grease on the comm. can also produce this. This is sometimes combined with small silver or blue colored spots on the comm. Copper drag this bad needs immediate attention as it normally leads to a flashover. Figure 21 depicts **Stall Burns** which are caused by keeping the locomotive under power but not moving. Bars under the brushes get hot because of localized current flow. This intense heat can weaken the bars and cause them to lift from centrifugal force. Sometimes even resurfacing is not the long term answer as the weakened bar will raise again. **Grooving** is sometimes called ridging and is shown in Figure 22. It is simply wear on the commutator in the brush paths and is expected on high mileage motors. Rapid grooving is caused by airborne abrasive material, poor air filtration, an abrasive brush material or very light brush pressure. **High TIR** ( Total Indicator Runout ) indicates the commutator is no longer round. A typical new motor spec calls for .001" or no more than .0015" TIR. A comm with more than .003" TIR needs to be resurfaced since high brush wear will result from the increased vibration and brush distress. High TIR can be noticed on the commutator by the wavy appear-ance of the brush path, see Figure 23. High TIR on the brushes ( Figure 24 ) shows as excessive side polish, frayed shunts, pads with grooves from the spring fingers, chipping or chunks of brush missing.

### Maintenance Practices

Correct maintenance practices sometimes need a keen eye to ensure even the simplest jobs are completed properly. In the case of EMD style brush holders, the spring fingers need to be pulled forward then released so the flat part of the finger seats on the peak of the pad and not on the side of the pad. Figures 25 & 26 show detail of the correct placement of EMD style spring fingers. Figures 27 & 28 show the difference with the Incorrect finger placement.

Spring force and brush pressure need to be correct to ensure maximum brush and commutator life. Consult the Motor maintenance manuals for the correct spring force. There are two components of brush wear: electrical and mechanical. Electrical wear is dominant with light brush pressure, whereas mechanical wear is dominant with very high brush pressure. Figure 29 which also show the best range of brush pressure for auxiliary motors. Since traction motors are axle mounted they are subjected to very high G forces and need much more brush pressure to keep the brush in intimate contact the commutator surface, see Figure 30 for the best range of pressure. It's better to be a little higher than on the low side. Figure 31 shows the proper way to calculate brush pressure.

It is very important to properly set the height of reaction style brush holders above the commutator to ensure equal brush spacing around the commutator. Since the brush is at an angle to the commutator, a higher than specified brush holder setting will move the footprint of the brush further out or away from the commutating zone. This is sure to work against sparkless commutation as it will also change the electrical neutral setting. This gap between brush holder and commutator or slip ring is usually between .060" and .187" for most traction motors, generators and alternators. See Figure 32. Readjusting this gap should only be necessary after replacing brush holders or turning or stoning a substantial amount off the commutator or slip ring diameter. Too large of a brush holder gap setting will cause an unstable brush and can promote a friction chatter condition in both radial and reaction style brush holders. See OEM manuals for the proper gap.

### Important Visual Checks

Examine commutator wear or film and bring questionable conditions to the proper people

Ensure the correct brush is used in the application, probably an OEM recommendation

Always make sure brush shunt connections are secure to the brush holder and properly routed so brush movement is not restricted or shunts do not rub on spring fingers.

Be sure spring fingers are properly seated on the brush pad top.

Be alert for any unusual conditions, like flashover damage

# Commutation

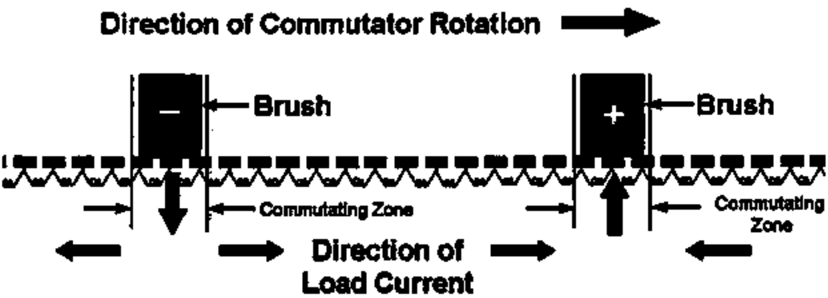
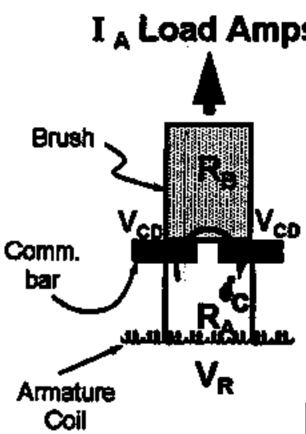



Figure 1

# Circulating Currents within Brush




$$V_R = i_C \times R_A + V_{CD} + i_C \times R_B + V_{CD}$$

$$i_C = \frac{V_R - 2V_{CD}}{R_A + R_B}$$

$i_C$ Becomes less as $R_B$ increases

- Use higher resistivity brush grade for difficult to commutate machines

Figure 2

## Equation Terms

$I_A$ = Load current or Amps in the armature

$i_C$ = Circulating current in the brush face

$V_R$ = Reactance Volts

$R_A$ = Resistance of the Armature coils

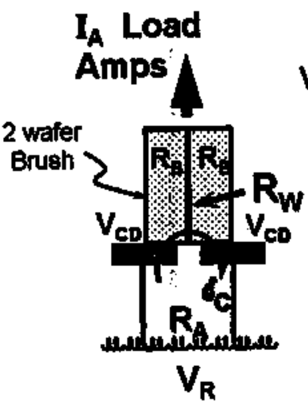
$R_B$ = Resistance of the Brush

$R_W$ = Resistance of the Brush Wafers

$V_{CD}$ = Contact drop volts

Figure 3

## Reducing Circulating Currents




$$V_R = i_C \times R_A + V_{CD} + i_C \times R_B + V_{CD}$$

$$i_C = \frac{V_R - 2\,V_{CD}}{R_A + R_B + R_W}$$

$i_C$ Becomes less as $R_B$ increases

- Use a 2 or 3 wafer brush construction for difficult to commutate machines.

Figure 4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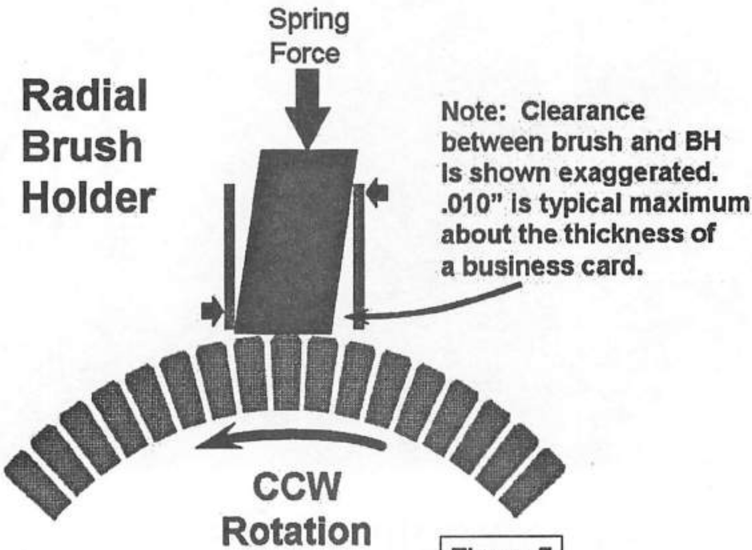



Figure 5

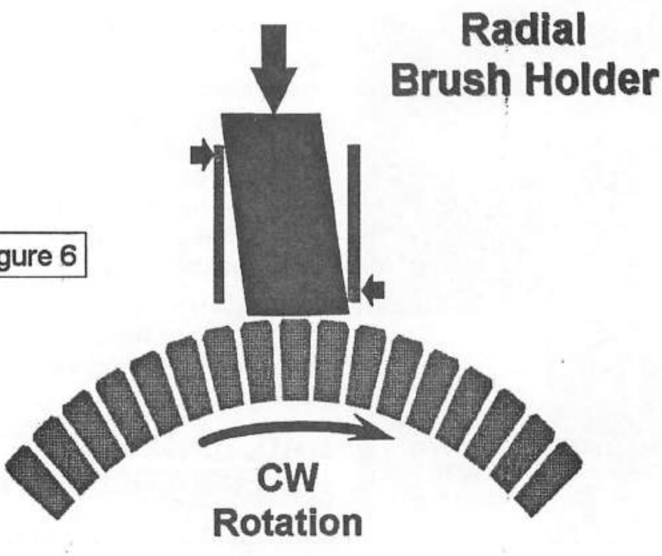
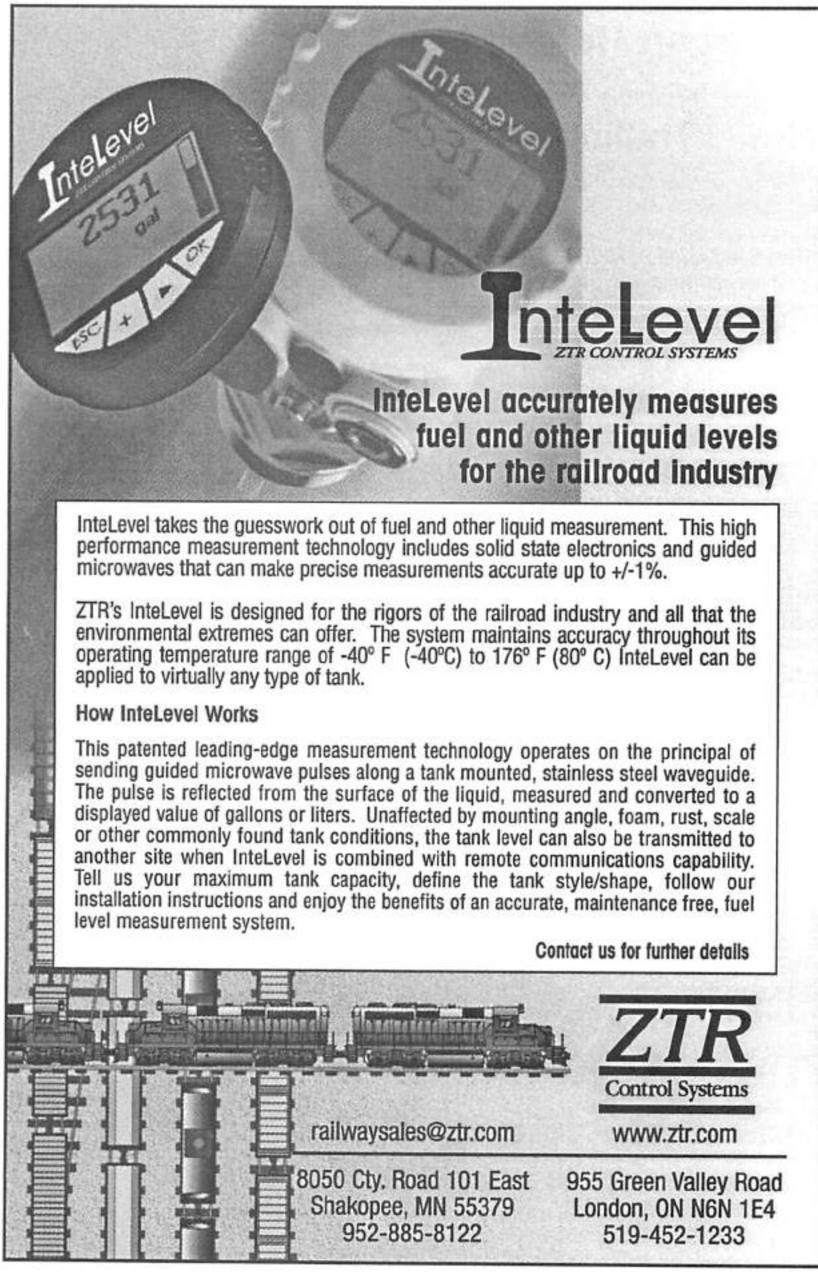



Figure 6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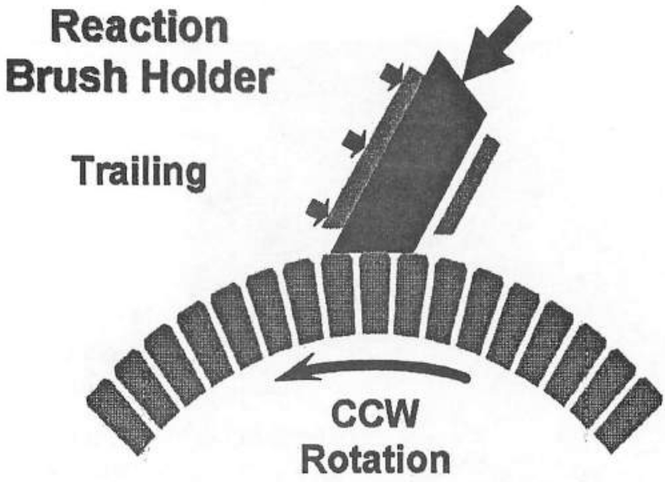


Figure 7

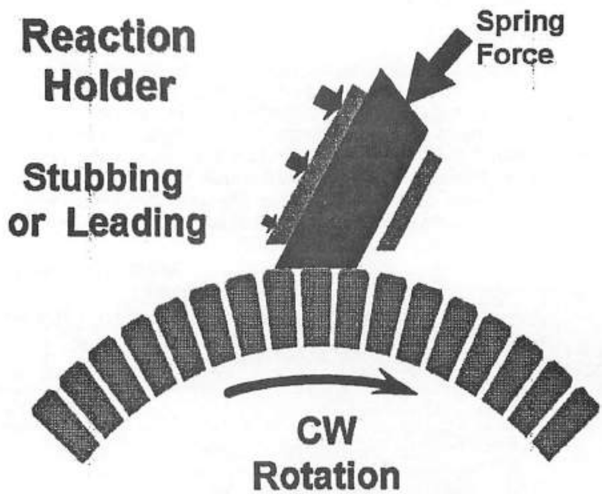


Figure 8


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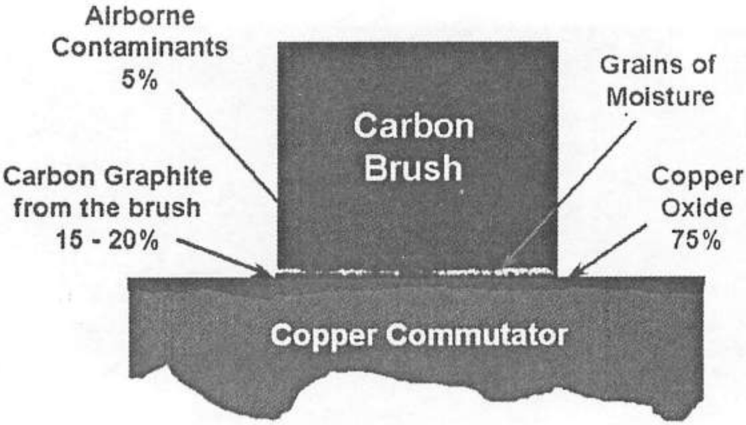


## Commutator Film Makeup

( Electro - Chemical Reaction )

Figure 9

Typical film on an EMD commutator

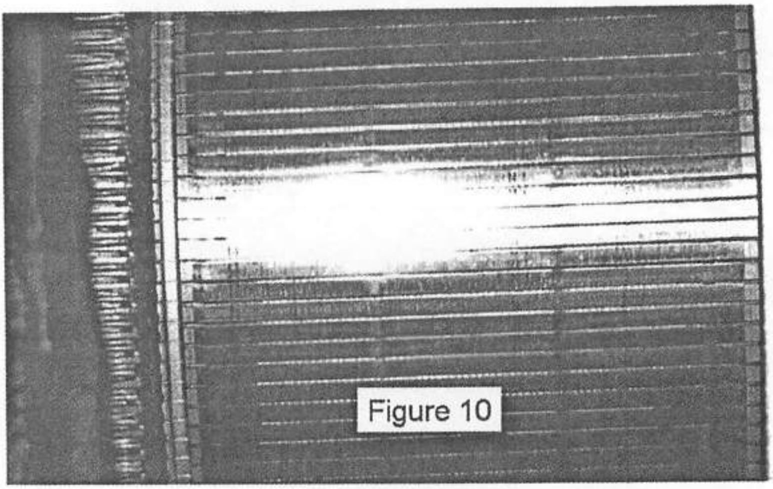

Figure 10


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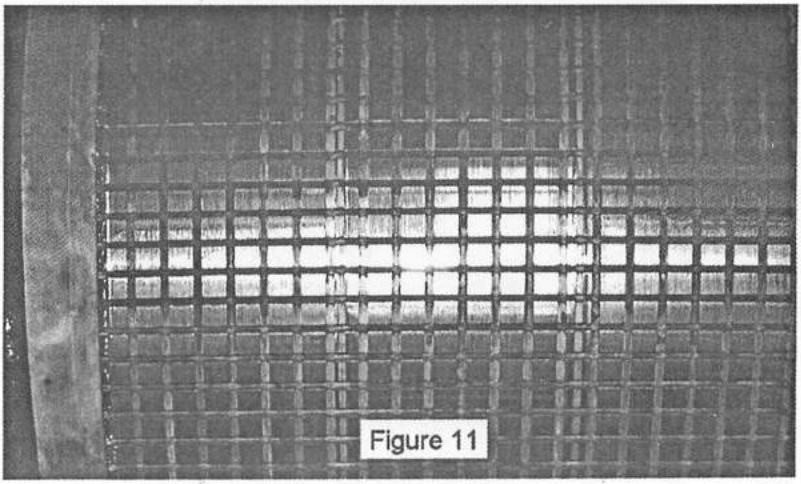
Typical film on a spiral grooved GE commutator



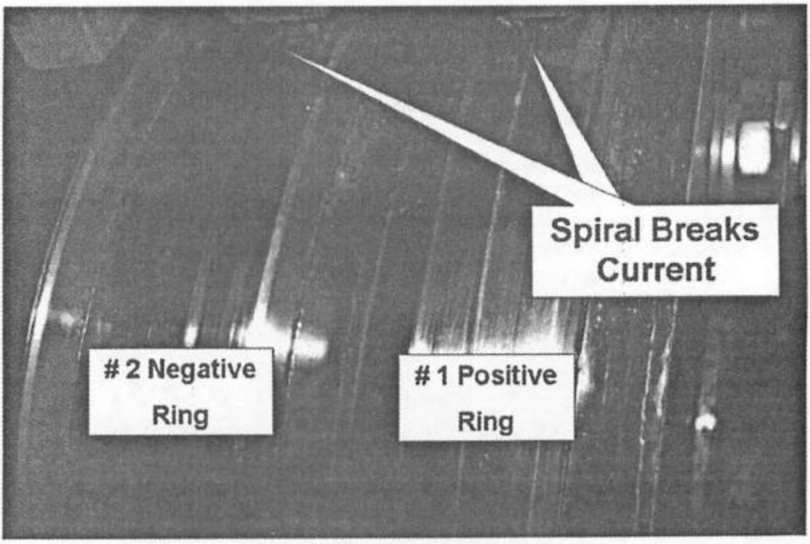




Figure 12 EMD slip ring assembly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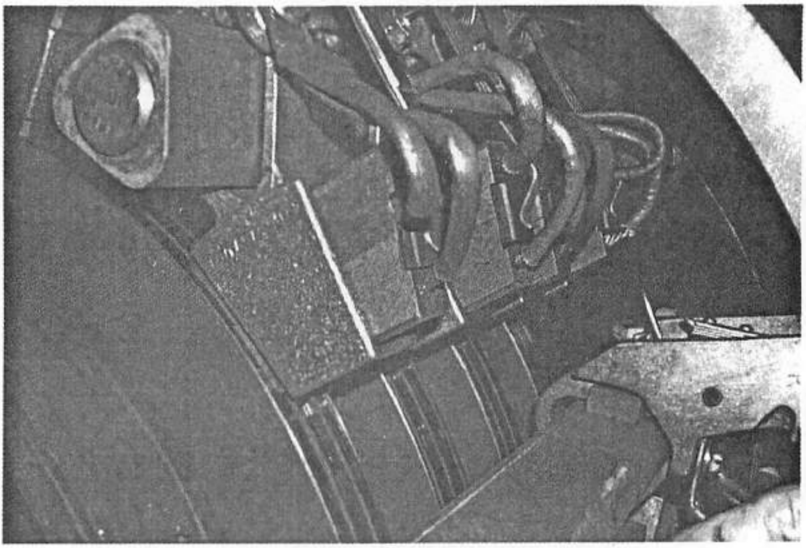

Figure 13 GE steel slip ring with R318 grade brush

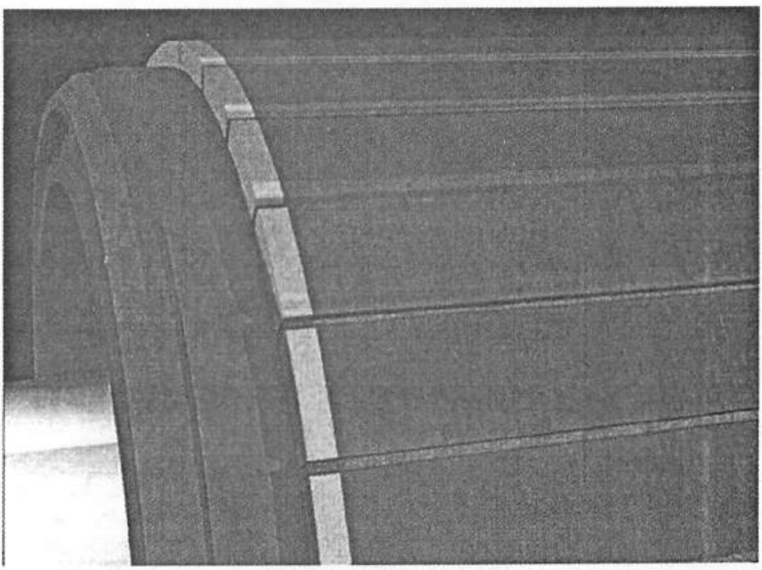

Figure 14 great looking commutator film


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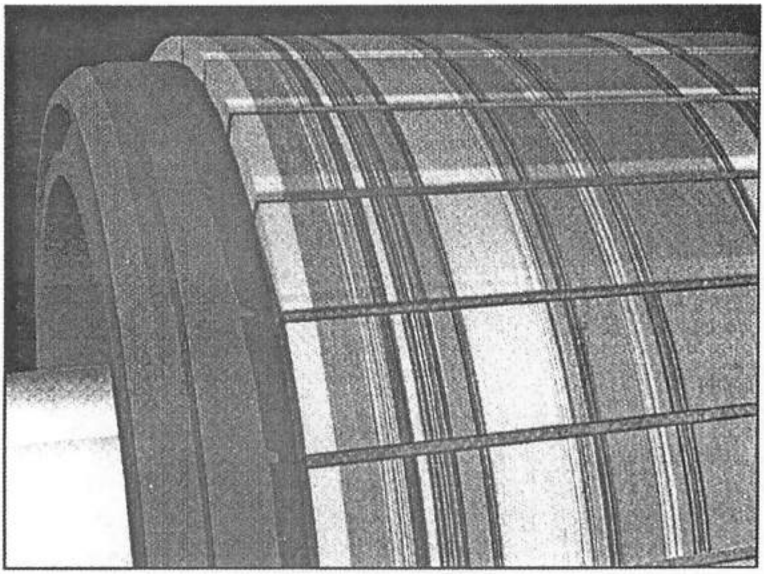

Figure 15 - Streaky film

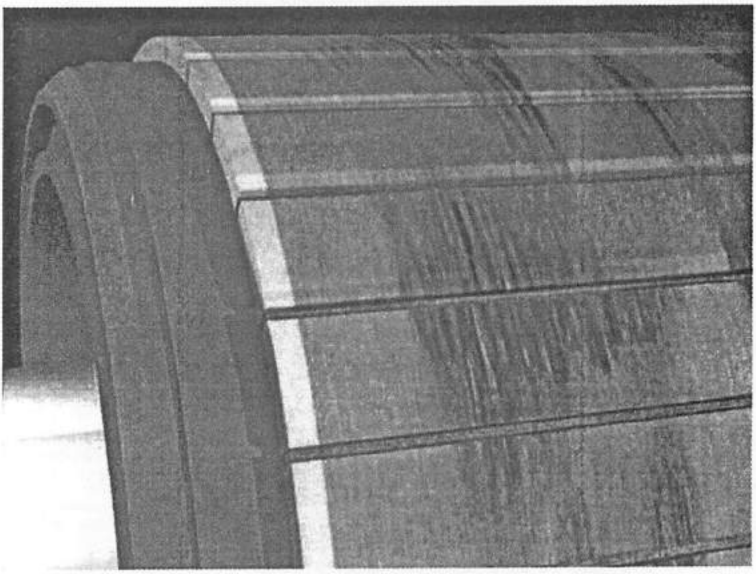

Figure 16 of a common Mottled film

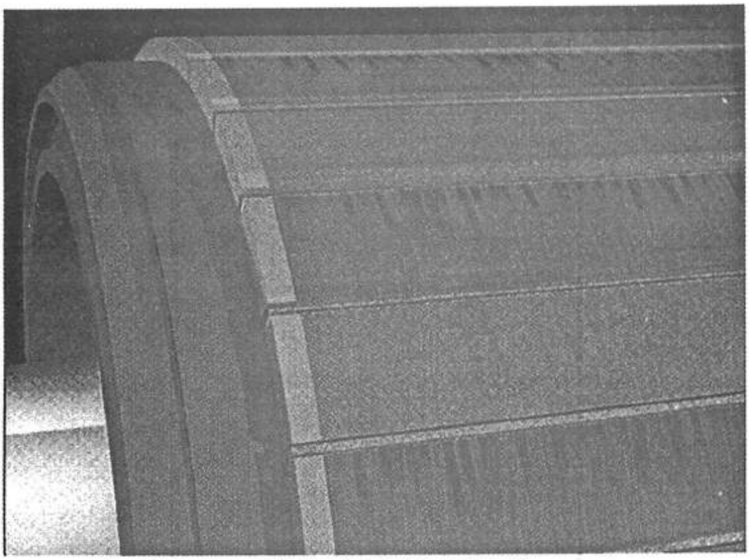

Figure 17 - Slot Bar Pattern

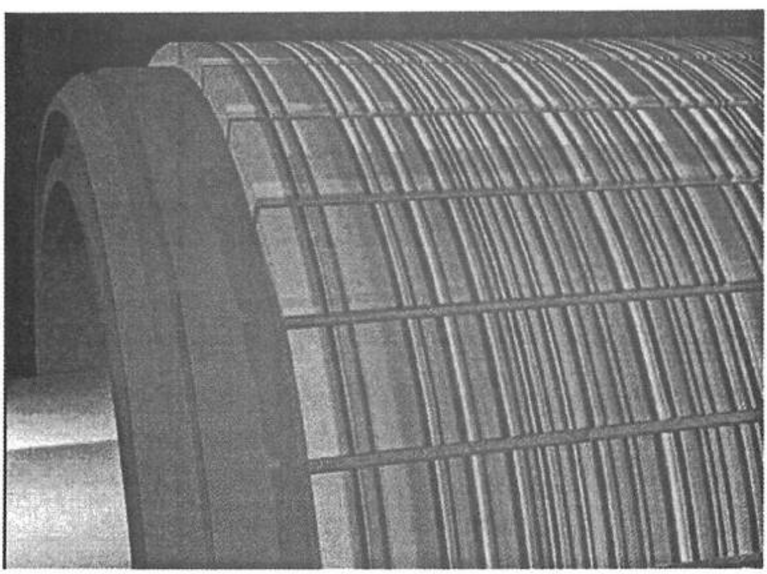

Figure 18 - Threading commutator condition

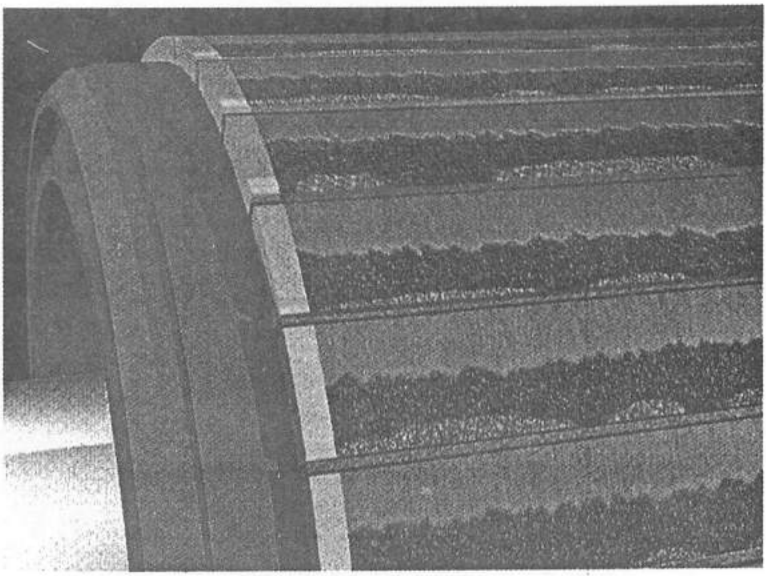

Figure 19 – Bar Burning

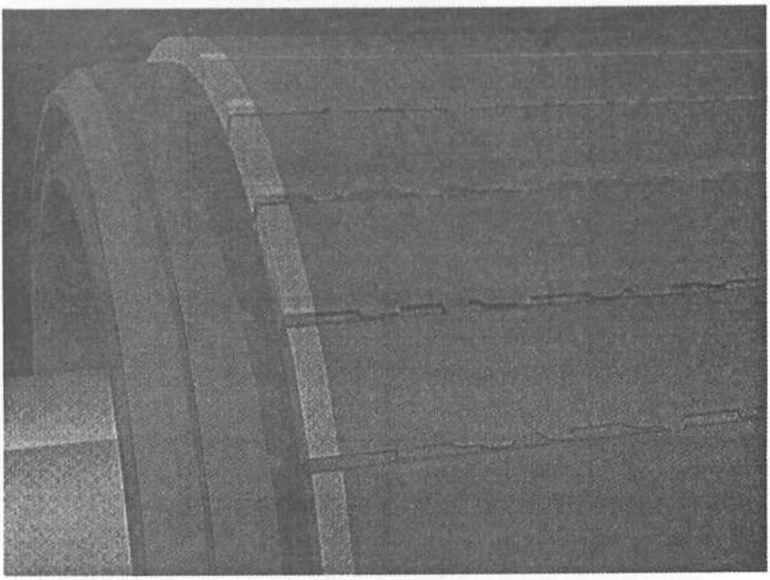

Figure 20 – Copper Drag leads to flashovers

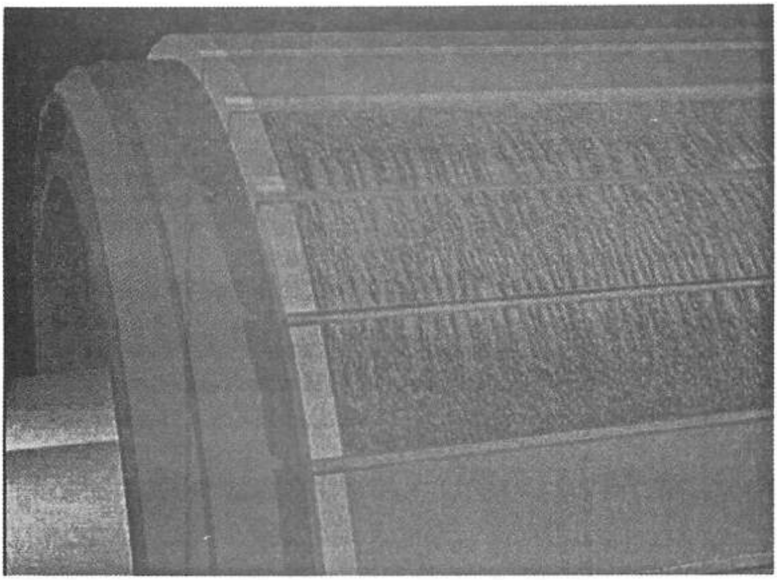

Figure 21 – Stall burns

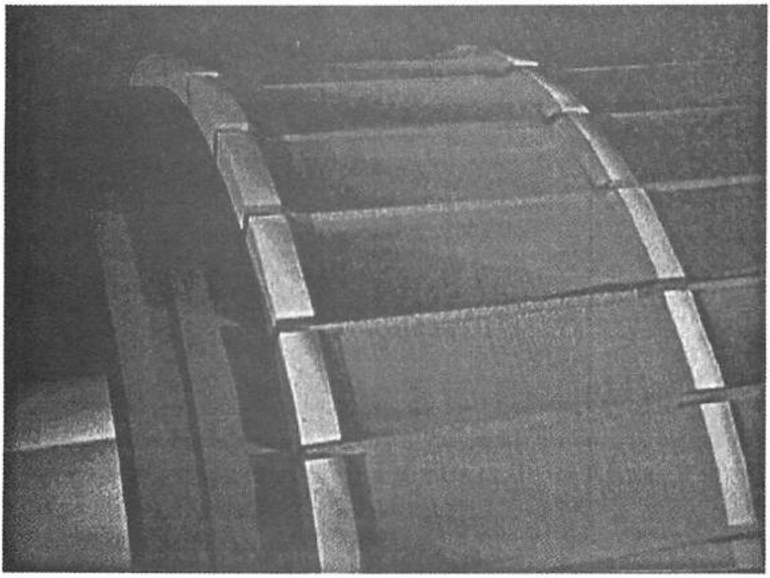

Figure 22 - Grooving

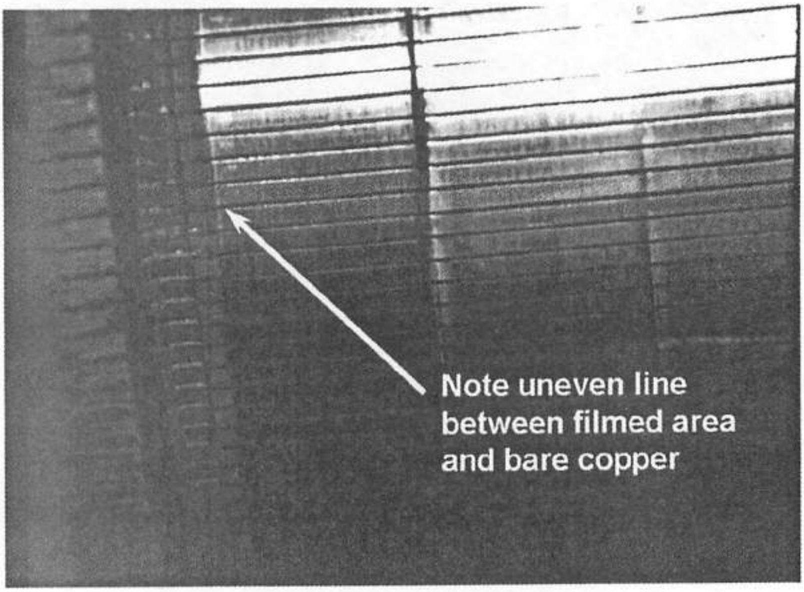


Figure 23 – Commutator with high TIR

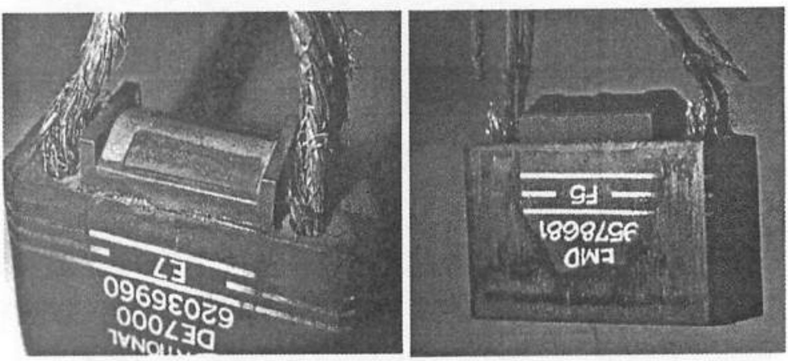

Figure 24 – Brush damage from high commutator TIR

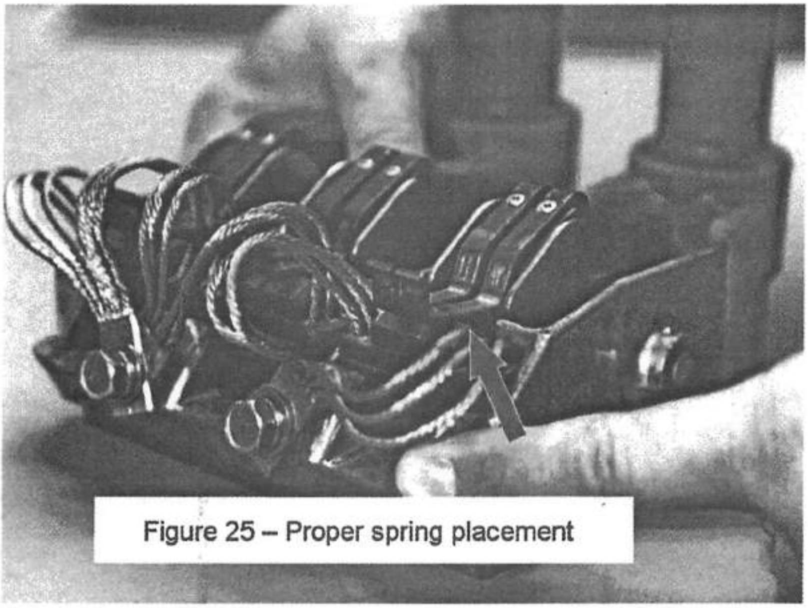

Figure 25 – Proper spring placement

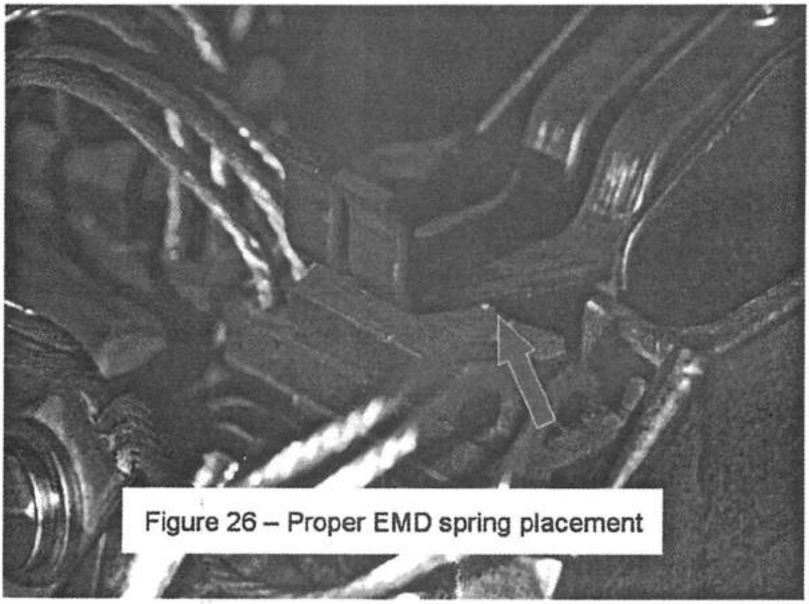

Figure 26 – Proper EMD spring placement

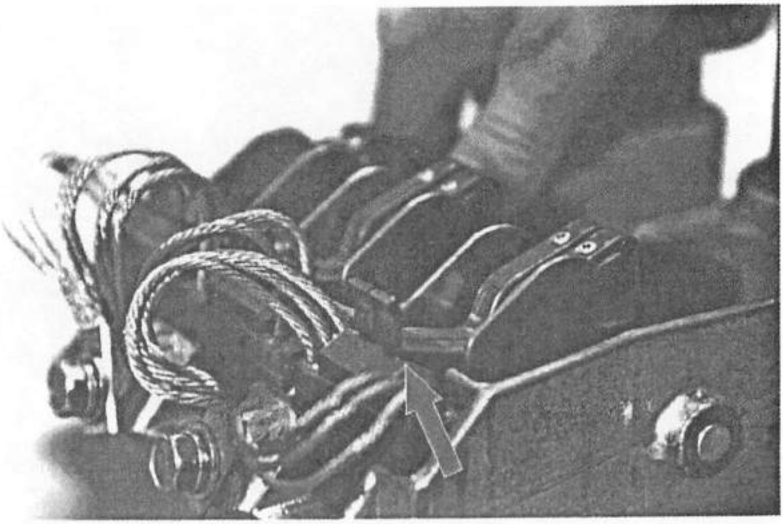

Figure 27 - Improper spring finger placement on EMD brush holder

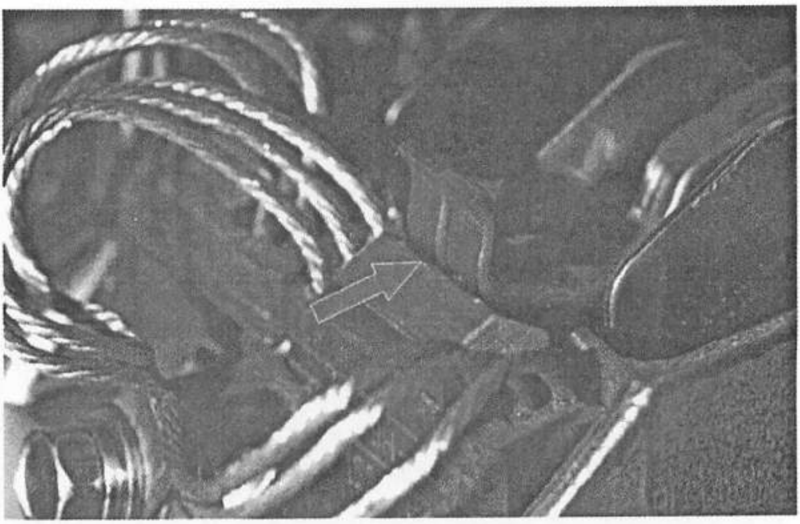

Figure 28 - Improper spring finger placement on EMD brush holder

## Total Brush Wear

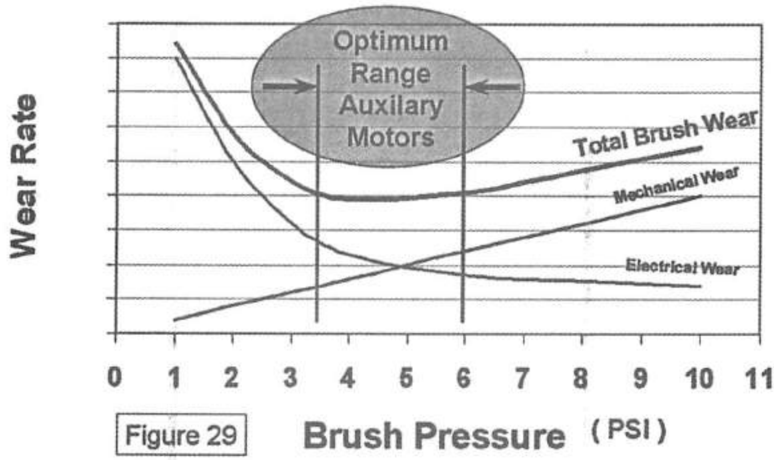


Figure 29

## Total Brush Wear

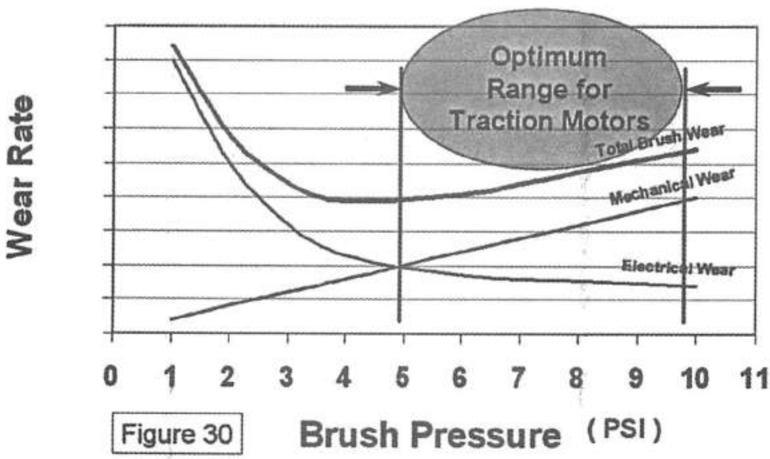


Figure 30

# Calculating Brush Pressure

$$\text{BRUSH PRESSURE (Lbs per Sq. Inch (PSI))} = \frac{\text{Measured Spring Force}^{*}}{\text{Brush Thickness (inches)} \times \text{Brush Width (inches)}}$$

* Average of IN & OUT movement

Figure 31

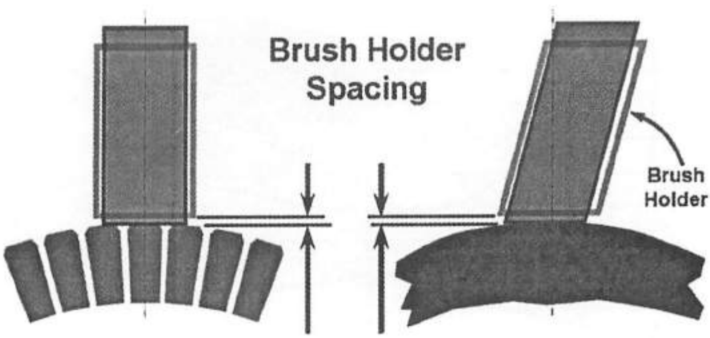


Figure 32 – Proper measuring of brush holder height

# REPORT OF THE COMMITTEE ON DIESEL MATERIAL CONTROL

# TUESDAY, SEPTEMBER 23, 2008
# 11:00 A.M.

Chairman
**BOB HARVILLA**
Sales Manager
Standard Car Locomotive Group
Strongsville, OH

Vice Chairman
**JOHN MINNIE**
Materials Manager
BNSF Railway
Burlington, IA

## COMMITTEE MEMBERS

| | | | |
|---|---|---|---|
| C. Aday | Inventory Manager | SCRRA/Metrolink | Los Angeles, CA |
| D. Behrens | Managing Director | ALSTOM Transport | Naperville, IL |
| R. Delevan | Mgr.-Transp. Prod. | Nat'l Electrical Carbon | Wilkes Barre, PA |
| P. Foster | President | Power Rail Dist. Inc. | Wilkes Barre, PA |
| J. Fronckoski | Senior Procure. Mgr. | CSX Transp. | Jacksonville, FL |
| M. Gast | Sr. Materials Mgr. | CSX Transp. | Huntington, WV |
| J. Hartwell | VP - Locomotives | Progress Rail | Jacksonville, FL |
| P. Johnson | Supt.-Loco Matl. | Norfolk Southern Corp. | Atlanta, GA |
| B. Lechner | Sr. General Foreman | Norfolk Southern Corp. | Altoona, PA |
| C. Mainz | Dir.-New Bus. Dev. | Coast Engine & Equip. | Tacoma, WA |
| F. Miller | VP - Marketing | JMA RR Supply | Seymour, IN |
| A. Pettigrew | Purchasing Mgr. | Rail America | Jacksonville, FL |
| K. Smith | Sales Mgr. | GE Rail Transp. | Jacksonville, FL |
| R. Sulewski | Nat'l Sales Manager | Rail Prod. Int'l Inc. | St. Louis, MO |
| B. Young | Matls. Manager | Montana Rail Link | Livingston, MT |
| M. Zerafa | Purchasing Mgr. | Nat'l Rwy. Equip. | Chicago, IL |

Note: Bill Lechner is a Past President of LMOA

# PERSONAL HISTORY

*Bob Harvilla*
*Regional Sales Manager*
*Standard Car Truck Co., Standard Locomotive Group*

Bob Harvilla began his career in 1973 at the General Electric Co. Cleveland Apparatus Service Center, and had a total of 22 years of service with GE. He is currently responsible for sales of the Standard Locomotive Group Companies - Durox, Triangle Engineered Products and Railway Equipment Associates. He resides in Medina, Ohio, and works out of the Durox offices in Strongsville, Ohio.

Bob and his wife Barb have been married 32 years and have two sons: Rob, 30 and Ryan, 25.

THE DIESEL MATERIAL CONTROL COMMITTEE WOULD LIKE TO EXPRESS THEIR SINCERE APPRECIATION TO THE FOLLOWING COMPANIES FOR HOSTING THEIR COMMITTEE MEETINGS THE PAST YEAR

FLORIDA EAST COAST RAILWAY
IN JANUARY 2008 IN
JACKSONVILLE, FLORIDA

NORFOLK SOUTHERN CORPORATION
IN JUNE 2008 IN
ALTOONA, PENNSYLVANIA

## LEAN MANUFACTURING AS IT APPLIES TO MATERIAL HANDLING

*Prepared by*
*Chris Mainz,*
*Director of New Business Developemnt*
*Coast Engine and Equipment Co.*

The term Lean Concepts evolved from Lean Manufacturing, a term coined in the James P. Womack book, *The Machine That Changed The World,* based largely on his observations of the Toyota Production System. The Focus at Toyota was **absolute elimination of waste**, especially anything that prevents the most optimum flow and assembly of material, from raw material to finished goods delivered to the customer. Initially, most people misinterpret the concept of Lean Manufacturing to apply only to the manufacturing assembly line, but in practice, Lean Manufacturing or Lean Concepts (the absolute elimination of waste) apply to the entire business model, including suppliers and customers. In practice, the significant gains in efficiency, profitability and customer service are only achieved when Lean Concepts are applied across the entire business model, especially material handling, not just at the point of production.

Unlike many other business "fads", Lean is effective and being utilized by some of the most successful companies in the world (i.e. General Electric, Toyota, Wabtec, Boeing, Caterpillar and CN). Organizations who have successfully implemented Lean Concepts have typically seen the following improvements:

**In Manufacturing:**

- Cycle Times down by at least 20%
- 10-day standard Customer order lead time
- Productivity gains of 62%
- 98% or better on-time delivery

**In Administration:**

- Order Entry from 2 days to 7 minutes
- Engineering changes from 7 months to 1 month
- Accounts Payable from 2 days to 4 hours
- New Product Quote 35 days to 10 days

**In Healthcare:**

- Same Day office visits
- No-wait emergency room
- Productivity gains of 62%
- 20% increase in number of surgical procedures by reducing operating room changeover time from 42 to 15 minutes

### Lean Manufacturing Philosophy - Key Concpets:

The ultimate objective of Lean Manufacturing is to eliminate all non value orientated activity or waste involved in the delivery of a product or service to the customer. This elimination of waste begins with the raw material and the transformation and handling of this raw material until it arrives as a perfect, on-time finished product in the customer's hands.

**The Three Pillars:**

1. The Problem - waste exists at all levels and in all activities
2. The Solution - the identification and elimination of waste
3. The Who - all of the employees and departments comprising the organization

**Seven Types of Waste:**

1. Over-Production-producing more than is needed, faster than needed or before needed.
2. Wait Time - idle time that occurs when co-dependent events are not fully synchronized.
3. Transportation - any material movement that does not directly support immediate production.
4. Processing - redundant effort (production or communication) which adds no value to a product or service.
5. Inventory - any supplies in excess of process requirements necessary to produce goods or services in a Just-in-time manner.
6. Motion - any movement of people which does not contribute added value to the product or service.
7. Defects - repair or rework of a product or service to fulfill customer requirements as well as scrap waste resulting from materials deemed to be unrepairable or un-reworkable.

**The 5 Lean Principles:**

Because Lean thinking is counterintuitive and a bit difficult to grasp on the first encounter, (but then blindingly obvious once "the light comes on"), it's very useful to examine the five lean principles:

1. Value - the critical starting point for lean thinking. Value can only be defined by the ultimate customer; and it's only meaningful when espressed in terms of a specific product (a good or service and often both at once) which meets the customer's needs at a specific price at a specific time.
2. The Value Stream - is a set of all the specific actions required to bring a specific product (whether a good, a service or, increasingly, a combination of the two) through the three critical management tasks of any business: the **problem-sovling** task running from concept through detailed design and engineering to production launch, the **information management** task running from order-taking through detailed scheduling to delivery, and the **physical transformation** task proceeding from raw materials to a finished product in the hands of the customer.

3. Flow - once real value has been indentified and the

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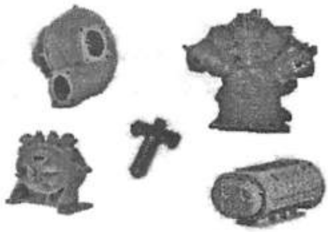
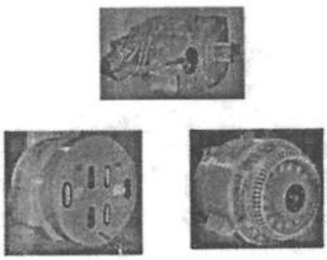


*PowerRail Mfg.*



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process fully mapped to eliminate wasteful steps, it is time to make the value creating steps flow. Flow, in Lean speak, requires a total arragement of your mental furniture: the elimination of the batch and queue philosophy (i.e. the CN has moved over 50% of it's grain business from dedicated unit trains to general purpose trains), of depart mental boundaries and functions; yes, that means - get rid of rules and policies that provide no "real" value.

4. Pull - Making exactly what the **customer** wants and delivering it exactly when the **customer** wants it. Let "real" demand dictate the supply chain and production schedule vs. the traditional approach of letting the supply chain and production capabilities dictate what and when you will deliver your product or service to the customer.
5. Perfection...is simple. Never stop eliminating waste from the value stream. Continue to evaluate the value stream to eliminate waste at all levels; this will create "real" efficiency or value.

**Toyota Motor Company:**

"Two Tinny sedans left the port of Yokohama in August 1957, bound for California - the first exports from Toyota. The four-door clunkers flopped. The car, which looked like a brick with a roof on top, was prone to overheating and vibrated at speeds of more than 60 miles per hour. By late 1960, Toyota realized it had made a mistake and pulled the Toyopet Crown off the market."

Toyota's journey with Lean Concepts started back in 1934 when it moved from textiles to produce the first car. Kiichiro Toyoda, founder of Toyota, directed the engine casting work and discovered many problems in their manufacture. He decided he must stop the repairing of poor quality by intense study of each stage of the process. In 1936, when Toyota won its first contract with the Japanese government, his processes hit new problems and he developed the Kaizen improvement teams. This was the beginning of the development of the Toyota Production System or Lean Manufacturing.

In 2008 Toyota's dedication to Lean Concepts, value and the elimination of waste not only has made it the most profitable car manufacturer in the world with one of the best quality records, but, is forecast to become the world's largest automaker in 2008. Additionally, from its failed Toyopet Crown in 1960, it is forecast to overtake GM in US market share by the end of 2008 (Figure 1).

**Canadian National (CN):**

Hunter Harrison's concept of Precision (scheduled) railroading has brought CN to the lowest operating ratio of any Class 1 while giving it one of the best on-time performance records in the industry.

CN's scheduled railroading is based upon seven principles that utilize the basic tenant of Lean Concepts, **"The absolute elimination of waste,"** especially anything that prevents the most optimum flow and assembly of material, from raw material to finished goods delivered to the customer"

CN Seven Principles of Scheduled Railroading:

1. Minimize car dwell time in yards
2. Minimize classification
3. Use multiple traffic outlets between yards to keep traffic moving
4. Run general-purpose trains
5. Balance train movements by direction to reduce power and crew deadheading
6. Minimize power requirements
7. Space trains to support a steady workload flow through various yard processes

The focus of the seven concepts is eliminating waste in the system to improve velocity and create consistency. These elements of Lean have allowed the CN to become the first Class 1 to offer customers guaranteed cars, with CN paying the penalty if the guarantee is not met.

The latest proposed acquisition of the "J", is another counterintuitive example of an out-of-the-box strategic move to improve flow by increasing velocity and eliminating bottlenecks; ultimately providing superior service and creating value for the customer, while improving financial performance.

**Lean Techniques Applied To Locomotive Power Assembly Availability**

The goal of the cooperative effort between a Class 1 customer and a power assembly provider is to Shorten Locomotive Repair Dwell time by increasing power assembly availability.

**Assumptions:**

- Shortening Locomotive Repair Dwell Time is critical to railroad operations in that it contributes directly to locomotive availability
- Eliminating power assembly shortages contributes directly to decreasing Locomotive Repair Dwell time
- Having the proper power assembly available at the correct location can be accomplished using Lean techniques
- Power assembly consumption can vary dramatically due to fleet age and operating conditions
- Typical safety stock or Min Max strategies lead to excess inventory and/or shortages
- The typical cycle times created by normal purchasing schemes exaggerate the problem

**Agreements:**

- Customer agrees to sole source agreement with supplier

- Customer and Supplier agree to increase the premium content of power assembly to improve power assembly performance
- Customer and Supplier agree to a 3 year warranty on power assemblies
- Customer and Supplier agree to warehouse (consign) minimum qty of power assemblies (645 and 710 model PA's) at customer's Shreveport warehouse.
- Customer agrees to refill (order) power assemblies as picked from consignment-
- Supplier agrees to ship order within seven business days of receipt of order (Figure 2)

**Summary**

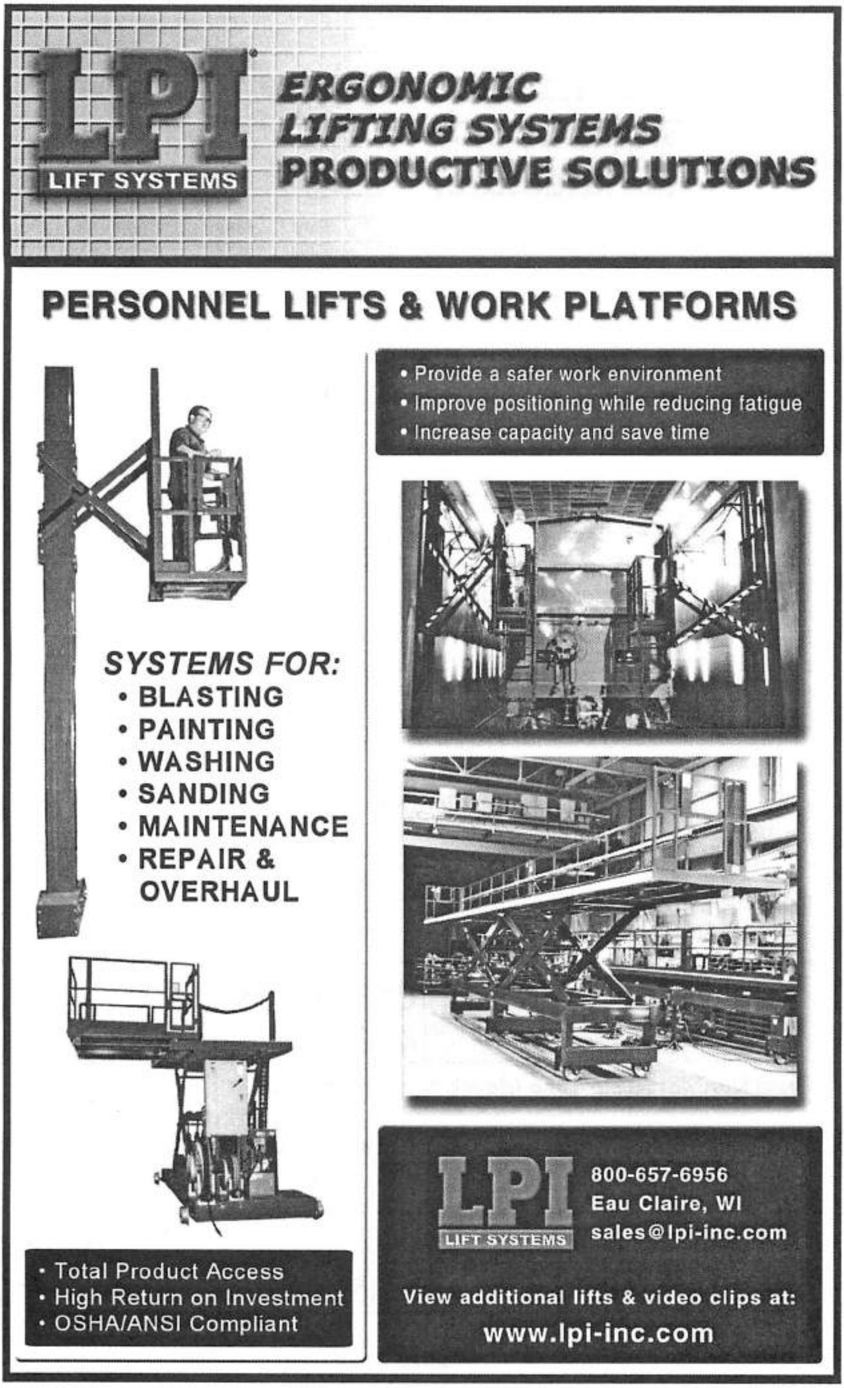
Clearly the original plan did not meet the requirements of the customer. Upon analysis of the value stream, additional lean techniques were applied to improve the flow to increase the service levels while benefiting both the customer and the supplier financially.

**References:**

1. Lean Thinking, James P. Womack and Daniel T. Jones, 2003
2. The Lean Manufacturing Pocket Handbook, Kenneth W. Dailey, 2003
3. The CN does it, Railway Age, May 2001
4. The CN again shows the way, Railway Age, February 2008
5. America's Best Car Company, CNN Money.com, March 7,2007
6. How Toyota Could become the US Sales Champ, U.S. News and World Report, Monday, July 28th, 2008

**Contributions**

Cullen Burdette, V.P. HK Engine Components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## U.S. Market Share by Manufacturer

| | May 2007 | May 2008 |
|---|---|---|
| GM | 23.8% | 19.3% |
| Toyota | 17.2 | 16.4 |
| Ford | 16.5 | 15.4 |
| Chrysler | 12.8 | 10.7 |
| Honda | 9.3 | 12.0 |
| Nissan | 6.0 | 7.2 |
| Hyundai | 4.6 | 5.6 |
| BMW (includes Mini) | 2.0 | 2.3 |
| Volkswagen (includes Audi) | 2.0 | 2.2 |
| Mercedes (includes Smart) | 1.4 | 1.6 |

**Figure 1**

**Results (Key Metrics):**

| | Original Process-(2003) | Current Process |
|---|---|---|
| Total Reorder Cycle Time (days) | 30-45 days | 10-15 days |
| Inventory $'s employed | $250,000 | $250,000 |
| Inventory Service Rate (%) | 50% | 95% |
| Total Sales volume ($) | $670,000.00 | $1,500,000 |
| Average Open order value $'s | $150,000.00 | $50,000.00 |

**Figure 2**

# REPORT OF THE COMMITTEE ON SHOP EQUIPMENT AND PROCESSES

# TUESDAY, SEPTEMBER 23, 2008
# 1:45 P.M.

Chairman
**BILL PETERMAN**
President
Peterman Railway Technologies, Inc.
Baie D'Urfe, Quebec

Vice Chairman
**TOM STEFANSKI**
President
Tom's Locomotives and Cars
Plainfield, IL

## COMMITTEE MEMBERS

| | | | |
|---|---|---|---|
| R. Begier | Consultant | Portec Rail Products Inc. | Broomfield, CO |
| R. Collen | VP-Sales | Simmons Mach. Tool Corp. | Albany, NY |
| C. Fette | President | TESCO | Erie, PA |
| M. Hofmann | Dir.-Labor Rel. | BNSF Rwy. Co. | Ft. Worth, TX |
| D. Louder | Product Manager | Macton Corp. | Mount Airy, MD |
| J. Morin | President | NEU International Inc. | Paoli, PA |
| R. Quilley | Reliability Spec. | CN RR | Winnipeg, MB |

**THE SHOP EQUIPMENT AND PROCESSES COMMITTEE WISHES TO EXPRESS THEIR SINCERE APPRECIATION TO THE FOLLOWING COMPANIES FOR HOSTING THEIR COMMITTEE MEETINGS THIS LAST YEAR.**

**UNION PACIFIC,**
**CHICAGO, IL - NOVEMBER, 2007**
**SPECIAL THANKS TO**
**RICHARD JACOBS OF THE U.P.**

**METROLINK,**
**LOS ANGELES, CA - MARCH, 2008**
**SPECIAL THANKS TO**
**CHICK ADAY OF METROLINK**

# PERSONAL HISTORY

## *Bill Peterman*

Bill was born and raised in Ontario Canada and has worked and lived in various parts of Canada during his railway career including major stints in Calgary and Montreal where he presently resides. His business career included 25 years with Canadian Pacific Railway and several years with Dominion Bridge Canada in numerous industrial and facilities engineering positions including various positions in the maintenance facilities and head office. Gained a world of rail experience working in all aspects of service facilities. His railway career began as a Time and Motion Analyst completing his time with the railway as Manager Facilities Engineering.

Presently Bill is President of Peterman Railway Technologies a company specializing in assisting with Rail Maintenance Facility designs, equipment and processes, providing specialized rail maintenance services and acting as a liaison between railroads and non railroad entities.

He has been Chairman of the Shop Equipment & Processes Committee for several years. Bill lives in Montreal and is married with 5 children and finally has one grandchild.

## VEHICLE PROGRESSION SYSTEMS

*Prepared by,*
*Roger D. Collen*
*Vice President, Sales*
*Simmons Machine Tool Corp.*

Presentation Overview
- What is a Progression System
- Why use a Progression System
- System Applications
- Types of Systems
- System Performance Capabilities

What is a Vehicle Progression System?
- Equipment for the transfer/movement of rail bound vehicles using a separate independent power source

Why use a Progression System?
- Increased personnel and equipment safety - operating a locomotive engine generates air contamination and noise, movement of locomotive in congested shop requires visibility around locomotive.
- Improved environmental conditions - elimination of air contamination and noise.
- Improved operating efficiency - systems reduce manpower necessary to move vehicles.
- Reduced operating costs - car progression systems apply power only when required.

System Applications
- Typical Service & Maintenance Shop Applications
  - Wheel truing equipment - advance vehicle to truing location as required.
  - Drop table.
  - Shim table.
  - Complement transfer table.
- Other applications
  - Bulk material car loading/unloading.
  - Car movement through paint shop.
  - Support of spot systems for truck/wheel set change out.

Progression System Types
- Fixed Systems - equipment is permanently mounted to structure.
  - Open winch systems - use rope or cable wound on a powered drum to provide pulling power.
  - Capstan Systems - uses a rope wrapped around a drum to provide pulling power. Rope is not contained on drum.
  - Loop Systems - uses wire rope wrapped around a series of pulleys and powered drum to provide pulling power.
  - In-Ground Systems - uses a guide track and chain system to drive a shuttle that pushes or is manually attached to the rail vehicle.
- Mobile Systems - car progressions systems with independent power source that are not permanently fixed in one location.
  - Diesel Powered - Rail Bound - lower horsepower

locomotives dedicated to movement of rail vehicles over short distances through yards or shops.

- Diesel Powered - Road & Rail-low horsepower vehi cles capable of operating on rail or road with rubber tires and steering wheels.
- Electric Powered - Rail Bound - battery powered locomotives dedicated to movement of rail vehicles.
- Electric Powered - Road & Rail - battery powered vehicle capable of operating on a rail or road with rubber tires and steering wheels.

Performance Capabilities

- Winch Systems
  - Ease of use with minimal operations training
  - Systems require routine safety inspection
  - Requires one operator
  - Single direction systems provide poor vehicle position ing accuracy
  - Dual direction systems provide better positioning accuracy
- Capstan Systems
  - Ease of use with minimal operations training
  - Systems require routine safety inspection
  - Safe operation requires two operators
  - Single direction systems provide very poor positioning accuracy
- In-Ground Systems
  - Ease of use with minimal training
  - Requires one operator
  - Single direction systems provide poor positioning accuracy
  - Dual direction systems provide better positioning accu racy
- Capstan Systems
  - Ease of use with minimal operations
  - Systems require routine safety inspection
  - Safe operation requires two operators
  - Single direction systems provide very poor positioning accuracy
- In-Ground Systems
  - Ease of use with minimal operations training
  - Requires one operator
  - Single detection systems provide poor positioning accuracy
  - Dual direction systems provide better positioning
  - Use of programmable controllers and software provides a platform for operator and equipment safety
- Mobile - Diesel Rail Bound
  - Higher horsepower than fixed systems provides higher capacity
  - Requires one operator
  - Car mover can be operated with remote control
  - Provides good positioning accuracy
- Mobile - Diesel Rail & Road
  - Diesel power provides good movement capacity

- Requires one operator
- Car mover can be operated with remote control
- Good positioning accuracy
- Flexible

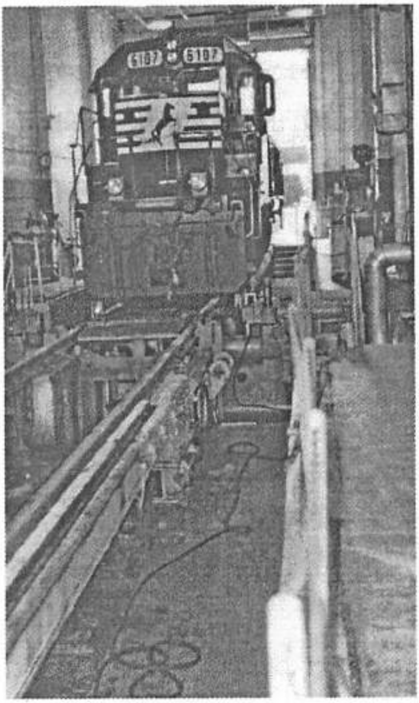
- Mobile - Electric Rail Bound
  - Available in large range of moving capacity
  - Requires one operator
  - Car mover can be operated with remote control
  - Good position accuracy
  - Optional de-railing system for movement of unit off rails
- Mobile - Electric Road & Rail
  - Good moving capacity
  - Requires one operator
  - Car mover can be operated with remote control
  - Good position accuracy
  - Flexible

Thanks to support from shop equipment committee members associated with:

Whiting Corporation
Portec Corporation
NITEQ Corporation
Trackmobile
Simmons Machine Tool Corp.

**Editor's Note**

This paper was presented at the 2007 convention at the Chicago Hilton & Towers.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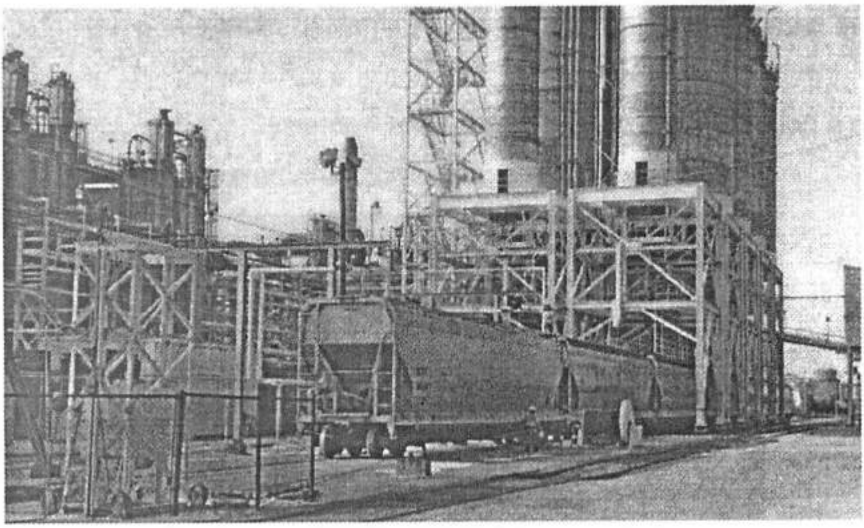
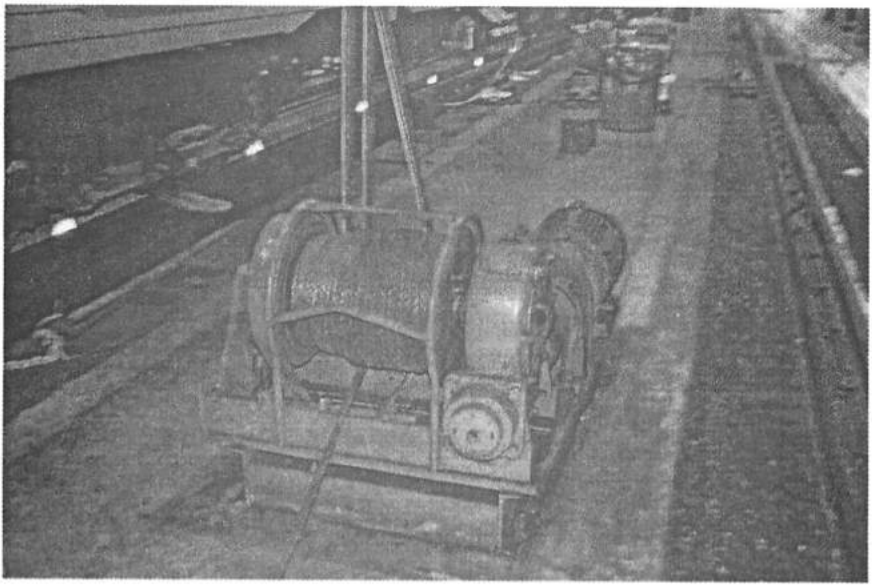
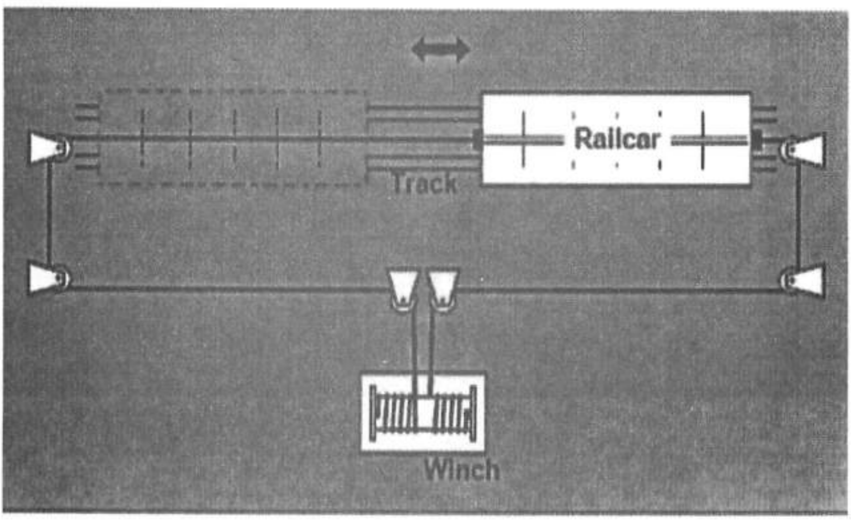
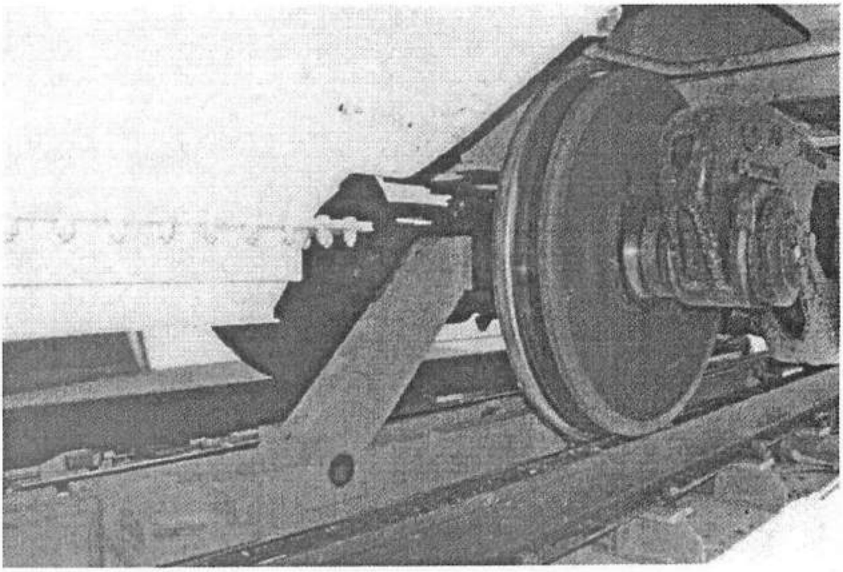





Railcar
Track
Winch

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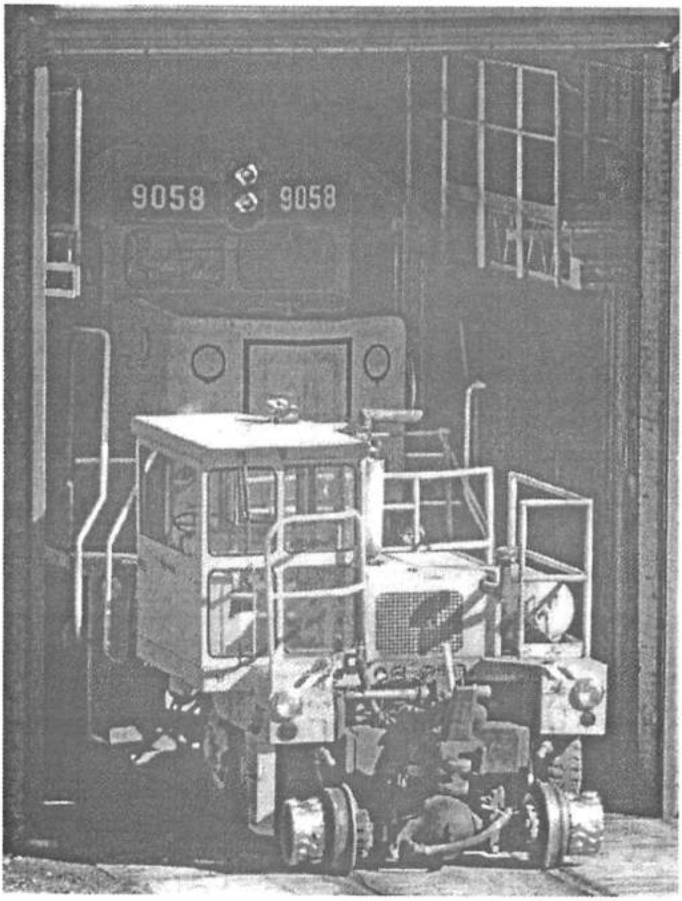
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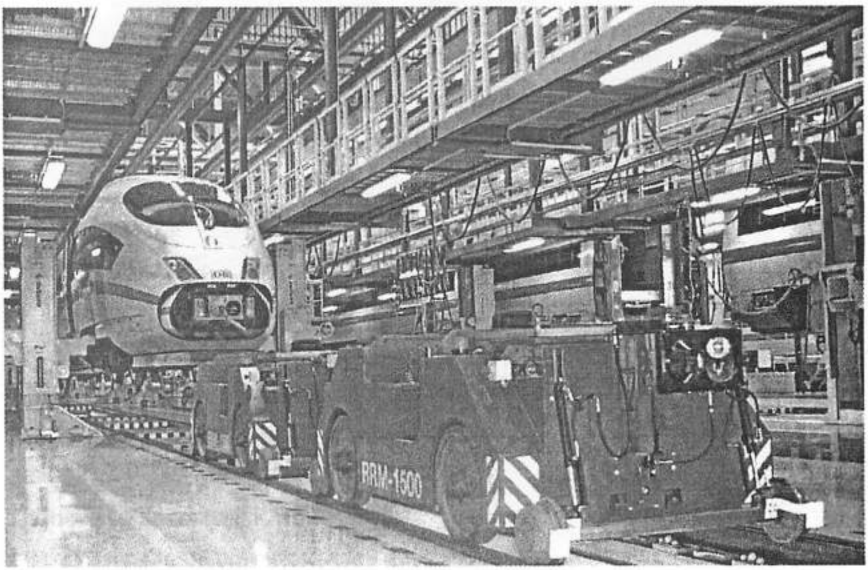
NITEQ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## CONSTITUTION AND BY-LAWS LOCOMOTIVE MAINTENANCE OFFICERS ASSOCIATION

*Revised September 22, 2003*

### Article I - Title:

The name of this Association shall be the Locomotive Maintenance Officers Association (LMOA).

### Article II - Purpose of the Association

The purpose of the Association, a non-profit organization, shall be to improve the interests of its members through education, to supply locomotive maintenance information to their employers, to exchange knowledge and information with members of the Association, to make constructive recommendations on locomotive maintenance procedures through the technical committee reports for the benefit of the railroad industry.

### Article III - Membership

**Section 1** - Railroad Membership shall be composed of persons currently or formerly employed by a railroad company and interested in locomotive maintenance. Membership is subject to approval by the General Executive Committee.

**Section 2** - Associate Membership shall be composed of persons currently or formerly employed by a manufacturer of equipment or devices used in connection with the maintenance and repair of motive power, subject to approval of the General Executive Committee.

Associate members shall have equal rights with railroad members in discussing all questions properly brought before the association at the Annual Meeting, and shall have the privilege of voting or holding elective office.

**Section 3** - Life membership shall be conferred on all Past Presidents. Life membership may also be conferred on others for meritorious service to the Association, subject to approval by the General Executive Committee.

**Section 4** - Membership dues for individual railroad and associate membership shall be set by the General Executive Committee and shall be payable on or before September 30th of each year. The membership year will begin on October 1 and end September 30. Members whose dues are not paid on or before the opening date of the annual convention shall not be permitted to attend the annual meeting, shall not be eligible to vote and/or shall not be entitled to receive a copy of the published Pre-Convention Report or the Annual Proceedings of the annual meeting. Failure to comply will result in loss of membership at the end of the current year. Life members will not be required to pay dues, but will be entitled to receive a copy of the Pre-Convention Report and Annual Proceedings.

**Article IV - Officers**

**Section 1** - Elective Officers of the Association shall be President, First Vice President, Second Vice President and Third Vice President. Each officer will hold office for one year or until successors are elected. In the event an officer leaves active service, he may continue to serve until the end of his term, and, if he chooses, continue to serve as an executive officer and be allowed to elevate through the ranks as naturally occurs, to include the office of President.

**Section 2** - There shall be one Regional Executive officer assigned to oversee each technical committee. Regional Executives shall be appointed from the membership by the General Executive Committee for an indefinite term, with preference given to those having served as a Technical Committee Chairperson. A Regional Executive who leaves active service may continue to serve as such, and shall be eligible for nomination and election to higher office.

**Section 3** - There shall be a General Executive Committee, composed of the President, Vice Presidents, Regional Executives, Technical Committee Chairpersons, and all Past Presidents remaining active in the Association.

**Section 4** - There shall be a Secretary-Treasurer, appointed by, and holding office at the pleasure of the General Executive Committee, who will contract for his or her services with appropriate compensation.

**Section 5** - All elective officers and Regional Executives must be LMOA members in good standing. (See Article III, Section 4.)

**Article V - Officer, Nomination and Election of**

**Section 1** - Elective officers shall be chosen from the active membership. A Nominating Committee, composed of current elective officers and the active Past Presidents, shall submit the slate of candidates for each elective office at the annual convention.

**Section 2** - Election of officers shall be determined by a voice vote, or if challenged, it shall require show of hands.

**Section 3** - Vacancies in any elective office may be filled by presidential appointment, subject to approval of the General Executive Committee.

**Section 4** - The immediate Past President shall serve as Chairman of the Nominating Committee. In his absence, this duty shall fall to the current President.

**Article VI - Officers - Duties of**

**Section 1** - The President shall exercise general direction and approve expenditures of all affairs of the Association.

**Section 2** - The First Vice President, shall in the absence of the President, assume the duties of the President. He shall additionally be responsible for preparing and submitting the program for the

Annual Meeting.

The Second Vice President shall be responsible for selecting advertising. He will coordinate with the Secretary-Treasurer and contact advertisers required to underwrite the cost of the **Annual Proceedings.**

The Third Vice President will be responsible for maintaining a strong membership in the Association. He will ensure that membership applications are properly prepared and distributed, monitoring membership levels and reporting same at appropriate time to the General Executive Committee.

The Vice Presidents shall perform such other duties as are assigned them by the President.

**Section 3** - The Secretary-Treasurer shall:

A. Keep all the records of the Association.

B. Be responsible for the finances and accounting thereof under the direction of the General Executive Committee.

C. Perform the duties of the Secretary of the Nominating Committee, and General Executive Committee, without vote.

D. Furnish surety bond in amount of $5000 on behalf of his/her assistants directly handling Association funds. Association will bear the expense of such bond.

**Section 4** - The Regional Executive officers shall:

A. Participate in the General Executive Committee meetings.

B. Monitor material to be presented by the technical committees to ensure reports are accurate and pertinent to the goals of the Association.

C. Attend and represent LMOA at meetings of their assigned technical committees.

D. Promote Association activities and monitor membership levels within their assigned areas of responsibility.

E. Promote and solicit support for LMOA by helping to obtain advertisers.

**Section 5** - Duties of General Executive Committee:

A. Assist and advise the President in long-range Association planning.

B. Contract for the services and compensation of a Secretary-Treasurer.

C. Serve as the Auditing and Finance Committee.

D. Determine the number and name of the Technical Committees.

E. Exercise general supervision over all Association activities.

F. Monitor technical papers for material considered unworthy or inaccurate for publication.

G. Approve topics for the Annual Proceedings and Annual Meeting program.

H. Approve the schedule for the Annual program.

I. Handle all matters of Association business not specifically herein assigned.

**Section 6** - The General Executive Committee is entrusted to handle all public relations decisions within LMOA and coordinated associations with confidentiality.

**Article VII - Technical Committees**

The technical committees will consist of:

**Section 1** - A chairperson, appointed by the President and approved by the General Executive Committee.

**Section 2** - A vice chairperson, selected by the chairperson and approved by the President.

**Section 3** - Committee members, selected as follows:

A. Representatives of operating railroads and regional transit authorities submitted by their Senior Mechanical and Materials Officers and approved by the President of LMOA.

B. Representatives of locomotive builders designing and manufacturing locomotives in North America.

C. The Fuel and Lube Committee will include members from major oil companies or their subsidiaries as approved by the General Executive Committee.

D. At the direction of the General Executive Committee, non-railroad personnel may be allowed to participate in committee activities.

**Section 4** - All individuals who are on technical committees must be LMOA members in good standing. (See Article III, Section 4).

**Section 5** - Subjects for technical papers will be selected and approved by the General Executive Committee.

**Article VIII - Proceedings**

**Section 1** - The Locomotive Maintenance Officers Association encourages the free interchange of ideas and discussion by all attendees for mutual benefits to the railroad industry. It is understood that the expression of opinion, or statements by attendees in the meeting, and the recording of papers containing the same, shall not be construed as representations or statements ratified by the Association.

**Section 2** - Those present at any meeting called on not less than thirty days advance written notice shall constitute a quorum.

**Article IX - Rules of Order**

The proceedings and business transactions of this Association shall be governed by Roberts Rules of Order, except as otherwise herein provided.

**Article X - Amendments**

The Constitution and By-Laws may be amended by a two-thirds vote of the active members present at the Annual Meeting.

## DIESEL MECHANICAL MAINTENANCE COMMITTEE TWENTY-SIX YEAR INDEX

Cylinder Inlet Port Cleaning
4. What's Ahead in Plastics for Locomotive Applications
5. Cast Iron, Composition Brake Shoe Arrangements vs. Type-J Relay

**1998**

1. LMOA Best Practices Series: GM Engine Crankcase Pressure Troubleshooting
2. Union Pacific's New EMD Diesel Engine Rebuild Line At Downing B. Jenks Locomotive Facility-No. Little Rock, Arkansas
3. GE Turbo Rebuild Procedures
4. Mechanical Impact of Locomotive Emissions Regulations
5. Locomotive Engine Bearing Developments

**1997**

1. LMOA Best Practices - GE Water Leaks
2. Locomotive Update - MK 1200G LNG Powered Switcher
3. Proper Use of Gaskets and Seals

**1996**

1. Air Brake Trouble Shooting-Where We Are Now
2. Best Practices - Internal Water Leaks on EMD Locomotives
3. Best Practices - Oil Out Stack

**1995**

1. General Electric New 7HDL 6000 HP Diesel Engine
2. LMOA Best Practices Series - Low Oil Pressure Trouble-shooting Procedures for EMD Turbocharged Locomotives
3. How Can a Regional or Shortline Justify a Wheel Truing Machine?
4. EMD SD60M Natural Gas Locomotive Development

**1994**

1. Electronic Fuel Injection.
2. ICAV - The Physical Affects on Instantaneous Crank Shaft Angular Velocity Technology
3. Maintenance Practices Com-parison Between Regionals and Class I Railroads
4. Amtrak Document Manage-ment.

**1993**

1. EMD's Three-Axle Radial Steering Truck
2. The Natural Gas Locomotive at BN RR
3. Locomotive Waste Oil Reten-tion
4. Fragmented Maintenance

**1992**

1. Mechanical Quality Progress Developing on Major Railroads.
2. Coal Fuelled Diesel Locomotive Development.
3. 18:1 Upgrade for the 645E Engine
4. Automatic Stop and Start Control System
5. Acquiring Locomotives for Regionals and Shortlines

**1991**

1. Recommended Practices for upgrading 567 to 645 Design.
2. Conversion of SD40 Loco-motives to SD 40-2 on CSX
3. Update: Diesel Engine Emission Controls
4. Stationary and Dynamic Test Procedure for Locomotive Fuel Efficiency Measurement
5. Personnel training on New Technology.

**1990**

1. Caterpillar Power in Reman-ufactured Locomotives.
2. The EMD 710G3A Engine
3. Improving Performance of Traction Motor Friction Sus-pension Bearings.
4. Fluid Leaks on GE 7FDL Engine.
5. Rebuild of the EMD F3B Fuel Injector.

**1989**

1. Wheel Axle Gear Wear/Impact on Traction Motor Life
2. 710 Engine - Operational and Overhaul Update
3. GE Power Assembly Improve-ments on Welded Head-to-Liner
4. Assembly Rework Procedures.
5. EMD Engine Oil Leaks. Secondary Air Filtration - Barrier vs.

Impingement

1988

1. Low-idle Operating Costs vs. Fuel Savings.
2. Rebuilding GE's EB Liner
3. The Extended Maintenance Truck
4. Flange Lubricator Update
5. Permaspray II - Cylinder Liner

1987

1. EMD Water Pump Rebuilding
2. On Board Flange Lubricator
3. Gear Case, Bull Gear and Pinion Gear Longevity in the 1980's - Gear Cases - Canadian National Experience.
4. Maintenance of Locomotive Fueling Systems for a Spill Free Operation

1986

1. Rebuild of Valve Bridge Assemblies
2. Update of New Locomotive Service Problems, EMD and GE Effecting Quality Performance
3. Chromium Plating and Its Uses
4. Development of a New Diesel Engine for Heavy-Duty Locomotive Service

1985

1. Procedures for Storing Serviceable Locomotives for Quality Performance
2. New Locomotive Service Problems, EMD and GE
3. 92 Day Service Requirements: EMD, GE and Bombardier

1984

1. Mechanical Aspects of New Locomotive Designs
2. Maintenance of Locomotive Components

1983

1. Leaks: Cooling Water, Lube Oil, Fuel Oil and Air
2. Torquing Recommendations.
3. Update on Fuel Efficient Locomotives
4. Radiator Screens
5. Alternate Starter Systems

1982

1. Fuel Conservation - Effects on Maintenance
2. Fuel Conservation - What It Costs.
3. Diesel Fuel Receipt and Disbursement
4. Turbochargers

1981

1. Running Gear
2. Filtration
3. FRA Rules
4. Follow-up on Previous Topics

## DIESEL MATERIAL CONTROL COMMITTEE
## TWENTY-SIX YEAR INDEX

**2007**

1. Insourcing vs. Outsourcing "The Altoona Story"

**2006**

1. PDAs for Inventory Control
2. Inventory Management System

**2005**

1. Centralized Materials Management
2. Centralized Component Core Management-Centralized Warehouse-Locomotive Comonents - Part A: BNSF Rwy. Centralized Component Core Management-Rotable Warehouse - Part B: Norfolk Southern Corp.

**2004**

1. Milk Run: Norfolk Southern's Dedicated Locomotive Parts Shipping System

**2003**

1. Just in Time Delivery - The Juniata - Shop Material Control Program
2. The Continuous Improvement Approach

**2002**

1. "Mentored Champion Process" - CSX Supply and Service Management

**2001**

1. RAILMARKETPLACE.COM - The Industry's Market Exchange

**2000**

1. GE Global eXchange Services
2. My.SAP.Com

**1999**

1. Composite Floors and Doors for Locomotives
2. Packaging Standards

**1998**

1. Tighter is Not Better
2. Are Vending Machines the New Wave for Safety Items?

**1997**

1. Raising Our Standards for Safety
2. The Rail Industry's Electronic Parts Catalog Exchange Standard (EPCES) - A Better Way

**1996**

1. Technology Transfer-The Hot Process of the 90's-Condition Based Maintenance
2. Warehouse Automation

**1995**

1. Warranty and Reliability Man-agement
2. Railroad Industry Group (RIG) Exchange Standard for Parts Catalog Information

**1994**

1. Material Consignment
2. The Next Step in Electronic Information Management - Interactive Technical Manuals.
3. Electronic Catalog Alternatives.

**1993**

1. Technology Transfer
2. Electronic Cataloging from a Material Perspective
3. Computerized Reordering from the Mechanical Employee's Point of View
4. Electronic Catalogues: OEM /Supplier Point of View

**1992**

1. Warranty Overview and Issues
2. Recycling - 1992
3. Bar Coding
4. Material Packaging

**1991**

1. The World of Recycling
2. Problems with Solution
3. Problems with Opportunities

**1990**

1. Waste Minimization.

2. Hazardous Materials End Cost
3. The Role of the Suppliers

1989

1. Packaging and Containerization for Today's Railroad.
2. Innovations in Material Distribution Resulting from Shop Consolidations.
3. Outsourcing! Does Anyone Really Understand the Difference Between UTEX and Repair and Return and the Affect on the Budget?
4. "Stuff" Happens! - A Skit About the Necessity of Feedback from Suppliers - Suppliers to the end User

1988

1. Communication - The Vital Link in Materials Acquisition
2. Quality Assurance Through Communications and Feed-back
3. Paperless Requisitions
4. A Practical Application of Bar Coding in the Railroad Industry

1987

1. Suppliers Selection for Component Failure Analysis
2. Vendor Performance or Service Level
3. Bar Codes
4. Bar Coding - Railroads
5. Material Handling Innovations by the Airline Industry

1986

1. The In-House Electronic Re-quisition System
2. Electronic Data Interchange.
3. RAILING and Electronic Pur-chasing
4. Quality Evaluation of Material Sourcing Decisions

1985

1. Evaluating Locomotive Maintenance Projects
2. Reconditioning Material: In-House vs. Vendo
3. Identification and Disposition of Surplus Material
4. Cost of Carrying Surplus
5. Evolution and Future Directions of Material Handling Equipment in Railroad Use

1984

1. Bar Coding of Material
2. Forecasting Material Requirements
3. a. Fuel Security - Are You Getting What You Pay For?
   b. Fuel Oil Is Expensive
4. Pros and Cons of Material Purchasing Contracts (Single Source - Just In Time Inventory)

1983

1. Improved Locomotive Produc-tivity Through Computerized Dat
2. Inbound Material Inspection
3. Minimize Maintenance Cost Through Material Management Systems
4. New Ideas In Material Storage Containers

1982

1. Use of kits in locomotive maintenance
2. Cost effective methods of shipping material from vendors.
3. Union Pacific's Component Inventory Maintenance System (CIMS).
4. Advantages of using shipping containers

1981

1. Disposal of Unserviceable Component Parts: What is the Most Profitable Method?
2. Innovations in Stores Material Handling, Via Computer

Technology

3. Locomotive Held for Material: an Update for the 80's
4. The Best Approach to Procuring

Material; New, UTEX, Repair and Return or Shop Repair

## SHOP EQUIPMENT AND PROCESSES COMMITTEE
## TWENTY-SIX YEAR INDEX

**2007**

1. Evolution and Improvements in Locomomtive Rerailing Cranes

**2006**

1. Wheel Gauge Technology
2. Train Washing
3. EnvironmentalRailroad Containment Products

**2005**

1. Mobiturn Wheel Truing Services

**2004**

1. Under the Hook Lifting Devices
2. Sanding in the Railroad Industry-Part III - A Gentle Answer for an Abrasive Situation

**2003**

1. Locomotive Shop Support Systems and Equipment
2. Hand Tools - An Ergonomic Update
3. Locomotive Lifting Systems

**2002**

1. NOTE: PAPER ON LIFTING SYSTEMS WAS PRESENTED BY RON BEGIER OF PORTEC AT THE 2002 CONVENTION; HOWEVER IT DID NOT APPEAR IN PUBLICATION - WILL APPEAR IN THE 2003 PROCEEDINGS PUBLICATION

**2001**

1. Standing in Railroad Industries - Part II - How to Specify Reliable and Safe Sanding Systems

**2000**

1. The Tandem Wheel Truing Machine at Amtrak's Ivy Shop
2. Shop Talk 2000: Fall Protection Technology
3. Sanding in the Railroad Industry

**1999**

1. Increasing Diesel Shop Capacity
2. Conrail-Cold Asphalt Processing of Environmental Waste Sand and Sludge
3. Dry Ice Cleaning of GE Intake Ports
4. AAR-LFIS No Spill Fueling System

**1998**

1. Smoke Opacity Testing-Emission Detection Equipment and its Use
2. Hydraulic Tensioning Tools and its Use
3. High Speed Portable Align Boring Series
4. Locomotive Mobile Servicing

**1997**

1. Wheel Truing as Preventive Maintenance
2. Conrail-Selkirk Diesel Terminal Wastewater Treatment Facility Recent Evnironmental Improvements

**1996**

1. Locomotive Painting
2. Drop Table Tooling for New EMD and GE Locomotives

**1995**

1. Pre-Maintenance Inspection
2. Railroad Turntable Modification
3. Mobile Locomotive Service Vehicle

**1994**

1. Electronic Fuel/Unit Injection Tooling.
2. Locomotive Roller Support Bearing Tooling.
3. Fall Protection and Man Lifts.
4. Locomotive Washing Systems.

**1993**

1. Dynamic Balancing for GE Dash 8 Model Locomotives
2. Air Compressor Automated Station
3. Ergonomics in the Work Place
4. Hydraulic Traction Motor Shimming Table

**1992**

1. Automated Test and Production Equipment
2. Safety Corrective Action Team

3. Automated Locomotive Wheel Shop
4. Cleaning and Surface Pre-paration with Sodium Bicar-bonate Based Abrasive Blasting
5. Trainline Continuity Tester
6. BN - Railroad Power Assembly Shop of the 1990's

**1991**

1. Economic Separation of Emulsified Oil from Waste Water Using Ultra Filtration Membranes
2. EMD Cylinder Head Valve Seat Machining
3. Automated Barring Over Machine for EMD Diesel Engines
4. New Equipment for Testing EMD Engine Protectors
5. Compressed Air for Railroad Facilities Issues and Solutions to Achieve Clean, Dry, Oil Free Air

**1990**

1. EMD Valve Bridge Machine
2. GE Traction Motor Roller Suspension Bearing Replace-ment Equipment and Pro-cedure.
3. Locomotive Component Re-placement Forklift Attachment.
4. Locomotive Sanding, Fueling and Drop Tables.
5. Hazardous Waste Disposal

**1989**

1. Automated Locomotive Wheel Shop
2. Laser Guided Material Handling Vehicles
3. Bulk Rail Lubrication Storage & Fill Systems
4. Pilot Plate Straightening Equip-ment

**1988**

1. Fuel Management Control Systems
2. Locomotive Mounted Rail Lubrication Fill Systems.
3. Comparison of Shop Air Compressors
4. Locomotive Toilet Servicing Equipment
5. Innovations in Blue Flag and Derail Protection

**1987**

1. Modern Servicing Facility for Improved Reliability and Availability
2. New Developments in GE Tools.
3. Implementation of a Quality Process
4. A Quality Traction Motor Shop.
5. Wheel Truing Machine Tech-nology

**1986**

1. Robotics Update 1986 - Now What?
2. CNC Machine Tools
3. A New GE Power Assembly Area
4. Locomotive Wash System - 1986

**1985**

1. Computer-Assisted Preventative Maintenance
2. New Tools for Material Handling and Overview of Balancing Technology
3. Effect of Governmental Re-gula-tions on Locomotive Finishing

**1984**

1. Shop Tools.
   A. New Tools
   B. Shop-Made Tools
2. Traction Motor Shop Equipment Up-Date
3. Hazardous Waste Handling and Disposal

**1983**

1. Locomotive Maintenance Using a Production Line Process
2. Shop Tools to Increase Productivity and Improve Quality.
3. Dynamic On-Line Performance of Locomotives Without On-Board Tele-Metering
4. Management in Action
5. New GE Training Cente
6. Welding Qualifications

**1982**

1. Tools
2. Rebuild line for EMD turbocharg-ers
3. Air brake equipment line
4. Industrial robots

5. Automated machines
6. Safety related items and equipment

### 1981

1. Training Aids.
2. Testing Devices Inspired by New FRA Laws
3. Tools and Training for Pro-ductivity
4. Changes to Shop Facilities Required by Newly Adopted EPA & OSHA Regulations
5. Tour through Conrail Altoona Shop
6. Supply/Service Facilities
7. GE Assembly Shop

## DIESEL ELECTRICAL MAINTENANCE COMMITTEE TWENTY-SIX YEAR INDEX

1. Review of Battery Maintenance and Available Options
2. Battery Charger/Booster
3. Locomotive System Integration
4. Electronic Governors

**1996**

1. EMD SD80MAC High Voltage Safety
2. GE AC Locomotive Electrical Safety Features
3. Electromagnetic Interference (EMI on AC Locomotives)
4. QTRAC 1000 Adhesion Control System
5. Locomotive Health Monitoring-The Key to Improved Main-tenance

**1995**

1. Canadian National Battery Water Usage
2. Remote Diagnostics-Radio Download
3. Programmed Preventive Maintenance
4. Commutation Monitoring in Locomotive DC Traction Motors
5. The EMD Diesel Engine Control (EMDEC) System

**1994**

1. Safety First - Video on Electrical Safety
2. Locomotive Health Monitoring Systems
3. Event Recorder Update
4. SD60 Dynamic Brake Improvements

**1993**

1. Automatic Engine Shutdown and Restart System
2. Layover Systems/Standby Power Systems
3. CN North America - Electronic Temperature Control
4. Speed Sensing Devices
5. Adhesion Alternative
6. Modern Tooling Update

**1992**

1. Nickel-Cadmium Batteries as an Alternative
2. Overview of Locomotive Microprocessor Based Controls
3. Locomotive Air Conditioning
4. Testing Traction Alternator Fields on EMD Locomotives
5. Flange Lubricators

**1991**

1. Locomotive Rebuilding - Something Old - Something New. Standardization of Elec-trical Equipment
2. Locomotive Batteries
   a. Storage Handling Proced-ures
   b. Recommended Maintenance Procedures
   c. Recommended Repair Procedures
3. Amtrak's AC Traction Locomotives
4. Modern Tooling for Electricians Recorders
3. Why Can't We Have One Central Computer?
4. EPA and Regulation Driven Cleaning

**1990**

1. Modern Tooling of Electrical Troubleshooting
2. Maintaining Solid State Event Recorders
3. Why Can't We Have One Central Computer?
4. EPA and Regulation Driven Cleaning

**1989**

1. Modern Tooling for the Troubleshooting Electrician: a) test meters available (single function); b) test meters available (multiple functional); c) analysis and diagnostic tools
2. Sound Electrical Repairs and Practices for: a) traction motors; b) grids and fans; c) wire and cable solderless termination
3. Guidelines for Preparing Electricians for the 1990s

**1988**

1. Utilizing Magnetic Tape Event Recorders for Locomotive Maintenance
2. Solid State Locomotive Data Recorder
3. Improved Utilization of GE DASH 8 Data Recording Systems
4. Locomotive Health Data and Its

Uses To The Railroad
5. Improved Data Acquisition From EMD's 60 Series Display Computer

**1987**

1. Proper Maintenance of Electrical Fuel Savings Options
2. Preliminary Report on AAR Traction Motor Study

**1986**

1. Cleaning, Handling & Storage of Electrical Equipment
   A. Solid State Components
   B. Rotating Equipment
2. Qualification of Locomotive Power plants through self load

**1985**

1. Locomotive Microprocessor Technology in Retrospect
2. Dynamic Brake Protective devices and Troubleshooting EMD-2 and GE-7 Locomotives
3. Indicators and Recorders for Locomotive Retrofit Application - Fuel, Speed, Power and Selected Events

**1984**

1. On-Board Diagnostics
2. GE's **CATS** (Computer Aided Troubleshooting System)
3. Fuel Conservation Through
4. Electrical Modifications
5. Performance of Locomotives After Storage

**1983**

1. Ground Relay Trouble Shooting
2. Specification for remanu-factured D87 Traction Motor Frames (Using D-77 Armature Coils)
3. Locomotive Storage (Electrical)
4. Water Cooling and Refrigerating Methods for Locomotive Cab Application

**1982**

1. Tests on Traction Motors
2. Transition Trouble-Shooting
3. Onboard Diagnostic Systems
4. Starting Systems

**1981**

1. Evaluation of Improved Test Methods
2. Teflon Bands
3. New Generation Locomotives
4. Electrical Troubleshooting
5. Batteries and Charging Systems
6. Troubleshooting EMD AC Auxiliary Generator System
7. Selection of Locomotives for Major Locomotive Overhauls

## NEW TECHNOLOGIES COMMITTEE
## TWENTY-FOUR YEAR INDEX

### 2007
1. Fuelcell Hybrid Switcher Locomotive: Engineering Design
2. Locomotive Digital Video Recorder
3. CN Distributed Braking Car

### 2006
1. Variable Hybridity Fuelcell-Battery Road Switcher
2. GE Transportation-Hybrid Freight Locomotive
3. Dynamic Brake Status Reporting

### 2005
1. PL42AC Locomotive-Overview
2. Fuel Cell Locomotives
3. Locomotive Electric Hand-brake Systems

### 2004
1. GE Evolution Locomotive - An Overview
2. EMD SD70Ace Locomotive-Reliability for 2005 and Beyond
3. Get Them into Condition: Condition Based Traction Motor Reliability
4. Making the Switch - An Update on the EMD GP20D/GP15D Switcher Locomotive
5. "Fuel Proof Tank Repairs" - A Best Practice for your Locomotives

### 2003
1. New MPXPRESS Commuter Locomotive Models MP 36PH-3S & MP36PH-3C
2. The Green Goat Hybrid Locomotive
3. Observation on Auto Engine Start/Stop

### 2002
1. On Board Rider - A Remote Locomotive Condition Monitoring System
2. Cool Your Jets: A Low Cost High Performance Rooftop Air Conditioner

### 2001
1. Performance and Economic Aspects of Various Environmentally Friendly Coatings for Rolling Rail Equipment
2. Non-destructive Testing: Crack Detection Technology - EMFaCIS

### 2000
1. FIRE: EMD Turns up the Heat on Railroad Electronics Integration
2. Put the Chill on Air Condition-ing Costs
3. Do Not Get "Steamed" Over Fuel Tank Repairs
4. Industry Responses to Emission Regulations
5. Improved Adhesion Through the Use of Individual Axle Inverters

### 1999
1. Locomotive Filteration-Where are We Going?
2. EMD Markets a New Line of Switchers

### 1998
1. Expert Systems
2. EMD SD90MAC 6000 HP Locomotive - Where Are We Today? GE AC6000CW Locomotive - Where Are We Today?

### 1997
1. An Overview of the Electro-pneu matic Train Brake
2. Locomotive 6724, Where Are You? GPS, Mobile Telemetry and GIS Technologies in a Railroad Environment
3. Runout Measurement Using Non-Contact Sensor Tech-nology
4. Common Rail Fuel Injection

### 1996
1. Activities Toward New Safety Standards for Passenger Equipment
2. SP-3 Thin Sensor Technology for Variable Force Measurement
3. Top-Of-Rail Lubrication
4. Traction Motor Vibration and its

Effects

**1995**

1. Beltpack Locomotive Control System
2. The MK1200G Switching Locomotive
3. Advanced Traction Motor Testing

**1994**

1. Electronic Fuel Injection Sys-tems.
2. Status of Distributed Power in Freight Trains.
3. Advances in Distributed Power-Iron Highway.

**1993**

1. New Technology to Solve Old Problems
2. Developments in Off-Shore Technology
3. Updates on AC Traction Developments

**1992**

1. Talking to the "Smart' Locomotive
2. Cab Noise Abatement
3. Electronic Management of Locomotive Drawings
4. Update on High Productivity Integral trains
5. AC Traction - A New Development

**1991**

1. Locomotive Cab Integration and Accessory Management
2. Improvements in Locomotive Adhesion Performance
3. The Role of Duty cycles in Locomotive Fuel Consumption.
4. What's New in Gadgets and Black Boxes: What do our Locomotives Really Need?
5. Failure Analysis

**1990**

1. Motor Driven Air Compressors for Diesel-Electric Locomotives
2. Locomotive Cab (HVAC) Heating, Ventilation and Air Conditioning Systems
3. Effect of Technology on Standardization of Cab Control Equipment
4. Locomotive Durability, Reliability and Availability - Understanding Your Abilities

**1989**

1. A Rational Approach to Testing Locomotive Components
2. New Developments in Locomotive Cab Design

**1988**

1. Amtrak F69 PH AC Passenger Locomotives
2. New Component Develop-ments Retrofittable to Older Model Locomotives
3. Locomotive Applications of Catepillar Engines
4. Wheelslip Control for Individual Axles

**1987**

1. Electronic Fuel Injection Sys-tems
2. Update on Electronic Gover-nors
3. Recent Advances in Steerable Locomotive Trucks - the E.M.D. 4 Axle, 4 Motor HT-BB Articulated Truck
4. Converting an F40 Locomotive to A.C. Traction

**1986**

1. Future Train Control Systems
2. Bringing Future Train Control Systems Back to Earth
3. Low Maintenance Locomotive Batteries
4. Electronic Engine Control Systems

**1985**

1. The Sprague Clutch for E.M.D. Turbocharged Engines

2. A.C. Traction Locomotives Update
3. Natural Gas Locomotive Update
4. Ceramic Coated Engine Components
4. Locomotive Cab Develop-ments

**1984**

1. G.E. Dash 8 Locomotives
2. E.M.D. 50A Series Locomotives
3. Natural Gas Locomotives
4. Appraisal of the A.C. Traction Locomotive

**1983**

1. Microprocessors for Locomotive Control and Self Diagnosis.
2. Locomotive Fuel Tank Gauges
3. Locomotive Aerodynamics
4. Bombardier HR 616 Locomotive
5. Missouri Pacific - Phase III Locomotive Heavy Repair Facility, N. Little Rock, Arkansas

## FUEL, LUBRICANTS AND ENVIRONMENTAL COMMITTEE TWENTY-SIX YEAR INDEX

**2007**

1. Automatic Self-Cleaning Lube Oil Filters and Centrifuges
2. Diesel Fuel 2007 and Beyond - What will be in Your Tanks?

**2006**

1. Fuel Additives-A Possible Method to Reduce Fuel Consumption in Railroad Diesel Locomotives

**2005**

1. Engine Oil 202 - Refined Base Oils and their Importance in Lubrication
2. Biodiesel - A Potential Fuel Source for Locomotives

**2004**

1. Discussion of the LMOA Fuels, Lubricants and Environmental Committee Pentane Insolubles Procedures Revision 4
2. Engine Oil 101 - Viscosity and Additives
3. Used Oil Analytical Results, What do they Mean, How to Interpret the Results and How do you Respond?

**2003**

1. Laboratory Results May Put Your Locomotive at Risk
2. Top of Rail Friction Modification Studies on the BNSF

**2002**

1. Improved Generation 5 Lubricant Provides Potential for Extended Lube Oil Filter Life
2. Corrosion Protection of Locomotive Cooling Systems

**2001**

1. On-Board Oil Management System
2. Evaluation of Locomotive Engine Oil Analytical Laboratories
3. Fuel Additives - Friend or Foe

**2000**

1. Biodegradability and its Relevance to Railroad Lubricants and Fluids
2. Engine Lubricating Oil Evalua-tion Field Test Procedure
3. Detecting Abnormal Wear of AC Traction Motor, Pinion End, Armature Bearings Through Lubricant Wear Debris Analysis
4. Further Development in Top-of-Rail Lubrication Testing

**1999**

1. Lube Oil Analysis-Achieving Quality Results
2. Effects of Engine Lubricants on Oil Filtration
3. Recycling and Re-refining of Used Lubricated Oils

**1998**

1. Safety and Chemical Cleaners
2. Development of a Low Emissions, Dual Fuel Locomotive
3. Fuel Oil Stability Update
4. Ten Questions on EPA's Locomotive Exhaust & Emission Regulations

**1997**

1. Ferrography-Used Oil Analysis Program
2. 2000 - A New Millennium for Locomotive Maintenance: EPA Exhaust Emissions Regulatory Impacts
3. Standardized Test Procedures - Current Developments
4. Industry Updates and New Developments

**1996**

1. Standardized Test Procedures-The Annual Subcommittee Update
2. Diesel Fuel Standards and their Applications to Railroad Fuel Quality Issues
3. A Look at Generation 5 Oil Performance and Future Oil Needs
4. LNG as a Railroad Fuel

**1995**

1. MSDS'S - What do they tell us?
2. Applying Satellite Communications Technology to On-Line Oil Analysis of Crankcase Diesel Engine Lubricants
3. Standardized Test Procedures -

Past, Present & Future Developments
4. Locomotive Exhaust Emissions Regulations

**1994**

1. TBN-A Review of Currently Accepted Methods.
2. GE Multigrade Lubricating Oil Testing and Specification.
3. The Economic Impact of Low-Sulfur Diesel Requirements.

**1993**

1. Used Oil Analysis of Multigrade Oils and Condemning Limits.
2. Insoluble Determination with the Advent of Multigrade Diesel Engine Oils
3. Bioremediation

**1992**

1. Environmental Issues Relating to Multigrade Railway Issues
2. Readily Biodegradable and Low Toxicity Railroad Track Lubri-cants
3. Support Bearing Oils
4. Recycling and Re-refining Locomotive Oils

**1991**

1. Infrared Spectroscopy as an Analytical Tool
2. Diesel Exhaust: Health Effects Research and Regulations
3. Traction Motor Gear Case Seals and Lube Containment (Oil Lubricant)
4. Partnership in Development

**1990**

1. The Responsibility of Railroads and Facility Managers in the Handling and Disposal of Hazardous Materials
2. Update on Diesel Fuel Regulations
3. Diesel Exhaust and Worker Exposure
4. Field Experiences with Multigrade Railroad Locomotive Oils.
5. Conrail Wheel/Rail Lubrication Update

**1989**

1. Field Test Data Follow-Up and Description of "Generation 5" Locomotive Crankcase Oil
2. Diesel Emissions: Regulations and Fuel Quality
3. Petroleum Storage Tank Regulations - Guest Speaker - George Kitchen, International Lube & Fuel Consultants

**1988**

1. Used Oil Analysis and Condemning Limits
2. Review of A.A.R. Procedure RP - 503, "Locomotive Diesel Fuel Additive Evaluation Procedure"
3. Update on Improved Oils - Multigrade
4. Wheel Flange Lubrication Update - Lubricants Being Used
5. Survey of Disposable Practices or Locomotive Engine Lube Oil and Lube Oil Filters
6. Speaker on Overview of Environmental Requirements for The Use of Petroleum Products in The Railroad Industry - Peter Conlon - AAR

**1987**

1. Common Fuel Additives and their Effectiveness
2. History of LMOA Lubricating Oil Classification System
3. Performance Requirements Needed by the Railroads for a New Generation Lube Oil
4. How do we Provide the Performance Needed for a New Generation Oil

**1986**

1. Extended Performance Lubricants Through Better Chemistry
2. Fuels and Lubricants Handling Hygiene
3. Fuels Availability and Price Outlook
4. Selection of Lubricants for Wheel Flange and Rail Lubricators

**1985**

1. Disposal of Lube Oil Drainings
2. Non-ASTM No. 2 - D Fuel
3. Oxidation Analysis
4. Wheel Flange and Rail Lubrication

### 1984

1. Locomotive Filters
2. Traction Motor Gear Lube Field Test

### 1983

1. Field Test Update of Multigrade Oils
2. Update of Alternate Fuel Testing
3. A Review of Locomotive Fuels

### 1982

1. Energy Conserving Lube Oils
2. Alternative Fuels Update
3. Availability of Medium and High Viscosity Index Railroad Oils
4. Journal Box Oil and Aniline Point.
5. Traction Motor Gear Lubricant Update
6. Traction Motor Gear Case Seals

### 1981

1. Effects of Using Alternate Fuels on Existing Diesel Engines
2. Update on Cold Weather Procedures for Fuels
3. New Techniques in Lube Oil Analysis
4. Traction Motor Gear Lubri-cation.
5. Multi-Viscosity Oils as an Energy Conservation Technique

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