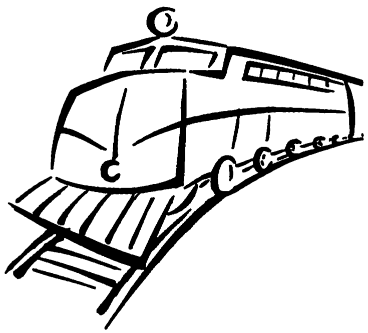
LMOA

Locomotive Maintenance Officers Association



Proceedings of the 71st Annual Meeting

September 16 - 18, 2009

Chicago Hilton & Towers

720 S. Michigan Ave.

Chicago, Illinois

2009 ADVERTISERS INDEX

LOCOMOTIVE MAINTENANCE OFFICERS ASSOCIATION

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Be sure to read their ads in the Annual Publication.

INDEX

2008 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 2008.

Name	Committee
Steve Fritz	Fuel, Lubricants & Environmental
John Hedrick	Diesel Mechanical Maintenance
Chris Mainz	Diesel Material Control
Bill Peterman	Shop Equipment and Processes
Randall Slomski	Diesel Electrical Maintenance
Tad Volkmann	New Technologies

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
TO THE NORFOLK SOUTHERN AND ESPECIALLY
TO DON FAULKNER AND HIS STAFF FOR
HOSTING OUR ANNUAL JOINT TECHNICAL
COMMITTEE MEETING IN
ALTOONA, PENNSYLVANIA ON
MAY 4TH AND 5TH, 2009
DON TOOK TIME OUT OF HIS BUSY
SCHEDULE TO CONDUCT SHOP TOURS OF
THE JUNIATA SHOPS
THANK YOU VERY MUCH, DON**

**WE ALSO WISH TO THANK LARRY CONRAD
OF BROOKVILLE EQUIPMENT CORPORATION
IN BROOKVILLE, PENNSYLVANIA FOR
TAKING MEMBERS OF THE LMOA COMMITTEE
ON A SHOP TOUR OF THEIR FACILITY**

**RICK ORTYL OF METRO EAST AND
BRIAN MARTY OF HELM HOSTED LUNCHES
FOR THE LMOA COMMITTEES ON
MAY 4TH AND 5TH IN ALTOONA -
WE APPRECIATE THEIR CONTINUED SUPPORT**

LMOA ALSO WISHES TO EXPRESS THEIR
DEEP GRATITUDE TO
DWIGHT BEEBE
OF TEMPLE ENGINEERING
FOR AGAIN HOSTING
THE LMOA LUNCHEON ON
TUESDAY, SEPTEMBER 23, 2008
DURING THE ANNUAL CONVENTION
AT THE CHICAGO HILTON AND TOWERS.

THANK YOU VERY MUCH, DWIGHT.

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
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1992 - K. ALLEN KELLER, Retired, Supt. Loco. Maint., Reading, R.R., 241 E. Chestnut, Cleona, PA 17042
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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
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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, Sr. Mech. Supvr., CN Rwy. Gary, IN 46402
2007- LES WHITE, Technical Sales Rep., Bach-Simpson London, Ontario N4W 2C2
2008- MIKE SCARINGE, Director-Locos., Amtrak Beech Grove, IN 46109

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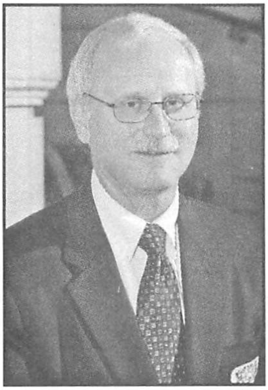
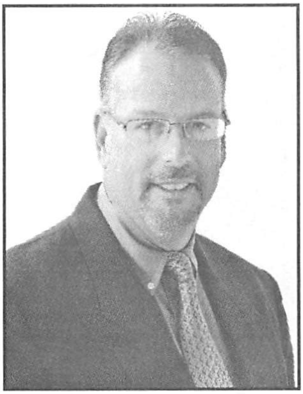
OUR OFFICERS



Our President
MR. DENNIS NOTT
Northwestern Consulting, LLC
Boise, ID 83703



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MR. MIKE SCARINGE
Director-Locomotives
Amtrak
Beech Grove, IN 46107

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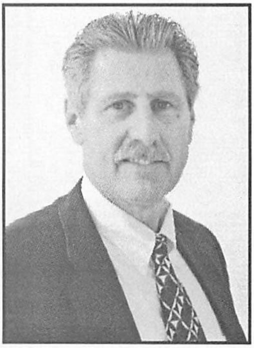
MR. BOB REYNOLDS
Sales Rep.
Amglo Kemlite Laboratories
Calgary, Alberta T2Y 2V8



2nd Vice President
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Senior Director Business Development and Sales
Graham White Manufacturing
Jacksonville, FL 32259

3rd Vice President
MR. GLENN BOWEN
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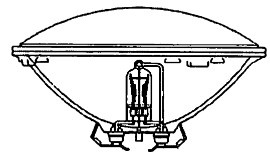

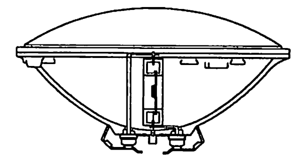

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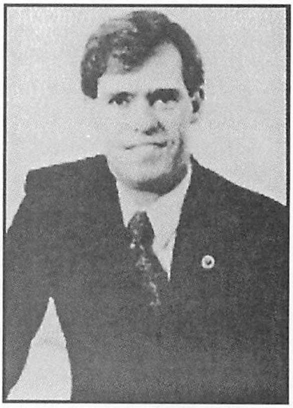
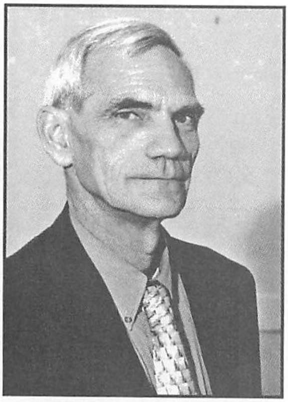
MR. MARK COLES
Senior Manager
Engineering & Quality
Union Pacific Railroad
Omaha, NE 68179



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



MR. BRIAN HATHAWAY
Consultant
Port Orange, FL 32129

MR. BRUCE KEHE
Senior Mechanical Supervisor
Canadian National Rwy.
Gary, IN 46402

OUR PAST PRESIDENTS

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

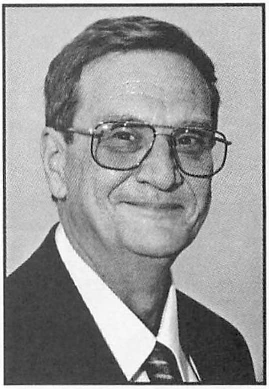
MR. H.H (MIKE) PENNELL
Ellcon National
Keller, TX 76248

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

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

OUR PAST PRESIDENTS

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



MR. LES WHITE
Application Engineer
Bach Simpson
St. Hubert, Quebec J3Y 6J1

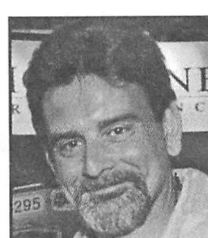
OUR REGIONAL EXECUTIVES

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

MR. BOB HARVILLA
Asst. VP - Regional Sales
Power Rail Distribution
Duryea, PA

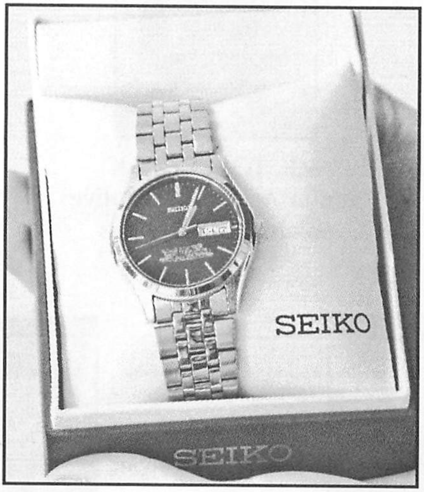
MR. TOM PYZIAK
Senior Account Executive
Safety-Kleen Systems
Palatine, IL

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



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

Picture of Past President's Pin.



Picture of LMOA watch given to outgoing President.

Outgoing President Mike Scaringe, Amtrak, presents gavel to newly elected President Dennis Nott, Northwestern Consulting. Past President Les White, Bach Simpson, looks on.

Past President Bob Runyon presents watch to outgoing President Mike Scaringe, Amtrak. Past President Tad Volkmann, Union Pacific, attended the ceremony.

Newly elected 3rd VP Glenn Bowen, BNSF, presents attache bag to new Chairman of the Fuel, Lubricants and Environmental Committee, Bob Dittmeier, Afton Chemical, as newly installed Regional Executive Tom Pyziak, Safety-Kleen, looks on.

Past President, Tad Volkmann, Union Pacific, presents Past President's Pin to outgoing President, Mike Scaringe, Amtrak. Ceremony was witnessed by Past President Les White (far left), Bach Simpson, Past President Bob Runyon (far right), and Past President Bruce Kehe, Canadian National.

Past President Bruce Kehe, Canadian National, presents LMOA blazer to newly elected 3rd VP Glenn Bowen of the BNSF. Newly elected 1st VP, Bob Reynolds, Amglo Kemlite Laboratories, looks on.

LMOA Executive Board - seated (left to right) - Outgoing Past President Mike Scaringe, Amtrak; newly elected President Dennis Nott, Northwestern Consulting; Past President Tad Volkmann, Union Pacific; Past President Bob Runyon - standing (left to right) - Past President Bruce Kehe, Canadian National; newly elected 2nd VP Glenn Bowen, BNSF; Secretary Treasurer Ron Pondel; Past President Les White, Bach Simpson; newly elected 1st VP Bob Reynolds, Amglo Kemlite Laboratories; and newly elected 2nd VP, Jack Kuhns, Graham White Manufacturing.

STATE OF THE UNION SPEECH
President Michael Scaringe
September 22, 2008

Mr. Chairman, members of the Executive Committee, Mr. Secretary-Treasurer, fellow members and honored guests.

Good afternoon and welcome to the 70th annual meeting and conference of the Locomotive Maintenance Officer's Association. My name is Michael Scaringe, Director of diesel locomotives for Amtrak and President of the LMOA. I would like to personally thank everyone for taking the time to support the LMOA by attending this year's conference and technical presentations.

The LMOA has faced many challenges over the past several years; loss of financial backing for non exhibit years, decline in membership, and rising energy costs that have caused the companies to put financial restraints on travel. The LMOA continues to push the envelope on overcoming these adversities by strategically developing alliances with railroads, suppliers and new organizations.

This year the LMOA Executive Committee reached out to form a new alliance with an old supporter, the "American Short Line and Regional Railroad Association." The LMOA Executive Committee and representatives from the Diesel Mechanical Committee and the New Technology Committee attended the American Short Line and Regional Railroad Association's 95th annual convention in San Antonio, Texas in May of 2008. The LMOA presented technical papers during the convention. The paper given by Jeff Cutright from Norfolk Southern on the new Federal Railroad's Administration's, (CFR) Code of Federal Regulations 49 Part 229.129 "Horn Rule," will be the first in a series that will be distributed to the American Short Line and Regional Railroad Association's members via their "Tech Tracks" technical papers.

This new alliance will hopefully foster a long term partnership between the two groups by providing technical papers on best practices and new technology on locomotive topics in the future. I would like to thank Jack Kuhns of Graham White Manufacturing Company for all his hard work in coordinating this partnership between the two organizations.

The LMOA will continue to have their next two annual conventions in 2009 and 2010 in Chicago, however due to cost cutting measures the 2011 annual convention will move to Minneapolis.

I have full faith in the commitment and leadership of the LMOA executive committee and our regional executives to preserve the future of the LMOA.

In May of 2008, the LMOA held our joint technical committee meetings in San Antonio, Texas. I wish to extend the gratitude of the LMOA to the Southwest Research Institute Center and specifically to John Hendrick of Southwest Research Institute for sponsoring and coordinating the plant tours and meeting rooms. I would like to give a special thanks to Dennis Nott, Northwestern Consulting for coordinating and finalizing the arrangements for our well-attended joint technical committee meetings at Southwest Research Institute. In addition I would like to thank all of the railroads and suppliers who have hosted our individual committee meetings during the past year and continue to support the LMOA. I would also like to thank the suppliers who place ads in the Annual Meeting book. Without their support, the printing of it would not be financially possible. Without the continuing support of the supplier industry, the LMOA could not survive.

On a personal note I would like to thank Ron Pondel. Without his help and the commitment, this year would not have been possible. I would also like to thank my employer, Amtrak, for allowing me to be an active participant in the LMOA for the past 25 years.

I want to thank you and the LMOA again for the opportunity to serve as your President of the LMOA in 2008.

Editor's Note: There is a possibility that the 2010 convention may be held in a location other than Chicago.

ACCEPTANCE SPEECH
Dennis Nott
Tuesday, September 23, 2008

Ladies and Gentlemen, Mr. Chairman, members of the Executive Committee, Mr. Secretary-Treasurer, and fellow LMOA Members,:

I am indeed honored to assume the responsibilities of this great organization that had its first meetings in 1939.

Over the years I have seen many changes and challenges that have affected our railroad industry, locomotives and our organization. Some were driven by mergers and consolidations, others by the need to be more productive, safe and cost effective and, of course, those driven by legislation or the AAR. The LMOA, if nothing else, has been on the cutting edge for all of these challenges and changes.

Every year the LMOA brings to the table the latest developments that affect our world of locomotives. This includes, but is not limited to, new locomotive technology, the latest information on regulations such as emissions requirements and horn testing requirements; the latest developments in fuel and lubricating oils; the latest developments in shop equipment, locomotive maintenance and purchasing/material handling techniques; and last, but not least, papers that address the best way to perform a locomotive maintenance task that we at the LMOA like to call "Best Practices."

This year was no different.

Of the eighteen papers presented there were four papers that had content relating directly or indirectly to locomotive emissions; one paper that covered new locomotive propulsion development; one paper that updated progress on RP 503; two that covered maintenance on the new Gen-Set switchers, six that covered locomotive maintenance issues; one that covered electrical safety issues; one that covered the ins and outs of shop design; and two that covered new material management concepts.

I ask you, where else, but the LMOA, can anyone involved in locomotives go to get such a diversified update on what the latest developments are; how to do locomotive maintenance the best way; how to work safely; or get a layman's view of the latest regulations?

That pretty well sums up the "why" of the LMOA and brings me to the topic of challenges.

As Mr. Scaringe pointed out in his State of the Union address the LMOA has faced many challenges over the past few years and has some new ones on the horizon.

With respect to support from RSI, the LMOA has been informed that the RSI will be reinstating their support of the Coordinated Associations for the non-exhibit years. We at the LMOA, as well as the other three members of the Coordinated Association, are very appreciative of this news and the continued support from the RSI, particularly since the next two years will be non-exhibit years and are transitional years for the move to the "big" outdoor exhibit in Minneapolis in 2011.

Speaking of the next two non-exhibit years, it seems it is always difficult to get participation in the annual meetings in non-exhibit years. I would encourage the LMOA membership, the employers who support our Committee Members and the sponsors that host our Committee and Joint Committee Meetings to continue their support of the organization through the next two years as if they were exhibit years. While plans have not been finalized for the next two years, I'm sure there will be some discussion within the Coordinated Associations regarding table top displays; and if table top displays are on the agenda, I would hope that our suppliers will participate as they have in the past non-exhibit years. Editor's note: Approximately 70 suppliers will display their products and services at the 2009 convention.

Mr. Scaringe also noted that the LMOA has formed an alliance with the "American Short Line and Regional Railroad Association" and the LMOA will be providing information on "Best Practices," new technology, regulation changes and other locomotive maintenance topics for their "Tech Tracks" publication. This has been an important step for the LMOA as, with the consolidation and mergers of the Class 1 railroads, the short line and regional railroads now outnumber the Class 1 railroads by about 100 to 1. The LMOA has recognized that the short line and regional railroads are a large audience within the railroad industry and we are confident that the information and networking that the LMOA can offer them will be to their benefit.

While we have recognized that the short lines and regional are becoming a bigger part of the audience, we do not want to forget the Class 1 railroads and their contribution to the LMOA as a source of Committee members and information. After all, the Class 1 Railroaders are truly the ones on the firing line when it comes to new locomotive development. Our goal would be to have more Class 1 railroad Committee members and I would like to encourage the Class 1 railroad management to recognize the technical and networking benefits that your employee will bring back to the office if they join a LMOA Committee.

The LMOA would also like to hear more from you, the audience, regarding new topics for papers. Each year each Committee sets their agenda for papers at this time. If you have a burning issue that you would like the LMOA to address, grab one of the Committee members after this session and let them know. I can't guarantee that the topic will become a paper, but we will surely consider it.

As we look to this next year and beyond, there is no doubt in my mind that there will be a host of changes that face the industry as well as the LMOA. However, there is no question in my mind that the LMOA will again be at the forefront ready to meet those challenges and I look forward to the support that I will receive from the Executive

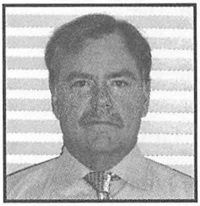
Committee, the Members of the LMOA and the supplier community to help meet those challenges over the next year.

In closing, I would like to recognize Mr. Ron Pondel who for over two decades has been the Secretary-Treasurer of the LMOA and the glue that keeps the LMOA together.

Thank you Ron, thank you ladies and gentlemen.

REPORT OF THE COMMITTEE ON FUEL, LUBRICANTS AND ENVIRONMENTAL

FRIDAY, SEPTEMBER 18, 2009 8:45 A.M.



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PERSONAL HISTORY

Bob Dittmeier

Bob Dittmeier grew up in St. Louis, Mo. and has been an employee of Afton Chemical Corporation for over 35 years. He received his education from Rockhurst College, the University of Missouri and Washington University.

His career with Afton (then called Ethyl Corporation and located in St. Louis, Mo.) started in their mechanical research department in 1973. He held various positions within the mechanical research group including managing automatic transmission fluid research testing and the gear lubricant research testing group. This involvement with gear lubricant research also included formulation and testing for gear lubricating oils that were developed and targeted for U.S. military approvals. During this timeframe he was also involved with Afton field trial activities for both gear and crankcase technologies. He transferred from mechanical research to chemical research and into customer technical service for gear oil additive technology. From that position he was promoted to technical coordinator for medium speed diesel (MSD) research. He continues with Afton's MSD group, managing the technical service aspects of this business while also directing the field research for this group.

During his many years with Afton he has been involved in the design, writing and editing of various manuals published by the Coordinating Research Council and in addition to the Locomotive Maintenance Officers Association (LMOA) Fuels, Lubricants and Environmental Committee chair he has also chaired the Society of Automotive Engineers (SAE) Technical Committee Nine which was involved with medium speed diesel engine and railroad locomotive technical issues.

He has enjoyed riding motorcycles for most of his adult life. He and his wife Barb enjoy motor racing, world travel, and are avid skiers. They currently reside in Richmond, VA.

THE FUEL, LUBRICANTS AND ENVIRONMENTAL COMMITTEE WANTS TO EXPRESS THEIR SINCERE APPRECIATION TO AMERICAN REFINING CORP AND TO DAVE TUTTLE FOR HOSTING THE COMMITTEE'S MEETING IN NOVEMBER 2008 IN BRADFORD, PA

THE COMMITTEE ALSO WANTS TO THANK AFTON CHEMICAL AND BOB DITTMEIER FOR SPONSORING THE COMMITTEE'S MEETING IN FEBRUARY 2009 IN DENVER, CO

NEW GENERATION OIL ADDITIVE TECHNOLOGY FOR ENGINES OPERATING ON LOW & ULTRA-LOW SULFUR DIESEL FUEL

Prepared by
Chevron Oronite Company, LLC

ABSTRACT

In March 2008, the Environmental Protection Agency (EPA) finalized stringent emission standards (Tier 3 and Tier 4) for locomotive and marine compression ignition engines. Fuel sulfur levels in diesel fuel consumed in locomotive, coastal and inland marine applications have been decreasing since 2006 (nominal 5,000 ppm) and are approaching 15 ppm levels which will be mandated by the EPA in 2012 for large refiners. In preparation of the issuance of these emerging regulations, locomotive engine manufacturers have redesigned their engines to address Tier 2 mandates with the capability of implementing additional modifications to effectively address the new Tier 3 and Tier 4 regulations.

Current and future changes in engine design and metallurgy may result in reducing oil consumption, and minimizing engine blow-by. Additional engine modification considerations, such as Selective Catalytic Reduction (SCR) to reduce nitrous oxide (NOx) emissions and the use of Diesel Particulate Filters (DPFs) to reduce particulate matter will impact engine oil additive technology properties and performance attributes. Concurrent with these drivers, modern railroad operations have increased locomotive efficiency and utilization which has also influenced the engine oil's stress, degradation and overall useful operating life. Greater demands on the engine oil's performance have resulted.

Given the significant changes the locomotive industry is experiencing, the development of an optimized engine oil additive chemistry specifically designed for use with low and ultra-low sulfur diesel fuels and tailored to meet the expected Tier 3 emissions control systems with special consideration for possible Tier 4 engine designs, was commissioned. This paper describes the development of a new low ash additive package formulation designed to meet these requirements in support of the expected Locomotive Maintenance Officers Association (LMOA) Generation 6 engine lubricants.

INTRODUCTION

The Generation nomenclature was adopted by the LMOA Fuels, Lubricants & Environmental (FL&E) Committee to denote a significant advance in lubrication technology. Its aim was to clearly identify a classification system for railroad lubricating oils, distinguishing major changes in oil performance from one generation to the next. Since 1940, only five generations of lubricating oil have been defined. Though performance attributes of each Generation's advancement have been associated with alkalinity as measured by the American Society of Testing and Materials (ASTM)

D2896 method, improved performance or advances in technology are not limited to alkalinity alone. Table 1 shows the transition from Generation 1 through the current LMOA Generation 5 / GE Generation 4 Long Life (4 LL).

Generation 1 was introduced in 1940 with a Base Number (BN) of less than 7 and represented lubricants as either straight mineral oils or ones with minimal additive compounding with detergents or anti-oxidants. Dispersants had not yet been developed. Many locomotive lubricants performed poorly, quickly losing alkalinity and causing lead corrosion and subsequent bearing failures. The most recent category, Generation 5 / GE 4 LL, was introduced in the mid 1980's with a typical BN of 13, 17 and 18. These oils demonstrated an overall improvement in performance, including oxidation, viscosity increase control, alkalinity control, liner and bearing corrosion, and extended oil and filter life.

During the 1990's new additive technologies were introduced to address the emergence of multigrade oil formulations, handling and disposal issues associated with engine oils containing high levels of chlorine and the introduction of new and highly effective dispersants. Individually these changes were not considered enough to warrant a classification change, but collectively they continued to improve locomotive engine oil performance.

Since the millennium, several factors have influenced the railroad industry at a rate never experienced before. There have been significant reductions in fuel sulfur levels and allowable emissions levels forcing Original Equipment Manufacturer's (OEMs) to implement hardware as well as operational changes at a time when railroads are experiencing high locomotive utilization rates. These industry trends were instrumental in establishing the development requirements of a new low ash additive chemistry for locomotives consuming low sulfur diesel (LSD) and ultra low sulfur diesel (ULSD) supporting a proposal to define a new generation of engine oils, LMOA Gen 6.

NORTH AMERICAN DIESEL FUEL TRENDS

During combustion, diesel fuel sulfur leads to the formation of sulfur oxides (SOx), which in turn react with water from combustion to form sulfuric acids which can further lead to the formation of sulfates and are detected as exhaust particulate matter. In addition to the sulfur derived particulates, soot and unburned oil are also contributors to the overall particulate emissions of a diesel engine. In an attempt to address diesel engine emissions, the use of low and ultra-low sulfur diesel fuels was mandated for the on-highway segment. During the mid-1980's, the maximum allowable sulfur per ASTM standard D975 for No. 2D diesel fuel was 5,000 ppm (0.5 percent by weight of sulfur); and the sulfur for No. 2D diesel fuel in the U.S. was typically between 0.3 and 0.4 percent. By 1994, regulation of on-highway fuel was limited to a maximum of 500 ppm (0.05 percent) sulfur, known as LSD. It followed with the phase-in of 15 ppm (0.0015 percent) sulfur maximum, ULSD which began in mid 2006 and will continue through 2010.

Class 1 railroads consume approximately 4 billion gallons of diesel fuel each year. In May 2004, as part of the Clean Air Non-road Diesel Rule, the EPA finalized new requirements for non-road diesel fuel that would decrease the allowable levels of sulfur in fuel used in locomotives by 99 percent. Lower sulfur fuels were even mandated for particulate filter testing on switchers. The specific U.S. regulations for locomotive and marine applications required large refiners and importers to use LSD by 2007. A grace period was allowed for small refiners. Table 2 summarizes the EPA Regulations for non-road diesel fuel sulfur levels.

EMISSION REGULATIONS

Medium speed diesel engines are the workhorse of the locomotive industry in North America. These engines are also utilized in industrial marine applications and for primary and emergency electrical power generation. The EPA first issued regulations in March, 1985, for the on-highway heavy-duty trucking industry. These regulations defined specific emission reductions of particulate matter (PM), and NOx. The regulations proved to have a significant and lasting effect on the design of high speed diesel engines used in this service and consequently, on the formulation of fuels and lubricants used in those engines. In addition, the California Air Resources Board (CARB) passed new diesel fuel standards in December 1988, specifically addressing fuels sold in California.

Estimates placed the railroad industry annual NOx emissions to exceed one million tons; representing 5% of the total NOx emissions from diesel engines prior to any regulations. Having addressed the on-highway / high speed diesel market beginning in the mid 1990's, it was just a matter of time before similar regulations were mandated for the railroad industry. The EPA's first ruling for locomotive engine emissions went into effect in April of 1998. The regulations encompassed three separate sets of standards, applicable depending on the original date of manufacture of the locomotive engine. Three levels of standards were defined as Tier 0, Tier 1 and Tier 2 which affected 1973 - 2001, 2002 - 2004 and 2005 - 2012 locomotive engine production model years, respectively. These regulations established standards for emissions of NOx, PM, hydrocarbon (HC), carbon monoxide (CO) and smoke opacity.

The EPA has since updated these regulations and established new exhaust emission standards which will dramatically reduce even further emissions from medium speed diesel locomotives with specific limits for line haul, switcher and passenger rail service. The new regulations are being phased in commencing in 2008 and will be fully in effect by 2015. The regulations aim to reduce PM emissions from these engines by

90% and NOx emissions by 80%. New Tier 3 emissions standards were established along with idle reduction requirements for locomotives beginning in 2012. The newly established standards also tightened emissions from existing locomotives when they are remanufactured, which will be effective as soon as certified rebuild kits are available (as early as 2008) but no later than 2010. Longer term, Tier 4 standards for newly built engines have been defined which may require catalytic after treatment technology coupled with DPFs beginning in 2015 for locomotives, and 2014 for inland marine applications. The exhaust emission standards for locomotives can be found on the EPA website, http://www.epa.gov/otaq/locomotv.htm. Tables 3 and 4 detail the specific Tier 3 and Tier 4 emissions standards for the locomotive industry.

LOCOMOTIVE UTILIZATION & ENGINE DESIGN

As noted, significant changes have occurred in the railroad industry. Railroads have implemented operation practices to enhance efficiency and increase locomotive utilization. This has resulted in longer intervals between scheduled maintenance. Until the recent economic downturn in 2008, freight movements had been on a steady rise with hundreds of new locomotives being added to Class 1 fleets to meet traffic demand.

Parallel to the increased demand and utilization of locomotives is the drive to significantly reduce emissions. The primary focus of emissions regulations is to reduce NOx emissions, and PM secondary. Unfortunately, the technology and emission strategy to reduce one tends to increase the other. Retarding injection timing lowers peak combustion temperatures resulting in reduced NOx formation. However, this leads to increased PM, CO and smoke formation along with a decrease in peak cylinder pressure resulting in lower engine efficiency.

North American railroad locomotives represent a mixture of two and four-stroke cycle engines. Four-stroke engines have traditionally utilized less engine oil than their two-stroke counterparts and have therefore been more sensitive to oil consumption changes. Typical oil consumption rates based on an oil to fuel ratio were averaging around 0.5%. With the engine lubricant being a significant contributor to PM exhaust emissions, lowering oil consumption is one method of effectively controlling the volatile and non-volatile fractions. However, lowering oil consumption not only increases residence time of the lubricant in the crankcase, but also increases insoluble levels and accelerates the rate of BN depletion and oil oxidation, thus negatively impacting oil life. Table 5 and Figures 1 through 3 detail the impact oil consumption has on insoluble formation, BN retention and oil oxidation from models developed by M. R. Logan [17].

In combination, increased locomotive utilization, longer maintenance intervals, extended oil drain intervals and decreased oil consumption are all factors which stress the engine oil leading to increased oxidation, viscosity, insolubles and wear metals. The extent of oil life is further influenced by the type of service, the diesel fuel consumed, terrain and other environmental conditions.

Changes in emissions regulations and fuel sulfur levels continue to impact the railroad industry as a whole. Though engine design strategies to meet Tier 3 and Tier 4 regulations have not yet been finalized, parallels may be drawn from the on-highway high speed diesel engine industry.

While the operation of the on-highway heavy-duty diesel trucks tends to be at high speed and transient in duty cycle, it is nonetheless instructive to compare the emission regulations impacting both industries. The on-highway segment has been subjected to very restrictive emissions standards since 1988 and their designs and lubricant formulations have been significantly affected. A comparison of NOx and PM emissions for on-highway heavy-duty trucks and locomotives is represented in Figure 5.

The railroad OEMs were able to meet the first three Tiers of emission regulations by a variety of techniques including retarded fuel injection timing, incorporation of improved engine intake air cooling, increased engine compression ratio, increased fuel injection pressure and injection rate, optimized notch and duty cycle operations, and reduced overall oil consumption.

Tier 3 may require further reductions in oil consumption while Tier 4 targets will more than likely require exhaust after treatment technologies. Technologies already employed by the on-highway sector include: Exhaust Gas Recirculation (EGR), DPFs, Diesel Oxidation Catalysts (DOCs) and SCR.

ENGINE OIL FACTORS & DRIVERS

It is well known that engine oil sulfated ash is a leading contributor to the collection of incombustible materials in DPFs. Research has shown that the incombustible material is primarily derived from the combustion by-products of lubricant additives. In the case of zinc-free railroad engine oils, the additives in question are associated with traditional calcium detergents. During combustion, these detergents generate ash in the form of calcium sulfate (CaSO4). The deposition of this incombustible ash on DPFs effectively shortens their service life. In addition, lubricant additive sulfur (similar to diesel fuel) as well as phosphorous are known to poison many SCR and DOC materials.

Oil formulation and its influence on exhaust after treatment devices are concerns which have been raised by the OEMs prior to the EPA's final ruling. Though not required for their feasibility analysis, the EPA has commented that low Sulfated Ash, Phosphorous, and Sulfur (SAPS) engine oils would be beneficial with regards to the durability, performance and maintenance of exhaust after treatment devices [9].

The authors have also heard reports from the field of excessive ash deposits forming in the combustion chamber and exhaust systems of engines operating in markets where traditional high ash (LMOA Generation 5) lubricants are used with ULSD. Similarly, during the September 2008 LMOA meeting (Diesel Mechanical Maintenance Committee), Standish [6] has also reported on excessive ash buildup causing turbo screen plugging, and valve failure stemming from the use of high ash oils with ULSD under light load applications.

ADDITIVE PACKAGE DEVELOPMENT

Development and commercialization of a new railroad additive package requires significant time and resources. All the OEMs have formal approval systems in place that involve bench tests, engine tests and extensive field tests, all of which must be successfully completed to secure approval. The specific process of additive technology and new engine oil development is proprietary for each company. Individual additive components are manufactured and are then formulated into additive packages which comprise a complicated blend of dispersants, detergents, wear and oxidation inhibitors which need to function cohesively in order to prevent corrosive attack and wear of critical engine components and keeping pistons and rings clean and free of carbonaceous deposits. The development process starts with establishing targets and requirements, screening new additive technologies, developing prototype engine oil formulations, conducting numerous bench and engine tests. Successful candidates may undergo additional evaluation prior to selection of the best candidate for field performance and approval testing.

FORMULATION & LAB TEST DEVELOPMENT

Optimizing the detergent system was done around a significantly lower starting BN. Determining an appropriate starting BN was determined with a number of theoretical equations, including one from General Electric Transportation System (GETS) that was used to determine oil life, or time between oil changes. The variables are fresh oil BN, oil consumption rate, oil sump volume, and fuel burned (mileage).

The mathematical equation is:

$$BN_L = BN_0 - 0.35 * S * F * y * OSF$$

where,

BN_L = Base Number depletion at a given charge life L

BN_0 = BN of the fresh oil

S = Fuel Sulfur content, (% m/m)

F = Specific Fuel consumption, (g/kWh)

y = percentage conversion of sulfur into species neutralized by the basicity of the oil

OSF = Oil stress factor

Where $OSF = 1/R * (1 - e^{(-Rt/V)})$, (kWh/g) [16] and,

R = Brake specific fuel consumption, (g/kWh)

t = the oil charge life in hours

V = oil charge in g/kW

The dispersancy system of the new additive package was determined with the aid of a proprietary soot dispersancy test which measured the ability of an oil to disperse soot and keep viscosity increase to a minimum. Individual and combinations of dispersants were tested in a matrix to evaluate relative performance. With the expected lower oil consumption and subsequent increased residence time in the crankcase, a more robust dispersant system than that provided by current LMOA Generation 5 / GE 4 LL was identified.

Special consideration was made to ensure that in lowering the sulfated ash and BN, no compromise to current oil drain intervals (184 days) would result while increasing oxidation control to address the higher residence time of the oil in the crankcase. Improving wear protection was also taken into consideration due to the expected higher injection pressures resulting in increased thermal loading on pistons, and the need for robust yellow metal wear protection. A number of standard and proprietary tests were used to evaluate components.

FINISHED OIL DEVLOPMENT

Each OEM has a formal approval process for engine lubricants. OEMs require that additives be screened in some tests before going into field trials. GETS allows a new candidate oil formulation to be field tested once granted "Fundamental Approval" and EMD refers to such a candidate as being "Worthy of Full Scale Field Test (WOFSFT)". The bench tests which are used for approval include the EMD Silver Corrosion test and GE Bronze Friction and GE Oxidation test. Laboratory engine testing includes the EMD 2-Holer and GE Power House endurance test and the Caterpillar 1MPC engine test.

The screening work detailed in the previous section led to the development of a new candidate engine oil which passed all the OEM bench and engine test requirements. The new formulation embodied the following characteristics:

- Reduced ash content
  - o Lower fresh oil BN (TBN = 9)
  - o Reduced non-VOF
  - o Reduced PM filter maintenance
- Advanced dispersant technology
  - o 180 Day maintenance interval
  - o Neutralize higher soot loading
  - o Maintain oil filter life
- Enhanced oxidation and thermal stability
  - o Addresses increased residence time due to lower oil consumption
- Improved yellow metal wear protection

FIELD APPROVAL TESTING

As previously discussed, bench and engine tests are important to develop and define performance characteristics of new additive packages. However, the performance of the new technology must be evaluated in numerous engine types operating under various conditions in the field. No bench or laboratory engine test can evaluate the performance of an oil as effectively as actual field service. As such, the new 9 BN low ash, zinc-free technology was rigorously tested in both GE and EMD engines under severe, real world conditions.

GENERAL ELECTRIC ENGINE PERFORMANCE

A one year field test was conducted in cooperation with GE to evaluate the performance of the new generation railroad engine oil additive system. The new additive package, nominal 9 BN, in a Group I base oil with a constant fixed viscosity index improver (VII) dosage was field tested in six GE locomotives. Four were designated as test units, and operated using the test oil while the remaining two were reference units and operated on the fleet oil, a 13 BN LMOA Generation 5 / GE 4 LL oil. All units were in excellent operating condition and had been re-built within the previous year. During the course of the one year field test, the locomotives were in severe service, averaging 422 megawatt hours per month while accumulating mileage at an average rate of 6,853 miles per month. The locomotives operated on a 92-day inspection schedule and the oil was changed at 184 days.

After one year of testing, four premeasured power assemblies were removed from each of the test and reference units. The piston deposits of the test units using the new 9 BN additive package were comparable to the reference units using the 13 BN LMOA Generation 5 / GE 4 LL fleet oil. The average piston deposits for the test units were 142 demerits versus 149 demerits for the reference units using the Coordinating Research Council (CRC) rating method. The CRC engine sludge rating showed that the test units were very clean throughout the test duration and were as clean as or cleaner than the reference units. Figures 6a and 6b and 7a and 7b provide representative photos of ring belt and undercrown deposits for the 9 BN test oil and the 13 BN reference fleet oil, respectively.

Engine cleanliness was evaluated using the CRC engine sludge rating method. The rocker box covers, rocker box and valve gear, crankcase cover and crankcase "A" frames were all rated for sludge. The test units exhibited comparable performance to the reference unit with very little measurable sludge depth. The average sludge rating for the tests units was a CRC rating of 9.70 versus 9.68 for the reference unit, with 10.0 designating a part devoid of any measurable sludge. Figures 8a and 8b compare the rocker box of the test and reference units, respectively.

The piston, liner and rings showed very low wear. The liner, ring gaps, ring thickness, and ring weights were measured and evaluated. The liner wear rates were less than 1 mil per 100K miles, indicating good wear control. Visual inspection showed that all the liners had minimal bore polishing in the upper ring reversal area and no scoring or scuffing of the liners occurred. Ring wear was also minimal and well within GE specifications, and near new specifications.

The used oil for the designated units participating in this test was analyzed and indicated good performance attributes overall.

Viscosity increase for both the test and reference oils show a slow but positive slope during the time between oil changes and are indicative of superior viscosity control. Figure 9 summarizes the viscosity data. The initial test oil viscosity was 14.83 cSt at 100oC as an SAE 40 while the fleet reference oil viscosity was 15.88 cSt at 100oC as an SAE 20W-40.

Midway through the second 184-day test interval, three of the units (Test Unit B and D, Reference Unit F) strayed from captured service. During the time the units were offline, no oil samples were taken and some cross contamination of lubricants occurred.

The BN shows a steady decay rate and ends up averaging about 6 BN (3 BN decrease) for the four test units and 8 BN (5 BN decrease) for the two reference units, with all above GE's condemning limit. Figure 10 summarizes the BN data, as measured per ASTM D4739.

The insoluble levels in the test and reference units were adequately controlled and the wear metals were very low. Insolubles were run using the coagulated LMOA (0.45μ filtration) procedure; ASTM D7317-07.

ELECTRO MOTIVE DIESEL ENGINE PERFORMANCE

As with the GE field test, a one year duration test was conducted with the new generation 9 BN test oil as an SAE 40 blended in Group II base oils with a fixed concentration of viscosity improver. The benchmark reference oil was a commercially available 17 BN SAE 20W-40 LMOA Generation 5 / GE 4 LL technology.

Designated units utilized the test oil and one unit utilized the commercial reference oil while two of the test units were used to evaluate the silver piston insert bearing as part of the EMD approval protocol. All units were in excellent condition as maintained by Class 1 railroad personnel. During the course of one year of testing, the locomotives averaged 4,189 miles per month and were known to experience very severe duty cycles and high megawatt hours per month utilization, as confirmed by the Class 1 railroad. At the end of the test four power assemblies were removed from each unit. There was negligible wear to the piston rings and cylinder liners. Piston deposits were comparable to the reference units and the engine sludge levels were noticeably lower than the reference units. The test oil also demonstrated good base retention, viscosity control, insoluble control, and low wear metals

The total piston deposit levels in the 9 BN test units were comparable to the 17 BN reference units, with 289 demerits versus 299, respectively. The average top ring groove fill with the test units was lower than the reference unit, averaging 62 demerits versus 75 demerits. Figures 11 and 12 highlight the piston deposit comparison.

The CRC sludge ratings revealed that the test units were very clean throughout the year on test having very little, if any, sludge depth or accumulation. The test units were cleaner than the reference unit with the reference unit exhibiting more sludge depth on the rocker cover, cylinder head and cam and coupling. The average CRC rating for the test units was 9.7 versus 8.6 for the reference unit. Figures 13 and 14 compare top deck cleanliness between the new generation 9 BN test oil and the 17 BN reference.

Cylinder liner and piston ring measurements showed minimal wear on the units using the new additive technology with all liners well under the EMD wear maximum specification. Visual inspection showed the liners exhibiting crosshatch over most of the liner surface with no scuffing or scoring of the liners. There was slight bore polish in the top ring reversal area on both the reference and the test liners. The ring wear measurements were minimal with most measurements within the new limits. For both liner and ring wear, the test units performed comparable to the reference unit.

The new 9 BN additive technology was also evaluated for connecting rod bearing, piston pin, insert bearing, and piston thrust washers wear. The bearings and thrust washers were removed from each unit on test and all were found to be in good, serviceable condition with no mechanical or corrosive wear attributed to oil condition. There was only a small, approximately 5%, amount of overlay removal on the connecting rod bearings of one test unit and reference unit, with the other test units showing no signs of overlay removal. It was determined that this over lay removal was from manufacturing and not due to mechanical or corrosive wear. The insert bearings only exhibited approximately 2% overlay removal, and the silver bearings had only slight feathering of silver with no silver removed. The thrust washers had very minimal wear with both the test and reference bearings being within the new washer specification.

The reference oil shows an initial decrease in viscosity due to shearing and then low but positive slope during the time between oil changes. The test oil shows no significant increase or decrease in viscosity over the course of the test. Figure 15 summarizes the viscosity data.

For the reference units the BN data shows a steady decay rate and ends up averaging about 10 BN. There are several spikes in the data which indicate that oil changes were performed on both reference units. For the 4 test units, the BN shows an initial drop at the beginning of the test and then flattens between 6 BN and 8 BN, well above the EMD condemning limit. Figure 16 summarizes the BN data.

Both the reference and test units exhibit adequate insoluble control, neither rising above 3%. The Inductively Coupled Plasma (ICP) spectrometer results for the major wear metals iron, lead and copper remained well below the EMD condemning limits. One test unit started to show a rise in the lead level toward the end of the test but this is likely due to the high incidence of water contamination the unit experienced throughout the duration of the test. Nevertheless, the unit remained below the condemning limit. The reference units show high copper levels, with both units being directionally higher than the test units. One reference unit reached 62 ppm copper at the 210- day mark at which point the oil was changed. The copper level immediately started to increase again after the oil change-out. The other reference unit reached 46 ppm copper at 108 days, when the oil was changed. Again, copper immediately started to increase reaching 74 ppm. Iron and lead levels remained in the normal range for the duration of testing. Figure 17 and 18 summarizes the ICP copper and lead levels, respectively.

CONCLUSIONS

As witnessed in various LMOA committee meetings and published papers in 2008 and from additional industry documents and publications in recent times, a fundamental change in engine oil composition, function and performance was required to work cohesively with the fuel and locomotive engine to ensure optimal performance.

The consumption of LSD and ULSD in locomotives operating in North America has increased substantially over the past two years, and now accounts for the majority of the diesel fuel consumed. To keep pace with this dynamic market, a new generation additive technology has been formulated to successfully cope with the engine oil lubrication requirements and demands of modern locomotives and to address emerging emissions trends. The proposed LMOA Generation 6 performance attributes entail:

- Improved anti-wear performance
- Advanced dispersant technology
- Optimized detergency and base retention established at 9 BN
- Improved thermal and oxidative stability

Table 6 delineates the new proposed Generation engine oil categories for current and forthcoming emissions standards.

ACKNOWLEDGEMENTS

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LMOA Generation	Year	Typical BN	Performance Milestones	Formulation Issues
1	1940	<7	Straight mineral oils	Lost alkalinity, Pb corrosion, bearing failures
2	1964	7	Ashless dispersants, improved alkalinity with Ca detergents	Reduced sludge & better oil filtration
3	1968	10	Improved alkalinity retention, higher dispersant levels, Ca detergents	Reduced piston ring wear
4	1976	13	Improved alkalinity retention with improved detergents & dispersants	Increased protection for adverse engine operating conditions
5 / 4LL	1989	13 / 17 / 18	Improved drain intervals in low oil consumption engines	Longer life oils that meet LMOA definitions & requirements

Table 1- LMOA Lubricant Generations

Non-road Diesel Fuel Standards

Who	Covered Fuel	2006	2007	2008	2009	2010	2011	2012	2013	2014
Large Refiners & Importers	NON-ROAD	500+ ppm	500 ppm	500 ppm	500 ppm	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm
Large Refiners & Importers	LOCOMOTIVE & MARINE	500+ ppm	500 ppm	500 ppm	500 ppm	500 ppm	500 ppm	15 ppm	15 ppm	15 ppm
Small Refiners & Other Exceptions	NON-ROAD, LOCOMOTIVE & MARINE	500+ ppm	500+ ppm	500+ ppm	500+ ppm	500 ppm	500 ppm	500 ppm	500 ppm	15 ppm

Except in California, compliance dates for Non-Road, Locomotive and Marine fuels in the years indicated are: June 1 for refiners and importers, August 1 downstream from refineries through fuel terminals, October 1 for retail outlets, and December 1 for in-use.

In California, all diesel fuel transitioned to ULSD in 2006. Locomotive and Marine diesel fuels were required to transition to 15 ppm ULSD effective January 1, 2007.

Table 2 -

		(g/bhp –hr)		
Standards Apply To	**Effective Year**	**PM**	**NOx**	**HC**
Remanufactured Tier 0 & Tier 1	2008 as available – 2010 required	0.22	7.4*	0.55
Remanufactured Tier 2	2008 as available – 2013 required	0.10	5.5	0.30
New Tier 3	2012	0.10	5.5	0.30
New Tier 4	2015	0.03	1.3	0.14

Note *: For Tier 0 locomotives originally manufactured without a separate loop intake air cooling system, these standards are 8.0 and 1.00 g/bhp-hr for NOx and HC, respectively

Table 3 - Line Haul & Passenger Locomotive Standards

		(g/bhp –hr)		
Standards Apply To	**Effective Year**	**PM**	**NOx**	**HC**
Remanufactured Tier 0	2008 as available – 2010 required	0.26	11.8	2.10
Remanufactured Tier 1	2008 as available – 2013 required	0.26	11.0	1.20
Remanufactured Tier 2	2008 as available – 2013 required	0.13	8.1	0.60
New Tier 3	2011	0.10	5.0	0.60
New Tier 4	2015	0.03	1.3	0.14

Table 4 - Switch Locomotive Standards

Oil/Fuel Ratio	Gallons Oil/Month	Months to Turn over Crankcase
2.00%	600	0.7
1.00%	300	1.3
0.50%	150	2.7
0.30%	90	4.4
0.10%	30	13.3
0.05%	15	26.7
Assumptions:		
Fuel Burned, Gallons/Mo =		30,000
Sump Size, Gallons =		400

Table 5 - Influence of Oil Consumption on Crankcase Oil Volume Turnover

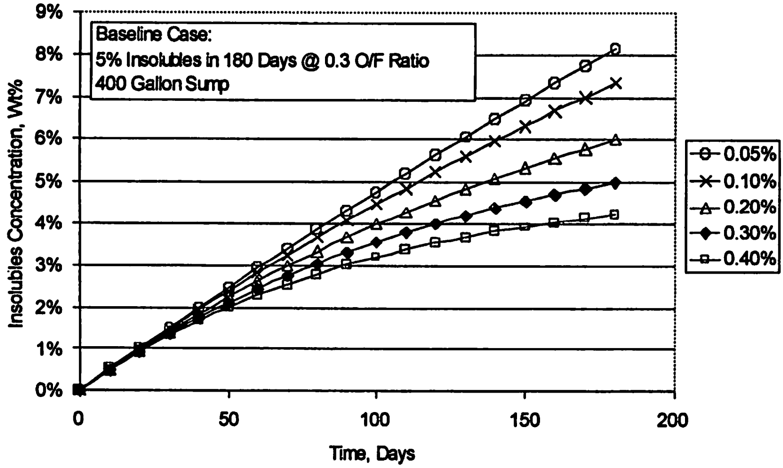


Figure 1 - Effect of Oil Consumption On Insolubles (Oil Consumption As % of Fuel)

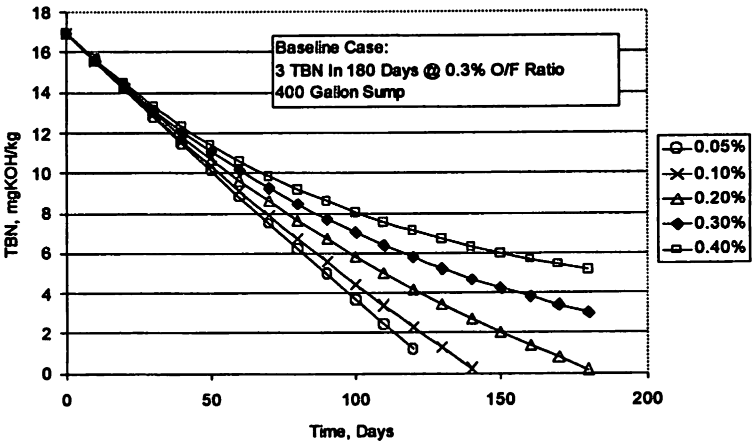


Figure 2 - Effect of Oil Consumption on BN (Oil Consumption as % of Fuel)

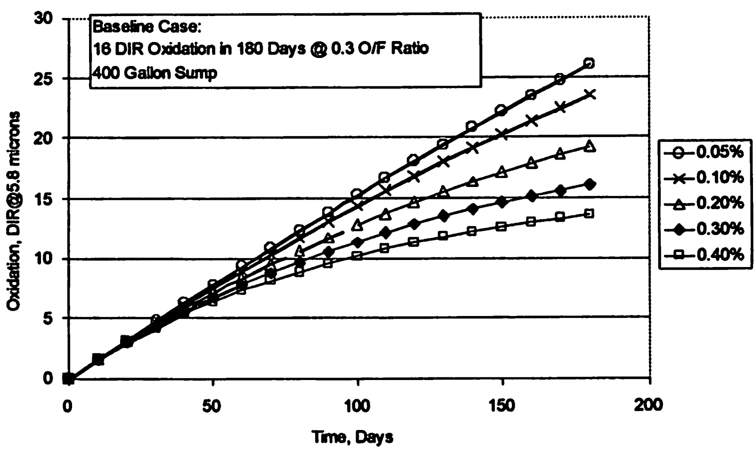


Figure 3 - Effect of Oil Consumption on Oxidation (Oil Consumption as % of FUel

These cumulative effects on oil stress have gradually increased during the past twenty years, as represented in Figure 4.

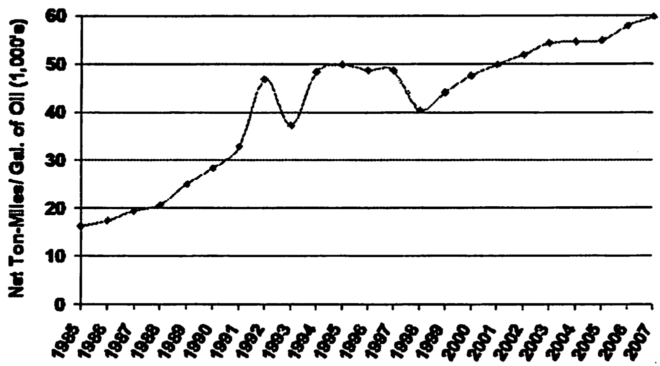


Figure 4 - Locomotive Engine Oil Stress

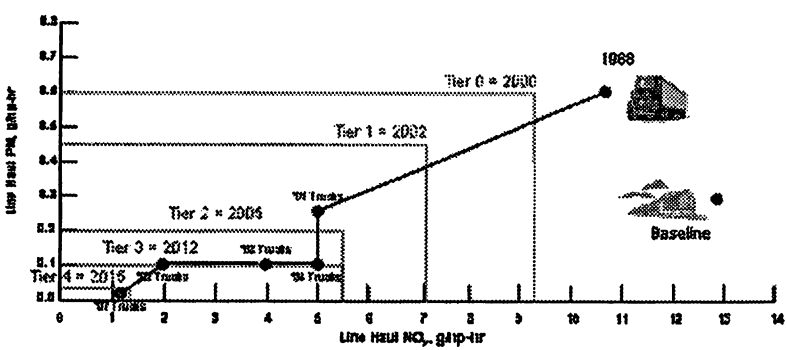


Figure 5 - EPA Locomotive vs. Heavy-Duty Truck Emissions Regulations

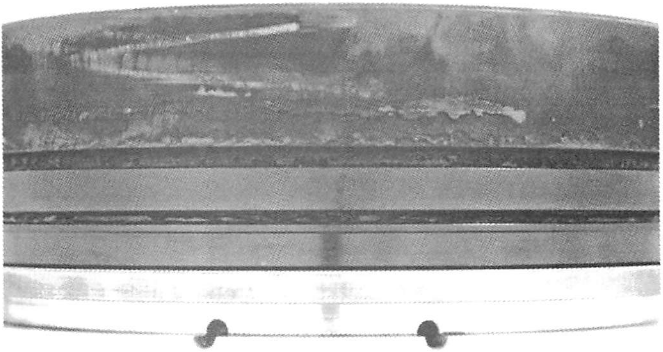


Figure 6A - Test Oil Ring Belt Deposits

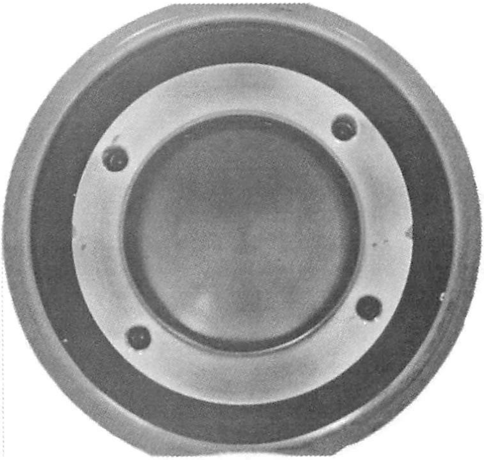
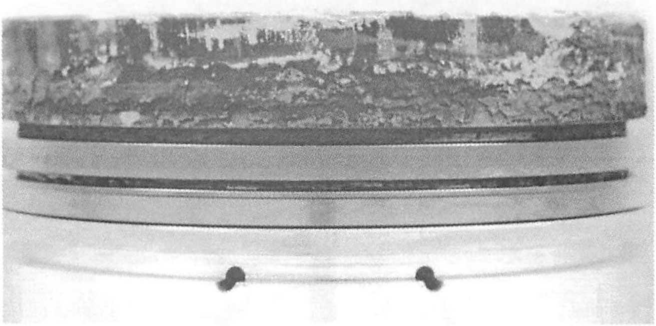


Figure 6B - Test Oil Undercrown Deposits



Fibure 7A - Reference Oil Ring Belt Deposits

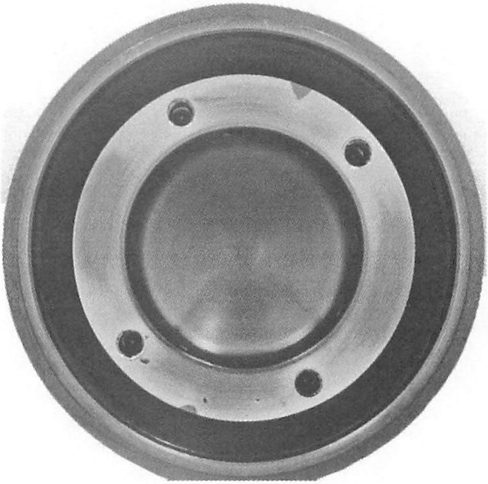
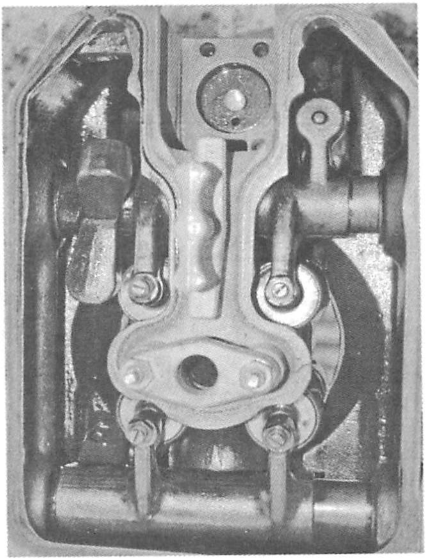
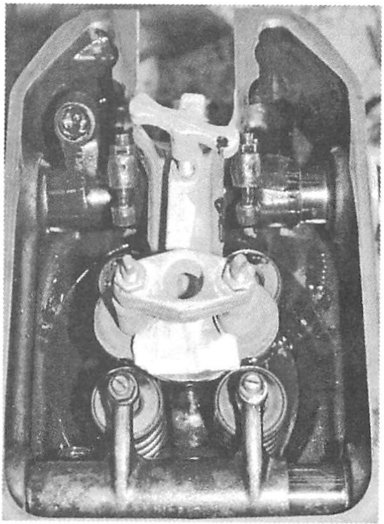


Figure 7B - Reference Oil Undercrown Deposits



Fibure 8A - Test Unit Rocker Box



Fibure 8B - Reference Unit Rocker Box Cover

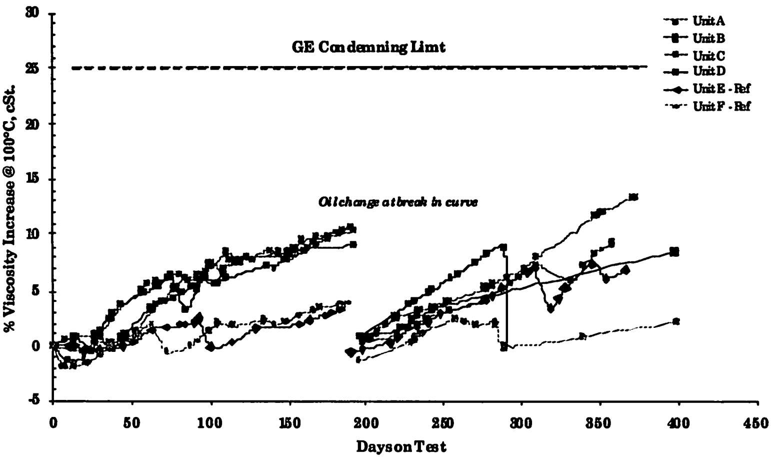


Figure 9 - GE Viscosity Data

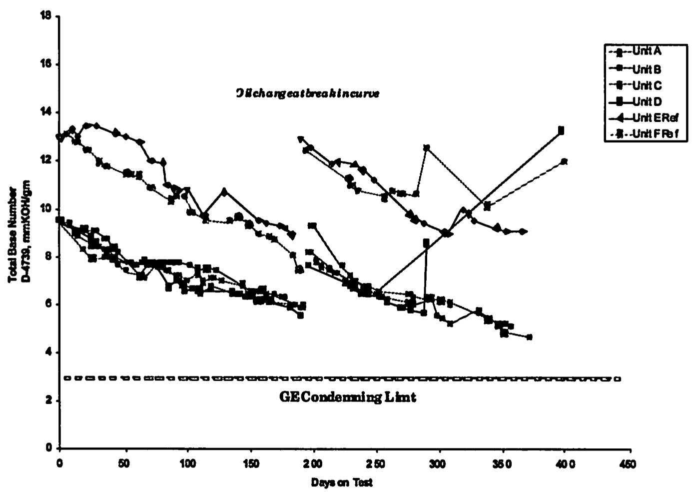


Figure 10 - GE Base Retention Data

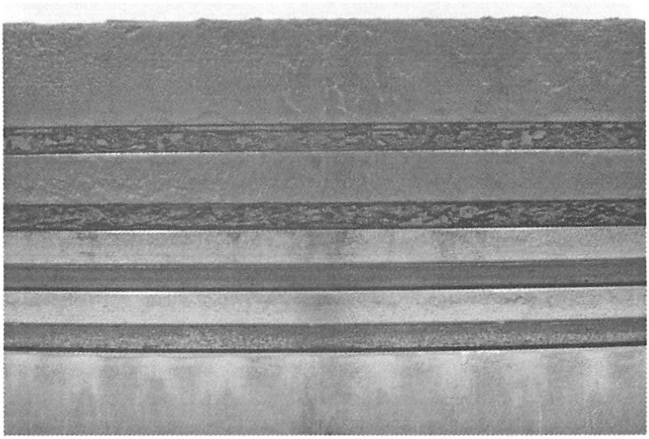


Figure 11 - Test Oil Ring Belt Deposits

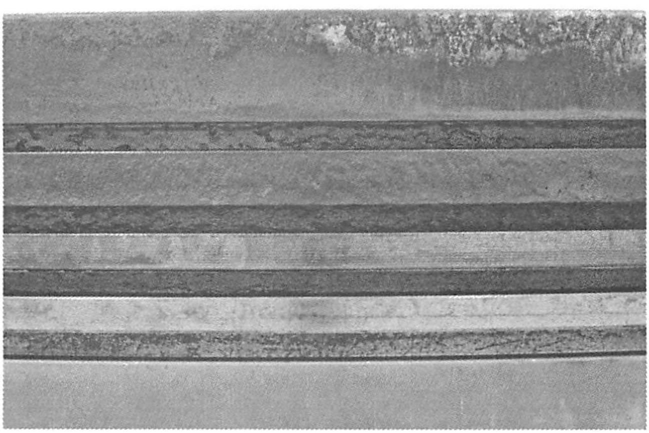


Figure 12 - Reference Oil Ring Belt Deposits

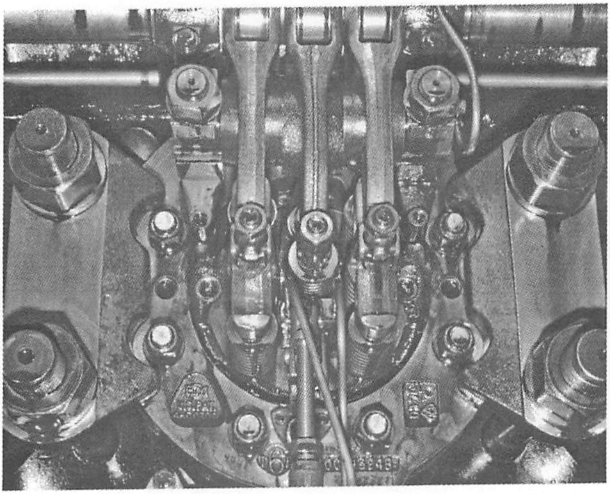


Figure 13 - Test Unit Top Deck

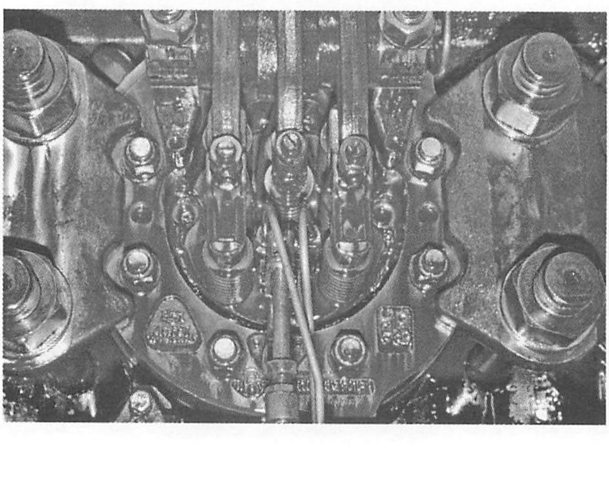


Figure 14 - Reference Unit Top Deck

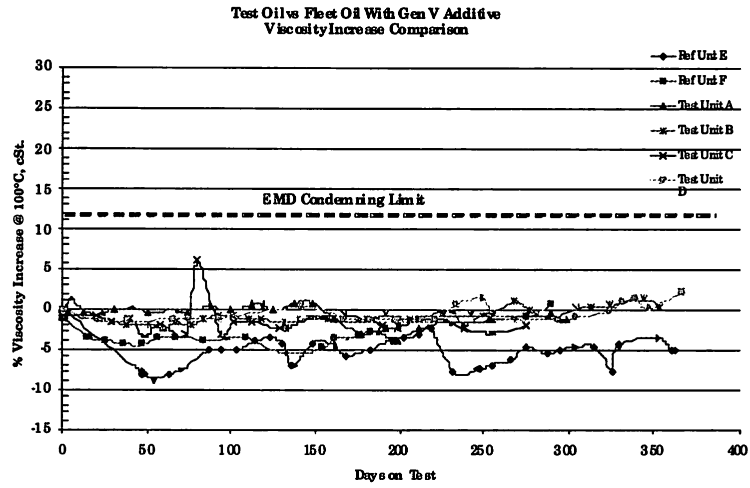


Figure 15 - EMD Viscosity Data

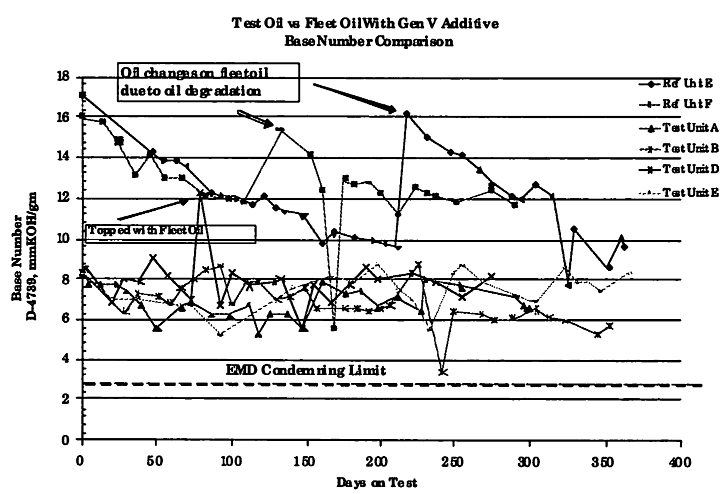


Figure 16 - Base Retention Data

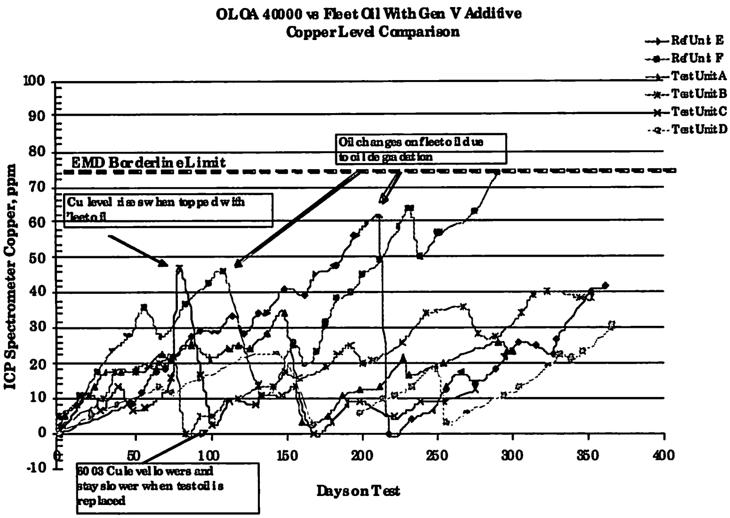


Figure 17 - EMD ICP Copper Data

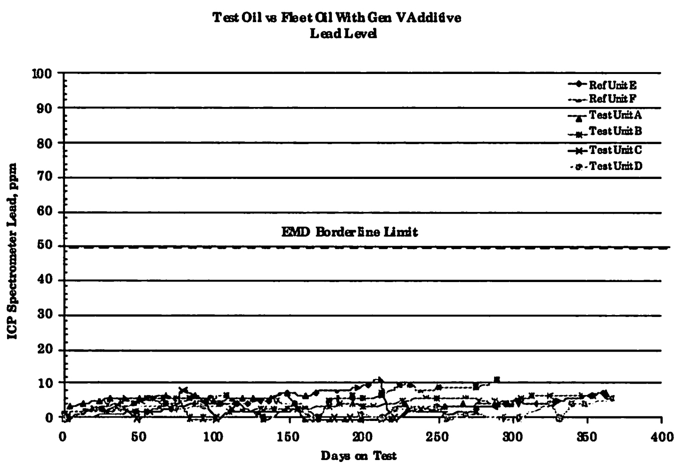


Figure 18 - EMD ICP Lead Data

LMOA Generatio n	Year	Typical BN	Performance Milestones	Formulation Issues
1	1940	<7	Straight mineral oils	Lost alkalinity, Pb corrosion, bearing failures
2	1964	7	Ashless dispersants, improved alkalinity with Ca detergents	Reduced sludge & better oil filtration
3	1968	10	Improved alkalinity retention, higher dispersant levels, Ca detergents	Reduced piston ring wear
4	1976	13	Improved alkalinity retention with improved detergents & dispersants	Increased protection for adverse engine operating conditions
5 / 4LL	1989	13 / 17 / 18	Improved drain intervals in low oil consumption engines	Longer life oils that meet LMOA definitions & requirements
6	2009	9	Optimized dispersant & detergent system for LSD & ULSD fuel for low consumption engines	Proper balance of alkalinity to fuel sulfur with no compromise to oil drain life; significant reduction in oil sulfated ash
7	2015 ?	?	TBD – based on Tier 4 requirements	TBD – based on Tier 4 requirements

Table 6 - New Proposed LMOA Generation Engine Oil Categories

THE CLEAN WATER ACT AND HOW IT AFFECTS RAILROAD OPERATIONS

Prepared by
Mike Maddox,
Industrial Specialty Chemicals, Inc.

This paper focuses on updates to Spill Control and Countermeasures (SPCC) plans, the implementation of recent changes, and your involvement. In addition it includes information on Wastewater Treatment, and Storm Water Pollution Prevention Plans (SWPPP).

To begin, SPCC is not new to the railroads but over the past few years has gone through quite a few changes. All railroad employees, in addition to training for Mechanical, Electrical, Buildings & Bridges (B&B), and Maintenance Of Way (MOW), receive annual training regarding the SPCC plan. The railroad managers carry the extra responsibility of enforcement of these programs and in general all railroad personnel hold the key to successfully adhering to these federal laws. Failure to do so can lead to civil and/or criminal fines for those responsible, as well as unwanted public relations issues for the railroad.

The background to this legislation is the federal *Clean Water Act of 1972* managed by the Environmental Protection Agency (EPA). This act federally protects surface and ground waters in the U.S. from pollution generated by private industry. Other countries carry similar laws such as *Canada's Clean Water Act and Pollution Prevention and Control Plan* and *Mexico's Ley General de Equilibrio Ecológico y Protección al Ambiente* (LGEEPA), which are not addressed in this paper but similar in content. A 1974 amendment added SPCC to the U.S. law. In 1977 the law was amended to include how spills were to be handled and reported. It further authorized enforcement capabilities to federal and state governments. In 1987 wetlands and storm water run-off were also included as important concerns; important because most of America is now considered as a protected area. In 1990 the *Oil Pollution Act* further regulated the transportation and storage of petroleum products to prevent water pollution. Finally in 2002 the Environmental Protection Agency (EPA) felt rail, farm and airline regulations were too lax so it legislated several more stringent regulations on these petroleum users. Litigation over these changes has pushed the implementation of these laws into the near future as clarification is sought for the proposed changes. Railroad implementation is currently scheduled for November 20, 2009.

The railroads have worked toward adhering to these new standards before the law takes effect and have prepared for the changes necessary.

The first of these *Clean Water Act* regulations to address is the compliance of waste treatment facilities. These facilities are a demonstration of a railroad's ability to meet the EPA regulations. If a railroad continually demonstrates unacceptable performance against the regulations at facili-

ties with past documented contaminations it does not instill any confidence within the EPA of how well that railroad will respond to an accidental release from either a derailment or a punctured fuel tank.

Waste water collection points vary in size and complexity but are critical points focused on by the government. The following are some points to consider based on size.

1) Smaller sites and fueling facilities will normally have an oil-water separator to remove and recover petroleum drippage. Even with their small size, these facilities cannot be ignored. If spillage occurs outside these control systems, storm water can be affected. They have limited holding capacity so should be maintained to prevent filling with sand or fuel. Most states require monitoring and sampling of discharges from these areas quickly after rain events to fulfill environmental reporting requirements. With the thinning of staff at railroad facilities some of the responsibility has shifted to B&B or MOW departments. Local facility personnel should receive training to under stand their responsibilities and roles to address any spill event. In addition the time to perform preventative maintenance needs to be included in the daily schedules which allow the facility to recognize their compliance to the government regulations between regulated events.

2) Larger shops often have full wastewater treatment facilities. These facilities remove contaminants from the wastewater which are typically introduced during the regular maintenance and washing of equipment. These treatment facilities can be costly to operate and generate large amounts of waste oil and sludge mixtures that must be disposed of properly. There are new cleaners and chemicals that have been or can be intro duced within the shop to improve treatability of the waste water. Segregation of engine oil drains also limits treatment needs. When these systems have been installed in the shop, training and oversight is needed to ensure employees and contract employees adhere to proper disposal needs and chemical use. Within the treatment plants waste oil demulsifiers have made great strides in maximizing the amount of sellable waste oil, offsetting overall treatment costs, and sometimes becoming a profit center. This also leads to lower total environmental costs and improved environmental impact realization.

3) In locations with over one million gallons of "hydrocarbon" storage capacity even more stringent regulations kick in. Monthly inspections must be conducted and personnel have to conduct drills on spill

response. This is enough for most railroads to limit their capacity below this threshold.

4) One final waste consideration is the proper handling of wastes by 3rd party contractors. Years after a mishandled spill; whether it occurred in a rail yard or on a main rail line a rail road could be found liable because of a previous contractor's mishandling of the railroad waste. Rapid response is important, but tracking and follow up are also critical to managing the activities of contractors. By utilizing contractors that are actively involved with the railroad's environmental initiatives it can help to limit their level of impact at a localized site. Their training should better prepare them to dispose of the wastes collected at a spill site correctly. In addition their education can greatly facilitate any future inquires by state or federal governing bodies.

The next point is the (SWPPP). Most of you have probably had some landscaping activity in and around the yard. This is also due to the EPA's new clean water initiatives. Primary isolation is the directing of non-impacted rainwater away from industrial activity and is the best way to handle storm runoff in your yards. If you don't have any rain water contamination, you don't have to handle it. By engineering your facility to divert storm water away, treatment is unnecessary. Adding this strategy to accident and spill sites, further lowers the total cost of the cleanup to your railroad.

1) Limiting or minimizing the affected area at any site is the best way to reduce costs. Much engineering work has taken place since the 2002 regulations to direct storm water runoff away from impacted areas and out of required regulatory rules. Landscaping around storage tanks and ditches in the yard provide necessary secondary containment while properly maintaining slopes and ditches on the line offers the most cost effective long term practice to divert storm water away. If a spill was to occur in these areas of the line, quick response will minimize the environmental and legal impact of an incident.

2) In known impact areas such as spill sites or fuel pads, not only best practices need to be followed but also proper collection of water and maintenance of separator equipment is required. Personnel located at these sites are the best candidates for monitoring and reporting the equipment condition. Their assistance to the environmental personnel will help keep a railroad in compliance. Once trained, non-environmental personnel from B&B or MOW can perform simple inspections and sampling. Fixed position collection equipment normally requires storm water sampling

within 24 hours of a rain event, which can be a somewhat difficult task if the only railroad environmental representative is located on the other side of the state.

3) Some new requirements of the SWPPP plan that have been updated in this recent legislation which build on previous requirements already instituted:

1. Permitting of any impacted area. This can be as inane as clearing some trees or filling in a ditch. These activities, which previously were largely overlooked can now involve notifying the Army Corps of Engineers (COE), as well as the State and Federal EPA. The COE has stated they will try to not get involved, but without the proper COE permits additional fines could be issued because of alteration of the landscape.

2. Another new development is secondary containment required for any oil or grease storage container of 55 gallons or greater. This can be from something as simple as lube grease, bacon grease, motor oil or radiator treatment brought out to trackside up to large fuel trucks performing direct fueling.

3. But probably the most important change is the reduction of the size of the impact area to be permitted when the location is outside of a recognized rail yard. Previously a project or soil disturbance site under 5 acres did not necessarily need a permit. Now the new limit is one acre so unless there is a paved road trackside, it is very easy to go over that one acre limit. Several trucks and a backhoe working off the pavement by just 100 yards has already impacted enough ground to require permitting before the work begins. This can make any work, because of the needed permitting time consuming and the contractor knowledge of the permit needs is important. Space is a premium. Limiting traffic to and from the job site in a narrow corridor should minimize the area impacted by wheel traffic all of which must be included in the acreage calculations.

4) The final point regarding SWPPP is that every State is different. Some States have approved the use of statewide permitting, allowing a quicker response for performing necessary isolation and cleanup activities. Other States require individual site permits. With the movement of railroad per-

sonnel to new locations it is important to insure that this information is not being overlooked by incoming personnel. Additionally, the training of all employees and contractors will help build their understanding of what's required to help insure adherence to the plan rules.

A railroad's Spill Prevention Control & Countermeasures (SPCC) plan is another important point to cover. Understand that SPCC plans in general are not of the cookie cutter variety. The railroads of North America do not all have the same plan. Each facility that requires a plan must have one that is specific to that facility. Further, how each railroad implements and oversees their SPCC plan will, most likely be different than how another railroad implements its plan.

The primary purpose of the SPCC plan is to prevent oil spills into navigational waters hence the reason why the COE could possibly use the Coast Guard to respond on behalf of the responsible parties involved. A navigable waterway can be as small as a depression in the ground that has 3 inches of water in it for one day every hundred years. The Coast Guard could then become involved if a spill is related to a navigable waterway.

The SPCC plan must include these items;

1. Spill history, spills that could occur, control measures, tank descriptions and maps of piping, transfer operations, inspection records, security, lighting, rain water logs, training and must be approved by a Professional Engineer (PE).

2. The facility must have secondary containment for any potentially impacted area, piping, pumps, tanks and drums. All tanks when not in use must have any potential release point locked out to prevent accidental release. The entire facility is to be lit and fenced for security. Spill response equipment is to be on hand and maintained. Tanks of any size are to be tested and inspected regularly. Records of all activities are to be kept.

3. Other considerations are; petroleum of any kind; hydraulic, vegetable, asphalt or fuel. Fuel truck delivery points or holding fuel cars on a siding for direct fueling. What alternate security measures are in place to avoid the need of fencing the whole yard? MOW activities may need their own plan including security. Work trucks with portable fuel tanks on the back need to be included when in a SPCC covered area.

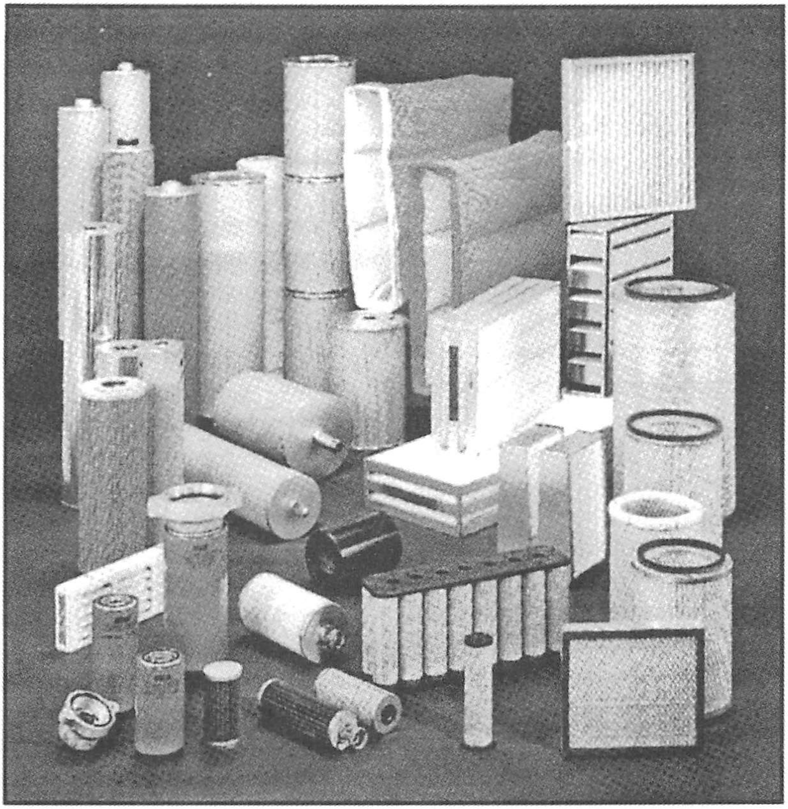
The final concern about any SPCC plan should be liability. Some railroad facility managers may have more potential liability than the environmental managers. I have been told by railroads and the EPA (unofficially) that no one will go to jail or have to dig in their own pockets for fines but these measures are written in the law. Why? Proper training and implementation of the SPCC plan will make everyone's life easier.

The final discussion point is that it never happened unless there is adequate documentation to confirm that it did happen.

1) Inspection records for all sites, tanks and former impacted areas should be maintained at the facility. Copies of the PE's credentials and approvals should be kept. State approvals and permits should be kept at the site and certainly afterward. All training records should be kept in detail as well as all disposal documentation.

2) Waste water treatment records and waste disposal records should be maintained as well as all operator certification. Any railroad activity requiring a SWPPP plan and/or permits should be kept.

With a firm understanding of why these procedures are needed and how personnel activities affect them, a railroad can avoid unnecessary costs and possibly reduce spending on environmental requirements. Environmental personnel and the emergency response center will handle most of the training and documentation, but know your part, and do your part because the environment is everyone's responsibility.



LOCOMOTIVE TESTING OF AN AUTOMATIC SELF-CLEANING LUBE OIL FILTER & CENTRIFUGES

Prepared by
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Leighton Haley,
Chief Chemist,
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INTRODUCTION

The locomotive industry has historically used paper cartridge filters for lube oil filtration that must be stocked, handled, and disposed of at each servicing location. Increasing environmental concerns and initiatives to reduce cost are driving the industry to consider alternative technologies. A September 2007 LMOA paper described how the combination of an automatic self-cleaning lube oil filter and centrifuge increases oil quality and life, reduces engine wear, and lowers operating costs [1]. The data presented showed this combined technology had been proven in other areas such as marine and stationary as well as in mining applications. The presentation also noted automatic self-cleaning filters are used on locomotives in other countries but they, nor the combined system with a centrifuge, have ever been tested on a locomotive in the USA. However, in September 2007 plans were already underway with an eastern US railway to provide proof of concept of the combined technology on an EMD GP60 locomotive. This paper details the operation, installation, and performance of an automatic self-cleaning filter and two centrifuges on a locomotive utilized in general freight service.

EQUIPMENT

The equipment used for this test consisted of the following:

- One 1991 EMD GP60 locomotive last overhauled in November 2005
- One Alfa Laval T-280-30-A03 Moatti automatic self-cleaning filter
- Two Mann & Hummel 600 centrifuges
- One OCV 108-2 pressure control valve

OPERATION

The primary difference between a paper cartridge filter and an automatic self-cleaning filter is a paper cartridge traps particles on and within the layers of the filtration medium until clogged, upon which time it has to be replaced. The automatic self-cleaning filter collects particles on the filter medium surface so they can be easily removed as the filter is cleaned. This has several benefits including the fact that cartridges no longer have to be purchased, changed, or disposed of which helps reduce environmental waste.

The automatic self-cleaning filter and centrifuge typically work together as shown in Figure 1 and detailed as follows.

As 100% of the engine oil flow enters the automatic self-cleaning filter, it passes through a strainer to catch any large debris that may be in the oil. The oil then enters a distributor where it flows along the length of the filter through a series of wire mesh elements. While approximately 97% of the oil continues to the engine for lubrication, about 3% is used to continuously clean the wire mesh elements in a back-flushing mode. The self-cleaning operation is controlled by a hydraulic motor which rotates the distributor in a step wise fashion to automatically back-flush the screen mesh. This process is continuous and will completely back-flush the entire filter system every two to three minutes.

The back-flushed stream from the filter sends the concentrated particles directly to the centrifuge which spins up to 3,900 RPM generating extremely high centrifugal forces. At this high rotational speed, the high density particles are separated from the lubricating oil and collect on the inside of the centrifuge housing. The low density polished lube oil is then allowed to drain to the engine oil sump.

Separation efficiency in the centrifuge is governed by Stoke's Law which states the greater the density of the particle relative to the density of the fluid, the greater the efficiency. However, other parameters have a positive effect on separation efficiency including a large particle size, a high gravitational force, and a low viscosity as shown in the following formula.

$$V = \frac{d^2\,(p_p - p_l)}{18\eta}\,g$$

V being the sedimentation velocity due to gravity
d is the diameter of the particle
p_p is the density of the particle
p_l is the density of the liquid
η is the viscosity of the liquid
g is the acceleration due to gravity = $\omega 2r$.

Although the centrifuge is highly efficient, it will not remove lubricating oil additives. The additives are typically sub-micron in size and become miscible with the oil.

Centrifugal force only increases gravity so if additives are not separated over time by natural decantation then a centrifuge will not impact them either.

The particles removed by the filter are then separated by the centrifuge and trapped within the centrifuge forming a "cake" of compacted solids. Should the centrifuge become clogged, the filter operates in a normal manner and the captured particles are simply returned to the sump (there is no impact on the engine). The engine is still supplied with 100% filtered oil from the automatic self-cleaning filter.

INSTALLATION

When retrofitting and testing the combined automatic self-cleaning filter and centrifuge on a locomotive, a number of factors needed to be considered including the type of automatic self-cleaning lube oil filter to use, the overall envelope of the system, the orientation of the filter, how many centrifuges should be used (if any), and the angle and diameter of the drain pipe.

The type of automatic self-cleaning filter used depends on the lube oil flow rate to the engine. Since locomotives are used throughout the world in hot and cold climates, cold temperature starts with increased oil pressures had to be considered for this application. Therefore, this test utilized an automatic self-cleaning lube oil filter with a maximum flow rate of 450 gallons per minute (gpm) and a screen mesh size of 25 micron absolute, 10 micron nominal. The automatic self-cleaning filter also includes an internal pressure safety bypass. If the differential oil pressure increases over 2 bar (29 psi), the bypass opens to minimize the pressure throughout the filter system. The bypassed oil continues through an 80 micron absolute safety mesh so the engine is still protected from larger particles. This bypass also protects the filter elements from being damaged by abnormally high pressures. Once the lube oil warms and the viscosity decreases, the bypass closes and the automatic self-cleaning filter operates normally.

Due to its smaller size, the automatic self-cleaning filter did not have any problem fitting in the same envelope as the existing paper filter canister. However, due to the low pressure oil flow to the EMD locomotive engine, a pressure regulating valve was used at the filter outlet to increase the pressure within the automatic self-cleaning filter so the back-flushing and centrifuge systems would work properly. The addition of this valve added size to the filter system which had to be considered for the installation. For future installations a *simple diaphragm* can be used instead of the pressure regulating valve to increase the pressure in the filter system if necessary.

The automatic self-cleaning filter can be mounted vertically, horizontally, or at any angle in-between. There are some limitations on the orientation of these filters but none of those came into play with this application or test. It was quickly decided to mount the automatic self-cleaning filter horizontally with a slight upward angle (about 15° off horizontal) to create enough room for the installation and also allow proper drainage and easier access to the filter for maintenance during engine overhaul. The installation of the automatic self-cleaning filter with attached pressure regulating valve is shown in Figure 2. Note the dark circle on the wall behind the filter where the previous paper cartridge canister was installed.

The automatic self-cleaning filter is often used without the addition of a centrifuge, however, that requires either returning the removed oil particles back to the engine sump or, as is usually the case, an automatic drain to a separate collection tank. Although this method protects the engine just as well, a secondary tank is required and creates potential oil loss and waste and adds space to the locomotive installation. The most optimized and efficient system is to use the automatic self-cleaning filter with a centrifuge which cleans the oil to a very fine filtration level. Because of this, it was determined this combined system should be used. The resulting flow diagram is shown in Figure 3.

When using a centrifuge in conjunction with the automatic self-cleaning filter, routine servicing is limited to just the centrifuge. What was unknown about the locomotive application was just how much soot would be removed from the oil and how quickly that would fill the centrifuge. Based on prior experience with testing on a stationary GE engine of similar size, the decision was made to move forward with two centrifuges with the capacity of six liters each. If after six months operation it was determined that only one centrifuge was required, the second centrifuge would be shut off and/or removed.

The next and probably greatest hurdle of this installation was proper draining of the two centrifuges back to the engine sump. The center line of the two centrifuges to the sump was over nine feet. Since the centrifuges are gravity drained, the pipe length, diameter, and angle all had to be considered. If the pipe was too small or the angle was not great enough, the oil may not drain properly and could flood the centrifuges causing them to reduce speed and efficiency or stop functioning all together. These factors were considered and instructions were provided to eliminate these piping concerns. Unfortunately the instructions were not followed and the installation yielded a smaller pipe inner diameter than desired (with half inch pipe walls) and the pipe angle was less than half of the requirement (Figure 4).

The oil was changed on the locomotive with the same lube oil additive package and base stocks that were used with the paper cartridge filter. The locomotive was released back into service and monitoring of this real world application began. Although not the perfect installation, it was sufficient for proof of concept. However, due to the concern about the pipe run installation verses what was calculated to be required, the decision was made to monitor the centrifuges every three months (instead of six) to ensure they were working properly. During normal servicing of the locomotive, oil was periodically added as required, as is standard practice with EMD locomotives and as was done when the paper cartridge filters were used.

MAINTENANCE

December 2007 brought the first servicing of the centrifuges. Since this was a new installation and none of the mechanics were experienced at servicing the centrifuges, just over an hour was required. Servicing of a centrifuge simply involves removing the cover, draining and removing the bowl from the spindle, opening the bowl, removing the particulate "cake" or sludge, and reassembling. Approximately three pounds of sludge was removed per centrifuge for a total of six pounds for the first three months with the new oil.

The next servicing took place in March 2008 and although different mechanics were assigned to the task, the lessons learned from the prior servicing were applied and the total time required dropped to 45 minutes. Since the locomotive had been sitting for over 24 hours the centrifuges were very cold which increased the difficulty of removing the sludge. Approximately two pounds of sludge was removed per centrifuge for a total of four pounds for the second three months of use (a grand total of 10 pounds over six months). The decreased amount of sludge removed from the first to second servicing brought concern about proper draining and functioning of the centrifuges.

The third servicing was in June 2008 and provided the opportunity to check the efficiency of the centrifuges. Servicing of the centrifuges was completed first, taking about 45 minutes due to a full and complete solvent cleaning of the bowls. Approximately 3.5 pounds of sludge was removed per centrifuge for a total of seven pounds (a grand total of 17 pounds over nine months). This was the most sludge removed to date and an indication the centrifuges may be functioning properly. Once reassembled, the locomotive was started, the oil temperature brought up to 190° F, and a tachometer used to determine the rotational speed of the centrifuges. What the tachometer indicated, however, was the centrifuges were rotating at 3,200 RPM which was lower than expected. The tachometer was then placed on other parts of the locomotive to verify the centrifuge readings were not simply caused by locomotive vibration. Although this centrifuge speed was not ideal, it did show the system was not flooding, at least not initially after startup.

In order to increase the rotational speed of the centrifuges, the pressure regulating valve was adjusted from the factory preset of 60 psi to almost 85 psi. Measuring the speed of the centrifuges again at an oil temperature of 195° F showed an increase to 3,650 RPM. This boost in RPM was calculated to increase the gravitational force by 30%, thereby increasing efficiency based on the equations found in Figure 5.

The next servicing was in September 2008. The decision was made to service only one of the centrifuges so the service interval could start to increase to the originally desired six months. Servicing of the one centrifuge took only about 20 minutes which meant every servicing since the start of the test took less and less time as more experience was gained. The sludge removal from this single centrifuge was positive as well yielding 4.75 pounds.

The September servicing was the last to be performed during this test period. Locomotive auxiliary generator and turbocharger problems unrelated to this installation and test caused the locomotive to be shopped for most of the remainder of 2008. However, since repairs have been made testing continues with the automatic self-cleaning filter and centrifuges for further studies.

TEST RESULTS

All testing utilized a single locomotive although oil and locomotive starting cleanliness conditions did vary between tests. Data collection for the paper cartridge began immediately after engine overhaul while data collection for the automatic self-cleaning filter and centrifuges began two years later. The oil was changed during installation to promote similar starting oil conditions for each test. Analytical results for oxidation, soot and sulfate were collected on a Perkin-Elmer Spectrum One Oil Express FTIR using JOAP software, metal values were measured on a Spectro, Inc. Spectroil M and viscosity measurements were determined on an ISL Automatic Houillon VH1 Viscometer.

Sufficient data was collected during the first operational year of the automatic self-cleaning filter and centrifuges to compare the performance against the paper cartridge data previously collected. Oil samples were taken from a sample drain valve located after the automatic self-cleaning filter which was right before the engine. Sampling frequency was scheduled for 15 day intervals but in reality was less frequent as was the case with the paper cartridge filter sampling. Regardless, the data obtained was adequate to allow for trend lines to be formed for each product tested. When the test data for the automatic self-cleaning filter and centrifuges was compared to the paper cartridge results, improved levels of oxidation, soot, sulfate, viscosity, and wear metals were observed.

Soot levels in the lube oil initially appeared to be the same or even somewhat higher with the automatic self-cleaning filter and centrifuges. These results were not totally surprising since the initial paper filter data was after overhaul and the automatic self-cleaning filter and centrifuge results were after a normal oil change. However, later results brought into question the return piping from the centrifuges to the engine sump and brought doubt the centrifuges were functioning at maximum efficiency. The soot levels started leveling off around 200 days and began improving against the paper cartridge data. Approximately 270 days into the test the rotational speed of the centrifuges was increased and the results improved even more as shown in Figure 6. Based on this data, 184 day centrifuge service intervals are also possible.

The viscosity levels of the automatic self-cleaning filter and centrifuges verses the paper cartridges seem to mirror each other (see Figure 7). However, closer examination shows that throughout the test period the viscosity range for the paper cartridges increased from 15.3 cSt to 16.2 cSt, a change of 0.9 cSt (a 5.9% increase). The automatic self-cleaning filter and centrifuges, however, shows a trending increase from 14.9 cSt to 15.2 cSt, a change of only 0.4 cSt (a 2.7% increase). This clearly shows a more stable viscosity and aids in longer oil life by continually removing the soot as indicated in Figure 5. It should be noted that no "day zero" viscosity data was available for either test and the first sample dates are different (14 days for the paper cartridge and 21 for the automatic self-cleaning filter and centrifuges). This, combined with the fact that new oil viscosity can vary, helps explain the 0.4 cSt starting difference in the data.

When larger oxidation particles are removed from the lube oil the oxidation number should stabilize. Conversely, higher oxidation numbers indicate degraded oil and a potential for increased wear metals in the oil which, in turn, reduces oil life as well as the life of the engine. As the power trend lines show in Figure 8, oxidation levels remained relatively stable with the automatic self-cleaning filter and centrifuges and were an improvement verses the paper cartridges. After the centrifuge RPM was increased around day 270, the data indicates a potential for even lower oxidation levels that should be confirmed as testing continues.

Studies show increased levels of iron correspond to increased wear rates and, therefore, reduced fuel economy, engine life, and even emissions profiles [2,3,4]. Figure 9 shows not only an overall reduction of iron in the locomotive's lube oil using the automatic self-cleaning filter and centrifuges but also a significant reduction past the 270 day period when the centrifuges were optimized.

Finally, another lube oil degradation indicator is the sulfate levels in the oil. Although the initial level for the automatic self-cleaning filter and centrifuge was slightly higher than for the paper cartridge, the levels dropped in comparison rather quickly and stabilized in a much smaller range. The automatic self-cleaning filter and centrifuge increased 17.6% with one anomaly verses an increase of 100% for the paper cartridge as shown in Figure 10. Again, it appears levels were reduced after the centrifuges were optimized.

WASTE DISPOSAL

Since this test was performed on a 1991 EMD GP60 locomotive and wear metals, such as lead, tend to run higher on older locomotives, there was some concern regarding the nature of the cake removed from the centrifuge. To characterize this material for disposal purposes, a Toxicity Characteristic Leaching Procedure (TCLP) for metals, volatiles, and semi-volatiles was performed and all levels were within acceptable limits with the only exception being lead. Based on this result, the waste would have to be classified as hazardous for disposal purposes. However, information received from other industries including mining, marine, and stationary show that disposal is not an issue; the sludge cake is simply discarded in the same manner as any spent paper cartridge filters. Given the fact that only one sample of sludge cake was analyzed from this older locomotive and given the differences between locomotive and engine types, ages, and servicing, additional testing should be performed in order to determine a proper disposal method for the locomotive industry.

CONCLUSIONS

Based on these test results from this one locomotive, the automatic self-cleaning filter and centrifuge combination protects the engine at least as well if not better than conventional paper cartridge filters. That being said, questions about the disposal of the sludge cake remain and retrofit costs may push this technology toward new installations. Initial maintenance time was excessive but was reduced significantly with proper tools and training. Additional testing will confirm if two centrifuges are required or if only one will suffice.

Testing continues on the EMD GP60 locomotive with the centrifuges at optimized speeds and testing on additional locomotives is being discussed in order to increase the sample size and further verify these results.

ACKNOWLEDGEMENTS

The authors wish to thank Norfolk Southern for volunteering their time, resources, and locomotive for testing this product, for analyzing the resulting data, and for being a leader in exploring new technologies for the locomotive industry.

The authors also thank Alfa Laval Inc. for contributing the automatic self-cleaning lube oil filter and centrifuges for this test and for assisting with servicing of the locomotive.

Finally, the authors would also like to thank the members of LMOA's Fuel, Lube and Environmental Committee for their review and input to this paper.

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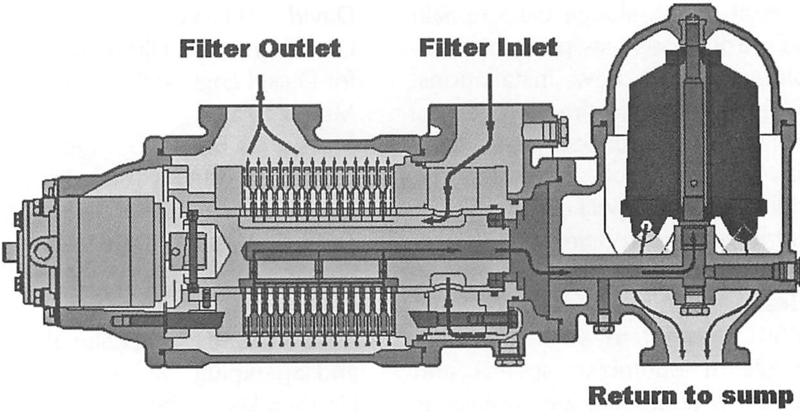


Figure 1 - Automatic Self-Cleaning Filter Combined with Centrifuge

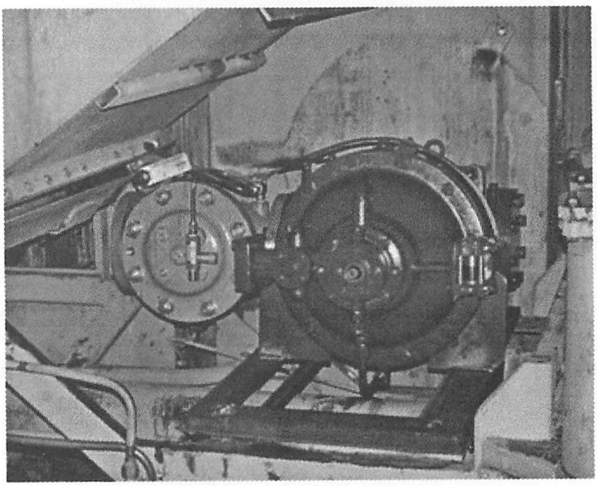


Figure 2 - The Automatic Self-Cleaning Filter with Attached Pressure Regulating Valve Installed on an EMD GP60 Locomotive

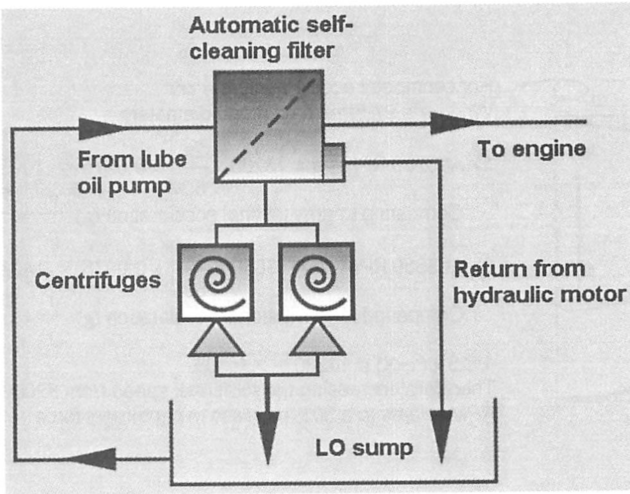


Figure 3 - Flow Diagram of the Automatic Self-Cleaning Filter and Centrifuges

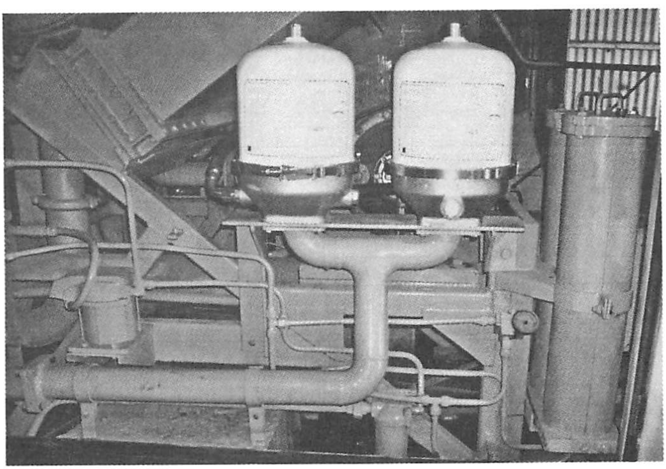
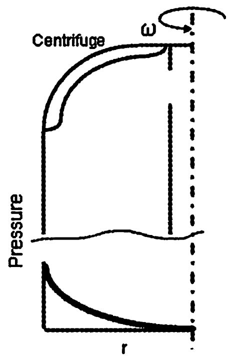


Figure 4 - Two Centrifuges at Six Liters Each Plus Parts of the Gravity Drain Piping to the Engine Sump



For centripetal acceleration: $a = \omega^2 r$

Where $r = 97.5mm$ (centrifuge diameter)

1) At 3200 RPM : $a = \left[3200 \times \frac{2\pi}{60}\right]^2 \times 0.0975 = 10938\ ms^2$

Comparing to gravitational acceleration (g) $\frac{a}{g} = \frac{10938}{9.81} = 1115$

2) At 3650 RPM : $a = \left[3650 \times \frac{2\pi}{60}\right]^2 \times 0.0975 = 14230\ ms^2$

Comparing to gravitational acceleration (g) $\frac{a}{g} = \frac{14230}{9.81} = 1451$

$1115 \times (1+X) = 14230 \quad X \approx 30\%$

Therefore, increasing the rotational speed from 3200 RPM to 3650 RPM relates to a 30% increase in centrifugal force.

Figure 5 - Higher RPM Impact on Centrifugal Force

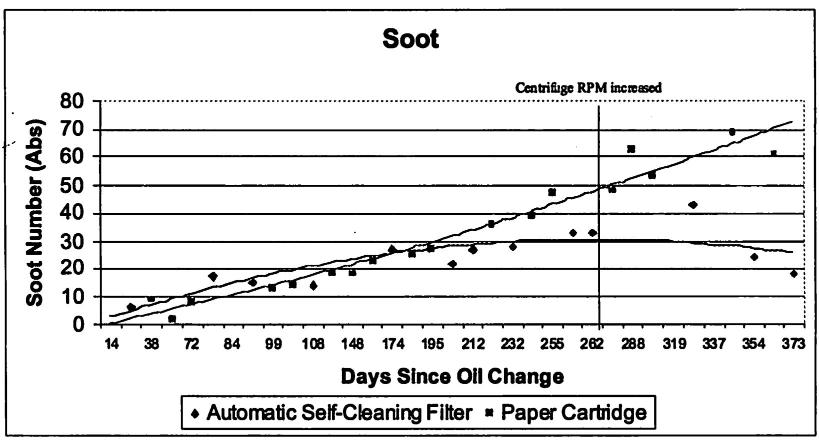


Figure 6 - Comparison of Soot Levels. Note the Increase in the Centrifuge RPM Around Day 270

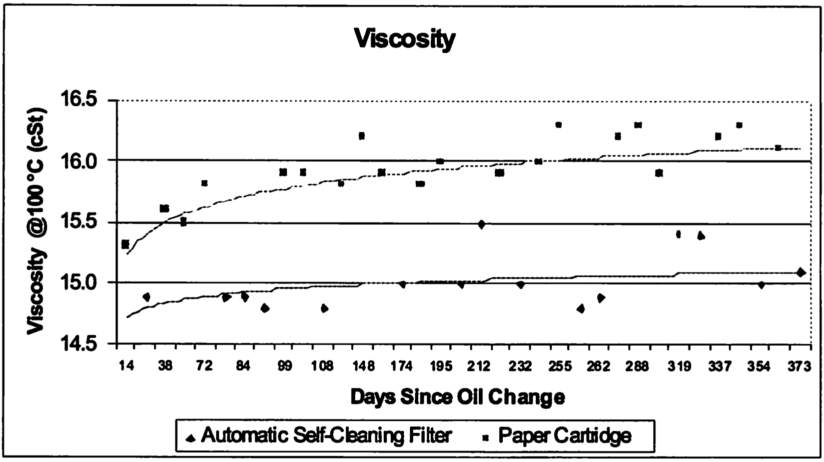


Figure 7 - Viscosity Power Trend Lines with the Automatic Self-Cleaning Filter and Paper Cartridges

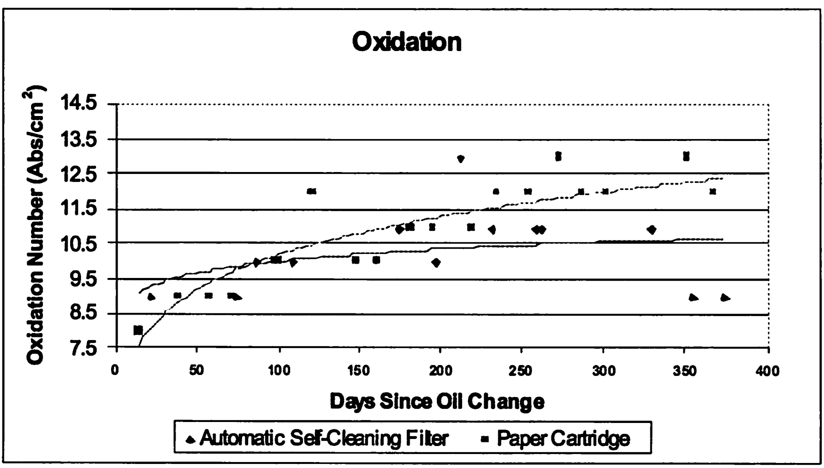


Figure 8 - Oxidation Level Comparison

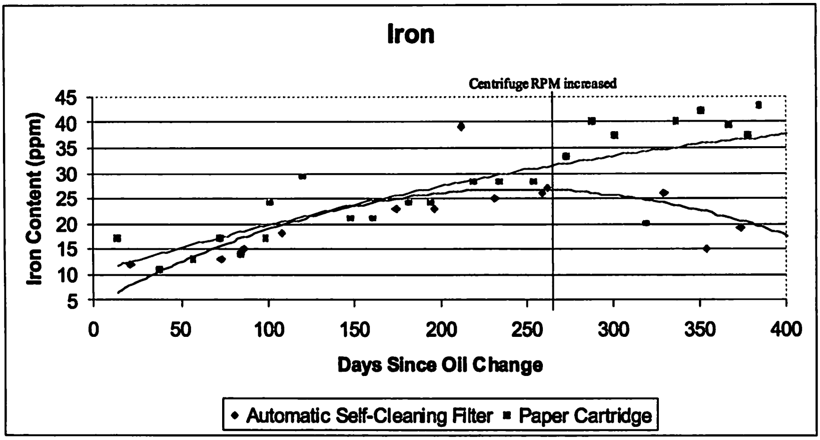


Figure 9 - Significant Decrease in Iron with the Automatic Self-Cleaning Filter and Centrifuges

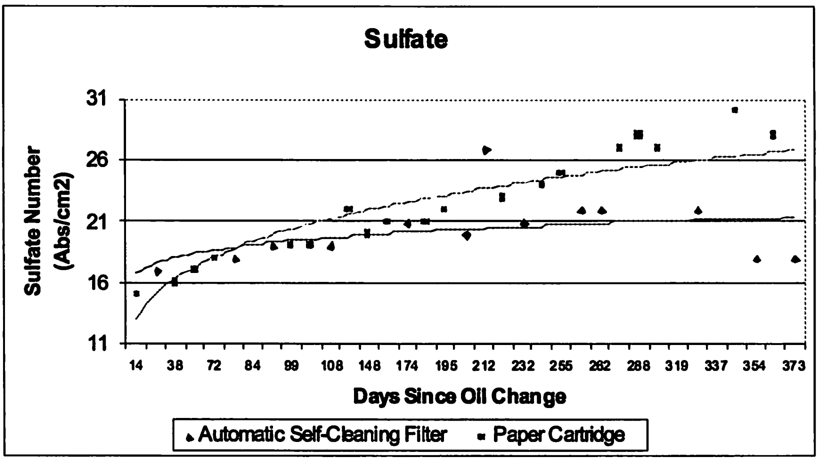


Figure 10 - Comparison of Sulfate in the Lube Oil

REPORT OF THE COMMITTEE ON NEW TECHNOLOGIES

THURSDAY, SEPTEMBER 17, 2009 1:15 P.M.

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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 20 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 TRANSPORTATION TECHNOLOGY CENTER IN PUEBLO, COLORADO FOR HOSTING THEIR COMMITTEE MEETING IN NOVEMBER 2008

SPECIAL THANKS TO ED GROVES AND ALAN POLIVKA OF TTCI FOR HOSTING THE MEETING

ALSO THANKS TO RICH DALTON AND WABTEC/MPI FOR HOSTING THE DINNER IN DENVER

ETHANOL-ELECTRIC HYBRID LOCOMOTIVES

Prepared by
Tom Mack,
Alternative Hybrid Locomotive Tech

Although railroads have long been considered one of the most fuel efficient and lowest emissions forms of transportation, railroads have never been more impacted by emissions regulations than in the 21st century. The enactment of Tier 2 emissions standards in 2005 required major locomotive manufacturers to develop new engines and engine technologies and redesign the locomotive offerings in order to meet significant NOx and PM reduction requirements. EPA Tier 4 requirements, that take effect in 2015, will require the addition of diesel particulate filters (DPF), selective catalytic reduction (SCR), or other new technologies to reduce NOx and PM to levels considered almost impossible a few years ago.

In 2009 a new emissions requirement was introduced, although not totally unexpected. This emissions requirement had to do with Greenhouse Gasses (GHG). Although many countries had previously taken a formal stand that GHG emissions, especially carbon dioxide produced from burning fossil fuel, were detrimental to the environment, a significant cause of global climate change, and in need of regulation, the United States had no formal policy on the issue. In fact, under the administration of President George W. Bush, the United States Environmental Protection Agency (EPA) refused to take a formal stand on the regulation of GHG.

All of that has changed in 2009. Under the new administration of President Barack Obama, the US EPA announced that regulation of GHG would be one of its top three priorities. Nevertheless, it was somewhat stunning to many in the transportation industry when the EPA made a formal statement in April 2009 calling carbon dioxide emissions a "significant human health hazard." These statements and the current EPA position on GHG make it clear that regulation of GHG emissions will soon affect all industries in the United States, including the transportation sector. Regardless of the increased fuel efficiency and lower emissions found in today's Tier 2 locomotives, GHG reduction will become a requirement for U.S. railroads, and no doubt Canadian railroads as well.

In order to meet upcoming GHG reduction requirements, as well as a growing desire by the U.S. to reduce its dependency on foreign oil, railroads need to be exploring alternative technologies now so as to make wise decisions to deal with GHG reduction and lessen dependency on fossil fuels. This means taking a serious look at renewable fuels. These renewable fuels are produced from biomass, such as corn and sugar cane (ethanol), and various vegetable oils such as soy oil, palm oil, canola (rapeseed) oil, etc. (biodiesel).

The move toward GHG reduction and reduced dependency on fossil fuel is a two-edged sword for today's railroads. On the one hand, due to the high efficiency of rail transportation, it makes sense to move more goods and passengers by rail, thus benefiting from reducing the number of high polluting cars and trucks from the nation's highway system. This will mean a growth in business for railroads as freight (and passengers) move to more fuel efficient modes of transportation.

On the other hand, GHG reduction cannot be achieved through advances in fuel efficiency alone. Many proposed carbon reduction plans use the concept of "additionality" to measure GHG reduction. These proposals look to the adoption of additional technologies to reduce GHG reduction beyond what the standard or currently available technology provides. In other words, if the standard locomotive offerings already provide a 10% increase in fuel economy (and thus a decrease in overall emissions), "additionality" says that there is no "penalty" for adopting these technologies, thus there is no credit given for GHG reduction. If there is a technology available that could reduce GHG even further, but it comes at a cost to the adopter, then this is going the "additional" mile, and these technologies would be eligible for subsidies, such as carbon credits, to offset the additional cost of the technology.

In addition to the environmental benefits of GHG reduction through the adoption of biofuels, there is the matter of energy security and independence. The massive fuel cost spikes of 2008 are a clear indicator of the effects that dependence on foreign oil can have on the North American economy. Although fuel was always available, the run up of the cost of crude oil to almost $150 a barrel brought about unheard of prices for transportation fuel (diesel and gasoline) at the pump. Although some percentage of these high costs could be passed on to the shipper in the form of fuel surcharges, there is no doubt that these high fuel costs ate into railroad profits. Even with some shippers switching to rail over trucks, the additional business for the railroads came at a high price. What concerns many railroads now is that the next round of higher fuel costs could be accompanied by reduced supply. This would be absolutely disastrous to the economy.

The only way to reduce these potential fuel shortages is to look to domestically produced fuel. This means taking advantage of the billions of gallons of biofuels produced domestically in the U.S. and Canada. Under the U.S. Renewable Fuel Standard (RFS), the production of biofuels is expected to increase to some 35 billion gallons of fuel per year. Sufficient quantities to supply a large portion of the North American railroads fuel requirements. By keeping the proceeds from the sale and production of these fuels in the local economies, there is a cyclical effect that can also benefit the railroads, since local money means increased purchase of goods, many of which ship by rail.

BIOFUEL TYPES

Over the years, multiple types of biofuels have been used by the transportation industry. In its early years the railroad industry was a large user of biofuels. Locomotives were fueled by wood, a renewable biofuel. (Today, wood used directly as fuel is more commonly referred to as biomass, to differentiate it from liquid biofuels.) Over the years, wood gave way to coal and oil, both considered non-renewable fossil fuels.

Today, the most commonly produced and used biofuels are biodiesel and ethanol. Other alcohol fuels such as methanol were also heavily experimented with in the 20th century. Methanol however, had many negative qualities, including a low BTU content and high corrosiveness which affected fuel systems and engines.

At first glance, the logical choice of biofuels for a locomotive would be biodiesel. According to Wikipedia: "Biodiesel refers to a non-petroleum-based diesel fuel consisting of long-chain alkyl (methyl, propyl, or ethyl) esters. Biodiesel is typically made by chemically-reacting lipids (e.g., vegetable oil, animal fat (tallow)) and alcohol. It can be used (alone, or blended with conventional petrodiesel) in unmodified diesel-engine vehicles. Biodiesel is distinguished from the straight vegetable oil (SVO) (sometimes referred to as "waste vegetable oil", "WVO", "used vegetable oil", "UVO", "pure plant oil", "PPO") used (alone, or blended) as fuels in some converted diesel vehicles."

The most commonly produced biofuel in the United States is ethanol, also called ethyl alcohol, or grain ethanol, because the most common feedstock in the U.S. used to produce ethanol is corn (wheat, barley, and other grains can also be used as feedstock for ethanol production). Ethanol is a "two-chain" alcohol, meaning it contains two CH2 carbon chains (methanol contains only one CH2 carbon chain, hence it has a lower BTU content). U.S. ethanol plants have the capacity to produce over 12 billion gallons a year of ethanol. Although corn continues to be the feedstock of choice, new plants are being built in the United States that use sugar cane, waste sugar, municipal solid waste (MSW), wood chips, waste paper and other "cellulosic" feedstocks. These "cellulosic" ethanol plants will produce ethanol with the greatest GHG reduction potential, some estimates stating that GHG reduction will be over 90%.

In the future, there are other biofuels that hold promise as well. Unfortunately, these biofuels are currently produced in very low quantities, and it is doubtful that all these fuels will become economically viable. Among these fuels holding promise are:

1. Renewable diesel and gasoline – fuels having virtually the same chemical and combustion properties as current diesel and gasoline, but produced from biomass feedstocks, and thus renewable. These fuels could be

used in existing engines with no change to the engine itself, engine fuel system, or fuel delivery infrastructure (pipelines, filing stations, etc.).

2. Biobutanol - Biobutanol is a four CH2 carbon chain alcohol. It is currently produced in quantity from petroleum, but new biological technologies are producing butanol from corn and wood chips using microbes (similar to the yeast that produces ethanol from grain). Because the butanol is pro duced from biological feedstock instead of petroleum, it is commonly called biobutanol to differentiate it from standard petroleum based butanol.
Biobutanol has a higher BTU content than ethanol due to the two additional CH2 carbon chains (114,000BTU for biobutanol vs. 78,000BTU for ethanol). Because of this higher BTU content (comparable to gasoline), biobutanol would have distinct advantages over ethanol for range and horsepower per gallon. It can also be shipped through existing pipelines due to the fact it does not attract moisture and contaminants like ethanol. Because biobutanol is an alcohol fuel, the transition from ethanol to biobutanol would be fairly straightforward, without major changes to infrastructure or engine systems. Unlike ethanol, biobutanol is not a human consumable. Hence, it does not need to be denatured before being shipped for fuel use.

3. Alcohol Mixes - Alcohol fuels, like any fuel, have trade-offs. For example, while biobutanol has a higher BTU content than ethanol, it also has a lower octane rating than ethanol. Hence, it cannot be combusted at the higher compression ratios of ethanol (and higher compression equals higher efficiency). But alcohol fuels such as ethanol and biobutanol can be easily mixed to form a "hybrid" fuel. This would result in a fuel have the best characteristics of each fuel (the higher BTU content of biobutanol and the higher octane rating of ethanol). The mix ratios of the alcohols could be varied, with higher biobutanol blends introduced over time as more becomes available. This would provide for a very gradual and controlled introduction of higher BTU alcohol fuels with no need to change infrastructure or upgrade existing ethanol-fueled locomotives. Since these fuels could be mixed at the alcohol plant (in fact, a single plant could potentially produce both ethanol and biobutanol from the same feedstock) there would be no need for an intermediate blender. And since biobutanol is a natural denaturant, the alcohol mix would not require a gasoline denaturant.

Use of any fuel (petroleum or biofuel), however, is not without pros and cons. So too, biodiesel and ethanol both have pros and cons. Biodiesel, for example, has the advantage of having a fairly high BTU content per gallon, although it is generally slightly lower than petroleum diesel. So the use of biodiesel can result in a fuel use increase penalty. Biodiesel blends can be used in many existing diesel engines without need for modification of the engine (as long as the blend level is approved by the engine manufacturer). Biodiesel has a substantial GHG reduction potential. The U.S. Environmental Protection Agency (EPA) estimates the GHG reduction of biodiesel at 67.7% per gallon. This is a fairly high GHG reduction potential, comparable to that of sugar cane based ethanol, and higher than most corn based ethanol.

However, there are a number of negative aspects of biodiesel that have held back widespread use in the transportation industry. First, there is the higher cost of biodiesel over petroleum diesel. Biodiesel has classically run as much a $1 per gallon more than petroleum diesel. Although this cost has been offset by a U.S. government subsidy of the same amount, it has not been unusual for the cost of biodiesel to run higher than petroleum diesel even after the subsidy. Studies of the use of biodiesel have also shown that it produces higher NOx levels than petroleum diesel. Since NOx is regulated by the US EPA locomotive emissions "Tier" regulations, this increase in NOx cannot be ignored. So the use of biodiesel will not do away with the need for Selective Catalytic Reduction (SCR) or Diesel Particulate Filter (DPF) systems to reach EPA Tier 3 and Tier 4 locomotive emissions requirements.

Since biodiesel is produced from vegetable or animal oils, the yield per acre of biodiesel from these sources is lower than that of fermented fuels such as ethanol. Because of this, some studies have indicated that it may be doubtful if biodiesel could fill the quantity needs of biofuels. New technologies, such as using algae as a feedstock for biodiesel may take care of these production quantity issues.

There are also known issues with using biodiesel in existing and even new diesel engines. Many engine manufacturers only warrant the use of low-level biodiesel blends, such as B5 or B20. At these low blends, the GHG reduction potential of biodiesel is almost eliminated. A B5 blend will only reduce GHG emissions by 3.4%, while a B20 blend reduces GHG emission by only 13.5%. Neither of these levels is enough to meet proposed GHG reduction goals which in many cases are in excess of 30% required GHG reduction. (The 2005 LMOA proceeding had a detailed study of biodiesel pros and cons, including detailed potential fuel system and engine issues.)

Ethanol fuel also has positive and negative aspects. On the positive side, ethanol is a very abundant biofuel. U.S. production capacity currently exceeds 10B gallons per year. Yields of 2.8 gallons of ethanol per bushel of corn are very common. With the addition of new technologies such as producing ethanol from corn cobs and corn stover, the ethanol yield per acre of corn grown could increase by 25% without planting any additional crop. Using this "cellulosic" feedstock (cobs and stalks), the overall GHG reduction of corn ethanol would increase substantially, and corn ethanol could equal the GHG reduction of biodiesel or sugar cane. So despite what the popular media portrays, there is no reason to consider corn-based ethanol as a dead-end fuel. Based on the current supply of ethanol and new plant capacity, ethanol can easily replace a large percentage of the fuel used not only in automobiles, but by ethanol fueled locomotives.

In addition to corn ethanol, new technologies are being introduced to produce ethanol sweet sorghum, sugar cane (not a common feedstock in North America), and from "woody" biomass such as switch grass, wood chips, paper, and municipal solid waste. These "woody" feedstocks are commonly called "cellulosic" feedstocks, because of their high cellulose content. Because cellulose is a tougher material than starch or straight sugar, it must first be converted with enzymes or through other processes to allow conversion to ethanol. These processes are quite diverse, and the first production "cellulosic" ethanol plants should be coming on line in 2010 or 2011. Not only does cellulosic ethanol hold promise to reduce the levels of what are currently considered waste streams (MSW, forest residue, waste wood chips and scrap paper), but because these feedstocks are either waste items or require little if any farming, the reduction of GHG emissions for cellulosic ethanol is quite high. The EPA estimates GHG reduction for cellulosic ethanol at over 90%. Thus the use of cellulosic ethanol would have a definite and dramatic effect on GHG reduction, far exceeding the 30-35% required to bring overall GHG levels down to pre-2000 levels, and offsetting the continued use of fossil fuel GHG emissions.

In addition to reduction of GHG emissions, ethanol can substantially reduce criteria emissions associated with diesel fuel. Ethanol produces virtually no particulate matter when burned in a spark ignited internal combustion engine. Also, a higher RPM spark ignited ethanol engine will produce much lower NOx levels than a comparable horsepower diesel engine. In fact minimal or no aftertreatment should be needed to reach EPA Tier 4 locomotive requirement. Thus an ethanol locomotive engine would not require DPF or SCR to meet EPA Tier 4.

Because of the high octane rating of ethanol (around 116 octane), a locomotive could use a high compression ethanol engine. Higher compression equals higher efficiency. Thus, some of the BTU differential between diesel fuel and ethanol could be recouped because of the higher efficiencies from an ethanol engine.

There are also potential benefits in fuel prices using ethanol. Because ethanol is produced domestically, and because an ethanol powered locomotive would not require the ethanol to be blended with other fuels, the railroads could purchase fuel directly from the producer. This would cut out any "middle man" mark-up. It also means that any subsidies available for the biofuel could be shared by the producer and the railroad.

As with biodiesel, there are also negative aspects to ethanol fuel. First and foremost is the lower BTU content. Regardless of engine efficiency, ethanol vs. diesel will no doubt incur a fuel use increase penalty. The use of ethanol will require a new fueling infrastructure. This issue can be minimized by starting with truck or tank car to locomotive mobile fueling. Also, by gradually phasing in ethanol locomotives into switching, local, or branch line service, the number of fueling points can be minimized while fleet size is increased.

Another known issue with ethanol is an increase in aldehyde emissions. This issue can be overcome by adding currently available aldehyde catalytic converters into the exhaust system. So while the production of aldehydes is a known issue, the solution for the elimination of those emissions is also well known and readily available.

GREENHOUSE GAS (GHG) EMISSIONS REQUIREMENTS

Although the U.S. EPA does not currently regulate GHG emissions, it has now openly stated that it plans to do so in the near future. The state that has probably spent the most amount of time studying the issue of GHG emissions and formulating a reduction plan is California. The California Global Warming Solutions Act of 2006 (AB 32) requires that the California Air Resources Board (CARB) approve a statewide greenhouse gas emissions limit equal to the GHG emissions level in 1990. In 2004 the rail sector in California produced 3.14M metric tonnes of CO2, compared to 2.75M metric tonnes of CO2 in 2003. That is a 14.5% increase in CO2. In 1990 the railroad sector in California produced 2.29M metric tonnes of CO2. CARB projections are that the rail sector will produce 3.7M metric tones of CO2 in 2020. To reduce the 2020 projected CO2 levels to the 1990 levels will require a decrease of 1.4M metric tonnes of CO2. 1.4M metric tonnes equates to a 1.55M U.S. tons reduction. This means the California plan is to reduce GHG emissions by 37.8% by 2020.

Locomotives produce approximately 11.192 tons of CO2 per 1,000 gallons of fuel consumed. An average diesel locomotive in yard and local service can easily consume 50,000 gallons of fuel per year. This equates to over 559 tons of CO2 per locomotive. Cellulosic ethanol is estimated by the EPA to reduce GHG emissions by ~90%. Since even cellulosic ethanol would be blended with gasoline as a denaturant, for the purposes of projections, ethanol GHG emissions reductions are based on an E95 blend (95% ethanol, 5% gasoline), which equates to an 85.5% overall CO2 reduction for cellulosic ethanol, and a 20.7% overall CO2 reduction for corn ethanol. Using these estimates, an ethanol powered locomotive would reduce annual CO2 emissions per locomotive by 483 tons using cellulosic ethanol and 116 tons using corn ethanol, when compared to a diesel locomotive consuming 50,000 gallons of diesel fuel annually and producing 596 tons of CO2. (It should be noted that newer corn ethanol plants have substantially lower carbon footprints, with some new design corn ethanol plants touting GHG reduction credit of over 70%.)

Based on the GHG calculation of 11.192 tons of CO2 per 1,000 gallons of fuel consumed per locomotive, to reduce locomotive GHG emissions levels to 1990 levels will require the replacement of at least 130M gallons of diesel fuel with a GHG reducing fuel. These calculations suggest that 805 locomotives, each using 200,000 gallons of diesel fuel annually, must be replaced with locomotives using cellulosic ethanol in order to meet just the California requirements.

The CARB 2004 Intrastate Locomotive Report shows that the average Intrastate locomotive on a Class I railroad in California (BNSF or UP) only uses 61,000 gallons of fuel per year. At that rate, it would require 2,640 intrastate Class I locomotives using cellulosic ethanol in order to reduce the GHG emissions to 1990 levels.

However, there is a large opportunity to begin CO2 reductions by first concentrating on high horsepower, high fuel consuming intrastate locomotives. For example, intrastate freight locomotives in California consume 26.6M gallons of diesel fuel per year (CARB estimates) producing around 298,000 tons of CO2 emissions annually. If these were replaced with locomotives powered by cellulosic ethanol, this would make a substantial contribution to reducing current levels of GHG emissions. The 2004 to 1990 CO2 differential for California is about 941,000 tons, so 32% of this differential could be quickly erased by moving California intrastate locomotives to cellulosic ethanol hybrids. However, even with the replacement of all intrastate locomotives in California, this still leaves a substantial shortfall in meeting the GHG reduction goal.

Although the use of biodiesel could also reduce GHG emissions, because of the lower blend levels for biodiesel, GHG reduction would not be sufficient (see Table 1). The EPA estimates the GHG reduction level of 100% biodiesel at 67.7%. But because biodiesel is normally blended at very low percentages with petroleum diesel, the overall GHG reduction levels are quite small. Most diesel engine manufacturers will support a B5 blend (5% biodiesel and 95% petroleum diesel per gallon) and some will support up to a B20 blend (20% biodiesel and 80% petroleum diesel per gallon). At these blend levels, B5 only provides a 3.4% overall GHG reduction, and B20 a 13.5% reduction. So even if every locomotive in California ran a B20 blend, this reduction would only meet 35% of the California AB 32 goal. So in order for biodiesel alone to meet the California GHG reduction goals, locomotives would have to use a very high blend, somewhere around a B55 or B60 fuel.

ETHANOL POTENTIALS

While final GHG emissions requirements for the U.S. will be shaped over the coming year, the railroad industry already is well aware of what it faces to meet the criteria emissions reduction requirements of EPA Tier 4.

First is a reduction of particulate matter. Since PM has been linked to cancer, the reduction of PM is a major issue with many communities and states. States like California are even pushing to increase the PM reduction from locomotive fleets. A spark ignition ethanol engine should meet even the most stringent PM reduction requirements without the use of any particulate filters. This is because alcohol fuel burns with virtually zero PM. Because ethanol uses gasoline as a denaturant, there may be some PM produced, but at such low levels as to be negligible, even by EPA Tier 4 standards. Also, when coupled with hybrid technology, the engine start and power increase cycles most associated with PM production (the classic black smoke when throttling up a diesel locomotive) can also be eliminated or minimized.

Probably the biggest challenge to meet EPA Tier 4 for locomotives is the reduction of oxides of nitrogen (NOx) which combined with ozone in the atmosphere create smog and contribute to breathing difficulties. (Recently it has also been suggested that GHG emissions contribute with NOx to health issues, because the higher global temperatures are more conducive to the creation of smog through NOx emissions. Thus, both NOx and GHG emissions are being linked as contributors to breathing problems in humans.)

Current diesel technology suggests the use of selective catalytic reduction (SCR) to reduce NOx levels. This requires the introduction of either urea (an ammonia compound produced from natural gas, a fossil fuel) or perhaps the diesel fuel itself (known as hydrocarbon selective catalytic reduction or HC-SCR) as a reductant to convert the NOX into free nitrogen, water, and CO2. Since ethanol burns differently in a spark ignition engine than diesel in a compression ignition engine, and because an ethanol engine would run at a higher RPM than a diesel engine of similar horsepower, the creation of NOx is greatly reduced. An ethanol engine should be able to meet EPA Tier 4 locomotive requirements with either no aftertreatment, or simply the addition of a standard 3-way catalytic converter. There is no need for the addition of SCR or carrying a reductant such as urea.

An issue that has been commonly raised, however, with the use of ethanol is engine durability. Some people have expressed concerns regarding the durability of an ethanol engine for several reasons. First, is that an ethanol engine would be running at a higher RPM than a diesel engine. While it is true that a higher RPM usually equals lower durability and less engine hours between overhaul, the cleaner burn of the ethanol fuel can have a tremendous impact on increasing engine life. Lower polluting fuels, such as LNG, have been shown to produce significantly less wear on engine parts such as rings and bearings. One reason for this is that the lubricating oil remains clean and as such, the higher lubrication properties of the clean oil over a longer period of time offset the increased RPM. This has been shown to be the case with airplane engines running ethanol fuel vs. avgas (which contains lead, a natural lubricant). Airplane engines running ethanol show substantially lower wear at overhaul time than their counterparts using avgas. Also, some lower horsepower engines using LNG fuel have been shown to have a 20,000 hour lifespan between rebuilds, thus rivaling many diesel engines.

The durability of an ethanol engine can also be increased by the use of higher durability components, such as high durability treated rings, and low friction cylinder honing techniques. The use of these components or techniques in engine preparation and production is not warranted in a low-cost automotive application where current engine life equals or exceeds that of the automobile itself. (Why would GM spend even an extra $10 per engine on a million automobiles to increase engine life by a few thousand hours when the engine already lasts the life of the car? It would be tantamount to spreading $10M in cash throughout an auto salvage yard - not a wise thing to do in this or any other economy.) But the addition of even $1,000 worth of high durability parts or assembly techniques into a locomotive engine to increase engine life by 2,000 or 3,000 hours will pay for itself within a few months on potential fuel savings and lifetime overhaul costs. Thus an ethanol locomotive engine would more closely match a diesel engine in components and durability, than a spark ignited automobile engine.

Since an ethanol engine would be smaller overall than a diesel engine of similar horsepower, the smaller parts could be less susceptible to the shock and stress associated with locomotive duty. Components, including the entire generator set, can be better shock isolated, thus extending durability.

It should also be noted that an ethanol powered hybrid locomotive, since it uses smaller, lower horsepower generators, would be a multi-engine design. Thus the overall combined genset time between overhauls would be longer than the between overhaul time of any single genset. Thus a 5,000 hour genset may last 8,000-10,000 hours on locomotive due to "load balancing" between multiple gensets. Load balancing may also include running two or three gensets at lower RPM and horsepower vs. one genset at higher RPM and horsepower (e.g. running two gensets at 250hp but 40% lower RPM than a single genset at 500hp at full RPM). Thus, there are methods for balancing engine efficiency and durability besides the actual design and components used in the ethanol generator set.

Finally, the use of hybrid technologies, specifically regenerative braking, will reduce overall engine run time thus increase the time between overhauls. Regenerative braking could supply 10-20% of the energy needs of the locomotive (some studies have suggested as much as 30-40% of the energy needs). Thus, the ethanol engines in an ethanol hybrid locomotive could last 20% longer (or more) between overhauls, although the actual engine hours between overhauls would remain the same.

PARADIGM SHIFTS

A switch to any new fuel, other than diesel (or a biodiesel blend) will no doubt require a paradigm shift in thinking about locomotive technology and maintenance techniques. The key is keeping the actual work required to a minimum, even if the change in thinking is radical.

For example, as long as the actual time between engine maintenance and/or overhauls remains the same as for current diesels, does it really matter if the engine itself runs at a higher RPM than current diesels, or the size of the engine is substantially smaller compared to its diesel counterpart? For many in the computer industry, it was hard to imagine that a smaller size disk drive could actually hold substantially more data, or be substantially more robust and shock resistant than its bigger and heavier counterpart. But it was shown that the smaller components actually increased the ability to store more data on the disk, and the smaller components, due to their lighter weight and lower mass, were actually less vulnerable to shock and vibration. If the same holds true for smaller ethanol engines, is there any reason not to accept the technology?

We also need to realize that ethanol engine technology is an engine change, not an engine modification. A true ethanol engine cannot be thought of as simply an automotive engine put in a locomotive. These are not diesel engines, gasoline engines, or even flex-fuel engines (capable of running on either gasoline or ethanol). A true ethanol engine is a new category of spark ignited engines (and may not even require a spark ignition with the use of some promising new technologies). All aspects of the engine design and development are for ethanol, with no compromises for gasoline or diesel fuel.

The changes in the engine technology are quite widespread. For example, because of the extremely high octane rating of ethanol, compression ratios can be significantly increased. As such, gasoline (except for the highest octane racing fuel) could not be used in a true ethanol engine. The bore and stroke of the engine, fuel injection system, intake and exhaust manifolds, block and heads, bearings, pistons and rings, and all other components are chosen based on the design of the ethanol engine, and not some previous gasoline or diesel engine.

The ability to take the base engine, and make incremental advances and changes to the engine during rebuilds will also allow an evolutionary approach to future enhancements in both efficiency and durability. Here again is where a paradigm shift in thinking must take place. If the multi-year cost and downtime for a multi-genset vs. a single engine locomotive is the same, how much opportunity is there for:

1. Increasing efficiency at each genset swap? How much of genset swap cost can be quickly captured by efficiency gain? Just a 1% fuel efficiency increase on a locomotive using 50,000 gallons of fuel per year can quickly add up. The 1% fuel efficiency increase would reduce fuel usage by 500 gal - lons year. At $2 per gallon, that is a $1,000 offset to "between overhaul" maintenance costs. At $4 per gallon of fuel, the offset is $2,000. And while effi - ciency gains will at some point no doubt plateau, durability will no doubt also increase, increasing mean time between rebuilds, and decreasing maintenance cost. Thus new technogy adoption cost can easily be offset by the positive results.
2. Decreasing emissions at each genset swap? For example, GHG reduction can equal carbon credits. Although these carbon credits are not formally adopted yet, it is expected these will be adopted along with a cap-and-trade carbon reduction plan. But perhaps more important is that the NOx/PM reduction available through normal genset swaps can mean moving to the next EPA Tier without the cost of a brand new locomotive. This will allow railroads to compete more with trucks, which due to the shorter lifespan of a truck compared to a locomotive, have a faster turnover rate to newer, cleaner, less expensive (compared to per locomotive costs), and more fuel efficient technologies
3. Performing genset swaps during regularly scheduled maintenance times, such as scheduled annual 2-day maintenance periods? This would mean that unscheduled down-time due to engine failures could be virtually eliminated. Engine replacement could be factored in to the normal annual maintenance costs of the locomotive, perhaps even becoming part of a standard maintenance contract. Any "unscheduled" downtime due to engine failure would be the responsibility of the maintenance contractor (probably the manufacturer), rather than the railroad.

The actual time between rebuilds for a true ethanol engine is still unknown, so while all of the above has yet to be proven through dynamometer and road testing, it is certainly worth considering.

Another area of "paradigm shift" thinking has to do with the acceptance of hybrid locomotive technology. The term "hybrid locomotive" unfortunately has some bad reputations around railroad circles. But it is justifiable to ask whether the first "hybrid locomotives" were truly "hybrids" or battery locomotives with on-board charge? There is strong argument that earlier designs of "hybrid" locomotives were not true hybrids, since a true hybrid would normally have an almost equal horsepower rating of batteries and engines, and the rate of battery charge on a true hybrid would usually remain relatively high. A "battery" locomotive, on the other hand, could use a lower horsepower generator and would take the battery charge down to a much lower charge level than a normal hybrid.

We must remember that all this new technology moves ahead and "new" technology may succeed where the first technology did not. In the development of an ethanol-electric hybrid locomotive, the design can use a totally different power mix of generator sets and battery. Since an ethanol powered generator set is smaller than its diesel counterpart, the location and number of ethanol generator can be different. For example, a six axle ethanol-electric hybrid locomotive could house six 500hp ethanol generator sets producing a continuous 3,000hp (the equivalent of an EMD SD40-2 or GE C30-7). By using a new design locomotive frame, cab, and electrical cabinet, the locomotive could also house a 1,000hp battery set and an additional energy storage system (beyond the battery set). With 3,000hp worth of generators, this is enough generator set power to power locomotive traction needs and recharge the battery simultaneously. This is more in line with proven hybrid technology where the system is not dependent on the battery system to be able to perform (i.e. even with a low-charged battery system the locomotive can still meet its duty requirements).

The battery technology chosen will also greatly affect the performance of the locomotive. Different battery technologies have been used on prototype hybrid locomotives. These include: 1) Sealed lead acid batteries; 2) Flooded lead acid batteries; 3) new generation Nickel Metal Hydride (NiMH) or Lithium Ion (LiIon) batteries; and even 4) Liquid Sodium batteries. Each battery type has its own pros and cons, but one of the biggest issues with NiMH, LiIon, and Liquid Sodium batteries is the price per kilowatt hour. A 1,000hp battery system for a locomotive could easily cost $750,000 to $1M. The ability to recoup this battery cost through fuel savings from regenerative braking is questionable. So part of the paradigm shift in battery choice is to consider "old" technology flooded lead acid batteries. These batteries can be very cost effective in a hybrid locomotive application, but require a redesign of the locomotive to take advantage of mounting potentials on an ethanol-electric hybrid locomotive.

In addition to the choice of batteries, different control technology must be employed. The charge levels of the battery and/or actual battery duty cycles can greatly change battery life and performance. Even the charge level of individual battery cells within the battery set must be taken into consideration. For example, a nominal 640VDC lead acid battery set will have 320 2vdc cells. If just one of these cells starts to "misbehave" or gets out of synch in charge level with the other cells, this can have negative consequences to the life of the entire battery set. In a worse case scenario, it can have disastrous consequences in the event of a battery fire. Proper control technology, battery types, cycle modeling, and battery and cell management systems, can provide tremendous performance gains and increase battery pack longevity. These technologies can allow energy to be stored at the same rate as discharge, with minimal efficiency loss from generator sets to battery. So in regard to hybrid technology, we need to ask ourselves: Have we really considered all these areas or just one or two projects that failed?

As hybrid technology becomes proven, with more empirical data available for consideration by railroads, another area of thinking that will come in to play is Continuous Horsepower (CH) rating (CH) vs. Continuous Duty Cycle (CDC) rating. Classically, locomotives have always been measured by their CH rating. The CH rating is the maximum amount of horsepower that a locomotive is able to produce (e.g. 2,000hp) at any time and for as long as liquid fuel lasts in the tank. Thus, a GE C30-7 was a 3,000hp locomotive that in theory could be placed in throttle notch 8 (full power), and left in that throttle setting until the tank ran dry. Refilling the tank would allow the locomotive to continue running in that throttle setting until the next refueling. This CH rating was particularly critical for road use where locomotives spend longer percentages of their time in higher throttle notches, and also in multimodal (e.g. yard and branch line) operation where the locomotive may operate some of its time in a switcher duty cycle, but also be needed to serve in road service at times.

On the other hand, Continuous Duty Cycle (CDC) rating takes into account that very seldom does a locomotive operate continuously at high throttle settings. Much of the locomotive's time is spent at idle, or lower throttle settings (50-60% of rated horsepower). Thus, as CDC rated locomotive must only be able to produce its full horsepower rating (e.g. 2,000hp) at any time for <u>as long as the normal duty cycle requires it</u>. It is assumed that the duty cycle will give time for battery recharge and enough generator horsepower exists to not only recharge battery but power the locomotive if need be. CDC ratings are more suited to yard, local, and branch line use where higher throttle notch percentage is low compared to lower notch percentage. It should be noted, however, that recharge time is not necessarily tied to idle time if the locomotive is put through heavy work between idle periods. This was a definite issue with earlier so-called "hybrid" locomotives. If the actual work time of the locomotive stretched outside the "normal" CDC, the batteries became overly discharged, and there was no time during this work period to recharge the batteries. The on-board generator was simply not of sufficient horsepower to recharge the batteries during the work period. This issue becomes less critical, and is virtually eliminated, if the generator power to battery ratio is correctly matched to the duty cycle.

Thus, a railroad needs to determine if "captive" service of locomotive allows it to take advantage of CDC rating. This can set new paradigms for a railroad's choice of power mix (generator set horsepower vs. battery set horsepower) on a hybrid locomotive. For example, Railroad A may opt for a 1,000hp twin genset hybrid with a 1,000hp battery system to create a 2,000hp CDC hybrid locomotive. However, Railroad B may opt to have 1,500hp in three gensets combined with the same 1,000hp battery system to create a 2,000hp severe duty cycle CDC hybrid locomotive instead of the twin genset 2,000hp hybrid chosen by Railroad A. This power mix can be left up to the railroad. And depending on locomotive design, a railroad could have the option of increasing or decreasing the number of generator sets on an existing locomotive as more empirical operating data becomes available.

EVALUATING EFFICIENCY TECHNOLOGIES

There is little doubt that new technologies can be introduced to increase engine efficiency and fuel economy, as well as engine durability. This has been the standard for decades - with each new generation of locomotives there comes more efficient or economical technology. The introduction of emissions control, however, has changed this. While fuel economy is important to the railroads, fuel efficiency becomes less important to regulating bodies such as the EPA if emissions levels cannot be met. So if increased back pressures or fuel burn to increase exhaust gas temperatures are required for introduction of DPF and SCR technologies, and this requires a decrease in fuel efficiency to meet the Tier standards, locomotive manufacturers will need to accept a next generation locomotive with poorer fuel economy than the previous generation of locomotives. This holds true for the multi-genset locomotive world as well.

There are technologies available for smaller engines, such as off-road truck diesels or an ethanol engine that could conceivably increase fuel efficiency, but are not currently being applied to these engines. Oftentimes when such technology is discussed, the question that arises is: "If the technology is so good that we are going to use it on locomotives, why aren't the automobile or truck engine manufacturers using it?" In some cases, this is a valid question in regard to the technology itself. But in other cases, it is not a valid technology question, but merely a question of economics.

To illustrate: If an engine manufacturer wants to increase a 10,000 hour engine's durability by 5,000 hours, it could be as simple a matter as using a specialty coated or treated piston ring. But if the engine only has to last 8,000 hours (the average life of the vehicle) and the engine will meet that requirement using the current less expensive piston rings, why would the engine manufacturer spend the extra money on a more durable piston ring? Even if the rings only cost $1.00 more per cylinder more, on a V-8 the engine manufacturer would spend $8.00 additional per engine. If 250,000 engines were built per year, the increase in cost would be $2 million. That extra $2 million in engine parts would end up in the junkyard along with a competitor's 10,000 hour engine that, while not having the durability of the "new" 15,000 engine, still outlasts the life of the vehicle it is installed in. There is no economic justification to using the 15,000 hour piston rings.

On the other, if we want to put that same engine in a locomotive, where the vehicle lifespan will be 100,000 hours, we reduce the number of engine overhauls from 10 (one every 10,000 hours), to 6.6 (a 33% reduction). Is the elimination of at least three engine overhauls, along with associated locomotive downtime worth the extra $8.00 per engine for higher durability piston rings? Absolutely!

A similar paradigm exists in regard to fuel efficiency technologies. While the so-called "200mpg" carburetor for automobiles may be a myth, there is no doubt that fuel efficiency technologies do exist that could decrease current engine fuel usage by 5%, 10%, or even higher. As with durability technology, these technologies have not been widely adopted because of economics. Table 2 shows an example of how vehicle cost and annual fuel consumption are major determining factors in the economical feasibility of fuel efficiency technologies.

The first thing to consider is how much the technology will add to the overall cost of the vehicle. While the cost may be the same for an automobile or locomotive, on a less expensive vehicle, the new technology cost could be perceived as a major cost increase by the consumer. On a $30,000 automobile a $1,000 increase in cost is a significant 3.33% price increase on the vehicle. On a $1.5M locomotive with three gensets, requiring $3,000 worth of parts (one $1,000 system per genset), the total price increase would be just 1/5 of 1 percent, negligible in the overall cost of the unit (to match this ratio the technology for the automobile would have to cost just $60).

The next issue to consider is that in either case, automobile or locomotive, any price increase in the vehicle must be justified in its payback. If our "new" fuel efficiency technology gives us just a 7% boost in fuel economy, while this is a significant boost, even at $3.00 per gallon for gasoline, it would take almost eight years to pay for the technology in an automobile that gets 20mpg and is driven 12,000 miles per year. However, on a locomotive that uses only 50,000 gallons of fuel per year (i.e. a switcher), at $2.50 per gallon for diesel fuel, the technology would pay for itself in about four months. So while the technology could probably not be justified for a car or truck, the technology can definitely be justified on the locomotive.

BIOFUELS VS. PETROLEUM COST COMPARISONS – NO SIMPLE ANSWERS

A final paradigm shift that comes into play when considering biofuels options in locomotives has to do with comparing new technologies with current technologies. It is sometimes easy to compare potential biofuels options, such as ethanol, with existing locomotive technologies available today. But this would be comparing apples to oranges. The driving force for considering ethanol in locomotives is not the issues faced today, but those that will be faced tomorrow. Today locomotives only have to meet the EPA Tier 2 emissions standard. Every current manufacturer can meet or exceed these standards. Some of the multi-engine genset locomotive manufacturers can show today that their locomotives already meet the EPA Tier 2 standard that takes effect in 2012. GE and EMD have both stated publicly that they expect their locomotives will meet Tier 3 standards without requiring major modifications or design changes.

The issue for the future is the Tier 4 standard that takes effect in 2015, along with any GHG reduction regulations that may be instituted between now and then. Not to be ignored is the next set of EPA Tier standards for locomotives. Can it be reasonably assumed that once Tier 4 levels are reached that the EPA will not begin looking at Tier 5 or Tier 6 emission levels? So while the emphasis today is on getting to EPA Tier 4, within 5-10 years the locomotive industry will no doubt be talking Tier 5 and Tier 6. Will diesel locomotive engine technology be able to meet those requirements? Or will it require a new clean fuel source, such as ethanol, biobutanol, or another new generation biofuel? So the industry must consider not just today, but the long-term emissions requirements that appear to be on the horizon under the new EPA and the Obama Administration's renewable fuel and GHG reduction agenda.

Although use of a lower BTU fuel such as ethanol may increase fuel costs, it should not require the addition of expensive aftertreatment devices (DPF, DOC, or SCR) or reductant agents such as urea. What will these devices cost? Since none have been proven in locomotive use, the actual cost of these devices is anyone's guess. EMD and GE have stated that aftertreatment devices could double the price of the engine. So it is very conceivable that these devices could add $300,000 to $500,000 to the cost of a new locomotive. But again, this is just speculation. The fuel efficiency penalty on Tier 4 locomotives is also unknown. Will it be zero, or will it be five or ten percent? Again, this is not known. So how does one compare the potential additional cost of the diesel aftertreatment systems to the additional fuel cost of an ethanol-electric hybrid locomotive? Only time and demonstration of the two will tell.

Another cost issue has to do with

fuel prices themselves. In 2008 the world saw the price of crude oil jump to $147 per barrel. By early 2009 the price had dropped to $37 per barrel. By mid-2009 the price was back up to over $70 per barrel. During this entire time the price of ethanol remained relatively stable at between $1.50 and $2.25 per gallon (there was a three month aberration at the height of commodities speculation where ethanol spiked as high as $2.80 per gallon on the spot market, but within one month had dropped back down to $2.00 per gallon). Thus, even comparing fuel costs has its difficulties. OPEC has stated openly that crude oil needs to trade at between $75 and $80 per barrel to be profitable.

To put this into historical perspective, from April 2006 to August 2006 crude oil traded at an average of between $70 and $73 per barrel. During this time, diesel fuel at the pump averaged $2.73 to $3.05 per gallon. From July 2007 to September 2007 light crude oil traded at an average of between $74 and $79 per barrel. During this time, diesel fuel at the pump averaged $2.87 to $2.95 per gallon. From July to September 2007 corn was trading at between $3.03 and $3.50 per bushel (depending on state) with ethanol prices between $1.50 and $2.00 per gallon (spot market price). Since October of 2008 corn prices have remained below $4.00 per bushel, with ethanol prices ranging from $1.38 to $1.31 per gallon (spot market price).

So based on a historical perspective, if oil were to stay in a $70 to $80 per barrel range, one would expect diesel prices to be somewhere between $2.75 and $3.00 per gallon at the fuel pump. (These prices include road tax, so railroad fuel pricing would be less.) Spot market prices for ethanol, if corn remains at or below $4.00 per bushel, would be expected to remain in a $1.60 to $1.80 range. (Railroads could potentially take advantage of dealing directly with ethanol producers, hence taking advantage of spot market prices.)

Finally, there are the maintenance costs associated with new diesel aftertreatment technologies to meet EPA Tier 4 and beyond. As with the systems themselves, the long-term maintenance costs are unknown since production DPF and SCR units have not been field tested. For example, it appears that DPFs will require regular ash cleaning and even washing at regular intervals. DPFs have been known to allow exhaust blow-by thus reducing their efficacy, and because they are made of a ceramic material they can crack or break apart in severe duty applications. DPFs produce back pressure and can affect fuel consumption. Just how much expense these issues will add to long term maintenance costs is currently unknown.

The same is true for diesel oxidation catalysts (DOC) and Selective Catalytic Reduction (SCR) systems. But these systems are even more complex than the DPF and it is doubtful that the catalytic elements will last the life of the locomotive. How often will these elements need to be replaced? How much fuel will be used if exhaust gases need to be heated to ensure proper operation of the SCR system? How much will urea cost for SCR systems and how much will be consumed by the average locomotive? Will urea costs go down as more is produced or will demand outpace supply and drive prices up? What type of maintenance costs will be incurred on the on-board urea systems? Only time and experience will provide the answers.

So although there are still many unanswered questions in regard to ethanol-electric hybrid locomotives, the same holds true for the next generation Tier 3 and Tier 4 diesel locomotives. One thing is certain: The locomotives of today, no matter how advanced, will not be the locomotives of the near future. Renewable fuel and GHG reduction will be key elements in transportation systems of the future. Railroads will be affected, new technologies will emerge, and the winners will be decided by results, not just ideas.

Fuel (Blend Level)	EPA Estimated GHG Emissions Reduction	% of Bio-fuel in Blend	Overall GHG Reduction For Blend	Ethanol GHG Reduction Increase Over Biodiesel Blend		Locomotive Fuel Usage (Gallons) - Showing CO2 Reduction (tons)				
				B5 Biodiesel	B20 Biodiesel	50,000	61,000	100,000	150,000	200,000
Biodiesel (B5)	67.7%	5%	3.4%			18.94	23.11	37.88	56.82	75.76
Biodiesel (B20)	67.7%	20%	13.5%			75.76	92.42	151.51	227.27	303.03
Corn Ethanol (E95)	21.8%	95%	20.7%	511.8%	53.0%	115.87	141.36	231.74	347.62	463.49
Sugar Ethanol (E95)	56.0%	95%	53.2%	1471.6%	292.9%	297.65	363.14	595.31	892.96	1,190.62
Cellulosic Ethanol (E95)	90.9%	95%	86.4%	2451.1%	537.8%	483.16	589.45	966.31	1,449.47	1,932.62

Table 1 - Estimated GHG Reduction Per Locomotive by Fuel Type (in tons)

	Automobile	Locomotive
Technology Cost ($$$'s)	$ 1,000	$ 3,000
Vehicle Cost	$ 30,000	$ 1,500,000
Percent Increase over base cost	3.33%	0.20%
Annual Fuel Consumption (Gals)	600	50,000
Average Fuel Cost Per Gallon ($$$'s)	$ 3.00	$ 2.50
Annual Fuel Cost ($$$'s)	$ 1,800	$ 125,000
Fuel Efficiency Increase	7%	7%
Fuel Savings Per Year	$ 126.00	$ 8,750.00
Payback (Years)	7.94	0.34

Table 2 - Fuel Efficiency Technology Economics - Automobile vs. Locomotive

TESTING OF THE BNSF FUELCELL SWITCH LOCOMOTIVE: PART 1

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ABSTRACT

A North American consortium - a public-private project partnership - has completed the development of a prototype hydrogen-fueled fuelcell-battery hybrid switch locomotive for urban and military-base rail applications. At 127 tonne, expected continuous net power of 240 kW (320 hp) from its fuelcell prime mover, and transient power in excess of 1 MW, the hybrid locomotive will be the heaviest and most powerful fuelcell land vehicle yet built. At the time of this writing, the locomotive is complete, has completed initial operational testing at the BNSF System Maintenance Terminal (SMT) in Topeka, KS, and is presently at the Transportation Technology Center Inc (TTCI) for impact testing. Following impact testing, it will be tested under working conditions at the BNSF Commerce and Hobart railyards in the Los Angeles Basin and in the vehicle-to-grid application at a US Army base. This paper focuses on the testing to-date of the powerplant subsystems (e.g., air and cooling modules), initial operational tests at the SMT, and it lays the foundation for the tests to follow at TTCI and in the LA Basin. When the paper is presented at the LMOA annual conference on 17 September 2009, data from the impact tests at TTCI will be included.

INTRODUCTION

A North American consortium - a project partnership among BNSF Railway, the US Army Corps of Engineers, and Vehicle Projects Inc - has developed a prototype hydrogen-fueled fuelcell-battery hybrid switch locomotive for urban and military-base rail applications (see Fig. 1). At 127 tonne (280,000 lb), expected continuous net power of 240 kW or 320 hp (but presently limited to 200 kW by the thermal capacity of the powerplant DC-DC converter) from its proton-exchange membrane fuelcell prime mover, and transient power well in excess of 1 MW, 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; Hess, 2008] 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 Inc in 2002 [Miller, 2000; Miller and Barnes, 2002].

At the time of this writing, July 2009, the locomotive is complete; it has completed initial operational

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testing at the BNSF System Maintenance Terminal (SMT) in Topeka, Kansas; it was showcased in a press conference at the SMT on 29 June 2009; and it is at the Transportation Technology Center Inc (TTCI) to undergo extensive impact testing. The timeline for the final phases of the vehicle development and demonstration project, which commenced in May 2006, is shown in Fig. 2. Following impact testing, it will be tested under working conditions at the BNSF Commerce and Hobart railyards in the Los Angeles Basin and then tested in the vehicle-to-grid application at a US Army base. In the Los Angeles yards, its tests will include the equivalent of tractive effort, quantitative noise measurements, and fuel costs. Naturally, as classified by the State of California, it is a zero-emissions vehicle.

This paper focuses on the testing to-date of the powerplant subsystems (e.g., air and cooling modules), initial operational tests at the SMT, and it lays the foundation for the tests to follow at TTCI and the LA Basin. When the paper is presented at the LMOA annual conference on 17 September 2009, data from the impact tests at TTCI will be presented.

RESULTS AND DISCUSSION

The hydrogen hybrid fuelcell locomotive is a prototype. Sound engineering design principles, state-of-the-art computer simulation, and CAD software were used throughout the development process. The use of Solidworks CAD software allowed the mechanical design to translate from sketch to a highly customized locomotive with very few design changes. Simultaneously, the fuelcell powerplant control system software underwent months of simulated tests to refine and tune control algorithms.

It was advantageous for the development team to use Ballard Power Systems fuelcell stack modules, as they have been used extensively in heavy-duty bus applications and have several years of development and operational experience behind them, collectively logging over 2 million km of service. Similarly, the carbon-fiber composite hydrogen storage tanks manufactured by Dynetek Industries have years of reliable use in multiple bus and truck operations. The combination of sound engineering, the proven Ballard fuelcell stack modules, and Dynetek hydrogen storage provided a solid foundation for success. It was a challenge, nonetheless, to build and operate the first fuelcell locomotive, which required a systematic and methodical approach to ensure success. Methodical and rigorous testing translates to a more robust product, minimized risk to personnel and equipment, and directly correlates to an overall reduction in time and money spent.

Table 1 outlines the four-stage (A, B, C, D) test approach and the phases within each stage, totaling 23 distinct phases and approximately one year of testing. The table outlines the actual series approach that was used to test this unique fuelcell system. Some system modules, such as the hydrogen storage and DC-to-DC converter, were developed and tested in parallel with the fuelcell powerplant system. Additionally, the mechanical fabrication of the locomotive continued in parallel with testing during the Oct 08 - Mar 09 time period.

The four stages are: (A) Off-board subsystem performance testing, (B) off-board system performance testing, (C) onboard and functional locomotive testing, and (D) locomotive performance testing. "Off-board" refers to testing that occurred in a lab setting versus onboard or in situ testing, in which the equipment was mounted and operating in the locomotive. Every test phase began with a detailed written test plan, which is prepared before any power or media (coolant, gas, etc.) is applied and ensures that the step-by-step process of executing the test and recording data is done correctly the first time. Each stage of testing is discussed below:

(A) Off-board Subsystem Performance Testing

Subsystem performance testing is foundational testing where individual subsystems such as cooling or air process streams are operated to validate that the specific performance values for flow, pressure, etc. are met. The control algorithms and physical electrical system are also confirmed at this stage, along with the module testing of the hydrogen storage and DC-to-DC converter. Subsystem validation is required before moving forward to the next stage of system performance. Eight of nine subsystems performed as designed and met the required performance metrics, the exception being the DC-to-DC converter, which was unable to handle its specified power rating of 250 kW net from the fuelcell module. The power rating of the DC-to-DC converter was thus lowered to 200 kW by the third-party designer and fabricator of the custom unit. The locomotive did not suffer performance degradation by the reduced net power because the former diesel engine, replaced by the fuelcell, had a maximum output of 200 kW. The compromise of de-rating the DC-to-DC converter offered greater benefits than the costs of undertaking equipment redesign.

(B) Off-board System Performance Testing

System testing combines the previously validated subsystems into a logical progression. This validates the interaction of the electrical and control systems and continuously provides a baseline condition. First, all auxiliary systems were operated and tested without the fuelcell stack modules in place. "Dummy" loops with valves were used to simulate pressure drop of the fuelcell stack modules, which allows "bugs" to be discovered before installing equipment, thus precluding damage to costly hardware if problems did arise. The fuelcell stack modules were then installed into the locomotive, and hydrogen fuel was supplied to allow the first system start-up. This phase of testing continued until reliable start-up, reliable shut-down, and step increases in power were successfully executed. This successful phase was followed by several weeks of transient tuning. Transient tuning ensured that changes in power demand could be met quickly without disrupting any process streams from their specified operating ranges. A database was used to log all sensor data as well as control system inputs/outputs, which was then reviewed to troubleshoot problems and analyze trends. Finally, the DC-to-DC converter was tested off-board, which accounted for approximately a week of transient tuning. Several challenges arose during transient tuning of the converter, but were mitigated by the establishment of a solid baseline of the fully functional powerplant in the previous phase.

(C) Onboard and Functional Locomotive Testing

The onboard functional locomotive testing combines all of the functional systems together for the first time. The powerplant was first installed and run independently of the locomotive by using an off-board load bank (as the same used in system testing) to accept the fuelcell power. This ensured all systems were properly installed and no damage had occurred during shipping between test facilities. The complete hydrogen system was then purged and tested to maximum pressure with inert gas, followed by fueling with hydrogen. The onboard hydrogen detection and locomotive emergency stop circuits were also installed and tested. Following successful fuelcell powerplant start-up, communications between the locomotive system controller and the fuelcell powerplant were established. After debugging, the system controllers successfully communicated and the locomotive was ready for operational testing. About 20 hours of locomotive operation on the rail have since been logged over a period of one month of intermittent operation and debugging. Thus far, no significant problems have been identified and the locomotive is operating as expected.

A notable aspect of the fuelcell locomotive is its low acoustic emissions compared with diesel locomotives. Decibel measurements on the walkway next to the powerplant are at most 85 dB when running at half power. In fact, when sitting in the operator's cab, one cannot hear the fuelcell powerplant running. The noise from the locomotive primarily originates from the multiple cooling fans for the traction batteries, traction motors, electrical cabinets, and track noise.

D) Locomotive Performance Testing

Testing of the locomotive at the Transportation Technology Center Inc. (TTCI) located in Pueblo, Colorado, will be the last testing phase before being shipped to the LA Basin for operational testing. The locomotive chassis, hybrid control, and traction control systems are fundamentally unchanged from their original design as a diesel-battery hybrid locomotive. Therefore, performance testing will focus on durability of the new equipment during impact situations. As a switch locomotive, impact with other cars will be a common occurrence, and the equipment must be able to withstand the daily rigors of switch operations. Each subsystem of the hydrogen fuelcell system (powerplant, cooling module, DC-to-DC converter, hydrogen storage) will be mechanically isolated from the chassis by some means, then instrumented with three axis accelerometers or with string-pot sensors. Additional accelerometers will be attached to the rigid mount structures of the isolated equipment as well as to the locomotive chassis and couplers. All data will then be logged by a data acquisition system for post-impact review. Additionally, clay blocks will be placed in multiple locations to monitor equipment movement. Impact speeds will start at 1 mph and increase progressively after a series of repeated impacts. The expected limiting factor of impact force is the battery rack reaching its hard stop. This condition will be closely monitored and will determine the maximum impact speed during testing. Additionally, the locomotive impact-detection system will be validated to trigger at or above a hit equivalent to 4 mph into a brake-locked locomotive. This limit point was previously established by the manufacturer of the platform diesel-hybrid locomotive.

Once confidence is established by extensive impact testing, the locomotive will go into service-testing in the Los Angeles Basin. The real-world durability and performance will then be put to the test of an actual working environment, providing the opportunity to validate fuel consumption models and determine the length of service available from a single hydrogen fueling.

Conclusions

The development of a prototype hydrogen-fueled fuelcell-battery hybrid switch locomotive for urban and military-base rail applications, the heaviest and most powerful fuelcell land vehicle yet built, is now complete. It has finished initial operational testing at the BNSF System Maintenance Terminal (SMT) in Topeka, KS, and is presently at the Transportation Technology Center Inc (TTCI) for impact testing. Following impact testing, it will be tested under working conditions at the BNSF Commerce and Hobart railyards in the Los Angeles Basin and in the vehicle-to-grid application at a US Army base. Sound engineering design principles, state-of-the-art computer simulation, and CAD software were used throughout the development process. Use of fuelcell stack and hydrogen storage technologies already used extensively in fuelcell transit buses in Europe facilitated system development. Validation of fuel consumption models and determination of the length of service available from a single hydrogen fueling will be part of the railyard demonstration phase in the Los Angeles Basin.

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Authors' Biographies

Arnold R. Miller

Until founding Vehicle Projects Inc 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. Prof. Miller published numerous papers in refereed journals such as the Journal of the American Chemical Society. As President of Vehicle Projects Inc, besides leading the company, he frequently presents its work at leading international conferences. In 2007, he founded the independent company Supersonic Tubevehicle LLC whose mission is basic scientific and engineering research 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 in advanced vehicle development beginning in 1998. His roles included Subsystem Design Engineer, Concept-Vehicle Lead Engineer, and Concept-Vehicle Program Manager. This diverse background has provided the depth of experience to successfully execute projects at both the technical level and total-vehicle integration level. As Design Engineer at Vehicle Projects Inc, 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 in engineering from Purdue University.

Timothy L. Erickson

Prior to joining Vehicle Projects Inc, Mr. Erickson spent 10 years as a software engineer designing intelligent process control systems utilizing impedance-sensing technology. Previous roles included Control Systems Engineer for a system-integration company as well as serving six years as a submarine officer in the United States Nuclear Navy. As Controls Engineer at Vehicle Projects Inc, Mr. Erickson works closely with the Design Engineer developing the control systems that run fuelcell vehicles. He earned his B.S. degree in electrical engineering with a computer science minor from the Colorado School of Mines.

James L. Dippo

Prior to joining Vehicle Projects Inc in 2007, Mr. Dippo spent 25 years working in research and development, both in the public and private sector. Project work included alternative-fueled vehicles, catalysis, catalyst reactor design, data acquisition, laboratory design and construction, manufacturing-line development, intellectual property creation, patent prosecution, and project management. Mr. Dippo is Project Manager at Vehicle Projects with responsibilities that include interfacing with funders, clients, and partners; negotiating agreements and contracts; and enforcing project timelines and projected work. He received his BA degree at Fort Lewis College in Durango, Colorado.

Figure 1 - Hydrogen Fuelcell Locomotive during press event held at BNSF 29 June 2009.

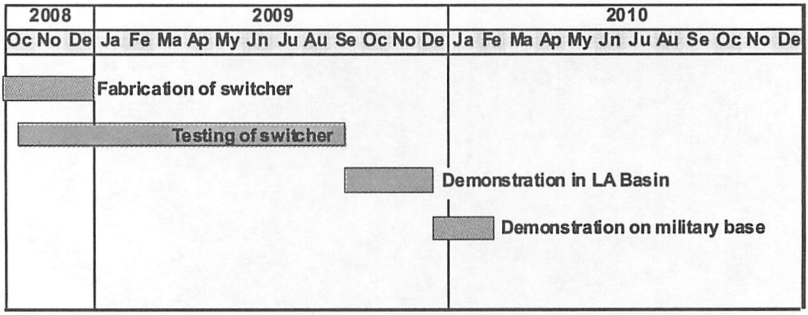

Figure 2 - Final Schedule for the Fuelcell Locomotive Project

This project commenced in May of 2006.

	TEST	STATUS	WHEN
A	OFF-BOARD SUB-SYSTEM PERFORMANCE		
1	Cooling module	complete	OCT 08
2	Primary cooling	complete	OCT 08
3	Lube oil (for fuelcell air system)	complete	NOV 08
4	Secondary cooling	complete	NOV 08
5	Fuelcell air	complete	DEC 08
6	Hydrogen (fuelcell powerplant only)	complete	JAN 08
7	Fuelcell stack modules, internal support systems	complete	JAN 08
8	Hydrogen storage - module test	complete	JAN 09
9	DC to DC converter - module test	complete	MAR 09
B	OFF-BOARD SYSTEM PERFORMANCE		
1	PH1 - all systems using "dummy" loops, no fuelcell modules	complete	DEC 08
2	PH2 - full system run, start up, shut down, step power loads	complete	JAN 08
3	PH3 - full system run, transient tuning	complete	FEB - MAR 09
4	PH4 - full system + DC to DC converter, tune for start up, shut down, transients	complete	MAR 09
C	ON-BOARD AND FUNCTIONAL LOCOMOTIVE TESTING - TOPEKA, KS		
1	Powerplant start up and shutdown	complete	APR 09
2	Hydrogen system purge, fill, leak check	complete	APR 09
3	Locomotive emergency stop and hydrogen detection	complete	APR 09
4	Fuelcell powerplant and locomotive control communication	complete	APR 09
5	Functional traction battery charge with fuelcell powerplant	complete	APR 09
6	On-rail move and operation check out	complete	APR 09
7	Low-speed move, ~ 20 hrs run time	complete	MAY 09
8	Noise assessment - determine if additional measures needed	complete	MAY 09
D	LOCOMOTIVE PERFORMANCE - TTCI * - PUEBLO, CO		
1	Impact, durability and shock detection validation	scheduled	AUG 09
2	Fuel economy - validate fuel storage to duty cycle	scheduled	OCT 09
*	Transportation Technology Center, Inc		

Table 1 - Hydrogen Hybrid Fuelcell Locomotive Test Plan

REPORT OF THE COMMITTEE ON DIESEL MECHANICAL MAINTENANCE

FRIDAY, SEPTEMBER 18, 2009
10:30 A.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

COMMITTEE MEMBERS

R. Aranda	Genl. Foreman-Locos.	Belt Railway of Chicago	Bedford Pk., IL
I. Bradbury	CEO	Peaker Services	Brighton, MI
S. Bumra	Fleet Engr.	Amtrak	Chicago, IL
D. Cannon	Mgr. Syst. Loco. Mech	BNSF Rwy.	Ft. Worth, TX
M. Daoust	Chief Mech. Off.	Tshiuetin Rail Transp.	Clarke City, Que
T. Frederick	Mech. Engineer	CSX Transportation	Jacksonville, FL
D. Freestone	Mgr.-Loco Opns.	Alaska RR	Anchorage, AK
C. Fukala	CMO	Rail America	Sherwood, AB
J. Hedrick	Principal Engineer	SW Research Inst.	San Antonio, TX
T. Kennedy	Mgr.-Mech Engr I	Union Pacific RR	Omaha, NE
J. Sherbrook	Vice President & GM	Loco Docs, Inc.	Morris, IL
T. Standish	Quality Mgr.	Electro Motive Diesels	LaGrange, IL
T. Stewart	V.P. Engineering	Advanced Global Eng.	Atlantic Bch. FL
*R. Svoboda	Mech. Compl. Off	METROLINK	Los Angeles, CA
*G. Winsel	Asst. Manager	Canadian National	Edmonton, Alberta

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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.

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VARIABILITY AND THE TOYOTA PRODUCTION SYSTEM

Presented by
Ian Bradbury
Peaker Services, Inc.

Introduction

There has been a lot of effort to apply methods from the Toyota Production System (TPS), which drew heavily from the work of W. Edwards Deming and Henry Ford. This has more recently been repackaged in the more generic form of "Lean Manufacturing System". It's also sometimes referred to as the "Just in Time (JIT) system". Application of the methods has extended far beyond traditional mass manufacturing processes into service industries (e.g., healthcare), logistics, engineering and so on. Problems have resulted from application of these methods in an ad hoc fashion, with the resultant admonition that the methods are interdependent and thus need to be applied as a systemic whole. Different forms of managing variation appear as objectives or methods within TPS. This paper explores whether managing variation is simply a method, or more fundamental to successful implementation of TPS.

The Toyota Way

The 14 Points of the Toyota Way are a long-term philosophy used by Toyota that contains the Toyota Production System:

- **Having a long-term philosophy that drives a long-term approach to building a learning organization**
  1. Base your management decisions on a long-term philosophy, even at the expense of short-term financial goals.
- **The right process will produce the right results**
  1. Create continuous process flow to bring problems to the surface;
  2. Use the "pull" system to avoid overproduction;
  3. **Level out the workload** (heijunka)
  4. Build a culture of stopping to fix problems, to get quality right from the first;
  5. **Standardized tasks** are the foundation for continuous improvement and employee empowerment;
  6. Use visual control so no problems are hidden;
  7. Use only reliable, thoroughly tested technology that serves your people and processes.
- **Add value to the organization by developing your people and partners**
  1. Grow leaders who thoroughly understand the work, live the philosophy, and teach it to others;
  2. Develop exceptional people and teams who follow your company's philosophy;
  3. Respect your extended network of partners and suppliers by challenging them and helping them to improve.
- **Continuously solving root problems drives organizational learning**
  1. Go and see for yourself to thor-

oughly understand the situation (Genchi Genbutsu);
2. Make decisions slowly by consensus, thoroughly considering all options; implement decisions rapidly;
3. Become a learning organization through relentless reflection (Hansei) and continuous improvement (Kaizen).

Leveling out the workload is reduction of variation in the scheduling of work. Task standardization is reduction of variation in the performance of work. Certainly management of variation appears here, but arguably also in basing management decisions in a long-term philosophy (constancy of purpose).

TPS Objectives

The three main objectives of TPS are to **design** out:

1. Muri - Overburden;
2. Mura - **Inconsistency**, and;
3. Muda - Waste
   a. Over-Production
   b. Motion (of operator or machine)
   c. Waiting (of operator or machine)
   d. Conveyance
   e. Processing Itself
   f. Inventory (raw material)
   g. Correction (rework and scrap)

Managing Variation appears as a top-level objective in terms of designing out inconsistency. Much of the focus of applying TPS, however, has been reduction of the seven forms of waste that has been designed into existing production systems.

In Figure 1, Load Leveling (eliminating variation from the production schedule) is depicted as being at the foundation of TPS. It should be noted that the ideal final stage of TPS application results in processes that exhibit "single-piece-flow", where production rates at each intermediate step are synchronized, and production matches customer demand throughout the entire value stream.

This brings us to question whether variation reduction is just a part of TPS, or is in some way at its foundation; an enabling strategy? To investigate this, we will look at simple queuing systems. It is recognized that the TPS approach includes defining and managing levels of standard-work-in-process to avoid large queues, however this is not always possible. The theory and discussion below applies to many actual processes.

A Simple Queue

Figure 2 shows a generic simple single server queue. In such a system, "inputs" arrive over time for "work/service". If the server is occupied by a previous arrival, the new arrival joins a queue and waits for service. Once the server becomes available, the work/service is performed and the inputs become outputs.

Any production system can be thought of in these terms; raw material or the work output of previous operations arrives, queues as in-process inventory until the operation becomes available, then work is performed to generate the finished product.

This model can also be applied to service systems, such as teller service or checking out at the grocery store. In such cases, it is the customer who is waiting and obtaining a service, rather than material being worked on.

The inspection and repair of locomotives can be seen fairly easily in terms of the production queuing model. Perhaps less obvious is application of the service view to the logistical operation of the railroad as a whole. In this case, customer goods are arriving with the server (railroad) performing the service of transportation.

Complex system models can be built from this simple foundation.

Principles for a Simple Queuing System[1]

The first principle for any simple queuing system is that the average rate of arrivals of units for service (R_i) must be less than the average rate of processing (R_p). If this is not the case, then over time the queue will just grow and grow. For example, if locomotives arrive for service at a running repair shop at an average rate of five locomotives per day, the shop will have to average at least five locomotives serviced per day to avoid this problem. For this example, let's assume the shop is capable of servicing six locomotives per day, on average. Another way of looking at this is that the average time between arrivals of locomotives for service is t_i = 1/5 day = 24/5 = 4.8 hours (assuming 24 hour operation). The average time to process a locomotive is t_p = 1/6 day = 24/6 = 4 hours The requirement that the average processing time must be less than the average time between arrivals is an alternative way of expressing this first principle.

The utilization, ρ, is $\rho = t_p/t_i = R_i/R_p$. In our example, we would have $p = 4/4.8 = 0.8333$, or 83.33%. This represents how much of the capacity is being used. The closer the value is to 1 (100%), the more efficient the operation.

If the locomotives were to arrive for service with perfect uniformity (i.e., every 4.8 hours, on the dot) and they were serviced with perfect uniformity (i.e., every locomotive serviced in exactly 4 hours), no queues would ever build up. Naturally however, locomotives vary in the length of time between arrivals and the length of time required to process them. As the rate of arrival exceeds the rate of processing from time to time, queues will inevitably develop. There can also be times when there are no locomotives in the queue or being serviced.

In order to look at the impact of variation, we need some relative idea of variability.

The standard deviation, σ_i (σ_p.) is used to describe the variability in arrival (processing) time respectively. The coeffficient of variation, $C_i = \sigma_i / t_i$ $C_p = \sigma_p/t_p$) is a standard measure of how variable the times are. Conventionally for queuing systems, If Cv is the coefficient of variation;

- Cv≤0.75 is considered low vari-

[1] A summary of symbols used is provided in Table 1

ability;

- $0.75 < Cv \leq 1.33$ is considered medium variability, and;
- $Cv > 1.33$ is considered high variability

We will use these conventions to frame the simulations that follow, intended to illustrate the effects of variation.

The P-K formula

It is possible to gain an understanding of the impact of variation through queuing theory. A useful formula gives the expected (average) steady state time that a customer or job must wait in the queue before being served. This is known as the modified Pollaczek-Khinchine (P-K)[2] formula:

$$T = t_p \ \frac{(C_i^2 \ C_p^2)}{2} \ \frac{p}{1-p}$$

The average number of customers or jobs waiting in the queue is given by the inventory version of this:

$$I = \frac{(C_i^2 \ C_p^2)}{2} \ \frac{p^2}{1-p}$$

In either case, the conclusion is that average queue time or number in the queue increases geometrically with variation in arrivals and/or variation in processing time and exponentially with increase in capacity utilization. These formulae represent the steady state, not extremes or transitions. To gain a better feel for this, a simulator was built in Excel.

Service Shop Excel Simulator

Figure 3 shows the input values for an Excel locomotive service shop simulator. It is set up so that the user inputs the number of locomotives serviced by the facility (125 in the example), the number of inspections (services per locomotive - quarterly in the example) performed per year and the number of active hours worked per day (example uses 24 for 3-shift operation). From this, the steady state average number of hours between arrivals is calculated (see output values in Figure 4) as t_i = (365*24)/125*4) = 17.52 hours and $R_i = 1/\ t_i$ = 0.0571 locomotives per hour. The standard deviation of times between arrivals of locomotives, σ_i, is input manually - chosen in the example to give 'medium' variability with $C_i = \sigma_i \ / \ t_i$ = 17.52/17.52=1. The example has a single 'server' representing the ability to inspect just one locomotive at a time. The average time to inspect a locomotive is 16 hours, with standard deviation of 16 hours (corresponding to medium variability also). In Figure 4, the utilization rate p =16/17.52 = 0.9132 is output as well as calculating the average number of locomotives in the queue (9.6) and average time waiting (154 hours, or 6.4 calendar days). In the example, an average of 7.7% of the fleet would be waiting for inspections at any given time.

Of course, the average doesn't tell the whole story. In Figure 5 are the results of running a simulation with the above assumptions for roughly two years. The top graph shows the number of locomotives shopped per week, the second graph the number of locomotives released back to service per week. Both are stable. The average number of locomotives

[2] In some texts, this approximation is attributed to Allen and Cunneen.

in the queue for this simulation was 10.53, so this run was slightly worse than the theoretical steady state average of 9.6. This is an average locomotive availability of 90.78% (if the locomotive is considered available when being worked to and from the shop). The bottom two graphs in Figure 5 represent the number of locomotives queuing and locomotive availability respectively. These both look well behaved, but note that even here, there were times when the number of locomotives waiting reached just above 40 - more than four times the average and almost 1/3 of the fleet serviced by this facility!

Shops 2 and 3

Now, let's assume that the results shown in Figure 5 are the results for one of three equivalent regional shops for the railroad. The total railroad fleet is 375 locomotives, with 125 assigned to each shop. Each shop is an identical design, with the same equipment and equivalent workforces. Scheduling of the locomotives for each shop is done using the same methods. The only differences seen from one shop to another are based on random differences in locomotive condition, availability and time to get to the shop and performance of people and equipment from day-to-day.

Hitting the 'run' button again on the simulation generated the results displayed in Figure 6 (shop 2). As before, the arrivals and departures from the shop exhibit stability with not much difference in appearance. However, the average locomotive availability for shop 2 is almost 5% better at 95.51%, with an average of 4.61 locomotives queuing. Furthermore, the number of locomotives queuing doesn't get above 20, but this is still 16% of the fleet at its peak.

Hitting the run button one more time for this set of assumptions produced the outcomes shown in Figure 7. The first two graphs again look little different, but the average number of locomotives in the queue was 12.83 with more than 20 locomotives out of service for well over six months.

We should note here that these three simulation results do not represent extreme cases, just three runs for the same set of assumptions. There is no reason to conclude based upon these differences in observed performance that the schedulers are treating one facility any different than another or that one shop manager is managing their facility any differently to another. In practice, the performance of each shop manager is not likely to be perceived as being the same with these differences in results. A more likely scenario is that shop manager one gets warned after six months that their performance had better improve. The warning clearly caused the manager to shape up for the next six months, but then they became complacent again. Three months later, an opportunity for early retirement is provided and shop manager one's replacement clearly sorts things out. Shop manager two, on the other hand, is clearly a star performer and obvious candidate for promotion. Shop manager three also needed a stern warning about their performance after six months, but that was all that was needed for them to permanently straighten up.

It is easy to see how these differences in observed performance could be falsely attributed to differences in treatment or management of the three shops. Such an interpretation, and action based on such an interpretation, would be both unfair and at best ineffective.

Reacting to Variation

In the cases of the three shops described in the last two sections, differences in performance of the degree observed would cause reactions in practice. Examples of what might have been done are:

- Diverting locomotives to a different shop
- Delaying the removal of locomotives from service until the shop gets caught up (creating a more difficult schedule later)
- Cutting corners on the work scope
- Working overtime
- Adding capacity
- Sending locomotives to outside vendors ...

There are many ways of reacting to the consequences of variation. The one thing that they all ultimately have in common is added cost.

The Results of Increased Variation

Now, let's take a look at what happens when we bump up the amount of variation in times between arrivals and in processing times. In the first group of simulations, both had a coefficient of variation of 1. This is considered 'medium' variability according to normal queuing theory conventions.

Figure 8 and Figure 9 show the input and output tables respectively for this simulation. All that has been changed from the prior simulations is to increase both coefficients of variation to 1.5 - a 50% increase in $\sigma_i$and σ_p . The long run steady state average number of locomotives in the queue has increased from 9.6131 in the prior case to 21.6294 - an increase of 125% in the average queue size as a result of increasing variability by 50%! This corresponds to increasing the average percent of the fleet waiting for service from 7.7% to 17.3%.

This is bad enough, but as before, the average does not tell the whole story - the size of the queue will vary. Figure 10 shows the results of a simulation run for these assumptions. It is a little worse than the steady state case, with an average of 27.31 locomotives queuing for service, or 77.35% availability. However, availability ranged from 43.2% to 99.2% with up to 70 locomotives in the queue! Note that the numbers of locomotives shopped and released per week are still stable here, though with more apparent volatility. This is better behavior than many real life situations that are not stable (in the statistical sense).

The Results of Reduced Variation

Finally, let's look at simulation results where we reduce the variability from the base case coefficients of

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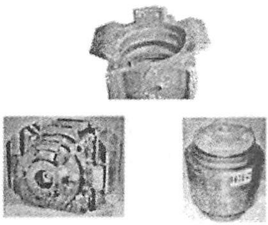
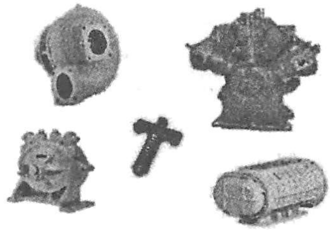


Cooper Bearings



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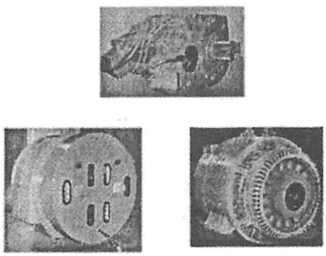

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variation of 1 to 0.5, considered 'low' variability. The input and output tables are shown in Figure 11 and Figure 12 respectively. The steady state average number of locomotives in the queue drops from the base case of 9.6131 to 2.4033 - a 75% reduction in average queue size for 50% reduction in variation, bringing average availability above 97%.

Figure 13 shows a simulation result that's slightly worse than the steady state long term average (2.63 vs. 2.40). This shows far greater consistency in the size of queue and therefore consistency of locomotive availability.

Reduced Variation Results through Increased Capacity?

It is possible to achieve the same average queue size observed for the reduced variation case (2.4033) with the base case 'medium' variability through increasing capacity instead. To see how much capacity has to be added, we need to solve the following inventory application of the P-K formula for ρ: $2.4033 = \frac{(1^2+1^2)}{2}\frac{\rho^2}{1-\rho}$, which gives $\rho = 0.7598$. In other words, capacity has to be increased tothe point that utilization is reduced to 76%. This is an increase in capacity of $0.9132/0.7598 = 1.2019$ or 20.19%.

The OM Triangle

The OM (Operations Management) Triangle is depicted in Figure 14. This is a graphical representation of the fact that variability (in arrival and processing times), inventory/delays and capacity (utilization) are inextricably tied together in any work system.

Systems with variability must be buffered by some combination of inventory, capacity or time.

If you cannot (or choose not to) reduce variability, you **will** pay in terms of high inventory (waiting times) or excess capacity.

It is fairly common to see a push for "across the board" improvement in asset utilization within an organization. If this were the case in our railroad model above, there would simultaneously be a push for maximizing locomotive availability (minimizing out of service time) and maximizing the capacity utilization of the shop. What the OM triangle illustrates is that these two objectives are directly in opposition to each other, variation held equal. This can also be seen in Figure 15, which shows that as you push harder and harder towards 100% capacity utilization, queue size grows geometrically (with the level of variability as a nonlinear multiplier).

The leverage of reducing variability is therefore very clear - the less variability you have, the closer you can get to 100% capacity utilization **and** minimum out of service time. Variation reduction helps simultaneously with two drivers of operating efficiency that are otherwise in tension.

This is the real key to the Toyota Production System - minimizing arrival time variation through level scheduling and minimizing process time variation through standardized work are the key enablers to allowing the system to operate with such high efficiency. Given the leverage of variation reduction, we will end by considering some methods for applications previously considered.

Reducing variability in arrivals

As mentioned above, in a production system (such as the typical application of TPS), the option of 'level scheduling' exists. The difficulty of this should not be minimized. Toyota fixes the production schedule for months at a time. This means that they produce more vehicles or fewer vehicles of a particular model than the market actually demands. They have determined that it is better to resist the temptation to respond to short-term fluctuations in market demand for the system benefits of high operating efficiency and assembly quality that result. Toyota also establishes limits to the level of inventory allowed before an operation, intentionally shutting down the prior operation when the limit is met. The investigations of why the shutdowns occur result in many small improvement cycles and resultant variation reduction in continual pursuit of the one piece flow ideal.

In customer service operations, it can be difficult to manage variability in arrival time. In many cases, it is necessary to just design the service system around it. Asking customers to schedule an appointment, as is done for example with doctors' or dentists' offices, is an effort to reduce the variability of times between arrivals.

In the example of the locomotive service facility we considered earlier, we could similarly schedule the locomotives for service. Managing the locomotives back to arrive for service appointments would likely add cost logistically - it would have to be determined whether the cost savings from reduced out of service time are a net benefit. It is also the case that condition based maintenance and run to failure will have more variability in their arrival times than scheduled maintenance. A cost/benefit analysis of these practices should not just compare the cost of parts, but also consider the variation impact on operational efficiency.

Finally, we consider provision of freight service by the railroad. If we look at the movement of freight from point of receipt to point of delivery as the service being performed, the arrival time variability is in the departure of trains. If we contrast waiting until the train is full to depart with departure on a fixed schedule, we can see the latter as a method for reducing variation in the arrival time distribution. This should result in improved operating efficiency and predictability of final delivery and reduced average shipment time.

Reducing variability in processing

Generally speaking, the work processes are what you manage, so there should be more options here.

In a traditional production system application of TPS, there are a number of things that can be done to reduce variation in process time. Looking back to the long term philosophy of TPS above, #5 - standardized tasks is most clearly aimed at (in part) reducing variation in the time taken to perform the work.

Most of the other elements of "The right process will produce the right results" can also be seen as supporting reduced variation in process time. #1 (Create continuous process flow to bring problems to the surface), #4 (Build a culture of stopping to fix problems, to get quality right from the first) and #6 (Use visual control so that no problems are hidden) are all aimed at fixing production problems at their root, which should lead to greater consistency (reduced variation) of process times over time. #7 (Use only reliable, thoroughly tested technology that serves your people and processes) also supports predictability and dependability of methods and therefore consistency (reduced variation).

In customer service applications, these same concepts can often be applied. It is sometimes argued that in such cases, you do not directly control the variability in the service requested by the customer. For instance, a computer help line doesn't directly control the problems that customers need help with and an emergency room doesn't directly control the injuries patients come in with. One variation management method is to limit the range of services offered. This may be a good approach in some circumstances, but problematic in others (a patient being turned away from the ER due to the hospital choosing to not treat their type of injury, for instance). One ER practice may be illustrative here though; that of triage. In triage, the receiving personnel classify the incoming patient according to severity and urgency of the injuries. In general, customer service requests can be 'triaged' according to the type of service requested and accordingly directed to service personnel. By this method, work can be streamed to allow for greater standardization and consistency within stream. Some overhaul shops have successfully employed this methodology before, where they separate the incoming work for instance as 'standard' and 'special'. The standard overhauls were sent down an internal line that was able to work very efficiently and consistently. The special overhauls were sent to outside vendors, but could equally well have been sent to a separate internal group.

Establishing procedures or work instructions, work stations with all of the required tools, standardized training by dedicated trainers and improved maintenance of service equipment are methods that can be employed to reduce the variability in time required to perform a given work scope. Generally speaking, it is also better if the order of operations can be organized to place the standard operations first, leaving differentiation to the end of the process. If there are predictable patterns to the variation in arrival rates, labor capacity can also be scheduled to compensate for this.

The same concepts of task standardization can be employed for the movement of freight. Generically speaking, variation in outcomes comes from variation in methods, equipment, environment, people and materials. Analysis of the main drivers would be necessary, but standardizing training, jobs, equipment and crew assignments to given routes could be considered. TPS techniques for making problems visible could also be employed.

Conclusion

Reduction of variation should be your focus if your interest is to improve operating efficiency and service level simultaneously. It has been key to Toyota's success.

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Symbol	Description
t_i	Average time between arrivals of units
t_p	Average time to process (service) units
σ_i	Standard Deviation of time between arrivals of units
σ_p	Standard Deviation of time to process (service) units
$R_i = 1/t_i$	Average arrival rate of units
$R_p = 1/t_p$	Average process (service, departure) rate of units
$\rho = t_p/t_i$	Utilization – proportion of theoretical capacity being used
$C_i = \sigma_i/t_i$	Coefficient of variation for time between arrivals of units
$C_p = \sigma_p/t_p$	Coefficient of variation for time to process (service) units

Table 1

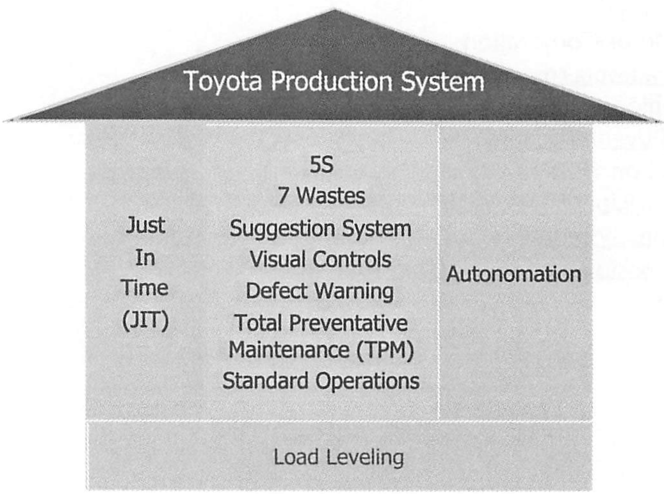

Figure 1

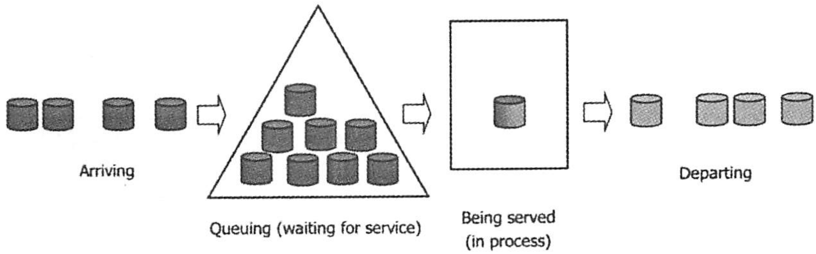

Figure 2

		Input values
Number of locomotives serviced by facility =		125
Number of inspections per year =		4
Number of active working hours per day =		24
St. Dev. Time between arrivals =	σ_i	17.52
No. of locos able to be serviced at the same time =	c	1
Average Process (Service) Time (hours) =	t_p	16.00
	σ_p	16.00

Figure 3

		Output values
Average Arrival Rate (units/hr) =	R_i	0.0571
Average time between arrivals =	t_i	17.5200
Arrival (Demand) Coefficient of Variation =	C_i	1.0000
Processing Rate (units/hour) =	R_p	0.0625
Process Coefficient of Variation =	C_p	1.0000
Utilization Rate =	ρ	0.9132
Average Number of Locomotives in Queue =		9.6131
Average Queue Time (hours) =		153.8092

Figure 4

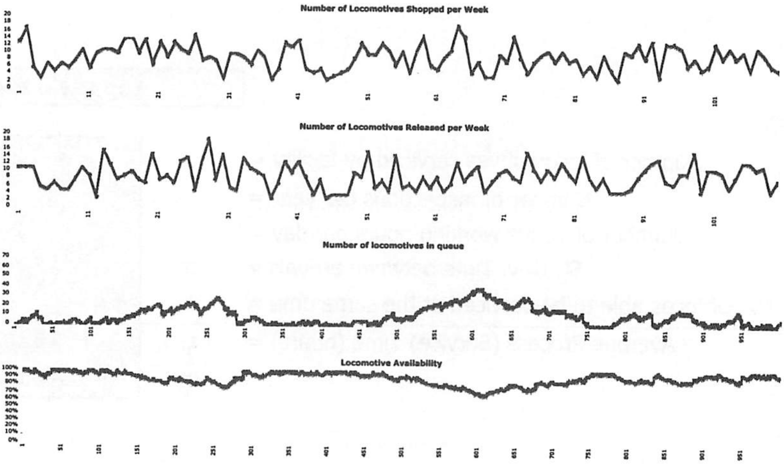

Figure 5

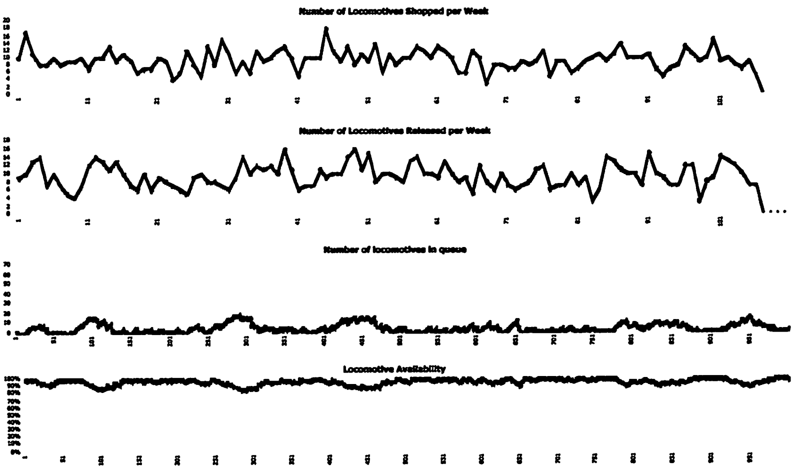

Figure 6

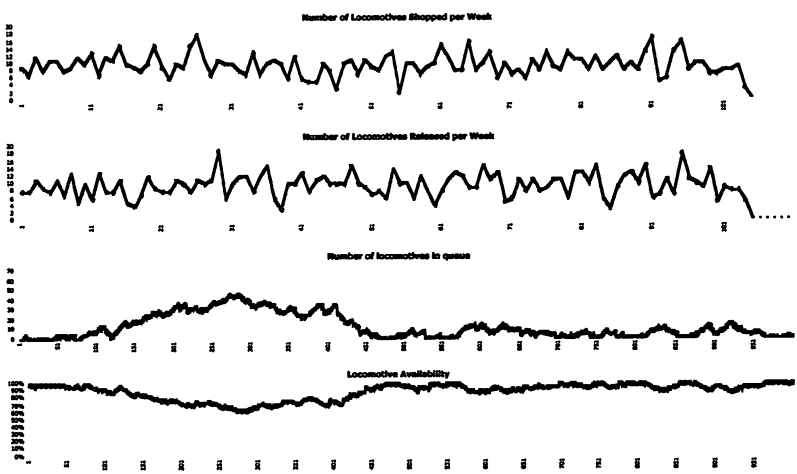

Figure 7

		Input values
Number of locomotives serviced by facility =		125
Number of inspections per year =		4
Number of active working hours per day =		24
St. Dev. Time between arrivals =	σ_i	26.28
No. of locos able to be serviced at the same time =	c	1
Average Process (Service) Time (hours) =	t_p	16.00
	σ_p	24.00

Figure 8

		Output values
Average Arrival Rate (units/hr) =	R_i	0.0571
Average time between arrivals =	t_i	17.5200
Arrival (Demand) Coefficient of Variation =	C_i	1.5000
Processing Rate (units/hour) =	R_p	0.0625
Process Coefficient of Variation =	C_p	1.5000
Utilization Rate =	ρ	0.9132
Average Number of Locomotives in Queue =		21.6294
Average Queue Time (hours) =		346.0707

Figure 9

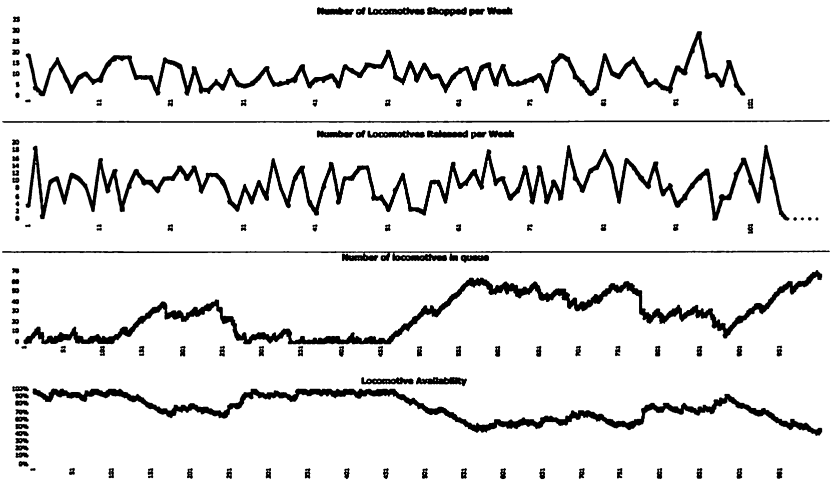

Figure 10

		Input values
Number of locomotives serviced by facility =		125
Number of inspections per year =		4
Number of active working hours per day =		24
St. Dev. Time between arrivals =	σ_i	8.76
No. of locos able to be serviced at the same time =	c	1
Average Process (Service) Time (hours) =	t_p	16.00
	σ_p	8.00

Figure 11

		Output values
Average Arrival Rate (units/hr) =	R_i	0.0571
Average time between arrivals =	t_i	17.5200
Arrival (Demand) Coefficient of Variation =	C_i	0.5000
Processing Rate (units/hour) =	R_p	0.0625
Process Coefficient of Variation =	C_p	0.5000
Utilization Rate =	ρ	0.9132
Average Number of Locomotives in Queue =		2.4033
Average Queue Time (hours) =		38.4523

Figure 12

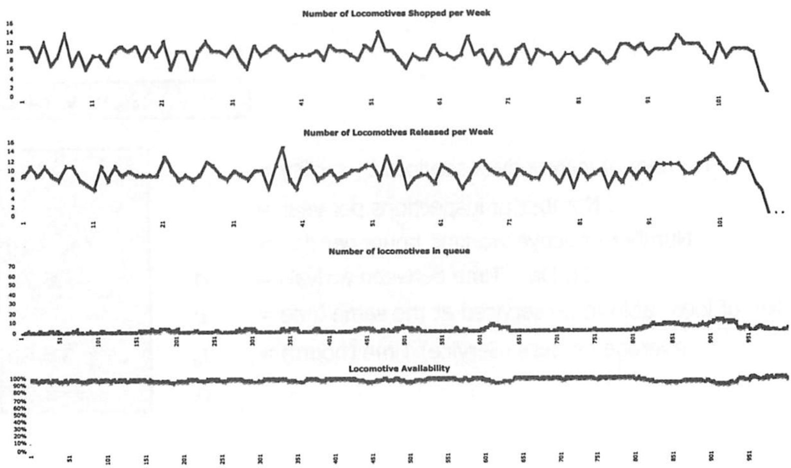

Figure 13

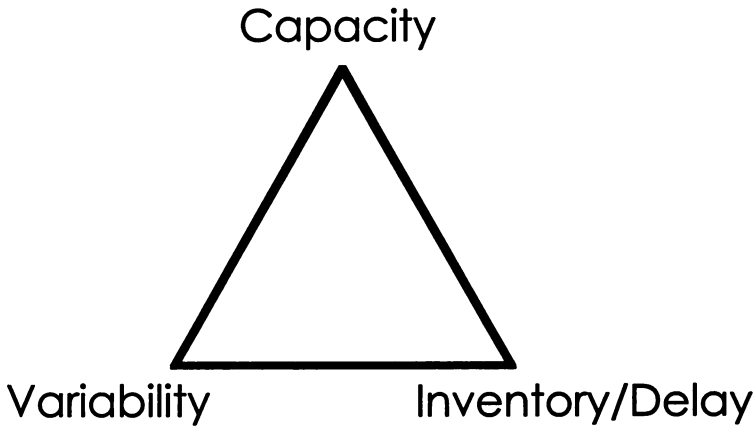

Figure 14

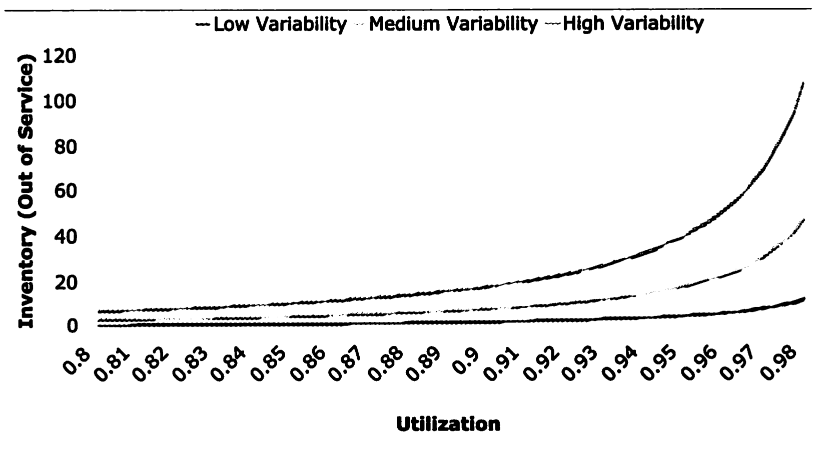

Figure 15

THE THOROUGHBRED MAINTENANCE SYSTEM

Prepared by
Don Graab,
Norfolk Southern

At Norfolk Southern, there are typically around 1300 people performing locomotive maintenance at six running repair shops. These shops are located in Bellevue, Ohio, Elkhart, Indiana, Pittsburgh, Harrisburg, Chattanooga, and Roanoke, Virginia. About another 1000 persons perform work at two backshops, located in Altoona, PA and Roanoke, VA. There are also 16 division shops located throughout the network where as many as another 300 persons perform maintenance, primarily on our yard and local fleet.

So let's take a few minutes to dive into our locomotive maintenance philosophy, which I have chosen to call the Thoroughbred Maintenance System. This is not a new system, but rather the product of two decades and two mergers. Thoroughbred Maintenance contains the fingerprints of numerous Mechanical Department officers, past and present, that have worked at Norfolk Southern.

Over the years, Norfolk Southern has been recognized for having the lowest out-of-service ratio. For more than a decade, we were averaging a 4.5% bad order ratio. In fact, in 1998, we had a 4.3% bad order ratio, our lowest for any calendar year. Unfortunately, recent performance has not been as favorable with our out-of-service ratio typically varying from five to six percent over the last 10 years.

In 2008, we again led the industry with an out-of-service ratio of 5.65%. CSX remains our strongest competitor on this metric, however Union Pacific has been on the move, emerging as a strong competitor.

We believe our success is attributable to some things we do differently than the other carriers. So, let's take a few minutes this morning to review six cornerstones of the Thoroughbred Maintenance System that we believe have contributed to our success.

The first principle is foundational in nature. We strive to buy new locomotives and retire select older units ever year. Since 1995 we've spent over $2 billion dollars on new units. Many older models, the B23-7's, B30-7A's, B36-7's, C30-7A's, C30-7's, C36-7's, GP38's, GP40's, SD40's, and others have been retired. Our road fleet today is as new as any major carrier. Our yard and local fleet, some 1300 units strong, is comprised of almost all Dash 2 or later model vintage with the exception of a dozen or so SW1500 units.

It may interest you to know that I represent the Mechanical Department on a team of eight persons representing Transportation Operations, Purchasing, Finance, Marketing, and Information Technology. Each year this team makes recommendations on what to buy, lease, or retire in the way of locomotives. We've also developed a number of programs using capital funds to keep our yard and local

fleet the best in the industry. As evidence of that, we have had substantial rebuild programs of GP38, GP40, and SD50 power, rebuilding approximately 230 units in the last eight years. We have also rebuilt a number of slugs and recently constructed some with operator cabs. Few carriers have invested in their yard and local fleet over the past decade as aggressively as Norfolk Southern. Clearly, one of the cornerstones of our Thoroughbred Maintenance System is the acquisition of new units for the road fleet and the on-going renewal of our yard and local fleet.

The second foundational element of our Thoroughbred Maintenance Services is what we call "program work". I am now speaking of our engine overhaul, truck overhaul, midlife tune-up and paint programs. When it comes to engine overhauls, Norfolk Southern has long been very aggressive. On a percentage basis, we overhaul more diesel engines than perhaps any other railroad. We perform the preponderance of these engine overhauls at Altoona, PA, however, we also perform GE engine work at our backshop in Roanoke, Virginia.

We consistently overhaul our trucks, or as the Europeans say, "Bogies". I think we reap the benefits of that on fuel racks and during 92-day inspections, where our inspectors find running gear that is well maintained and in good condition. I might also add that this level of maintenance is well received by our Motive Power and Equipment inspectors from the Federal Railroad Administration.

We also perform what we call "mid-life" tune-ups between overhauls, which have helped us immeasurably with diesel engine performance. Fuel test data indicate that mid-life tune-ups help with our fuel efficiency as well. The mid-life tune-up consists of a number of tasks that are required by the emissions kit provider, such as an injector change-out, as well as other tasks we at Norfolk Southern have found to be necessary and best performed in a backshop. Mid-life tune-ups on General Electric locomotives are performed at Roanoke shops, while EMD units receive their mid-life tune-ups in Altoona.

The third element of our Thoroughbred Maintenance System is what we call "routine maintenance". Perhaps it should more appropriately be described as scheduled maintenance because indeed it is scheduled around the federally mandated inspection requirements at 92-day intervals. In 2008, we focused on supplying the shops with a steady, predictable flow of units. As a result, we have experienced the benefit of decreased dwell time. In 2008, we added four "Lean Engineers" at running repair shops to promote involvement of our employees and efficiencies of our processes. We continue to focus on locomotive dwell time, quality of inspections and repairs at 92-day routine maintenance. Currently, we are undertaking an initiative called "pin-pointing", where we focus specific crafts on improving specific locomotive issues that hinder our success on post 92-day inspection performance. We encourage the system shops to audit their 92-day inspections and our Manager of Locomotive Maintenance, from our staff, completes unannounced "external" audits of 92-day inspection work quarterly.

The fourth element of our Thoroughbred Maintenance System is what we call "Specific Improvement Projects". Long ago, when 3M was on the property as our quality consultants, they talked about the virtues of specific improvement projects in promoting success with quality. No matter how good a locomotive maintenance program a large carrier may have, there are systemic locomotive problems emerging all the time. These usually affect specific models which share components or software. As part of our Thoroughbred approach to locomotive maintenance, we seek the input of our locomotive teams and our Mechanical Department staff to generate proposals on projects we can initiate to improve locomotive maintenance. We develop costs, projected improvements, and justification to move these 1-2 year programs ahead each year.

One of the realities of large scale railroading with a fleet the size of ours is, some locomotives will be lost in the shuffle and perform poorly in terms of reliability. To deal with this we have a safety net we refer to as the "WOW" (Worst of Worst) program. We have a full-time staff person devoted to managing the WOW program. This person selects bad actor locomotives from our active fleet, routes them to shops, coaches' shop supervision on proper repairs, and then monitors post-treatment performance. Units that continue to perform poorly are returned to the shop where the work was performed. All of the running repair shops participate in this program and are ranked for their performance. Our smaller division shops are also joining the battle as they work on bad actor yard and local engines assigned to their divisions. We have found that this technique of "pulling ourselves up by the bootstraps" is vital to our success if we are to reduce unscheduled shopping events.

The final element of our Thoroughbred Maintenance System can best be described as "Troubleshooting Methods and Technical Training". It is an unfortunate fact; the railroad industry is suffering from a continuous loss of locomotive knowledge. This is occurring in the face of increasingly complex locomotive technology. At the end of the day, not knowing how something works results in delays, and you are less certain it is fixed when you are done.

To deal with this, we continue to ramp-up technical training. In the first quarter of 2009, we finished an additional classroom in Roanoke, located within what we call our "Continuing Education Center. This classroom is equipped with a fully functional Dash 2 electric cabinet. Perhaps you are questioning why we would be training on this 35 year-old technology in 2009. Well, with nearly 1000 Dash 2 locomotives in our yard and local fleets, we expect some of these units to be around for a long time. Further, an employee who understands the Dash 2 electrical system has a useful foundation of knowledge for learning the control systems of more sophisticated locomotives. We've also finished an inspection pit, to be used for ground relay training. This facility is centrally located in Roanoke, where most shopcraft employees are able to drive there within five hours. Our two staff training positions, assisted by two dozen "Training Gang Leaders", continue to develop new training materials every year. Our course offerings, most of which are 4-1/2 days in duration, are complete with quizzes, hands-on training, and a final exam. This year we introduced a 26L air brake class and began a course on SW and MP type switch engines. Also beginning in 2010, we plan to start a CCBII electronic airbrake class and a course on A C Evolution Series locomotives.

At this time I want to tell you about our locomotive teams; specifically our Dash 8/9, Evolution, SD70 and SD60 teams. These teams are comprised of shopcraft employees who voluntarily participate. Typically, these teams have one or two salaried supervisors and a service engineer from EMD and GE, in addition to the six to eight agreement employees. Each team meets 4-6 times per year and are the source of many of our ideas for specific improvement projects to reduce unscheduled shopping events.

In summary, these are the six elements of success for our Thoroughbred Locomotive Maintenance system. It's a big system with many players. Although there are things I wish we did better, we have demonstrated what we are capable of in terms of safety, quality, and productivity.

AIR COMPRESSORS-
BEST PRACTICES-
BACK SHOP MAINTENANCE
PART II

Prepared by
James Sherbrook,
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Introduction

Continuing from last year's paper with air compressor overview of types, drives, suggested preventative maintenance practices and maintenance strategies, this paper will address failure corrective actions and unaddressed concerns.

Failure Corrective Actions

Back shop preventative maintenance personnel have developed retrofit procedures to combat water cooled compressor freezing and low oil levels. To prevent water cooled air compressors from freezing during cold weather operation, an East Coast railroad has drilled the blanking plate on WBG style compressors and added freeze plugs. The same railroad has also added freeze protection valves around the compressor. In the event of a freeze condition, the water system will drain itself. If the compressor begins to freeze internally, the freeze plug will push itself out allowing water to drain (Providence & Worcester Railroad).

A West Coast railroad has combated water cooled compressor freezing by replacing the original manifold block assembly with a modified manifold block assembly and freeze protection valve, mounting this assembly directly to the air compressor water inlet manifold. This eliminates freeze damage due to incomplete draining of the air compressor coolant by allowing the air compressor to drain independently of the engine cooling system automatic dump valves (Union Pacific Railroad).

To prevent inaccurate air compressor oil level readings, an East Coast railroad has opted to remove oil gauges and install dipsticks on all of its compressors. Dipstick readings have proven more accurate (PWRR).

Oil specifications for air compressors have changed over the years by original equipment manufacturers (OEMs) to improve performance. Earlier oil specifications allowed oil to travel by the piston and to be pumped into the cylinder heads, causing accumulation on the compressor valves. Air compressor intake and exhaust valves would then operate at temperatures high enough to turn the oil into carbon. Smaller air passages resulted from carbon build up on valves. This caused even hotter operation and reduced compressor efficiency. By modifying oil specifications and utilizing air compressor lubricating oils without anti-wear inhibitors, the piston rings will conform to the cylinder liner wall contours more closely and quickly after overhaul. As the piston rings and oil control ring wear in quicker, oil bypass to the cylinder heads and compressor valves is greatly reduced; thus, carbon build up on the valves is slowed facilitating compressor efficiency (GEMS 6).

With the removal of anti-wear inhibitors from the air compressor crankcase oil, air inlet filter contamination from excess oil bypass in the low pressure cylinder heads is avoided. Two major railroads using oil without anti-wear inhibitors extended the air compressor running maintenance cycle to four years without ring or valve replacement (General Electric Maintenance Service 6).

Installation of Reed style crankcase breather valves assist by reducing crankcase pressure keeping oil in the crankcase, not above the piston. This breather valve reduces carbon build up, oil pumping into the air filters and oil consumption when used with newly recommended air compressor lubricating oils (GEMS 6).

Heavy detergent oils form hard lacquer deposits on the cylinder walls and in the cylinder heads. This will result in oil carryover into the air system. Heavy weight oils cause excessive wear in the piston pin bearings. High film or detergent strength oils may improve piston pin bearing life, but cannot be used because piston ring seating is affected and oil bypass is carried over into the air system, which is more detrimental than piston pin bearing wear. The presence of any lacquer or carbon deposits indicates an unsuitable lubricant (Electro-Motive Diesel Maintenance Instruction 1144).

Currently, EMD recommends using a compressor lube oil for air compressors with deep crankcases (10.5 g and larger oil capacities) of a Society of Automotive Engineers (SAE) 10 weight turbine type grade containing anti-foam, anti-oxidation and anti-rust inhibitors with the following properties: Viscosity-Saybolt Universal American Society for Testing and Materials (ASTM) D88 or D2161: 100 degrees Fahrenheit (ºF) for 130 to 180 seconds and 210ºF for 42 to 45 seconds and a pour point of ASTM D97 maximum 0ºF (S00049EP).

For EMD applied compressors with other than deep crankcases (2.65 to 3.5 g oil capacities), an SAE 30 weight grade oil containing antiform, anti-oxidation and anti-rust inhibitors with the follow properties: ASTM D88, D2422 or D446 and a pour point of
ASTM D97 maximum 15ºF (M.I. 1756).

GE recommends using hydraulic oil with a ISO Viscosity Grade of 68; flash point of 400 ºF; a maximum pour point of 20ºF; without detergents and anti-wear characteristics; and with foam, rust and oxidation Inhibitors (GEK-76679B).

Seasonal changing of oil viscosity may be required, especially when SAE 30 is used in small crankcase capacity compressors (M.I. 1756) - Figure 1.

Compressor oil should be sampled and sent for analysis at half duty cycle (three months) (M.I. 1144). When analyzing compressor crankcase oil, a rapid increase in calcium would indicate that engine lubricating oil has been added instead of compressor crankcase oil (GEMS 7). If a rapid increase in calcium is found, visually inspect the compressor for abnormal conditions and change the crankcase oil and oil filter.

A rapid increase in silicon, followed by an increase in iron, would reveal that grit or dirt may have bypassed the air filters and is now present in the crankcase oil, accelerating cylinder wear. Inspect air filter seating. Clean the housing and replace air intake filters. Change crankcase oil and oil filter as well (GEMS 7).

One must know normal compressor operating conditions to determine abnormal conditions. Normal air compressor intercooler pressure is around 45 pound-force per square inch (psi). Normal main reservoir operating pressure is between 130 to 140 psi (GEMS 6). Air compressor oil pressure on start up will be approximately 45 psi when the oil is cold. As the oil temperature increases, the oil pressure should drop within the normal operation range between 15 to 20 psi. Normal compressor crankcase lube oil temperate operates between 50ºF and 300ºF (M.I. 1100). At idle speed, the normal lubricating oil temperature should be 140ºF with an oil pressure between 18 to 25 psi (GP38-2).

GE AC Evolution Series locomotive air compressors have two safety valves: one located on the intercooler and one on the aftercooler, set to open at 60 psi and 180 psi respectively (GEJ-6845).

The oil pressure relief valve, if equipped, is preset at 20 to 26 psi (GEK-76313).

The intercooler safety valve is provided to relieve excessive pressure buildup. This valve should be tested and adjusted as follows:

1. Air supply to the valve must be adequate and the piping to the valve not less than the size of the pipe fitting on the valve end. If air supply is inadequate, the valve cannot be properly set. The valve must be fully assembled before testing.
2. The valve must not apply before the proper pressure setting. The valve blowdown must not exceed 10 psi.
3. The valve should lift at a static air pressure between 64 and 66 psi (M.I. 1100).

If a leak is detected in a compressor magnet valve (CMV or MV-CC) when the coil is not energized, the cause can be traced to either the inlet seat or the "O" ring on the bottom cap. Replace the "O" ring and seats (M.I. 4707).

When investigating air compressor difficulties, troubleshoot all other appurtenances before disturbing the settings of the compressor control switch. Compressor control switches are designed to be maintenance free (M.I. 5512). If the switch is suspected as faulty, remove and bench test (M.I. 5514).

When replacing flexible coupling rubber bushings in elastomeric and flex gear coupling (GEJ-6693) in direct drive compressor systems, allow 24 hours to elapse before reattaching the couplings and aligning. This will allow the rubber lubricant to dry. If the lubricant used to install the rubber bushings is wet, the bushing can easily move from its desired location (M.I. 1765).

In EMD switchers, v-belts drive off the compressor powering the front traction motor blower and cooling fan. Should a v-belt break, the locomotive should no longer be operated, unless absolutely necessary. The locomotive should return to the maintenance point for belt replacement (SW1).

Properly installed air compressor suction and discharge valves require both the correct assembly procedure as well as quality components from the OEM. If one of the valves is improperly clamped, it may work loose during operation. This could result in valve breakage and potential compressor failure (GEMS 7).

Intercooler pressures can be an accurate indicator of air compressor valve performance used to pinpoint defect valves without unnecessarily removing valves from the compressor. To perform the test, first blow down the air system. Next, remove the plug in the intercooler tapped port at the top of the intercooler. Install an accurate zero to 100 psi pressure gauge in the intercooler tapped port. With the gauge in place, operate the locomotive at idle and manually load the compressor. Wait a few minutes for the intercooler and main reservoir pressures to stabilize. Normal intercooler pressure reads 45 psi. Normal main reservoir pressure reads between 130 to 140 psi (GEMS 6).

Troubleshooting for Defective Valves - Normal Operating Conditions (GEMS 6)

Above normal intercooler pressure indicates that a valve in the high pressure head is defective. Lower than normal intercooler pressure indicates a problem with valves in the low pressure heads (GEMS 6). When testing is complete, ensure that any installed test gauges are removed and the proper sized plug is inserted and tightened before returning the locomotive to service (S00049EP).

Other troubleshooting techniques for various improper operating conditions follow: Figure 2

1. <u>Low oil pressure shutdown:</u>
   Possible Causes:
   1. Low oil level.
   2. Blocked oil filter.
   3. Blocked suction tube

   Corrective Actions:
   1. Fill oil to "SAFE" on dipstick.
   2. Replace oil filter and crankcase oil
   3. Clean suction tube and replace oil filter and crankcase oil (GEK-76313).
2. <u>Excessive varnish on discharge valves:</u>
   Possible Causes:
   1. Air discharge temperature is too high.
   2. Improper intercooler function.

   Corrective Actions:
   1. Inspect for broken discharge valve.
   2. Clean intercooler sections per OEM maintenance instructions (GEK-76313).
3. <u>Compressor knocking:</u>
   Possible Cause:
   1. Unloaders do not have enough pressure to unload.

   Corrective Actions:
   1. Inspect unloader suppl lines for unusual conditions.
   2. Inspect unloader piston rings (GEK-76313).
4. <u>Insufficient output pressure or</u>

capacity:
Possible Causes:
1. Air filter silencer may be clogged.
2. The pressure switch is out of adjustment.
3. Valves leak, are stuck, are damaged or may be carbonized.
4. Liners and pistons may be scratched or scored, piston rings may be damaged.

Corrective Actions:
1. Inspect and clean.
2. Inspect and adjust.
3. Inspect and clean.
4. Inspect (GEK-76313).

5. Noisy while running:
Possible Cause:
1. Review compressor knocking.
2. Inadequate lubrication.
3. Connecting rod caps may be loose.

Corrective Actions:
1. For inadequate lubrication, check oil level and viscosity. Oil viscosity may be too high or too low. Change fi-l ter and oil.
2. To troubleshoot loose connecting rod caps, remove crankcase cover and inspect (GEK-76313).

Unaddressed Concerns

A recent study to find the cause of why alternating current (AC) motor driven compressors were being pulled from service found that air compressors rarely failed. The study found that the majority of compressors pulled from service were due to AC motor failure. Many of the failed motors could have been prevented by standardizing preventative maintenance practices (Norfolk Southern Railroad). Preventative findings follow.

AC motor failure was viewed on a locomotive sampling. Motor failure was traced back to faulty motor control: air compressor control contactor, computer control software, motor connections, motor defect failures and unknown issues (NS).

An on-site sampling of running locomotives in service found a third had loose AC motor connections and an additional third had loose contactor connections. Motor connections had been repaired during preventative maintenance inspections, but numerous variations of bolts and washers were used without standardization. Motor connections were not consistently torqued to proper connection values. Contactor connections were found in various states and repaired by various means. Contactor tips were found with random stages of arcing. No consistency regarding a contactor change-out program was determined by (NS).

An in-house review of bad order AC motors found a majority of failures were caused by: debris in the connection boxes, arcing at connection points, loose standoffs and absent lock washers at motor connection points. To remedy motor connection point failures, the motor repair vendor replaced all standoffs with a newly designed style standoff and applied Locktite® to the retaining studs from the frame to the standoffs. New universalized motor connection fasteners were supplied to the end user (NS).

To standardize air compressor AC driven motor preventative maintenance practices to prevent AC motor failure:

1. Ensure only OEM recommended fasteners are used on motor and contactor connection points.
2. Torque motor connection bolts to OEM recommended torque values.
3. Inspect connection boxes for debris and loose connections; clean and repair respectively.
4. Consistently clean contactor tips and change out failing contactors (NS). Figure 3

Conclusion

In conclusion, a clean, dry, reliable source of compressed air is essential to a healthy locomotive. With the integration of computerized technology and trends towards AC motor drive reciprocating style and rotary screw style compressor configurations, a consistent, documented, easy to follow maintenance plan must be outlined for all facets of the railroad industry's maintenance personnel to follow. At present, maintenance for air compressor logic control components is addressed as non-scheduled maintenance items due to variations in component wear and life related to operating conditions (M.I. 1777A / M.I 5511). Contractor, pressure switches, transducer and magnet control valve maintenance is suggested by OEMs and is not mandated by the Federal Railroad Administration, Department of Transportation (FRA). It is critical for modern locomotive air systems to function and should be addressed in a similar manner as are mandated brake valve change-outs.

Resources

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TABLE OF RECOMMENDED COMPRESSOR LUBRICATING OIL / LUBRICANTS

Source	Material	Use	Supplier
GEK-61240E and M.I. 1726	Tectyl 823EM	Petroleum based anti-rust solution	Ashland Oil
GEK-61241G	Nalco 41	Water treatment	Nalco Chemical Co.
GEK-76679B	D6B11D3	Air compressor hydraulic oil	(See Below)
GEMS 6	American Industrial Oil 68	Air compressor hydraulic oil	AMOCO
GEMS 6	DURO Oil S-315	Air compressor hydraulic oil	Atlantic Richfield
GEK-76679B	Energol HL-C 68	Air compressor hydraulic oil	BP Oil, Inc.
GEK-76679B	Chevron AIO 68	Air compressor hydraulic oil	Chevron Global Lubricants
GEK-76679B	RANDO HD ISO 68	Air compressor hydraulic oil	Chevron Global Lubricants
GEK-76679B	REGAL Oil R&O 68	Air compressor hydraulic oil	Chevron Global Lubricants
GEK-76679B	CITGO Pacemaker T68	Air compressor hydraulic oil	CITGO Petroleum Corp.
GEK-76679B	Mobil DTE Heavy-Medium	Air compressor hydraulic oil	Exxon Mobil Oil Co.
GEK-76679B	TERESSTIC 68	Air compressor hydraulic oil	Exxon Mobil Oil Co.
GEK-76679B	HARMONY R&O AW-68	Air compressor hydraulic oil	Gulf Oil Limited Partnership
GEK-76679B	Shell Tellus 68	Air compressor hydraulic oil	Shell Oil Products, USA
GEMS 6	SUNVIS 931	Air compressor hydraulic oil	Sun Oil
S00049EP and M.I. 1756	SAE 10	Air compressor lube oil - for high capacity crankcase compressors	

Figure 1

Source	Material	Use	Supplier
M.I. 1756	SAE 30	Air compressor hydraulic oil - for small capacity crankcase compressors	
GD	AEON 9000	Rotary screw air compressor synthetic lubricant	Gardner-Denver
GEK-76679B	GE D50E24, KOP-FLEX	Gear and coupling grease	KSG Standard Coupling Grease
GEK-76679B	GE D50E6B, Texaco Marfak "O" Code 927	Special purpose grease - "O" ring	Chevron Global Lubricants
M.I. 1756	Parker Super O-Lube	Compressor clutch seals	
M.I. 1756	N.L.G.I. No 2 E.P. lithium grease (8413019 - 14.5 ounces (oz.))	Grease lubricant for mechanical drives	
Falk 438-110	Falk Long Term Grease (LTG)	13F (8153703) compressor end Steelflex® coupling packing grease	The Falk Corporation
M.I. 1726	MIL-B-131	Barrier Material, Water-vapor proof, flexible	
M.I. 1726	MIL-B-121	Barrier Material, Greaseproof, waterproof, flexible	
M.I. 1726	MIL-C-16173	Corrosion Preventive Compound, Grade 4 (P-19)	
M.I. 1726	Petroleum Jelly	Coat contact tips for long term storage	Standard Oil Co. of Indiana
M.I. 1726	MIL-P-3420 - Type 1, Style C, Class 1 & 2	VPI-B (Vapor phase inhibitor barrier paper)	

TABLE OF AIR COMPRESSORS AND OIL CAPACITIES

Source	Compressor Make	Model	Type	# Cylinders	Oil Capacity	Recommended Oil
GEK-76313	Ingersoll-Rand (IR)	YHE	air cooled	2	14.5 gallons (g)	D6B11D3
SMI-00002B/LSM-1987	Westinghouse Air Brake Company (WABCO)	3CMDCB8L	air cooled	3	16.25 g	D6B11D3
SMI-00013D	WABCO	3CDCLA	air cooled	3	16.25 g	D6B11D3
M.I. 1300 and M.I. 1756	WABCO	3CD	air cooled	3	small crankcase - 3.25 g, large - 16.25 g	small - SAE 30, large - SAE 10
GEJ-6693 and M.I. 1756	Gardner Denver (GD)	WLN /WBO	water cooled	3	small crankcase 2.65, large crankcase 10.5 g	small - SAE 30, large - D6B11D3 or SAE 10
M.I. 1144 and M.I. 1756	GD	WLG /WBG	water cooled	6	17.5 g	SAE 10
M.I. 1110 and M.I. 1756	GD	WLO /WXO	air cooled	3	small crankcase 2.65, large crankcase 10.5 g	small - SAE 30, large -SAE 10
M.I. 1110 and M.I. 1756	GD	WLE /WXE (upgraded to WXO)	air cooled	3	2.65 g	SAE 30
M.I. 1110 and M.I. 1756	GD	WHL / WXG	air cooled	6	17.5 g	SAE 10
M.I. 1110 and M.I. 1756	GD	WLP / ABO	water cooled	2	3.5 g	SAE 30
M.I. 1110 and M.I. 1756	GD	WLQ / ADJ	air cooled	2	3.5 g	SAE 30
M.I. 1110 and M.I. 1756	GD	ADX (upgraded to ADJ)	air cooled	2	3.5 g	SAE 30
S00049EP	GD	WLA	air cooled	4	17.5 g	SAE 10
GD	GD	Electra-Saver	oil cooled	None - rotors	11.5 g	AEON 9000

Troubleshooting for Defective Valves - Normal Operating Conditions (GEMS 6)

Step 1 - Determine Condition Under Load	Suspect Fault, Go to Step 2	Step 2 - Determine Condition Unloaded	Valve to Inspect	Notations
Intercooler pressure is higher than normal	Fault is likely in the high pressure cylinder head	Intercooler pressure does not drop to normal reading (dropping 15 to 20 psi) within three minutes	Inspect high pressure discharge valve if no normal drop	None
Intercooler pressure is higher than normal	Fault is likely in the high pressure cylinder head	Intercooler pressure holds between 15 to 20 psi	Inspect high pressure suction valve if pressure holds	None
Intercooler pressure is lower than normal	Fault is likely in a low pressure cylinder head	Intercooler pressure drops below 15 to 20 psi	Inspect low pressure discharge valves if below normal drop	The faulty valve will have an erratic or weak suction sound, an unusually hot discharge valve cover plate or blowback through the air filter when pumping.
Intercooler pressure is lower than normal	Fault is likely in a low pressure cylinder head	Intercooler holds at 15 to 20 psi	Inspect low pressure suction valves if pressure holds	The faulty valve will have an erratic or weak suction sound, an unusually hot discharge valve cover plate or blowback through the air filter when pumping.

Figure 2

TABLE OF AC MOTORS

Source	Application	Make	Model	Description	Phase
SMI-00002B/LSM-1987	- 8 Locomotives	GE	5GYA28	air compressor drive motor	Single
SMI-00013D	- 9 Locomotives	GE	5GYA28/30	air compressor drive motor	Single
NS	SD90MAC	EMD	Delta	air compressor drive motor	Single

Figure 3

ALIGNMENT CONTROL COUPLER REQUIREMENTS

Prepared by,
George W. King, II,
New York, Susquehanna & Western Railway

Interchanging locomotives not equipped with alignment control draft systems is a source of frustration within the short line community. Many connecting carriers will refuse to transport locomotives over their lines if not equipped with proper alignment control.

Why do many carriers take this stance? Non alignment units have been identified as the root cause of numerous derailments. Analysis of these derailments found severe uncontrolled lateral movements during buff and draft events being a major contributing factor. As a result many carriers refuse to move foreign locomotives that are not equipped with alignment control.

What is alignment control as it relates to locomotive couplers?

Alignment control draft systems use a mechanical means to control lateral movement of the coupler. This normally consists of specific couplers that use wings to compress wedges that push against the draft gear in the direction of swing. Non alignment systems do NOT cushion nor control lateral forces.

Figure 1 displays the difference between alignment and non alignment control locomotive draft systems.

Why does this issue exist?

Locomotives often were not equipped with alignment control due to the service application for which they were destined. Non A/C allows for a tighter negotiated radius with successful coupler operation. Application of A/C reduces the operational ability of the platform in question.

As can be seen in Figure 1 full alignment control coupler swing is limited to 17". Non alignment control allows for twice the travel as measured in the arc of the movement. Thus non alignment control draft systems are best suited for many industrial applications and track engineered to standards that existed decades ago.

<u>Compliance impact</u>

- Cost
- Practicality
- Operational Needs

<u>Action plan</u>

Contact all carriers involved in the transport from origin to destination. Ascertain each carriers requirements, any and all movement restrictions, train marshalling standards and obtain documentation clearly stating the same. Establish a list of contact names and numbers for each railroad in the event of an unforeseen stoppage in the transport plan.

<u>Possible solutions</u>

- *Coupler lateral stops*

Not a true alignment control system. The blocks are sometimes welded in the coupler pocket or bolted in place to limit the lateral swing of the coupler. This is very cost effective and easily removable thus returning the unit to original configuration. This was permissible in many instances two decades ago but is not acceptable in most cases today.

- *Modified alignment control*

This application uses the existing pocket and draft gear mechanism. It requires the installation of an E7321/EMD # 8271631 "horned" coupler and welding two lateral stops in the pocket opening.

The coupler and stops are easily removed to restore the unit to original configuration. This method is somewhat expensive depending upon the availability of the E7321 coupler. This retrofit may or may not be acceptable to some interchange partners.

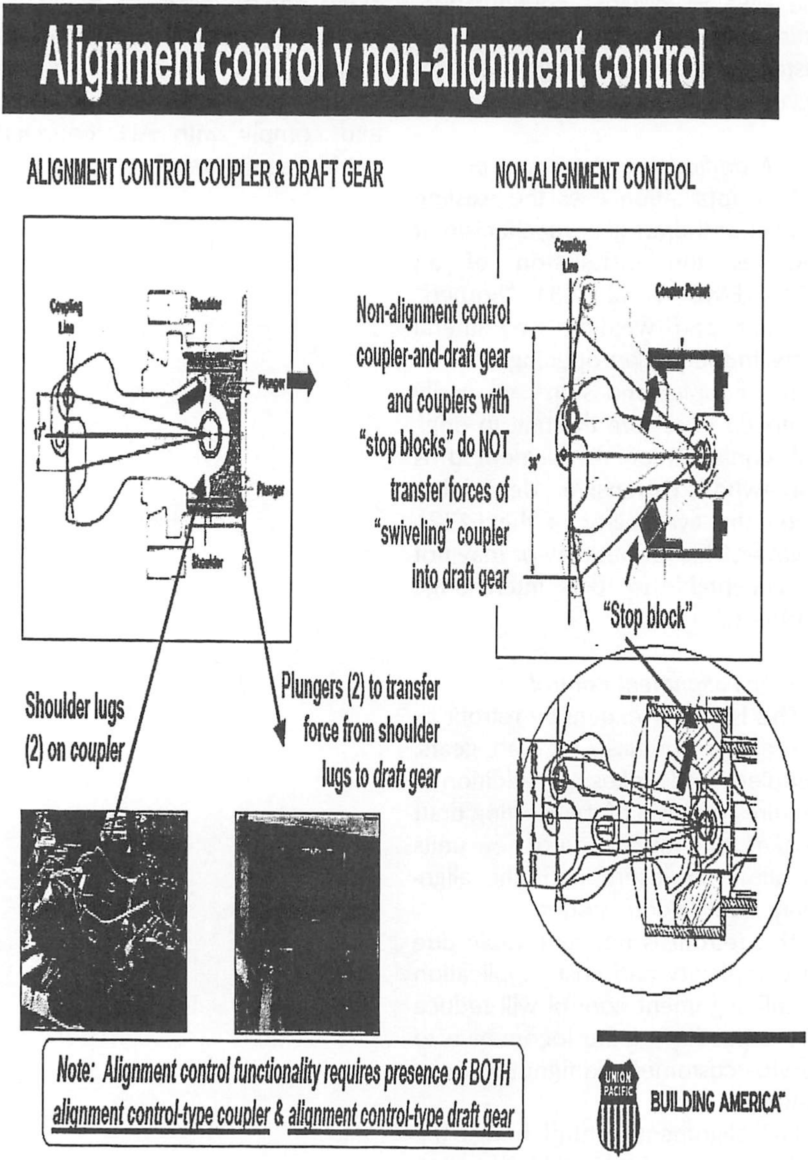
- *Full alignment control*

This is a very expensive retrofit as it requires purchase of draft gears, couplers and yokes. In addition it requires removal of the existing draft pockets and fabrication of new units to allow for insertion of the alignment control draft system.

This retrofit is not removable due to complexity and cost. Application of full alignment control will reduce the capability of the locomotive to service customers on tight track curvature.

Full alignment control brings the unit into compliance with connecting carriers but at a cost.

There are several companies that perform the different levels of draft system work as described in this paper. Using existing business profiles as listed in the railway industry periodicals and publications will allow one to establish a cost and scheduling time frame to adapt locomotives for interchange movement. The key issue is to fully understand and comply with ALL connecting carrier requirements.



Alignment control v non-alignment control
ALIGNMENT CONTROL COUPLER & DRAFT GEAR
NON-ALIGNMENT CONTROL
Coupling Line
Shoulder
Plunger
17°
Plunger
Shoulder
Non-alignment control coupler-and-draft gear and couplers with "stop blocks" do NOT transfer forces of "swiveling" coupler into draft gear
Coupling Line
Coupler Pocket
"Stop block"
Shoulder lugs (2) on coupler
Plungers (2) to transfer force from shoulder lugs to draft gear
Note: Alignment control functionality requires presence of BOTH alignment control-type coupler & alignment control-type draft gear
UNION PACIFIC
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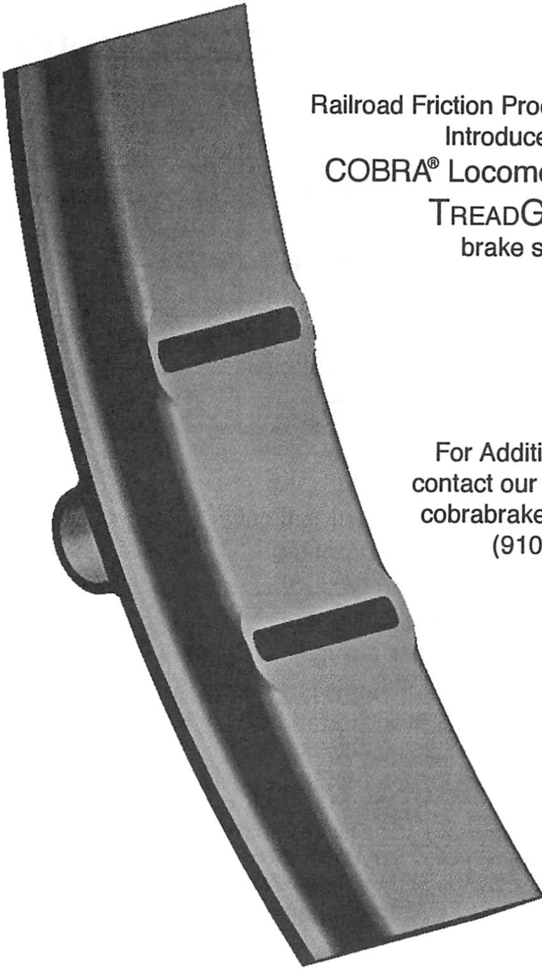
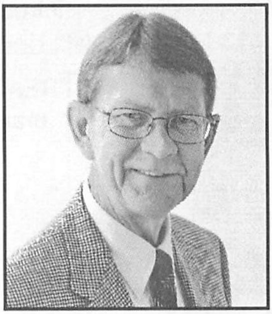
Figure 1



REPORT OF THE COMMITTEE ON DIESEL ELECTRICAL MAINTENANCE

THURSDAY, SEPTEMBER 17, 2009

8:30 A.M.



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Regional Sales Manager

Wabtec Corporation

Alpharetta, GA

Vice Chairman

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Electrical Systems Engineer

CSX Transportation

Jacksonville, FL

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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 WISHES TO EXPRESS THEIR SINCERE APPRECIATION TO SIEMENS TRANSPORTATION FOR HOSTING THE COMMITTEE MEETING IN FEBRUARY 2009 IN SACRAMENTO, CA SPECIAL THANKS GOES TO STEVE MUETING

WE ALSO WISH TO THANK THE UNION PACIFIC AND VICTOR TROUT FOR ALLOWING THE COMMITTEE TO TOUR THE UP'S ROSEVILLE, CA SHOPS

IN JULY 2009, THE COMMITTEE HAD A MEETING AT THE NORFOLK SOUTHERN IN CHATTANOOGA, TN. WHICH WAS ARRANGED BY RYAN STEGE - THANKS TO THE NS AND RYAN

EMD SLIP RINGS - BRUSHES & WEAR

By Jay Boggess
Alaska Railroad Corporation

Photos by the Author Unless Otherwise Noted

The carbon brush - the "lump of coal"[1] that transfers electrical power to the rotating portion of a motor or generator - may seem equivalent to buggy whips and corsets when compared to computers, microprocessors and LCD screens, but they are still essential to the operation of the most modern diesel locomotive. Our father's and grandfather's diesel locomotive had dozens of brushes all over the place. Let us look at the 2400-HP SD24 of 1959 as an example: (Figure 1)

- Six traction motors with a total of 72 brushes.
- One auxiliary generator with 8 brushes.
- One fuel pump motor & one turbo lube pump motor with 2 brushes each.
- One load regulator rheostat (directly controlling the D22 battery field) with 1 brush.
- Two dynamic brake grid blower motors with 4 brushes each.
- One D22 main generator with 12 brush-holders & 60 total brushes (5 brushes per holder).
- One D14 alternator with 4 slip ring brushes.
- Plus various little motors for cab heaters and refrigerators and such.

In the past 50 years, technological progress has dramatically changed the carbon brush picture (perhaps much to the chagrin of the brush makers), as exemplified by the 4300-HP SD70MAC: (Figure 2)

- NO traction motor brushes (replaced by Siemens inverter drive & 3-phase traction motors)
- NO auxiliary generator brushes (replaced by brush-less AC aux gen & Battery Charging Rectifier)
- NO fuel pump or turbo lube pump motor brushes (replaced by brush-less DC motors)
- NO load regulator (replaced by computer-controlled injectors, load control & digital serial links)
- NO little brushes for cab heaters & refrigerators (replaced by inverter-driven 74 VDC central HVAC units).
- Two 32-volt starter motors with 4 total brushes
- One DC series-wound grid blower motor, still with 8 brushes.
- One TA17-6 / CA6 (or CA7) traction alternator / companion alter nator, with 2 sets of slip rings & 8 total slip ring brushes.

This paper concentrates on those eight remaining brushes in the modern EMD locomotive. Slip rings & brushes are also not going anywhere; unlike the 74V brush-less aux gen, the main generator demands the quick speed of response afforded by brushes in both steady-state operation and under adverse circumstances like traction motor flashover & inverter crowbar. Thus these 8 bits of carbon, something you can hold in the palm of your hand become the single threaded weak point that separates successful

[1] Lump of coal - the literal translation of "traction motor brush" from Egyptian to English.

locomotive operation from road failure, capable of turning the high-horsepower diesel into a 420,000-pound boat anchor.

Origins

This project started back in 2007 when The Alaska Railroad was approached by Tim Keck (then of EMD) and Ron Delavan (still of National Carbon) and asked if we would like to serve as the location of a field test for a whole litany of main generator/ companion alternator slip ring brush ideas. Before they came to us, Tim & Ron had been busy trying to address slip ring/brush field problems in the laboratory. They were:

1. Poor brush wear on the companion alternator (CA) brushes, especially the CA negative brush.
2. Poor ring wear on the 3rd main generator (MG) ring, up to the point of visibly rutting of the ring.

The obvious question that one can now ask is: Why does the negative brush wear faster? Let us look at the brush/ring system and offer up some possibilities: (Figure 3)

Because actual electron flow is the opposite of "conventional current" flow (positive to negative), the face of the negative brush will always be depleted of electrons and thus (perhaps) causes mechanical weakness and breakdown in the structure of the carbon graphite, thus resulting in faster wear.

Let's look now at the rest of the EMD main generator / companion alternator slip ring / brush arrangement. Figure 4 is a photo of an EMD slip ring assembly; Figure 5 is a cutaway diagram of the same assembly. The front two rings (labeled "1" & "2" in the cutaway) feed the EMD companion alternator (which supplies main generator excitation and various auxiliary fans and blowers). Without these brushes, the companion alternator has no excitation, there is no main generator excitation nor are there cooling fans, blowers or no motor-driven air compressor and thus no compressed air. These 2 rings get 74 VDC from the aux gen any time the diesel engine is running. Two different flavors of companion alternators exist on Alaska 70MAC's; the CA7 (which most of the BNSF 70MACs have as well) and the smaller CA6. The important difference is that the CA7 draws about 60 amps thru the slip rings, while the CA6 only draws about 40 amps.

The second set of slip rings (#3 & #4) handle the field excitation to the main generator. AC-drive locomotive have fairly constant (but fairly high) field current requirements from zero to maximum track speed. DC locomotives, on the other hand, have peaks of field current near stall, maximum speed and near generator transition, with comparatively lower values in between; much like a pair of fishhooks. Since this field test was run on AC-drive locomotives, the results of the main generator brushes & rings may not be directly applicable to a DC-drive loco. Regardless of drive, when the brushes wear short, the locomotive will not move.

Tim and Ron were looking for a place to test brushes & rings, the Alaska Railroad was happy to try something new, as we were personally experiencing the poor negative polarity brush wear. One distinct advantage of Alaska testing is no loco is EVER lost up here. Unless a locomotive learns how to swim, any unit not in Anchorage will pass thru Anchorage in 48 hours or less. At absolute worst case, it can be seen in Fairbanks. Thus, every test subject can be seen quickly and often. The only real difficulty is that some of the test locos ended up being stored in winter due to the cyclic, seasonal nature of our railroad.

EMD/National Carbon provided 11 sets of new test slip rings and brushes, plus additional brushes to test a mitigation technique for existing slip rings (four more locos). Finally, Alaska had just purchased four brand-new SD70MACs from EMD, so two of those became control units for comparison, totaling 17 test locomotives. National Carbon D689 brushes were used for all the bronze rings, while the designation for the steel slip ring brush is National Carbon R1318 grade.

Variations Tested

Slip Ring Material

In days gone by, Electro-Motive made generator slip rings out of tin bronze, a copper alloy with 5% to 10% tin (abbreviated Sn-Cu), cast into an insulating plastic holder. Two small brushes are used on each CA ring, two larger brushes used on each MG ring. This design worked very well for a very long time, with old-timers recalling that slip ring brushes would easily last a year or more.

At least 10 years ago, Electro-Motive instigated a cost-savings on slip rings, where the tin in the bronze rings was replaced with aluminum (since aluminum is cheaper than tin). Thus, the world entered the era of aluminum-bronze (Al-Cu) and troubles began. The negative CA (#2) brush would wear about 3 times as fast as the positive CA (#1) brush. Brushes had to be changed every 6 months to insure they'd make it to the next 92-day inspection. Some railroads would swap field polarities to even out the wear.[2] Similar wear would also occur on the TA rings & brushes. One possible explanation would be oxidation of the aluminum on the surface of the ring, which besides being an insulator is also abrasive (just go check out "sandpaper" at the hardware store). It was felt a trial of the tin-bronze material would eliminate the aluminum and its problems.

CA Ring Spring Cell Problems

In the past few years, Tim Keck discovered various quality/dirt/wear-out issues with the "small" CA spring cell (the spring cell is a clip with a coiled spring leaf riveted on to provide spring pressure for holding the brush to the slip ring). Tim has found that the coiled spring leaf can accumulate dirt and/or kink. This can cause the spring to stick, thus leaving the brush with no pressure.

There are actually two leafs riveted

[2] This is a useful technique but has to be done at the generator terminal board of the brush-holders NOT at the slip ring studs themselves (Figure 1) as flipping the polarity of the fields alone does nothing for the wear.

together. By spot-welding the far end of the spring, the CA spring cell is made much more resistant to dirt. EMD supplied a quantity of this new-style CA spring cell for this test. All tests of the "small" brush utilized these new spring cells. This spring cell is EMD p/n 40132923 and ought to be replaced (at minimal cost and maximal benefit) after 3 to 5 years.

Interestingly, the MG/TA "large" spring cell is not susceptible to the same dirt effects and has not been modified, nor new large cells applied for the test.

Pitch of the Slip Ring Spiral Groove

Current in a brush does not flow to the ring uniformly across the contact surface. Instead the current actually concentrates in very small spots of high current density. The purpose of the spiral grove is to force the "current spot" to move across the face of the brush.

The spiral on the original EMD slip ring makes one revolution across the 1/2 inch width of the slip ring - hence the name "1/2 inch pitch". The CA brush (for various reasons) is only about 5/16" wide while the MG/TA brush is nearly 7/16" wide. In the case of the CA brush, the ring rotates for a major portion of the ring rotation under the brush without any spiral groove under it, thus losing the sweeping effect of the spiral groove. By halving the pitch of the spiral, there is always a groove under the brush face (this is the "tin-bronze 1/4 inch pitch" rings).

Besides forcing the "current spot" to move, the spiral groove cools the brush face as well. EMD old-timers also related to this writer that the original AR10 slip rings of 1966 did not have spirals and once they were added, brush performance improved dramatically.

Number of Brushes on the TA Slip Rings

One of the subtle aspects of slip ring design is achieving the proper current density on the brush; too high and the carbon wears away electrically or the current overloads the copper pigtail (also called a shunt), too low and the proper copper oxide film is not maintained and the brush (or ring) wears away mechanically. Classically, the MG/TA rings used two large brushes (as the MG field current varied from zero amps when the unit was idling and from 40 to 140 amps when the unit is loading). As an SD70MAC spends a lot of time at around 80 amps, EMD engineers felt they should use 3 large brushes per ring. However well this may or may not have worked on a "traditional" freight-only SD70MAC, EMD discovered excessive wear on TA17 MG slip rings on units that make head end power (HEP), which include the Alaska 4300's and NJ Transit locos. Since these units spend significant time at 370-490 engine rpm with only 30 amps on the MG/TA field rings (while idling making HEP), EMD alerted the railroad to remove 1 of the 3 brushes per ring, so as to raise the current density and avoid the low-amperage wear problem.

While the consensus is that in nearly all cases 3 brushes per ring is too much brush (especially with the older aluminum-bronze rings), 3 TA brushes per ring were being attempted with 1/4" and 1/2" tin-bronze as "control" experiments to make sure all possibilities are being tried and no experimental combination is missed.

In a similar vein, combinations of small and large brushes were tried on the CA rings. Here, we have the CA7 of the 4000-series SD70MACs locos drawing 60 amps every second the diesel engine is running, while the 4300's have the CA6, which only draws 40 amps while running.

Number of Slip Ring Brushes (In General)

EMD always made a conscious effort to use two brushes per ring AND to position them one brush on top of the ring and one on the bottom. This writer always was told that if the locomotive (and brushes) bounced, there would still be at least one brush in contact with the ring. So, it was with some trepidation that we attempted testing with just one brush per ring. Because of this, we limited the one per ring to the non-passenger 4000-series SD70MACs, but as experience has been gained and advantages of 1 brush per ring uncovered, a couple of single-brush-per-ring passenger-carrying 4300s were successfully added to the test.

Steel Slip Rings

General Electric uses steel slip rings on their locomotives and has done so for many years. Obviously steel is cheaper than either tin or aluminum bronze. They suffer from two limitations:

1. Special "steel grade" brushes are required to "polish" the rings. These are not interchangeable with bronze ring brushes.
2. The rings tend to rust when a unit is placed in storage and need to be cleaned up when a unit is returned to service.

The three steel ring locos (4320, 4006, 4004) should be considered the most "experimental" of the test locomotives. To our knowledge these are the first steel rings applied to an EMD locomotive in the field. Because of time constraints, only 1/2" pitch spiral grooves were attempted. Two small and two large brushes per CA ring were tried on the 4000-series locos, with 2 and 3 brushes per Main Generator ring tested at the same time. The 4320 test loco ran with a conservative 2 large brushes on both the CA & MG rings.

Mitigation Techniques For Existing Aluminum-Bronze Rings

Since a huge number of locomotives are out there with aluminum bronze rings, the last four test locomotives attempted to get good brush performance without changing the aluminum-bronze slip ring. On the CA rings, a single large brush replaces the two standard small brushes. By using the wide brush, there is always spiral groove underneath the brush face, by using only one brush, the CA current density is not too low. The single large brush utilizes a larger shunt so that it can handle the entire CA field current.[3] On the MG/TA ring, the 3-brush configuration is reduced to two brushes per ring, since we know 2 brushes are a better idea.

Test Array & Detailed Description

The best way to look at this flurry of test items/variables/conditions is in a table. Table 1 describes the test conditions. We attempted to catch nearly every combination to try as best as possible to capture each possibility. In 20/20 hindsight, we should have picked an existing 4000 loco with small CA brushes to serve as a control test unit.

Test Procedures

Test slip ring & brush installation began in July-August 2007. New "small" spring cells were supplied by EMD and installed on all "small" brush positions. Where "large" brushes were installed on the CA rings, EMD supplied new large brush-holders with new spring cells -otherwise, all other large spring cells were reused.

Brush inspection started about a month after installation (so as to get a good "brush seated" length). Brushes were measured with the same digital caliper operated by the same individual, so that particular variable was eliminated. At each inspection, locomotive Engine "On" time, mileage, engine horsepower-hours and kilowatt-hours were recorded. Inspections generally occurred on three-month intervals, but the passenger-service 4300's were explicitly inspected at the beginning and end of each summer passenger season.

Expressing the Results

In a previous lifetime, this author inspected DC traction motor brushes for life and commutator wear on EMD locomotives. During those inspections, we used to express brush life in "Miles per Eighth" - that is locomotive miles per one-eighth inch of brush wear. Since the MG/CA slip rings rotate (and wear) anytime the engine is on, whether the locomotive moves or not, it seemed more appropriate to replace miles with Engine On time (a number readily acquired from the EMD EM2000 Running Totals menu). In order to have a convenient unit size, we translated Engine On time into 24-hour days.[4] And, since our digital caliper is marked in 0.001" graduations & not 1/8ths, the brush wear rate unit quickly became "Days Per Tenth".

Let us spend a little time translating brush wear rates into prospective/projected brush change-out intervals.

Figure 7 shows a nearly new small CA brush in its brush holder. Figure 8 shows a brush where the spring cell is about to "submerge" into the brush box. Electrician's experience on the Alaska Railroad has taught us that if there is a portion of circular spring still visible, then the brush can easily go to the next 92-day inspection.

How does this change-out scheme translate into lengths? Table 2 translates the new & change-out schemes

[3] This large shunt will/has become standard on large National Carbon D689 brushes.

[4] As if an engine ran all the time, like in the good old days before Auto-Start and $4/gal. diesel fuel.

for both small CA and large MG brushes into brush lengths. As one can see, by replacing brushes at the submerged spring cell point, a little less than half the usable length is the reserve. Extrapolating these brush lengths into the range of brush wear rates gives us Table 3. Clearly, brush wear rate less than 60 days per tenth yield less-than-yearly maintenance intervals.

Test Results

Below are three separate tables of results:

1. Conventional companion alternator brushes & rings.
2. Steel companion alternator brushes & rings.
3. Traction Alternator (MG) brushes & rings.

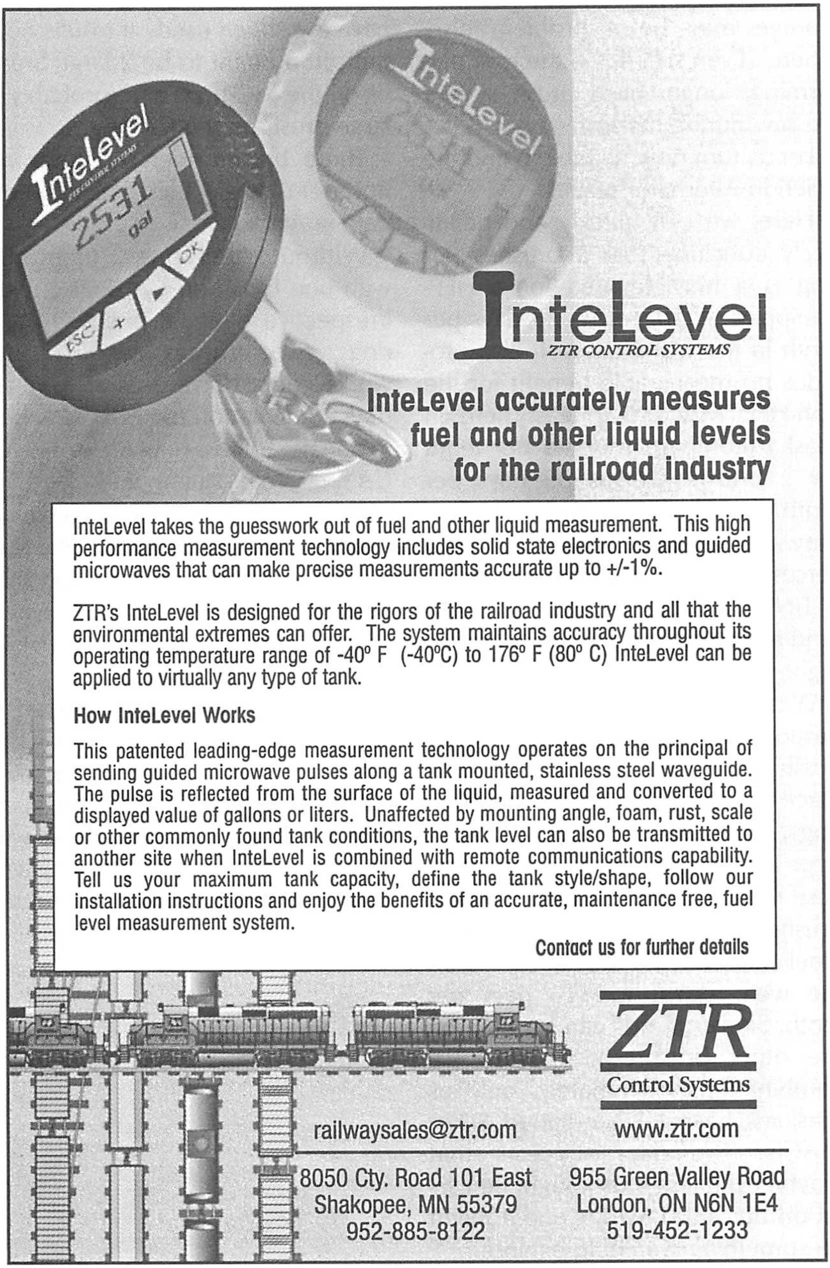
Since there is a negative and positive ring for each machine, and since one polarity (the negative ring) wears faster than the other, each entry lists 5 numbers - the lowest & highest wear rate for faster-wearing ring, then the lowest and highest for the slower wearing ring, finally followed by the total number of Engine On hours. If there is more than 1 locomotive in the configuration being tested, then the Engine On hours shown is the sum of all locomotives. Single brush per ring tests obviously can only show 2 wear numbers - the lowest and highest wearing ring.

What does Table 4's mass of data tell us about CA rings & brushes? Well, first of all, if we could make negative slip rings go away, our problems will be over! With that not possible, let us separate the low-field amperage CA6 from the higher amperage CA7.

The small CA brush under the light CA6 field current barely performs acceptably under any bronze ring combination. With 14,000 hrs under 2 locos, the stock Al-Cu ring gave us only 39 days per tenth wear worst case. Replacing the aluminum bronze with tin-bronze did not really change the situation and only the 1/4" pitch spiral makes the wear tolerable. Detailed analysis of the 1/4" pitch tin-bronze data shows that the small brush performed much better for the first 8 months of the test, then mysteriously & inexplicably got worse. Two large brushes on tin-bronze rings work pretty well, but one large brush (on either spiral pitch) is almost as good.

Everything works better at the 60-amp CA7 current - except aluminum bronze. Using just one large brush with an existing 1/2" pitch aluminum bronze gives an unhappy 33 days per tenth. Any form of tin-bronze is an immense improvement, quickly reaching 90 days or better days per tenth worst case wear.

For steel ring performance, let us look at Table 5. One of the fun troubles with steel brushes & rings is that they wear so slowly, it takes quite awhile to see wear results! These results look quite good, but suggest trying just one large brush per ring on the CA6 4300 Mac's and standardizing on two large brushes on CA7 4000 Mac's. No problems with rusting were found, even after a couple of the steel units were stored over the winter. Of course while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Anchorage is near the seacoast, it's not an exactly balmy ocean spray kind of winter, so perhaps rust in storage may be a problem elsewhere. Even still, this is the best performing, longest-lived brush system we saw during the test.

Let us turn now to Table 6 and the Traction Alternator results.

Here, we can quickly and definitively conclude that 3 brushes per ring is a horrible idea for a HEP-equipped SD70MAC - 25 days per tenth in the worst case. It also provides no measurable benefit for the non-HEP MAC - at least here in Alaska (compare 81 days per tenth for 2 brushes versus 89 days per tenth for the 3 brushes). The unanswered question would be how 3 versus 2 brushes might compare on a BNSF SD70MAC (which would tend to have longer periods of much higher field current).

We can see a price for inverter-based HEP in terms of MG slip ring brush wear. And the most obvious place to see it is with the steel slip rings. On the HEP-less 4000's 2 large brushes per ring yields a worst-case wear of 218 days per tenth, 3 brushes gives 226 days per tenth. Steel rings on the HEP-4300's drop the wear down to 116 days per tenth. Similar trends can be seen on the other brush/slip ring material combinations. Fortunately, only us Alaskans have HEP-equipped SD70 MAC's. The data suggests that maybe even less brush might be useful on our 4300 MAC's and it might be something we could explore.

Final Conclusions

Steel slip rings look extremely promising, though only three sets have ever been used. If results hold, the setup ought to be 2 large brushes on the MG rings and (probably) 1 large brush on the CA ring.

Three brushes per slip rings are not useful on any loco, based on our data in Alaska.

Without steel rings, tin-bronze with one brush on CA rings is best, irrespective of spiral pitch. On MG rings, two brushes on tin-bronze works good, but a possibility might be a combination of both old & new materials. That is, new tin-bronze on CA rings, old aluminum-bronze on MG rings. Since it is possible to change the first two rings while leaving the rear rings in place, this could be a viable strategy.

Thanks

I'd like to thank Ron Delevan of National Carbon and Tim Keck (formerly of EMD, now of Parker-Hannifin) for providing the rings and brushes to run this test, along with the Alaska Railroad electricians who did the work of applying all the test slip rings.

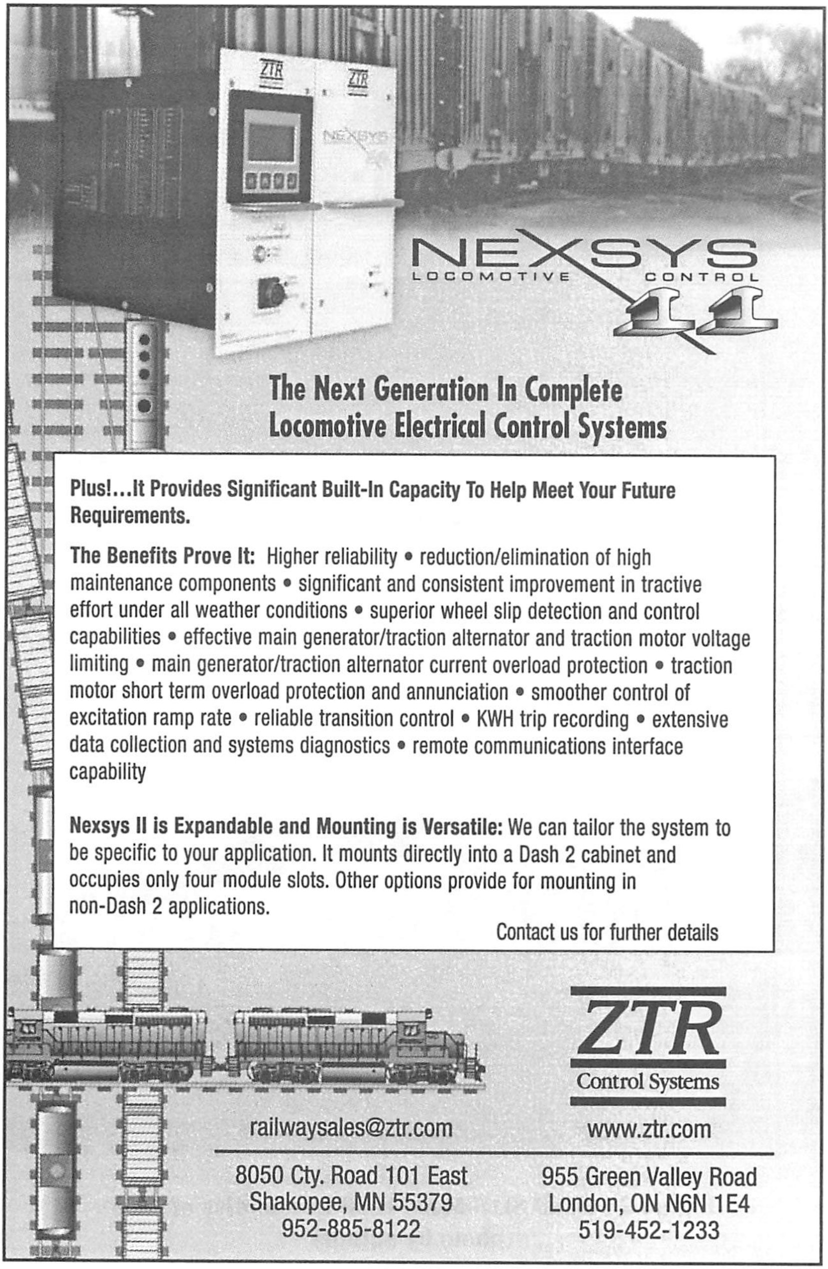
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Figure 1 - EMD SD24 Locomotive of 1959
(from EMD Service Manual)

Figure 2 - EMD SD70MAC-HEP Locomotive of 2004
(photo by author)


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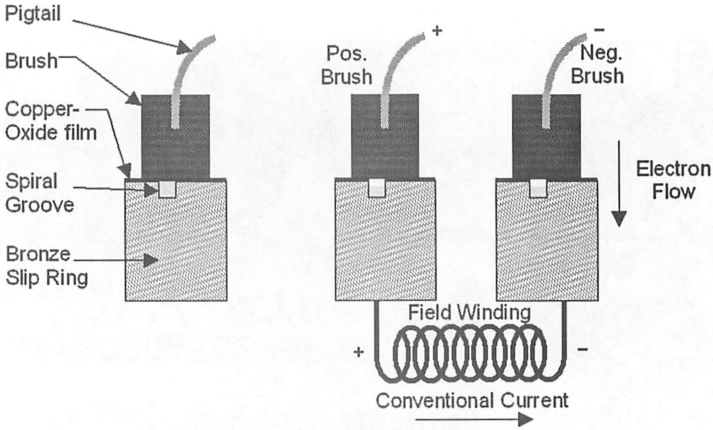

Figure 3 - Brush / Ring System

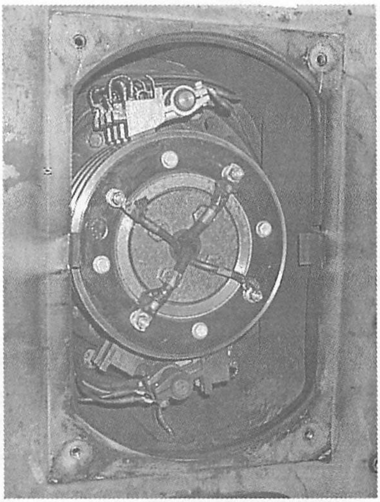

Figure 4 - EMD Slip Ring Assembly
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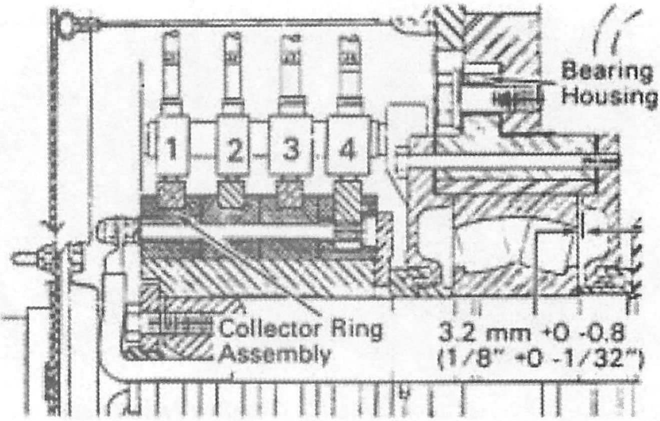

Figure 5 - Cross Section of EMD Slip Rings (Adapted from EMD Maintenance Instructions)

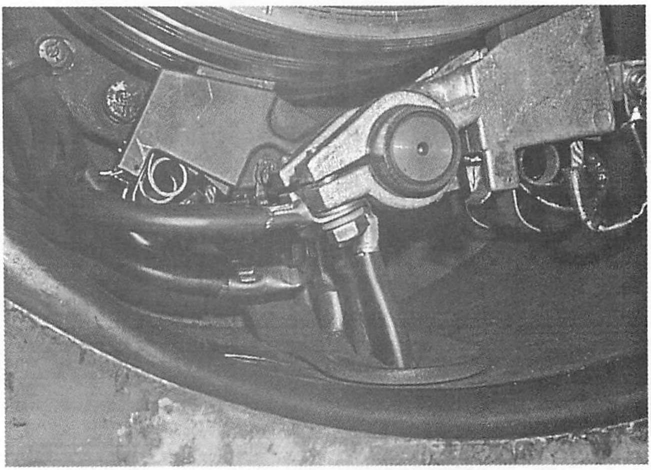

Figure 6 - Double Brush on MG Slip Ring


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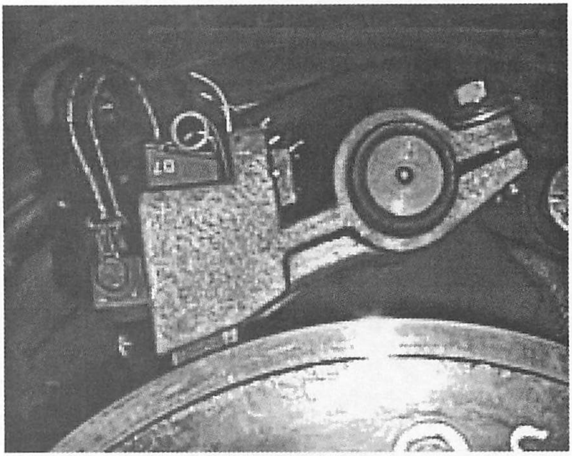


Figure 7 - Small Brush & Brush-holder

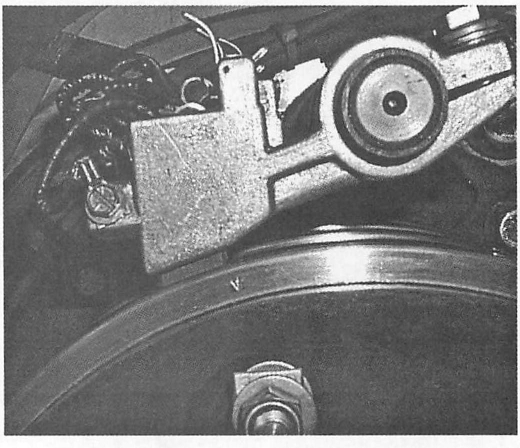


Figure 8 - Spring Cell Nearing Change-Out

	Ring Configuration	Companion Alternator Brush Configuration 2 small	1 large	2 large	Traction Alternator (MG) Brush Configuration 2 large	3 large
4300's	Sn-Cu 1/4"	4317	4322 2nd Test	4322	4317	4322
	Sn-Cu 1/2"	4324	4324 2nd Test	not tested	4324 2nd Test	4324
(HEP & 40-amp CA)	Steel 1/2"	not tested	not tested	4320	4320	not tested
	Al-Cu 1/2"	4326,4327	not tested	not tested	4326, 4327	orig.config, not tested
4000's	Sn-Cu 1/4"	4008	not tested	4014	4008	4014
(No HEP & 60-amp CA)	Sn-Cu 1/2"	4011	4005, 4016	not tested	4011, 4005,4016	~~4016~~
	Steel 1/2"	4004	not tested	4006	4004	4006
	Al-Cu 1/2"	all other locos	4003, 07,10,12	not tested	4003, 07,10,12	all other locos

NOTES:

- Sn-Cu: Tin-Bronze, Al-Cu: Aluminum-Bronze
- ¼" :One quarter inch pitch of the spiral groove, ½" (standard) one half inch pitch of groove
- While it was intended to test 4016 with 3 large brushes on the MG rings, we failed to install the 3rd brush & thus it was tested with only 2 large brushes per ring.
- "4xxx 2nd Test" indicates that after a particular configuration was run to brush wear-out, a new test configuration was ran.

Table 1 – Brush/Ring Test Array

	Small Brush	Large Brush
New Length - Inches	2.205	2.140
Spring Gone Length	1.575	1.500
No Pressure Length	0.875	0.985
Tenths to Change Out	6.8	6.4
Tenths Reserve To No Pressure	6.5	5.15

Table 2 – Brush & Change-Out Lengths

	Small Brush		Large Brush	
Wear Rate Days Per Tenth	Months To C/O Point	Reserve To No Pressure	Months To C/O Point	Reserve To No Pressure
25	5.5	5.2	5.2	4.2
30	6.6	6.3	6.2	5.0
60	13.2	12.6	12.4	10.0
80	17.5	16.8	16.5	13.3
100	21.9	21.0	20.6	16.6
150	32.9	31.5	31.0	24.9
200	43.9	41.9	41.3	33.2
300	65.8	62.9	61.9	49.8
400	87.7	83.9	82.6	66.5

Table 3 – Brush Wear Rates & Months To Change-Out

	Ring Configuration	Companion Alternator Brush Wear Data – Days Per Tenth: 2 small	1 large	2 large
4300's (HEP & 40-amp CA)	Sn-Cu ¼"	73/75/107/108 5,151hrs 53/55/98/104 4,655hrs	74/89 1,285hrs	78/88/87/93 6,318hrs
	Sn-Cu ½"	30/23/53/58 5,037hrs	99/112 4,317hrs	not tested
	Steel ½"	not tested	not tested	140/140/155/138 8,628hrs
	Al-Cu ½"	39/47/69/100 14,258hrs	not tested	not tested
4000's (No HEP & 60-amp CA)	Sn-Cu ¼"	108/111/180/184 2,077hrs 99/106/114/122 3,779hrs	not tested	118/122/121/117 3,552hrs
	Sn-Cu ½"	121/124/127/136 7,160hrs	93/107/110/127 15,695hrs	not tested
	Steel ½"	126/158/164/198 8,216hrs	not tested	202/212/182/218 7,745hrs
	Al-Cu ½"	all other locos	33/83/57/137 28,801hrs	not tested

Table 4 – Companion Alternator Brush Wear Rate Results

	Ring Configuration	Companion Alternator STEEL Slip Ring Wear Data – Days Per Tenth 2 small	1 large	2 large
4300's	Steel ½"			140/140/155/138 8,628hrs
4000's	Steel ½"	126/158/164/198 8,216hrs		202/212/182/218 7,745hrs

Table 5 – Companion Alternator Steel Slip Ring Wear Rate Results

	Ring Configuration	Traction Alternator (MG) Brush Wear Data – Days Per Tenth 2 large	3 large
4300's (HEP & 40-amp CA)	Sn-Cu ¼"	77/78/114/117 9,806hrs	25/28/28 3,304hrs c/o 91/98/100 5,747hrs
	Sn-Cu ½"	53/60/122/145 4,317hrs	37/40/59/64 5,297hrs
	Steel ½"	116/136/264/292 8,628hrs	not tested
	Al-Cu ½"	65/115/84/131 14,258hrs	orig.config-not tested
4000's (No HEP & 60-amp CA)	Sn-Cu ¼ "	81/90/159/178 6,244hrs	89/98/105/131 3,553hrs
	Sn-Cu ½"	59/134/116/161 23,125hrs	not tested
	Steel ½"	218/230/326/329 8,216hrs	226/227/448/576 7,745hrs
	Al-Cu ½"	82/173/144/230 28,801hrs	all other locos

Table 6 – Traction Alternator (MG) Brush Wear Rate Results

USING TEST INSTRUMENTATION SAFELY ON GEN-SET AND AC LOCOMOTIVES

Prepared by
Steve Mueting,
Field Service Engineer
Siemens Transportation Systems

Introduction

This paper is a continuation of this Committee's support of providing awareness to electrical safety. It is not intended to replace existing safety procedures, but rather to act as an overview of test instrumentation used in high energy circuits. All "Safety First" practices should be observed such as, but not limited to: work on de-energized circuits, connect ground lead first, use well maintained and calibrated tools, perform a visual inspection first, etc.

Last year in 2008, Keith Mellin of this Committee presented the paper Using Test Instrumentation Safely. The focus of this topic was safety features and operation of using handheld measuring devices. This paper is a continuation of this topic with focus on the unique application of circuits in AC and Gen-Set locomotives. These locomotives contain electrical equipment and 'high voltage conditions' not found on traditional locomotives.

The high voltage circuit in AC locomotives is commonly called 'DC Link' and can reach potentials of 3000V. Gen-Set locomotives can reach a potential of 700V. A common voltmeter is not rated for, and cannot withstand this level of voltage.

Other presentations in the past concerning safety and AC locomotives are as follows:

1996 EMD SD80MAC High Voltage Safety
By Mike Fitzpatrick of Conrail & Jerry Youngworth of EMD
GE AC Locomotive Electrical Safety Features
By John Chessario of GE

1997 SD70MAC Discharge Procedure
By Mike Barr of BNSF

All of the information in these past papers and presentations is still valid and practical. This paper offers an extension to these presentations, as well as an overview of steps an electrician can perform to safely work on these types of locomotives.

So What's New?

What does this paper have to offer that hasn't already been covered in the past? What's new? There are still valid reasons for revisiting this topic due to the growing presence of Gen- Set locomotives and questions from new electricians working on AC locomotives of how, what, when, and why?

My work as a Field Service Engineer involves me with the work the electricians do on AC locomotives, and I repeatedly hear these questions. My initial answers to these are with reference to the Safety Flow Chart in the locomotive cab, company safety policies and instructions, and personal safety evaluation. While all of these are fine to begin with, it is just the beginning and not the full picture.

For example, on SD90MAC locomotives there is a "DANGER" sticker on the high voltage electrical cabinet with safety instructions (Pic. 1) as well as the "DC Link Capacitor Discharge Procedure Flow Chart" posted in the cab of the locomotive (Pic. 2).

Both of these procedures recommend the verification of DC link voltage using a High Voltage Probe / Meter. This is where the information stops and the questions begin. Other than the probe manufacturer's general instruction sheet for proper use, there is no specific instruction on safely using this non-traditional device on high voltage circuits in these locomotives.

So why and how does an electrician safely use this non-traditional device on these locomotives? This paper will overview this measuring device and other devices for safety concerns on AC and Gen-Set locomotives.

Beyond the "DANGER" sticker

To begin, there are numerous redundant safety features built in to these locomotives such as the isolation and door interlock switches, computer self tests, and discharge resistors to dissipate any DC voltage. These systems are reliable and help provide a safe working condition, and have been covered in past papers and presentations mentioned earlier in this paper. But what if there is a failed self test, no battery power to perform a self test, or the unit has been in a catastrophic failure such as a fire or accident? The electrician needs effective knowledge and instrumentation to safely work in an area where the electrical potential is unknown.

There are three primary devices to help with working on high voltage equipment:

- High Voltage Probe with hand held meter
- Differential Probe with meter
- Discharge Resistor Assembly

So why is there a concern if the locomotive is not running, and why are these devices needed? The answer is the DC Link Capacitors.

AC locomotives require a stable, stored, DC Link voltage which is provided by a bank of capacitors. These capacitors hold a charge of voltage for extended periods of time. If the capacitors are not fully discharged a dangerous voltage may exist on some circuits. The redundant DC Link discharge circuits and self tests are effective, but what does an electrician have to independently confirm this in the event of a failed self test or no battery power?

High Voltage Measuring Devices

Devices for an effective safe means of measuring high voltage on electrical equipment are:

1.) High Voltage Probe with hand held meter
2.) Differential Probe/Meter
3.) Discharge Resistor Assembly

All of these devices have their appropriate instruction guides and here I will present their basic use. But first, always follow all related safety procedures and company policies. Additional recommendations are face shields and high voltage gloves when using high voltage measuring devices. Another important recommendation is a visual inspection of the high voltage equipment, to look for damage, burn or arcing marks, and particularly loose connections. A loose connection can create a false voltage reading or result in arcing if contact is made.

1.) High Voltage Probe with hand held meter

On the compartment doors are the "DANGER" and "Discharge Flow Chart" stickers and a reference to the High Voltage Probe and a hand held meter (Pic. 3). This is the first, most suitable type of probe for this application.

This high voltage probe can be plugged in to a hand held meter which will extend the measuring capability of the meter to 6000V at a 1000:1 division ratio. The probe has a two terminal molded plug with a "Ground" side indicator, with the Ground side plugged into the meter's common terminal. The probe also has a grounding lead, designed to avoid electrical shock, and is to be connected to the car body ground.

Before probing, qualify the high voltage probe by safely testing a known circuit, such as a good operating battery knife switch voltage. There is no calibration required and is for functional purposes only. Probe and measure the target circuit and then retest the original known circuit.

2.) Differential Probe/Meter

At the next level of high voltage measuring devices is a differential probe with an attached volt meter which has a maximum display of 1999V, and is safe beyond the display voltage to a maximum of 4000V. This device is made of two, 3 ft. fiberglass sticks with handles at one end and contact probes on the other. In the middle of the probe sticks is a voltmeter connected to the other stick with a wire (Pic. 4).

This device is designed for use in measuring circuits that may be located deeper in the compartment and allows the operator to measure at a safe distance.

3.) Discharge Resistor Assembly

The electrician now has safely measured and confirmed the high voltage circuit but has found it to be charged. Why is it charged and what is to be done?

Assuming the alternator is not energized, the reason for a charged DC Link circuit is going to be due to a charged DC Link capacitor. This capacitor will remain charged until there is an electrical path to dissipate or decay the charge either through a resistor or by shorting the capacitor terminals

But first, a capacitor which is not connected to a circuit can build up a residual charge if the terminals are not shorted together. A capacitor in a circuit that has been electrically charged will remain charged if it loses the electrical connection to the circuit, such as a connection coming loose. It will remain charged until it regains contact with the circuit or by some other inadvertent electrical path. Both of these conditions, along with shorting the terminals of a charged capacitor, can lead to a high discharge current resulting in arcing and potential harm to the electrician and the equipment.

This is where the use of the Discharge Resistor Assembly box (Pic. 5) can be used to safely and effectively discharge the charged DC Link capacitor and circuit.

It is similar to the Differential Probe/Meter containing two 3 ft. fiberglass sticks with handles at one and contact probes at the other. Between the probes there is a 4.4Kohm resistor box which will discharge a single charged capacitor or a block of charged capacitors. The assembly will safely discharge voltages up to 3400V DC.

The lengths of the probe sticks provide a safe distance for the electricians to discharge the charged circuit.

Other Devices

While a Clamp-on ammeter is another useful instrument for measuring current, it is not being covered in this paper. The safety concerns for AC and Gen-Set locomotives have to do with measuring the presence of DC Link high voltage.

And finally, with all high voltage measuring, the use of high voltage gloves (Pic. 6) and a face shield is highly recommended given the safety concerns working with this type of equipment.

Conclusion

Maintenance staff may be required to verify and discharge high DC voltage on modern AC locomotives and Gen-Sets. Knowledge of on-board safety systems, and what steps to take in the event of system failure are critical to a safe working environment. This paper is meant to provide an overview of proper instrumentation, which the maintainer may then incorporate into existing safe practices.

References

Safety Precautions SD80/90MAC Locomotives - EMD Document MM003010

Fluke Instruction Sheet 80K-6 High Voltage Probe

Users Manual for Differential Probe/Meter

Discharge Resistor Assembly Operating Instructions

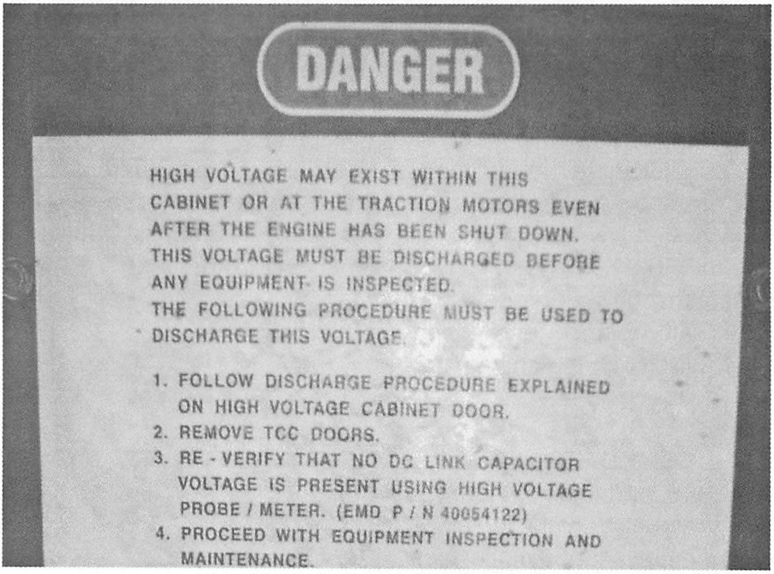


Figure 1 - Danger on High Voltage Cabinet

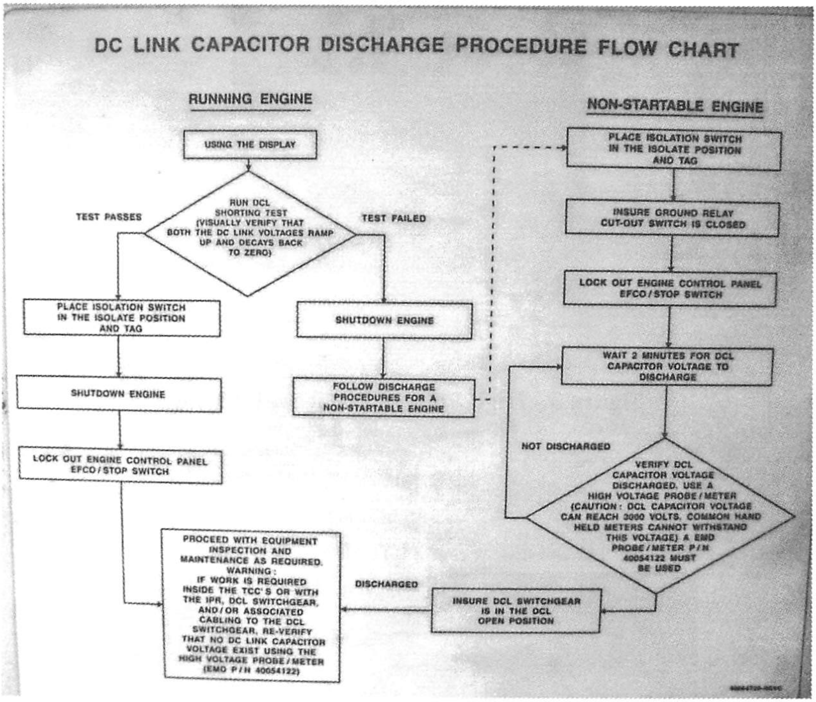


Figure 2 - DC Link Capacitor Discharge

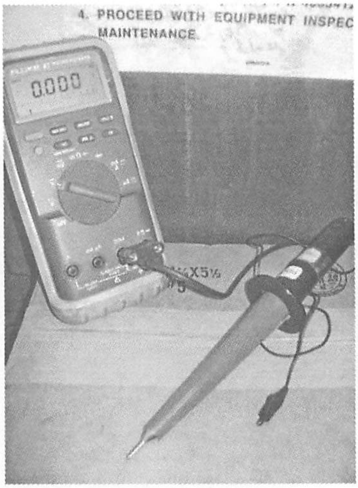


Figure 3 - High Voltage Probe with Meter

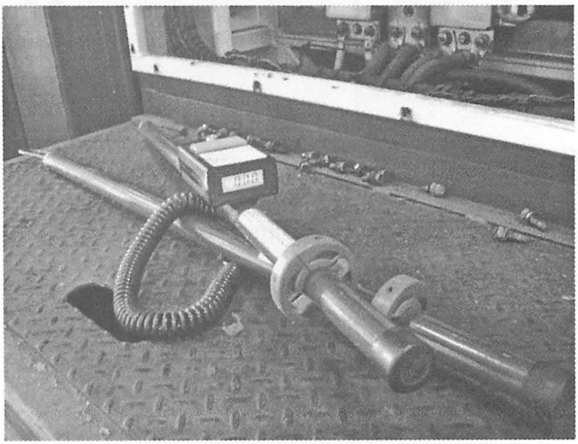


Figure 4 - Differential Probe/Meter

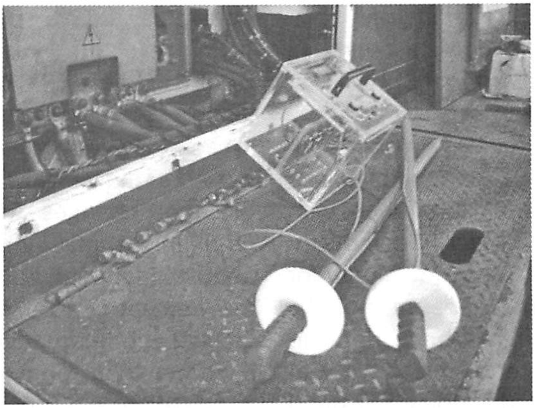


Figure 5 - Discharge Resistor Assembly Box

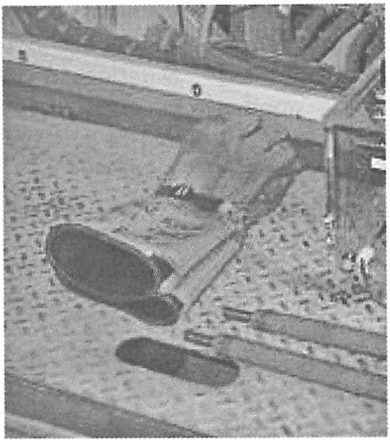


Figure 6 - High Voltage Gloves

EXTENDING LOCOMOTIVE MAINTENANCE

Prepared by
Michael (Mike) Drylie
Electrical Systems Engineer
CSX Transportation

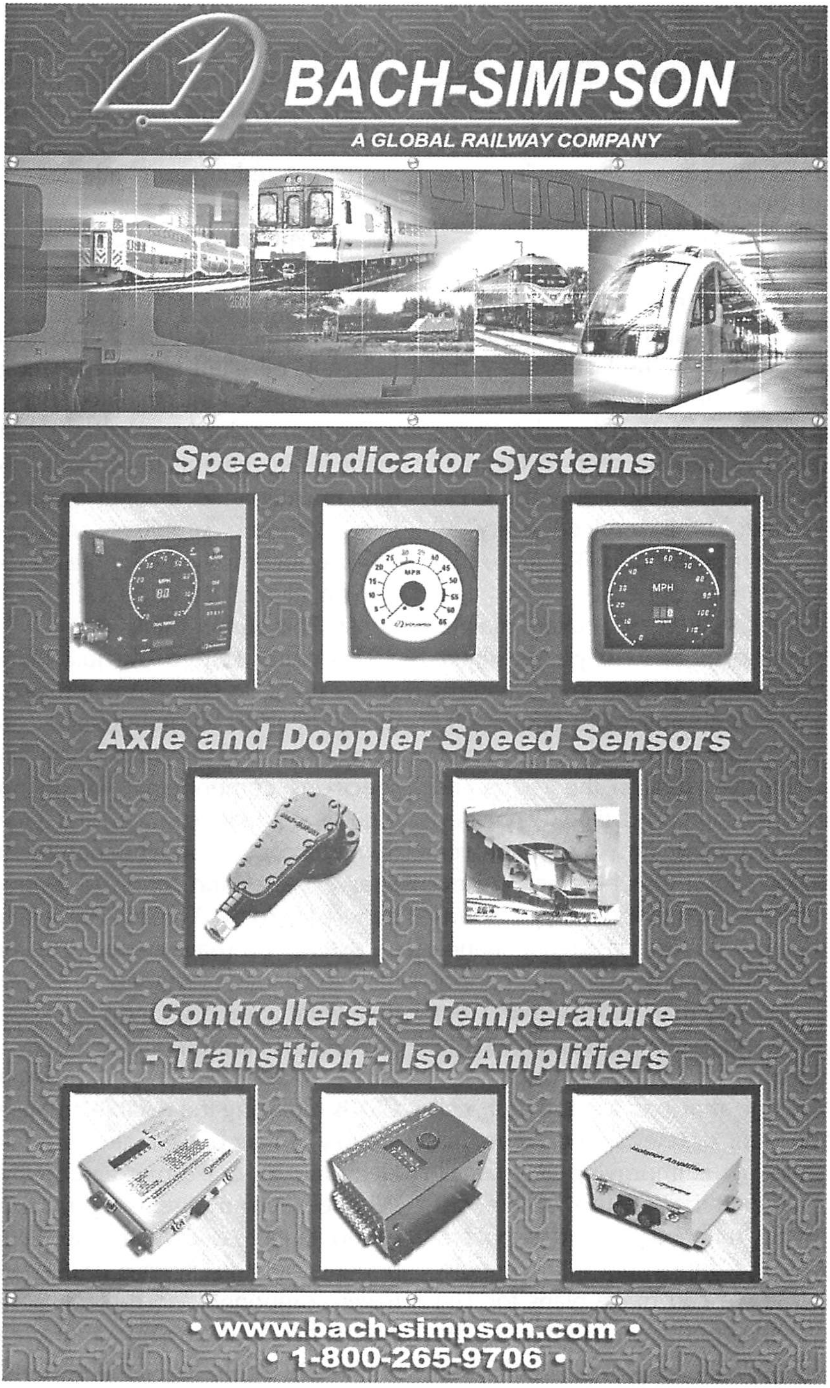
This paper deals mostly with extending the 92 day maintenance interval to 184 days. It deals with both new and older locomotives. The paper tries to provide a path for extending maintenance intervals by describing what has been done to get where we are today and what, at least, one railroad is doing to extend maintenance intervals.

Why would a railroad want to extend maintenance intervals? Having locomotives out pulling freight instead of occupying a space in the shop "just for inspections" is one big reason. Reducing the opportunity for a person to be injured by reducing the number of times that person is exposed to risk is a reason. Reducing the fleet size by not needing spare locomotives is another benefit. Finally, the EPA would be interested in a reduction in environmentally un-friendly waste such as contaminated sand and wash rack water.

How do you reduce maintenance requirements? This can be a long process and is one that needs careful consideration. Every maintenance item needs to be looked at to determine; why it is done; why it is done this way; can it be done differently; can it be eliminated; or what would we need to do to eliminate this inspection item. For example, CSX is looking to avoid the manual calibration of the speed indicator by utilizing a digital "smart" speed indicator coupled with a GPS device so that once a day, if GPS speed is above a certain level; the "smart" speed indicator would use GPS speed to re-calibrate.

Each requirement needs to be looked at individually, but it is possible that changes to eliminate a requirement may impact/eliminate another requirement. Eliminating a requirement is not inexpensive, but looking at other requirements to see if more than one item can be addressed at the same time reduces the "per item cost". Additionally, while trying to obtain an extra 92 days, it makes sense to strive for annual, or no maintenance, requirements.

Other things that need to be considered are items that are not necessarily inspection items, but actual maintenance items. For example, locomotive batteries have required watering at 92 day intervals for decades. If you move maintenance to 184 days how do you handle the water requirements? One way is to increase the volume of water above the plates. Two other ways are to use sealed cell batteries or batteries with a slightly different chemical make-up designed to use less water. Railroads are testing all these solutions with good results. Increasing the volume of water above the plates can be done in at least four ways. You can lower the plates in the battery (reducing life due to long term sediment build up), you can add room at the top by making the cells taller, you can use the larger capacity bat-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teries which provide you with wider cells (locomotives built after 1972 can accept the larger batteries), or you can redesign the battery to have shorter plates and the same overall height. The last item provides you with similar capacity by having more plates but each plate has less capacity than the original.

Ok, so where did we start and where are we now? This paper does not start back in the 1800's, but just the "middle" of the last century, the 1970's. Prior to 1980 our locomotives were on a 30 day maintenance interval as can be seen in Figure 1 which shows those items the OEM said had to be serviced every 30 days. There were also FRA items that needed to be done.

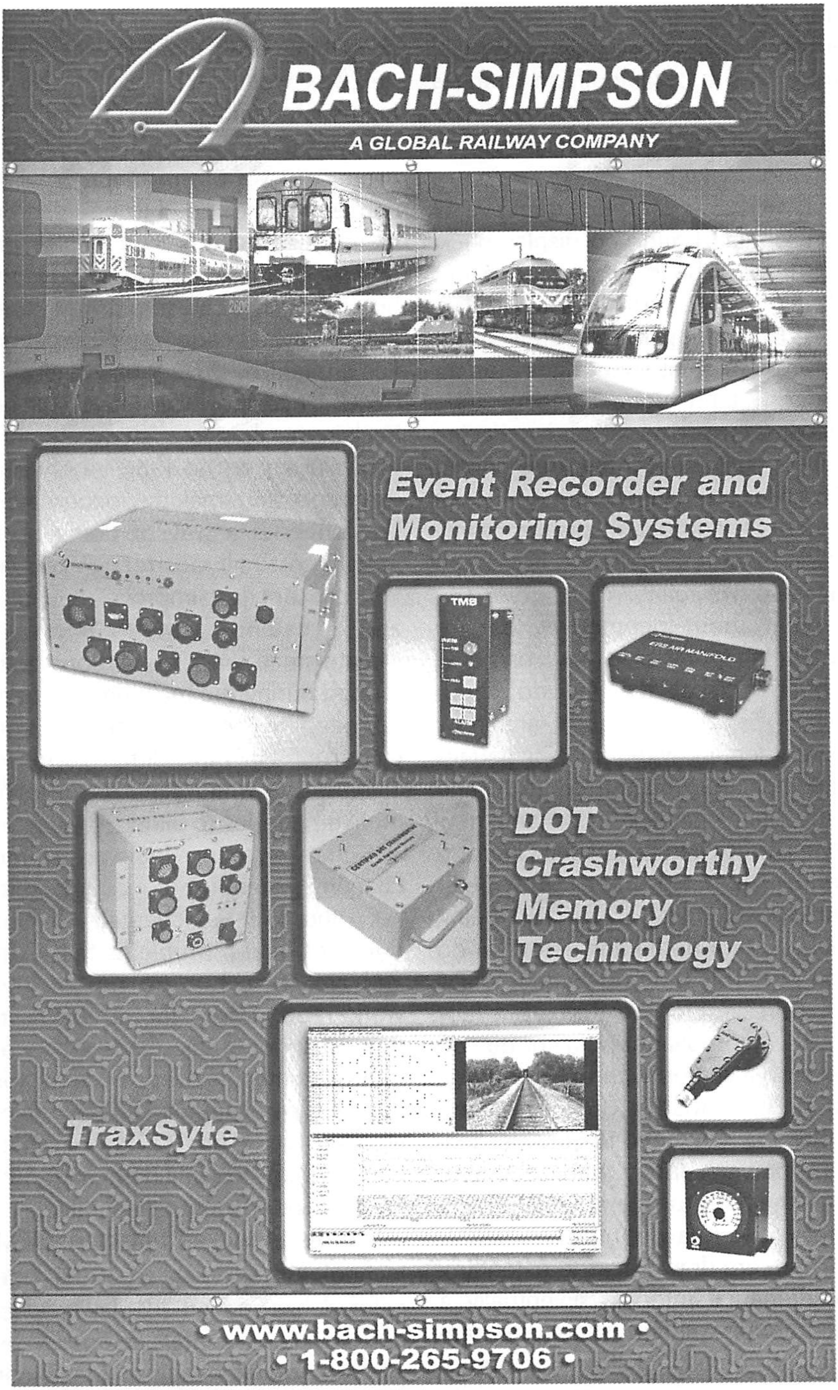
As technology improved maintenance moved to 92 days. See Figure 2 for some of the improvements made to locomotives to obtain a 92 day maintenance interval. Locomotives built in the 1970s and later had increased filter capacities, improved lubricants, and improved traction motor axle bearings. A few supplier maintenance items remained on 30 day maintenance cycles and items like train control were on less than 92 day cycles, but overall, maintenance was allowed to be moved to 92 days.

Anyone that has a computer, cell phone, car or television can see that technology is improving at a fantastic pace. It is because of the fast growing technology, and suppliers' abilities to implement that technology, that we can make plans for 184 day locomotives. Many of the improvements on new locomotives are shown in Figures 3 and 4. Some of these improvements; Brushless Fuel Pumps, AC Auxiliary Generators and AC Traction Motors have eliminated many, but not all, brush inspections. Electronic Fuel Injection has eliminated greasing linkages and oil filled governors. Digital Displays extend meter calibration/certifications from 92 to 365 days. Improved lubrication and gear cases have allowed 184 day lubrication intervals, and oil filled support bearings have eliminated that maintenance.

The two major locomotive OEMs made improvements to obtain a 184 day maintenance interval locomotive. With the suppliers providing 184 day locomotives is it time for the FRA to allow 184 day FRA inspections? This author thinks so.

This paper started out just being about going to semi annual maintenance intervals. The railroads are going way beyond that. We are specifying components that do not require any maintenance for 1 year; trying to get component change out after 8 years; and trying to extend battery life to 9-10 years. The goal is to extend overhaul periods. If you have to change everything at 5 years then what good does it do to extend the overhaul period?

In a locomotive rebuild program CSX is replacing the reliable and user friendly 26L air brake system with an electronic air brake package. Why? With fewer components the reliability should increase. With fewer components in the system there are fewer components to replace. The system has an increased component change out period of 8 years. It may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not be practical to replace the air brake system on every locomotive, but in a rebuild or major overhaul program the cost equation changes somewhat. In these programs you are already changing everything, so why not make it simpler?

CSX is also changing the overall control stand and cab display package in its rebuild program and this played a large part in system selection. Eliminating the separate event recorder, alerter, speed indicator, air gauges, stand alone Head of Train Device, power meter and replacing them with an integrated Event Recorder and Alerter along with an AAR LSI compliant display eliminates many maintenance items and increases reliability.

What about locomotives that are not being purchased new or being rebuilt? What do you do about them? Several railroads are now experimenting with replacing gauges and indicators on the control stand with digital gauges. Old and new style gauges can be seen in Figures 5 and 6. The power meter, flow meter and speed indicator are also being looked at for upgrading. How far do you go? This is a cost benefit analysis exercise. Do you develop a fully AAR LSI compliant display or do you develop a screen with only the basic information that is on the gauges. Either way you need to consider sensors, power supply, fitting a screen into the control stand and getting your crews to accept it.

There are draw backs to extending maintenance intervals. Eventually a locomotive will fail. When this happens the repairs must be done properly and the rest of the locomotive needs to be looked at to determine if something else might break in the next few weeks. The goal of reducing maintenance is to keep the locomotive out of the shop. With effective repairs your semi-annual maintenance practices need to be adhered to more stringently. Of course no one ever skips an FRA required item, but it would not be surprising to find that a few "headquarter" required items might be "overlooked just this once" since the locomotive will be back in the shop in a few weeks anyway. Trying to go longer between overhauls and making locomotives last longer is a way of doing business. Most railroads recognize that you can not just improve the parts and extend the intervals. Maintenance and inspections performed during the maintenance period need to be more precise and effective. It does little good to increase the water capacity of locomotive batteries to allow 184 day or 365 day watering intervals if the charging system is not maintained to keep the batteries charged. It also does not help if problems that exist and are seen, but are not on the work report, are ignored because they must not be that bad. If a locomotive comes in every 60 days for repairs then again for 184 day maintenance, or even 92 day maintenance, then the maintenance program is not efficient or effective.

In order to take advantage of OEM technology advances at least one railroad has moved 92 day inspections to service centers and performs 184 day maintenance in the major shops. This is not a true 184 day maintenance cycle but many benefits are obtained.

Some of the benefits are good for the environment. With 184 day maintenance less time is spent idling in the shops, burning precious fuel and exhausting emissions. Increased filter sizes doesn't just extend maintenance, it reduces the oily waste produced that must be disposed of in an environmentally friendly fashion. Fewer locomotive shoppings result in fewer locomotive washings, another source of environmental waste.

Besides the environmental benefit, there is also a potential safety benefit obtained with extended maintenance intervals. Since the 1980's the railroads safety record has improved significantly. By reducing the opportunity to get personnel injured, safety can be further improved.

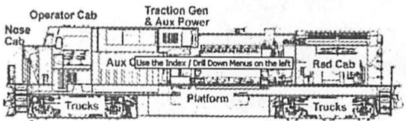
From a revenue and cost stand point, with work performed at service centers the locomotives are returned to freight service many shifts/hours sooner. This coupled with fewer locomotives in the shop allows the fleet size to be decreased slightly. A 1% reduction in fleet size can be expected with 184 day maintenance.

In conclusion: It can be seen that manufacturers are designing out those items that require 92 day maintenance. Railroads are looking for opportunities to improve systems and eliminate inspections where it makes sense. Both are looking for longer life out of traction motors, fans, air compressors and other equipment. The suppliers because it reduces their warranty costs and makes them a "better buy" than the competitor and the railroads because locomotives in the shop are not earning revenue. It is only a matter of time before the railroads are truly on a 184 day maintenance cycle.

1972-1980 Vintage GE Locomotive Maintenance Requirements
FRA Periodic inspection required every 30 days

30 day GE Required maintenance cycle items:
DC brush fuel pump motor
Fuel filters
Oil filters
Engine air filters
Mechanical fuel injection linkage requires greasing

Technology:
U Series
Dash 7



Hyatt oil filled axle bearings (30 day)

Crater type gear cases (30 day maintenance cycle)

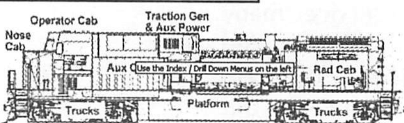
Oil filled support bearings (30 day maintenance cycle)

Figure 1 - 30 Day Maintenance Items on GE Locomotive
Information provided by GE

1981-1991 Vintage GE Locomotive Maintenance Requirements
FRA Periodic inspection required every 91 days

92 day GE Required maintenance cycle items:
DC brush fuel pump motor
Fuel filters
Oil filters
Engine air filters
Mechanical fuel injection linkage requires greasing

Technology:
Dash 7
Early Dash 8



Timken axle bearings (no maintenance)

Crater type gear cases (30/45 day maintenance cycle)

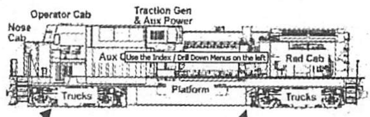
Oil filled support bearings (30 day maintenance cycle)

GE Increased filter capacity and capability to run 92 days
Also utilized improved lubricants, brushes and bearings to run 92 days

Figure 2 - GE 92 Maintenance Locomotive
Information provided GE

1992-2007 Vintage GE Locomotive Maintenance Requirements
FRA Periodic inspection required every 91 days

92 day GE Required maintenance cycle items eliminated or extended to 184 days:
DC brushless fuel pump motor, no maintenance
Fuel filters, capacity increased, life extended to beyond 184 days
Oil filters, capacity increased, life extended to beyond 184 days
Engine air filters, capacity increased, life extended to beyond 184 days
Engines upgraded to Electronic fuel injection, no linkage to grease



Technology:
Late Dash 8
Dash 9
CW44AC
CW60AC
ES44DC (EVO)

Crater type gear cases replaced with oil filled gear case which has proven leak reduction and extended top off interval to beyond 184 days

Oil filled support bearings eliminated with roller bearings, no maintenance

Figure 3 - Improvements to GE Locomotives to Obtain 184 Day Maintenance

Scheduled maintenance for EMD locomotives

The SD70ACe features a true 184 day maintenance cycle

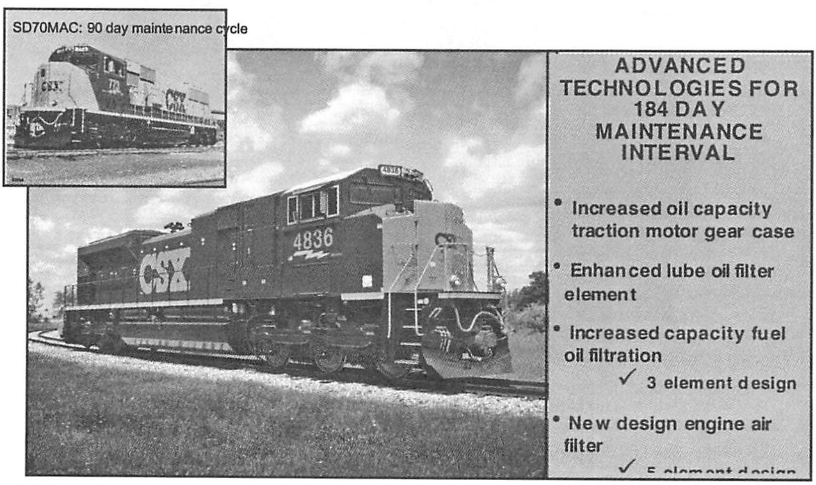


Figure 4 - EMD 184 Day Maintenance Locomotive (photo provided by EMD)

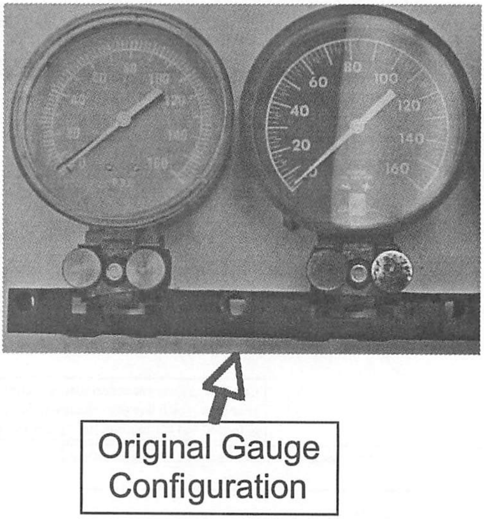


**Figure 5 - Older Locomotive Air Pressure Gauges
92 Day Calibration Required**

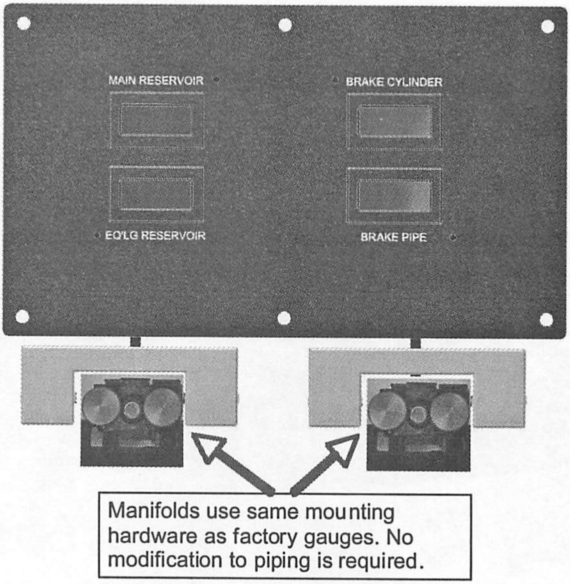


**Figure 6 - Digital Pressure Gauges
Annual Calibration Required**

710ECO™ REPOWER

Prepared by
Dean Becker,
Electro Motive Diesels

Rebuilt locomotives using the 710ECO Repower concept give new life to older units. Although rebuilt, these locomotives offer the performance, reliability, and maintainability that approach that of new locomotives. These locomotives meet current EPA requirements for Tier 2 emissions, which is significant ECOlogically. Furthermore, these locomotives use considerably less fuel than before, which is significant ECOnomically.

Just what is a 710ECO Repower? It is an older locomotive where most of the equipment has been removed above deck and replaced with a package of new or UTEX (unit exchange) equipment. The new equipment includes:

- New 710 engine
- New or UTEX AR10 main generator with CA6 companion alternator
- New engine cooling system (radiators, cooling fans, AC cabinet)
- New high voltage cabinet containing the EM2000 microprocessor control system
- Automatic Engine Start Stop (AESS)

The 710 engine has a proven design with more than 8000 engines in service. It is certified to meet Tier 2 emissions. An 8-cylinder version of the engine delivers 2000 THP while a 12-cylinder version of the engine delivers 3000 THP. These engines use electronic unit injectors controlled by an EMDEC computer. Both engines can operate continuously at maximum rated horsepower. The 710 engines use much less fuel oil and lube oil than their predecessors. For example, lube oil savings exceed 50%.

A rebuilt longhood provides the engine cooling system necessary to achieve Tier 2 emissions. In addition to the traditional radiators to cool engine jacket water, a second radiator loop is present for aftercooler water cooling. Lower water temperatures contribute to improved fuel economy and lower emissions. Furthermore, three, two-speed cooling fans are used, where the multiple speeds help to reduce fuel usage. Fan contactors are contained within a new AC cabinet.

A new high voltage cabinet is part of the ECO Repower. It contains the EM2000 control system as well as new or UTEX contactors/switchgear. The remaining wiring/cabling and incidental equipment are new, which helps increase locomotive reliability.

The EM2000 control system provides basic locomotive control functions. In contrast with the original locomotive, the new control system provides increased adhesion performance and thermal protection for the traction motors. To assist with fuel savings, the EM2000 control system provides optimum control of the engine cooling fans, intelligent logic for automatic engine shutdowns and restarts. A display screen is provided as a user interface. This provides crew messages, maintenance messages, and operating statistics.

The 710ECO Repowers can begin with virtually any GP or SD core. Units as old as a GP9 or as new as a rebuilt "-3" units have been transformed into ECO locomotives. Since the rebuild process includes a single, smaller engine, space has become available within the longhood compartment. This space can be used for future after-treatment equipment as emissions regulations evolve.

Emissions Reduction

The ECO Repower units provide significant improvements in emissions. Particulate matter (PM), nitrogen oxide (NOx), carbon monoxide (CO), and hydrocarbons (HC) have been reduced by 50% to 70%. While certified to meet EPA Tier 2 locomotive standards, the engine performs to even better levels. Note that the significant reductions in emissions qualify the ECO Repowers for various governmental funding as clean air projects.

Fuel Savings

Within the engine, technological improvement has led to reduced fuel usage. This includes an improved firing chamber and a turbocharger with increased efficiency. Also, a low idle engine speed (200 RPM) helps to save fuel. Perhaps the largest single contribution is using an engine with fewer cylinders. The 8-710 engine has half the cylinders of the 16-645 engine of the original units. When compared to locomotives with a "fresh" (new or recently-rebuilt) 16-645 engine, ECO locomotives deliver dramatic fuel savings. For example, an ECO locomotive with an 8-710 engine uses up to 25% less fuel and still achieves Tier 2. Moreover, since the core engines are worn and probably ready for an overhaul, the actual fuel savings may be as much as 30% to 40%.

In addition to the new 710 engine, fuel savings are achieved by new auxiliary equipment and its control. Reduced fuel is achieved by the use of two-speed cooling fans. Quite often, the full capabilities of the cooling system are not needed. In these instances, one or more fans may be running at half speed. A fan running at half speed uses one-eighth the energy than a fan running at full speed. Hence, a significant amount of fuel is saved.

More fuel is saved with a fully-integrated automatic engine start stop (AESS). By shutting down the engine when the locomotive is not in use, even more fuel is saved.

Improved Maintainability

The ECO Repowers have a 184 day maintenance cycle. Their engines have a 15,000MWh overhaul cycle. These locomotives will spend less time in the shop.

Due to the use of a 710 engine, AR10, and EM2000 controls, there is a high degree of parts standardization. A 90% parts commonality with existing locomotives with 710 engines means there are fewer new parts to maintain. Within railroad shops, labor personnel are already familiar with this technology. Furthermore, there is only a small impact to parts inventory.

Finally, the EM2000 control system provides diagnostic information, keeps track of fault information and accumulated operational data.

Other Benefits

By using new components, the ECO Repower units have improved reliability.

There is reduced noise with the AESS system.

The introduction of the EM2000 control system provides other benefits. Increased all-weather adhesion is achieved through wheel creep control. Traction motor thermal protection is inherent. Indeed, the numerous control algorithms developed for new locomotives are used for the ECO Repower units.

Summary

The ECO Repower concept provides new life to older locomotives. Performance, reliability, and maintainability rival that of new locomotives. And all this is done in an economical and ecological manner.

REPORT OF THE COMMITTEE ON DIESEL MATERIAL CONTROL

THURSDAY, SEPTEMBER 17, 2009
10:45 A.M.

Chairman
RON SULEWSKI
Sales & Marketing Mgr.
Business Development
Rail Products International Inc.
St. Louis, MO

Vice Chairman
C. MAINZ
Director New Business Development
Coast Engine & Equipment
Tacoma, WA

COMMITTEE MEMBERS

C. Aday	Inventory Manager	SCRRA/Metrolink	Los Angeles, CA
D. Behrens	Managing Director	ALSTOM Transport	Naperville, IL
J. Brix	Sr. Mgr.-Strat Sourcing	Union Pacific	Omaha, NE
R. Delevan	Mgr.-Transp. Prod.	Nat'l Electrical Carbon	Duryea, PA
E. Fonville	Supt. Loco Material	Norfolk Southern	Atlanta, GA
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
C. Mainz	Dir.-New Bus. Dev.	Coast Engine & Equip.	Tacoma, WA
F. Miller	VP - Sales	JMA RR Supply	Carol Stream, IL
P. Pinson	Purchasing Manager	Rail America	Jacksonville, FL
B. Young	Matls. Manager	Montana Rail Link	Livingston, MT
M. Zerafa	Purchasing Mgr.	Nat'l Rwy. Equip.	Dixmoor, IL

Note: John Minnie of BNSF is on standy by.

PERSONAL HISTORY

Ron Sulewski

Ron Sulewski was born in Erie, Pennsylvania and earned his BSME from Rensselaer Polytechnic Institute in 1970. He joined GE upon graduatoin and worked in Erie Locomotive and the GE St. Louis Apparatus Service Shop for over eighteen years with various positions in Sales Management. Ron joined Gardner Denver for seven years as a distributor Regional Manager and rejoined GE Transportation for a Parts Aftermarket Sales Management position in Denver.

Ron has been in his current position as National Sales Manager for Rail Products International since 2005. Ron and his wife Marje have five grown children and currently reside in St. Louis. He has been active in LMOA activities for over thirty years.

THE DIESEL MATERIAL CONTROL
WISHES TO EXPRESS THEIR
SINCERE APPRECIATION
TO CSX TRANSPORTATION
FOR HOSTING THEIR
COMMITTEE MEETING IN
JANUARY 2009 IN
JACKSONVILLE, FLORIDA

THANK YOU TO CSX FROM THE
MATERIAL COMMITTEE

CSX SUPPLIER QUALITY "SUPPLIER RATING SYSTEM"

Prepared by
CSX Supply Team

The objectives of the supplier quality program are as follows:

- Develop new and existing CSX suppliers to provide safe, reliable and cost effective components and services for CSX
- Hold CSX suppliers accountable for their performance

Six CSX Departments are involved in the supplier rating system

- Locomotive Operations
- Car Operations
- Engineering (Track Structure)
- Signals
- Maintenance of Way (MOW)
- TDSI

There are a number of supplier quality tools used in implementing the system

- Formal supplier approval process (P&M 270)
- On site supplier audits which involve both review of the product and the process
- Formal corrective action program involving the utilization of AAR 7.1 Material Nonconformance reports and CSX 5 step Corrective Action Process
- Supplier development projects
- Supplier Rating System

The CSX supplier performance rating system was conceived using benchmarked programs such as Trailer Train, General Electric and others. The General Electric model was selected.

Suppliers were tracked by criticality of the parts and/or how much CSX spent with them. Scores were updated on a semi annual basis. There were many benefits derived from using the GE model. The system was uniform for all CSX Departments. It allows input or feedback from end user. It uses "fact based" data to support scoring. Provides objective feedback to the supplier. Performance is tracked consistently over time. Supplier is held accountable for their performance and the system creates an effective negotiating tool for Purchasing Managers.

The categories that the vendors are rated on are

- Quality
- Cost
- Delivery

Scoring is as follows:

• "Green"	30 points
• "Yellow"	20 points
• "Red"	10 points

Additionally, the CSX Initiatives IMPACT Program is factored in. If a vendor submits an impact idea, they earn 10 bonus points.

Supplier "Quality" is measured using the following factors:

1. Survey responses from key CSX representatives
2. Product and process audit reports from the Supplier Quality Group
3. End user complaints reported from the field
4. Warranty issues
5. Corrective action responses

Supplier "Cost" is measured by comparing the supplier's current pricing for common parts over last year's prices against the average for all suppliers within that commodity group

Equal to or below average for all suppliers - 30 (green) points awarded

2% above average for all suppliers - 20 (yellow) points awarded

Over 2% for all suppliers - 10 (red) points awarded

Suppliers "Delivery" is measured by the date of purchase order vs. date of invoice – the number of days from P.O. date to invoice date and orders shipped complete

95% invoiced within 15 days
95% shipped complete -
30 (green) points awarded

85%-94% invoiced within 15 days 85%-94% shipped complete -
20 (yellow) points awarded

84% or less invoiced within 15 days 84% or less shipped complete -
10 (red) points awarded

The CSX Initiatives are measured through the IMPACT program. Suppliers are awarded 10 (green) points if their ideas are in progress and/or being implemented. Suppliers are not awarded any points if they have not submitted any ideas through the CSX Initiatives/IMPACT program.

The Overall "Scorecard" Rating

- Final score is derived by averaging scores for Quality, Cost and Delivery
- CSX Initiatives/IMPACT can add 10 bonus points to the average
- Suppliers have the ability to access their scorecards on line giving them immediate results on their performance
- Suppliers can get feedback through the Purchasing Managers
- An example of the supplier performance rating system scorecard is indicated below.

The CSX Supplier Quality Rating System is an ongoing program. CSX continues to add critical suppliers to the performance rating system. A list of key individuals from each department to complete the surveys continues to grow. Suppliers, not currently being evaluated, can still receive feedback on their performance by contacting the Purchasing Manager and/or Manager of Supplier Quality.

REPORT OF THE COMMITTEE ON SHOP EQUIPMENT AND PROCESSES

THURSDAY, SEPTEMBER 17, 2009
3:15 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	Project Mgr.	Simmons Mach. Tool Corp.	Albany, NY
C. Fette	President	TESCO	Erie, PA
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
M. Scaringe	Dir. Locomotives	Amtrak	Beech Grove, IN
S.G. Smith	Engr. Lean Prod. Systems	Norfolk Southern	Chattanooga, TN

Note: Mike Scaringe is a Past President of LMOA

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.

Currently 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.

GOING GREEN IN THE MAINTENACE FACILITY

Prepared by
Tom Stefanski,
Tom's Locomotives & Cars

In general the trend in the railroad industry has been to concentrate it's efforts to reduce energy consumption by improvements to it's motive power fleets. We know that the cost of diesel fuel is the major cost that affects the railroad's bottom line and every effort to reduce diesel fuel consumption is of prime importance. But now it is time for us to take a look at what we can do in the shops and other facilities to save and/or reduce our energy consumption.

First we need to look at what we are currently doing and then try to determine what steps we can take to make improvement. With all of the technological advancements that have taken place over the last decade, the door is wide open to the changes we can make. The cost of some improvements may be higher initially but it is far and away offset by the potential cost savings over it's life.

We can start by looking at the ways we currently use the systems that are available and ways that we can improve their usage. We can reduce our electrical consumption in many ways. I will now try to define some of the potential areas where we can make improvements and how they can provide cost savings. Then again this list is not all inclusive because each and every shop has it's own characteristics.

1. First let us look at lighting, what we can do and what is available in today's market. Some of these items apply to interior as well as exterior use.
   a. CFL (compact fluorescent lights), a 26 watt CFL provides as much light as a 100 watt incandescent bulbs. Average life of approximately six to 8 years. These are available for indoor and outdoor use.
   b. LED (light emitting diode), a 5 watt LED can provide as much lighting as a 50 watt incandescent bulb. These are available for indoor and outdoor use as well.
   c. New technology skylights can provide additional indoor lighting at no cost after installation.
   d. Motion detectors can be installed that will turn lights on and off as needed. Did you ever think about the lights in the locker room, bathrooms or lunch room staying on even when nobody is occupying those facilities?
   e. Photo cells can be used to turn outdoor lighting on at sunset and off at sunrise.

2. What about those power sucking motors used for many different purposes within your facility. They are used for heating, air condition-

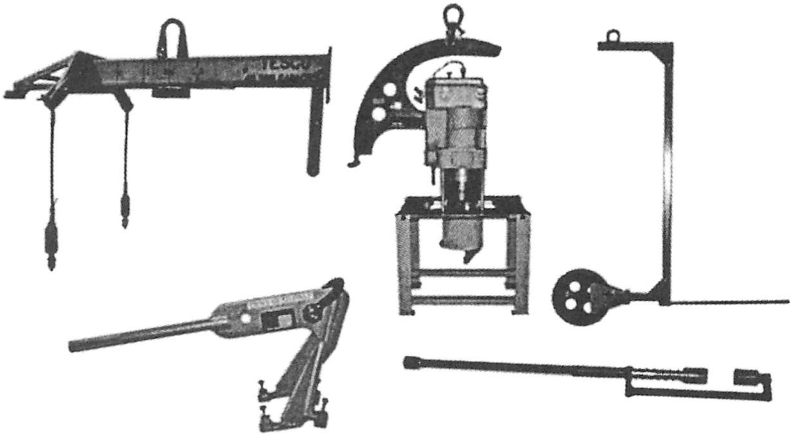
ing, ventilation, cranes, pumps, air compressors, drop tables and door operators just to name a few. There are now numerous manufacturers out there that are producing "ENERGY STAR" motors that reduce electrical consumption. I am sure that someone will have one that fulfills your requirements.

3. Compressed air systems can be another power robbing proposition. Many air compressors are running excessively in order to make up for the line pressure losses due to leakage at pipe joints, hoses and various connections. Most older compressed air systems run on average 25 to 50% more then they have to. Additionally a majority of the older piston variety of air compressors are less then desirable. If you are going to have an air compressor, have one that is of the rotary screw type configuration. To add to this problem, usage of inefficient pneumatic air tools compounds the compressed air problem. Did you ever stop and think about the fact that when you use a pneumatic tool you convert electrical energy to pneumatic energy in order to use that tool. Why bother with this additional energy drain. Consider using an electric impact wrench. Technological improvements have been made to electric impact tools of all varieties and are available today. Check with your suppliers I'm sure they will have something that will fit your needs.

Enough said about what we can do with the systems that we currently have available to us. Let us now step into the future and consider what we can do beyond that point. What about solar energy? The use of photovoltaic (PV) panels to generate electricity is now available in many forms. You know that after the initial cost of purchase and installation the operating cost is practically free with a grid tied system. Thank you Mother Nature. Dependent upon your location and system size, solar energy can provide up to 100% of you needs. It just depends on how large of a system you need and the length of time that you consider as practical from a payback standpoint.

You can also use solar energy to provide hot water and heat. The use of solar heat exchangers can provide supplemental heat and hot water for a facility. Again location plays a large part in whether or not this will work for you.

Wind energy is also an available option. It is another one of those things that Mother Nature can provide at no cost after initial installation and limited maintenance. The wind is free and all you need to do is harness it to get your free energy. There are numerous types of systems available on the market today. Wind turbines/generators come in many different configurations and there is one out there that can meet your needs. Again the use of wind generation is dependent upon location. You will have to decide if you want to be self sufficient and supply 100% of your needs or only provide a por-



tion of what you use.

This is just a broad brush approach to point out items that can be used to reduce energy consumption in the shop and facilities. The choice is yours, what do you want to do?

SHOP EQUIPMENT FOR TRUCK REMOVAL, MAINTENANCE AND REPAIR

Prepared by
Denise Louder of the
Macton Corporation

There are several different types of equipment used for the removal of rail trucks and wheel set assemblies:

Drop Tables are used as an efficient means to replace truck and wheel set assemblies. Full truck drop tables as seen in Figure 1 are used to replace a complete truck assembly. Some full truck drop tables also have a smaller auxiliary to remove single axles with traction motors. Single axle drop tables are smaller in size and capacity and are used to remove only the wheel set and traction motor assembly.

To better understand how the drop table operates we will quickly review the major components of the drop table:

The **Service Top** (pictured in Figure 2) is the area of the drop table where the locomotive is positioned for truck or single axle removal. The service top securely locks into the foundation walls when the drop table is not in use to prevent crossover loads from being transferred to the drop table carriage.

The **Body Stands** (as shown in Figure 3) are positioned under the jacking pad of the locomotive and are used to support the locomotive so that the truck may be lowered.

The **Carriage** (as shown in Figure 4) is the component that is used to raise the locomotive so that the body stands may be moved into position to support the locomotive. Once the locomotive is supported by the body stands, the carriage then lowers the truck or wheel axle assembly and transports it, usually under the shop floor to the release area. Full truck drop tables use screw jacks to raise and lower the carriage and the single axle drop table may use either screw jacks or hydraulic mechanisms to raise and lower the carriage.

Drop tables typically have one of three types of Release Areas:

The **Bascule Release Top** (as shown in Figure 5) consists of doors, in the shop floor, that open up to allow the truck to be raised to shop floor level and either pushed off of the drop table rail onto the shop rail or lifted with an overhead crane. When the drop table is not in use and the bascule doors are closed, there is no open area and the track may be used as a through track.

The **Canopy Release Top** (as shown in Figure 6) is a flat top that covers the release area. The top rises up with the truck assembly underneath. With this type of release top the truck assembly must be pushed from the drop table rails onto the shop rails, with the truck assembly under the canopy top, it cannot be accessed with an overhead crane. The canopy top may be used to load truck assemblies onto a flatbed truck by placing the trucks on top of the canopy top and raising the top to the level of the flatbed truck.

With the **Open Release Area** (as shown in Figure 7)the area of the shop floor where the truck assembly is raised to the shop floor level is left open and the area is usually closed off using safety railing which means that this area of the shop can not be used when the drop table is not in use.

A set of four **Portable Jacks** (as shown in Figure 8) may also be used to raise a locomotive so that the truck assembly may be disconnected and pushed out from under the locomotive. The jacks are placed under the locomotive jacking pads and then the jacks synchronously raise the locomotive. Portable jacks employ a machine screw jacking mechanism for raising and lowering the locomotive.

Overhead Cranes (as shown in Figure 9) may be used to raise a locomotive off of the truck assemblies or lower the locomotive onto the new truck assembly. The overhead crane is also used to move the truck and wheel set assemblies through the shop.

Split Rail Systems (as shown in Figure 10) are used primarily for transit and coach cars to remove wheel sets. The split rail carriage may use either a machine screw or a hydraulic jacking mechanism to raise the rail car to allow the truck to be supported. The rail is then moved out of the way so that the wheel set may be lowered onto a dolly and taken away and a new wheel set to be raised into place.

There are several different types of shop equipment that are used to move truck and wheel set assemblies through the work shop:

As mentioned earlier, **Cranes** are commonly used to move the truck and wheel set assemblies through the shop to the truck repair shop.

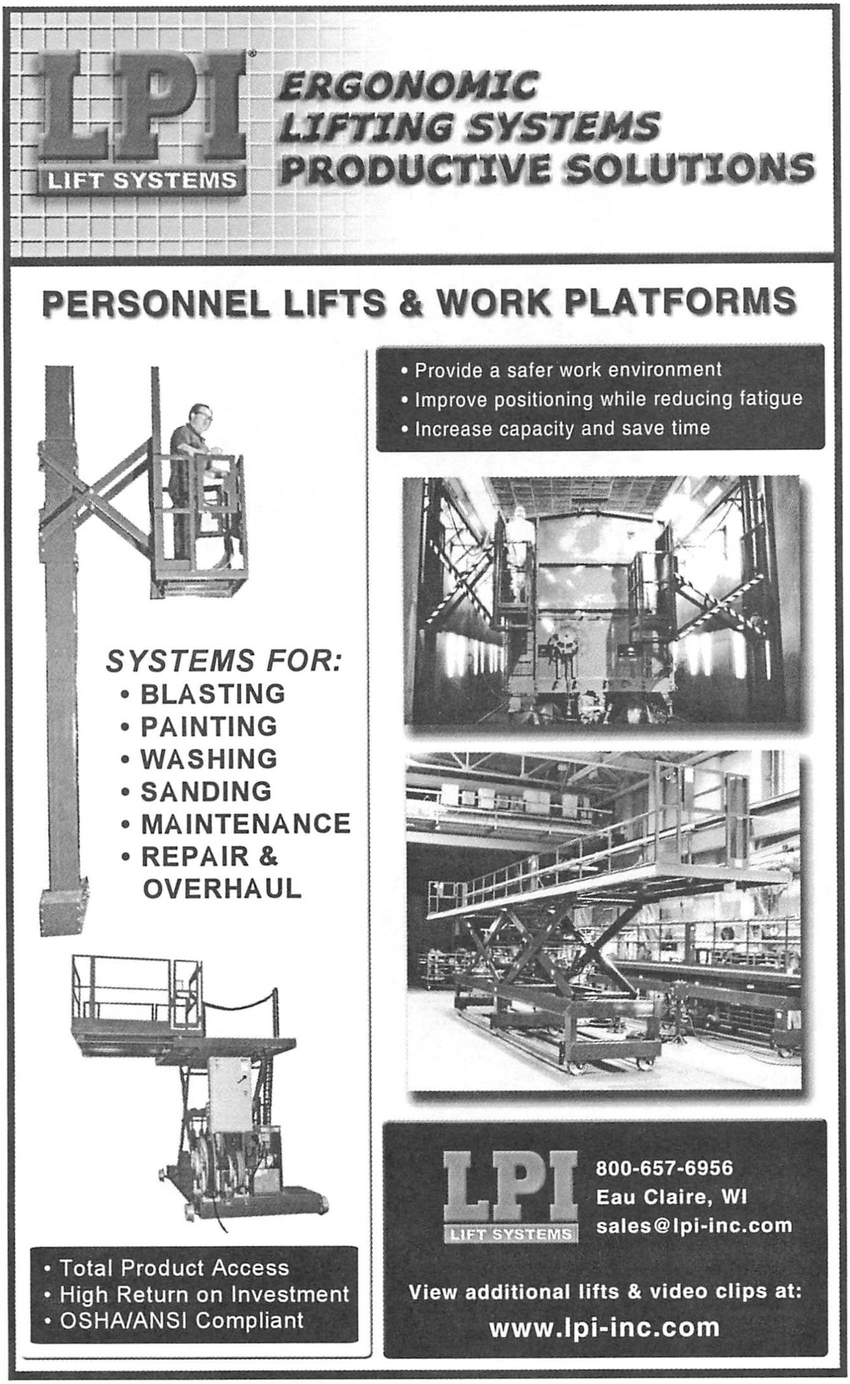
Fork Trucks are also commonly used to move wheel set assemblies and other truck components through the shop.

Truck Turntables (as shown in Figure 11) are used to transfer a truck from one track to another so that the truck, once removed may be pushed to the truck repair area. There are several different types of shop equipment used to perform maintenance and repair work on locomotive trucks and truck components in the work shop:

The Truck Repair Hoist (as shown in Figure 12) is used in many truck shops to raise the truck assembly to a height that allows shop personnel to easily access both the side and underneath the truck while standing.

Truck Rotators (as shown in Figure 13) may also be used in truck repair shops to rotate trucks or truck frames to allow easy access to the under side of a truck assembly. There are two types of truck rotators; the first will lift and rotate the truck assembly and with the second the truck assembly is loaded into the rotator with a crane and is then rotated.

Locomotive maintenance facilities have options in equipment and methodology when maintaining and servicing locomotive truck and wheel set assemblies. Fleet and shop size are important considerations when deciding on the appropriate shop equipment for truck removal maintenance and repair.


LPI
LIFT SYSTEMS
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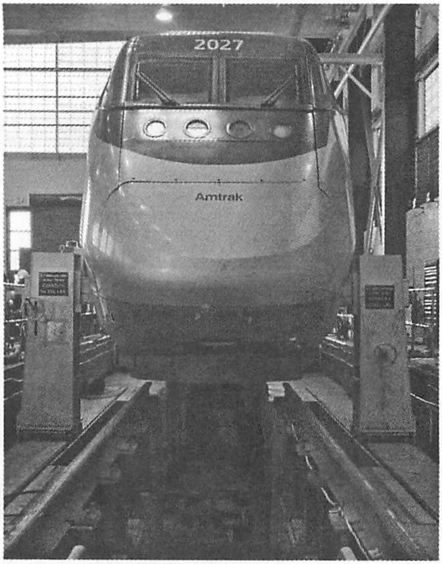

Figure 1

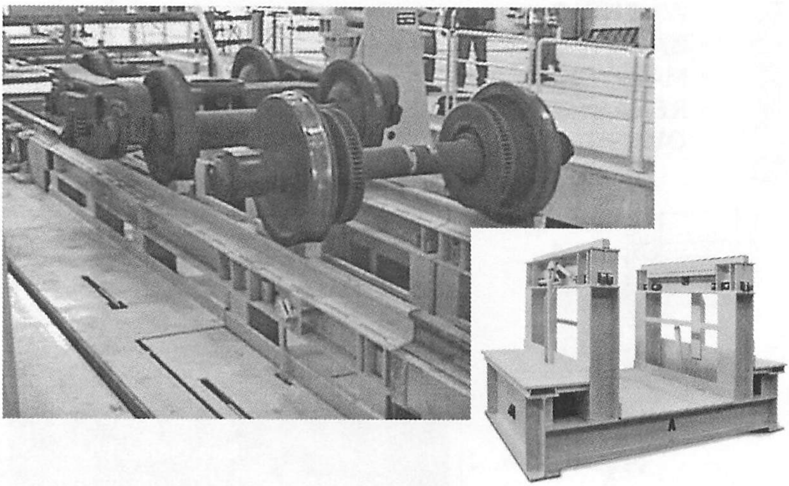

Figure 2

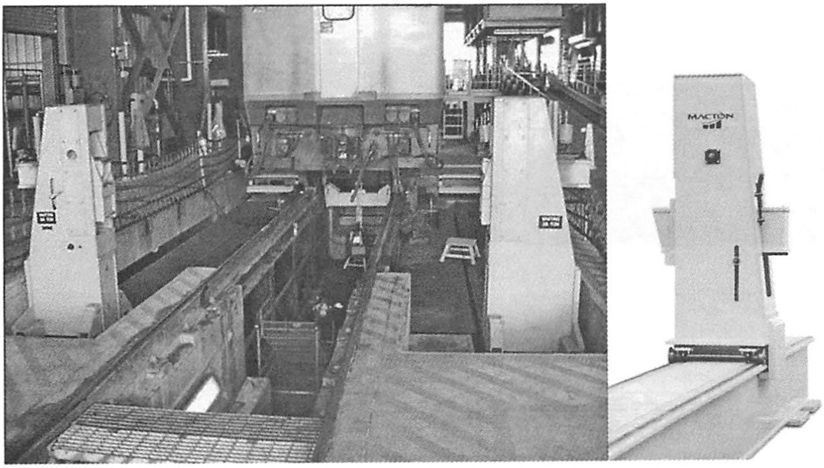

Figure 3

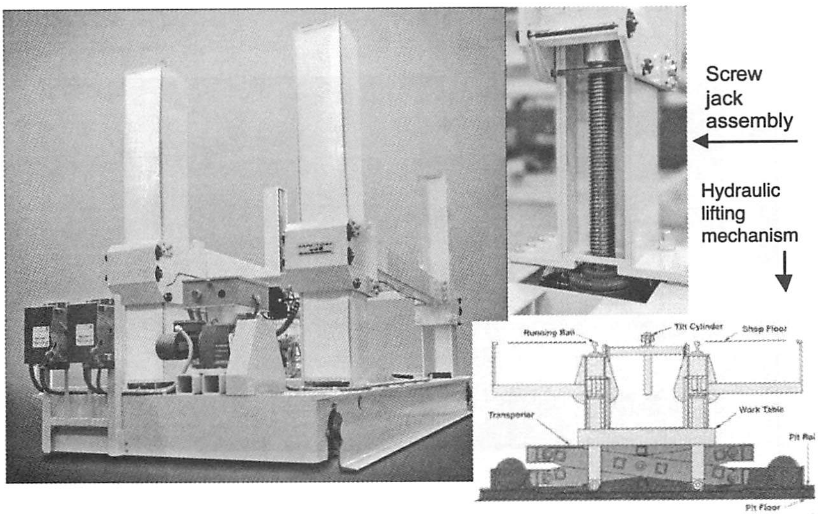

Figure 4

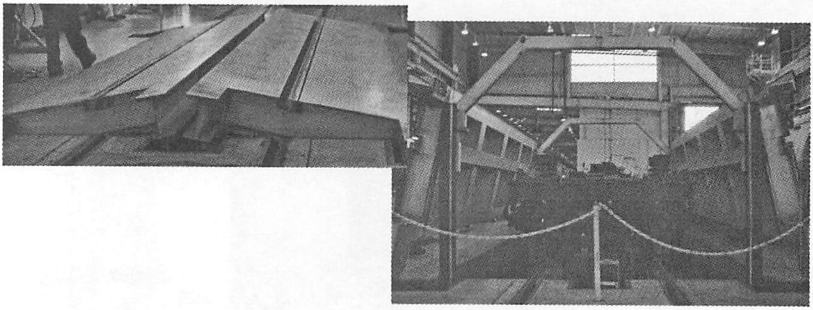

Figure 5

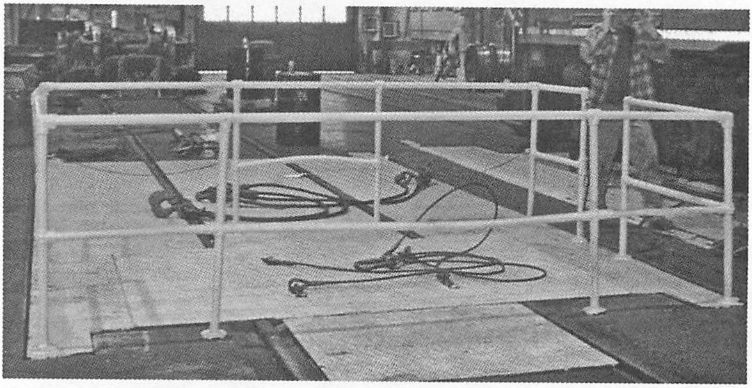

Figure 6

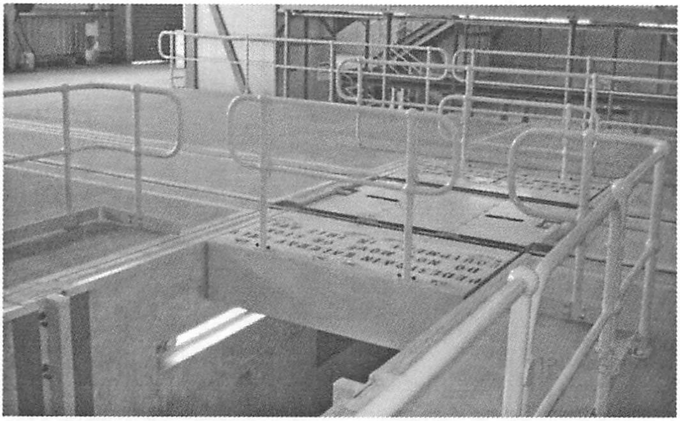

Figure 7

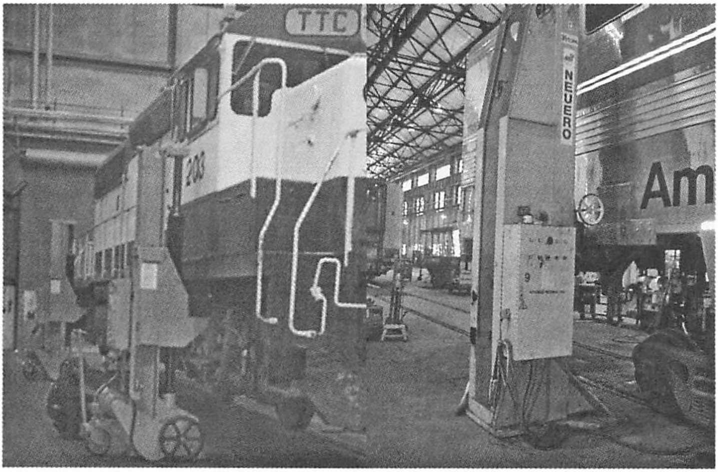

Figure 8

Figure 9

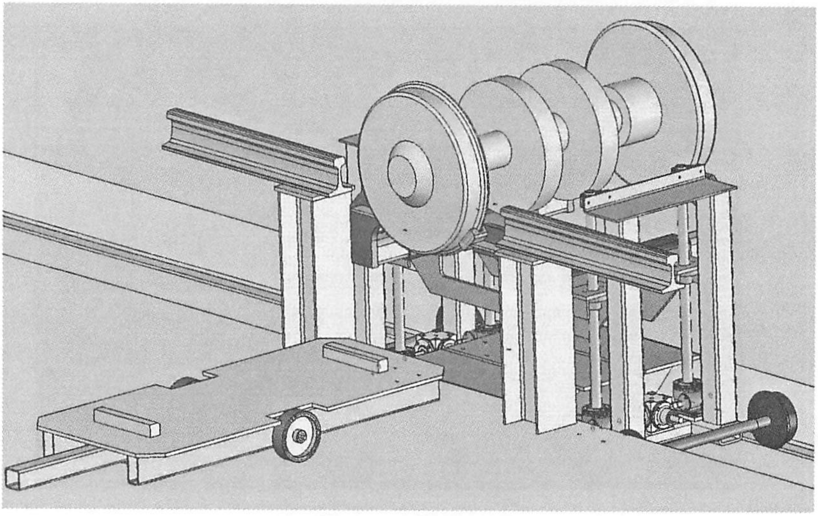

Figure 10

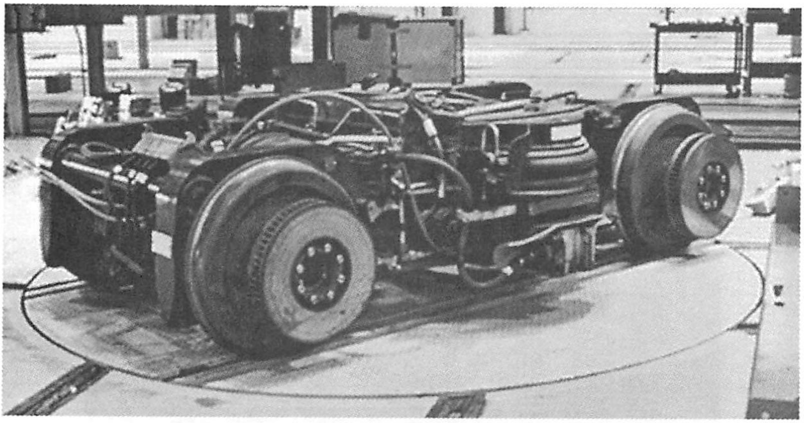

Figure 11

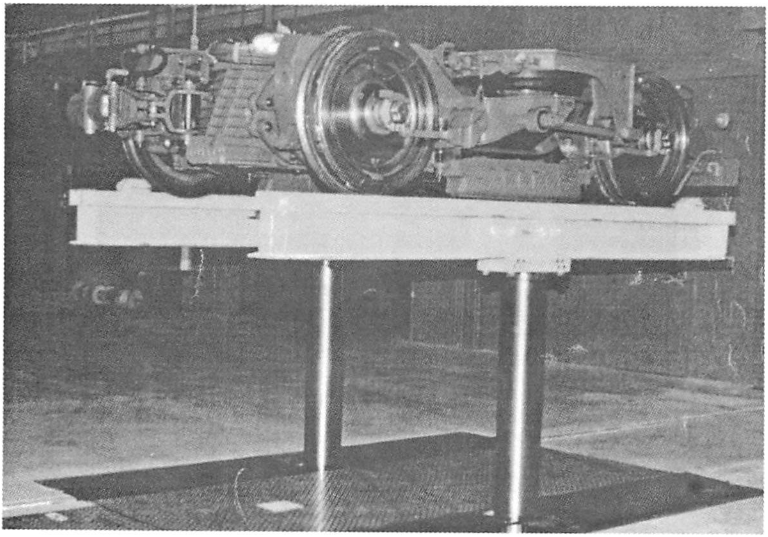

Figure 12

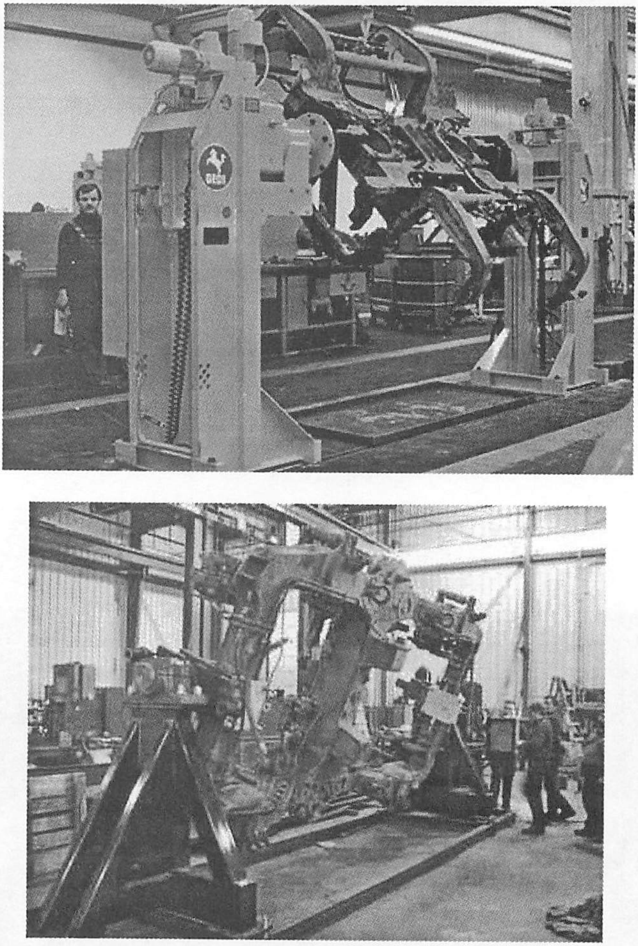

Figure 13


TIME-SAVING Tools and Machines
for Locomotive Maintenance,
Parts Reclamation, and Testing
INCREASE
SHOP PRODUCTIVITY
REDUCE
LOCOMOTIVE DOWNTIME
IMPROVE
YOUR QUALITY ASSURANCE
PROGRAM
MAIN BEARING WRENCHES
EMD & GE Engines
CRAB NUT TORQUE WRENCHES
EMD Engines
TRACTION MOTOR SUPPORT
BEARING CAP WRENCHES
EMD & GE Traction Motors
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Telephone: (706) 820-0397
Fax: (706) 820-9802
TAME INC

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

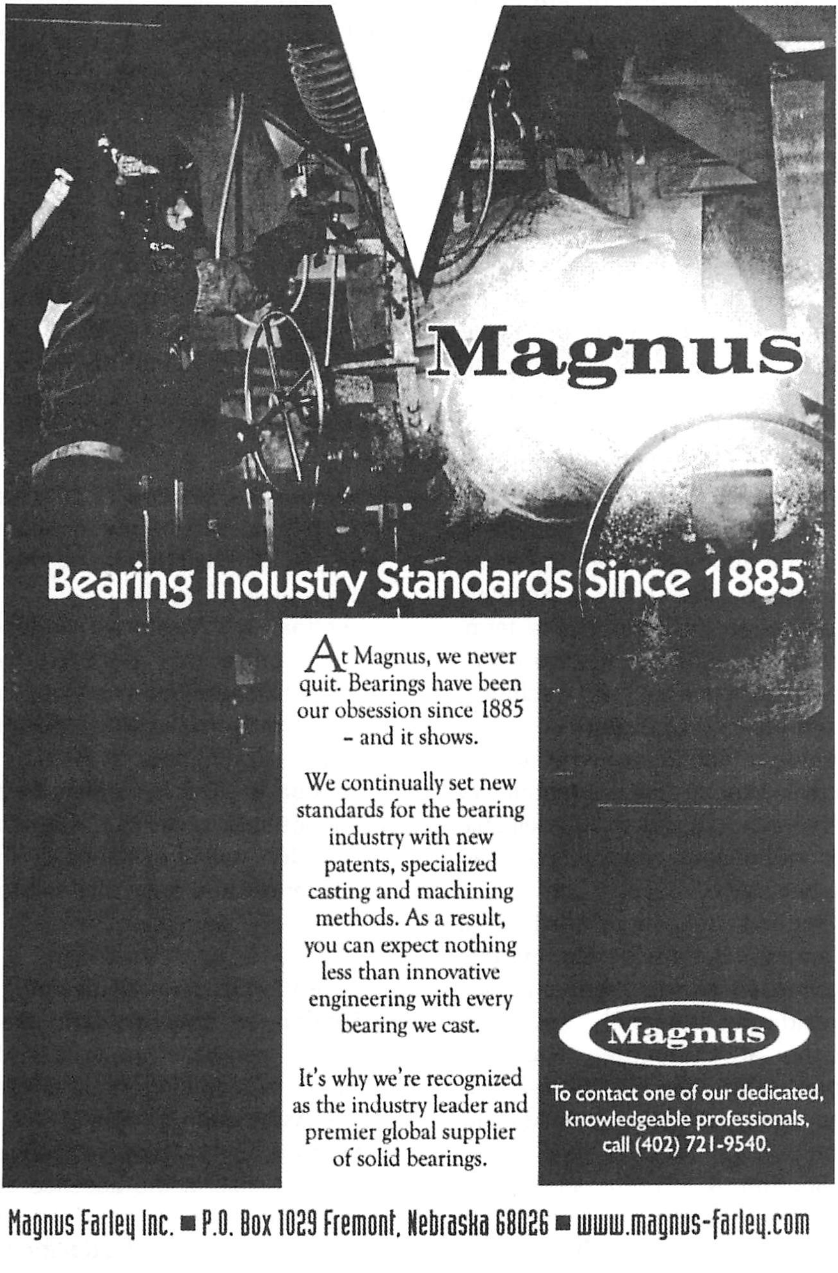
Section 1 - Railroad Membership shall be composed of persons currently or formerly employed by a railroad company and interested in locomotive maintenance. Membership is subject to approval by the General Executive Committee.

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.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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 deci-

FUEL, LUBRICANTS AND ENVIRONMENTAL COMMITTEE TWENTY-SEVEN YEAR INDEX

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

NEW TECHNOLOGIES COMMITTEE
TWENTY-FIVE YEAR INDEX

2008
1. Maintenance Experience with Gen Set Switcher Locomotives to Date
2. Maintenance of the BNSF Fuelcell- Hybrid Switch Locomotive

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

DIESEL ELECTRICAL MAINTENANCE COMMITTEE
TWENTY-SEVEN YEAR INDEX

2. Locomotive Electronic Brake Maintenance
3. SD70MAC Capacitor Discharge Procedure
4. Power Savings for Electrical Locomotives
5. Auto Stop/Start and Layover Systems

1997

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

SHOP EQUIPMENT AND PROCESSES COMMITTEE TWENTY-SEVEN YEAR INDEX

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-nolo-gy

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 MATERIAL CONTROL COMMITTEE TWENTY-SEVEN YEAR INDEX

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

DIESEL MECHANICAL MAINTENANCE COMMITTEE TWENTY-SEVEN YEAR INDEX

4. 2000 - LMOA Best Practice Series: Locomotive Truck Overhaul Procedures

1999

1. Vibration Analysis
2. EMD Power Assemblies Change Out Practices for Regional and Shortline Railroads
3. Improved Access to GE7FDL Engine Intake Manifold for 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 Locomotives 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 Improvements 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

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