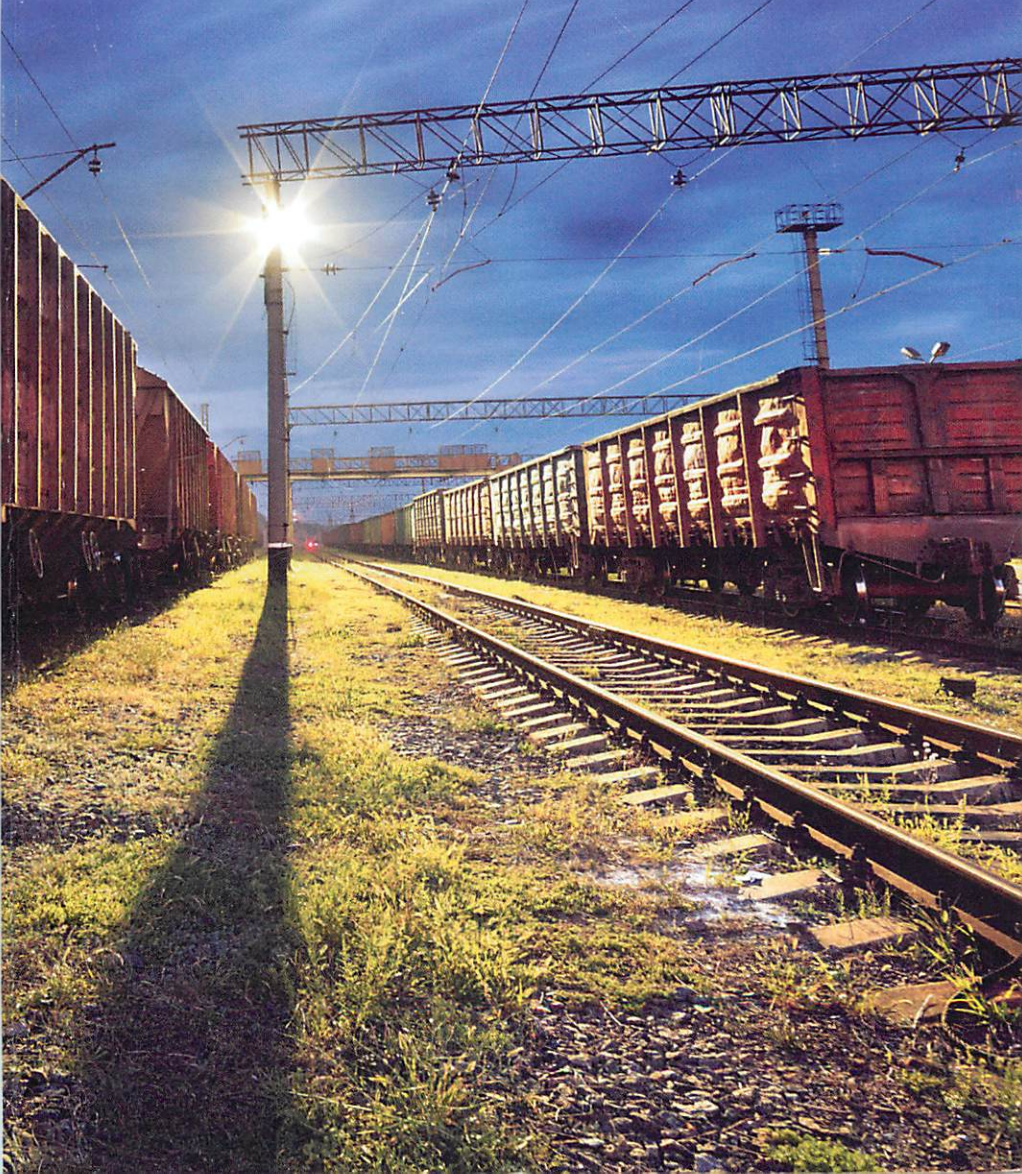
LMOA

Locomotive Maintenance Officers Association

Proceedings of the 78th Annual Meeting

OCTOBER 3 – 4, 2016

Omaha, Nebraska



2016 Advertisers Index

Locomotive Maintenance Officers Appreciate these 2016 Supporting Advertisers

ABB Traction

Amglo Kemlite

Amsted Rail Group

A.S.T. GmbH Germany

Bach Simpson

Clark Filter

Graham White

Hotstart

LPI Lift Systems

Magnus, LLC

Miba Bearings, U.S.

Morgan AM&T

National Railway Equipment

Peaker Services

PowerRail Distribution

RailProducts Intl.

Railroad Friction Products

Simmons Machine Tool

Snyder Equipment, Inc.

Tame, Inc.

Trains Magazine

Transportation Equipment Supply

ZTR Control Systems

2016 TOC and Index

2015 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 2015.

NAME	COMMITTEE
Amarjit Soora	Diesel Electrical Maintenance
David Caron	New Technologies
Roger Collen	Shop Safety, Practices & Equipment
Mark Duve	Diesel Mechanical Maintenance
Virginia Wiszniewski	Fuel, Lubricants & Environmental
Brian Marty	Diesel Material Control

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

LMOA EXECUTIVE COMMITTEE

The LMOA executive committee would like to thank the Norfolk Southern and Graham White for hosting and supporting the annual LMOA Joint Technical Committee meeting in Roanoke, VA on April 25-26, 2016.

Special thanks to the following Norfolk Southern officials for the use of the Roanoke Locomotive Shop facility
Don Graab, VP-Mechanical
C. Doug Corbin, AVP-Mechanical
Ryan Stege-Manager-Roanoke Loco Shop.

Sincere appreciation for providing lunches and bus transportation goes out to LMOA Past President Jack Kuhns and Graham White.

A big thank you to our 1st VP Jeff Cutright and NS for making all the necessary arrangements for the joint committee meeting and for co-sponsoring the lunches with Graham White.

The Executive Board of the Locomotive Maintenance Officers Association would like to express their deep and sincere gratitude to LMOA 2nd VP Dwight Beebe of Temple Engineering for sponsoring an Executive Committee meeting luncheon at the Minneapolis Convention Center on Tuesday, October 6, 2015.

Thanks Dwight for your long and continued support of the LMOA.

PAST PRESIDENTS

1939 & 1949	F.B. DOWLEY (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) Vice-Pres.- Equipment, Seabord 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, Seabord 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, Southen 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 Mechanical Officer, Louisville & Nashville R.R.
1964	H.N. CHASTAIN (Deceased) General 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 Mechanical Officer, National Railroad Passenger Corp. Washington, D.C. 20024
1968	G.F. BACHMAN (Deceased) Chief Mechanical Officer, Elgin Joliet & 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, Burlinton 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, Burlinton 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 Department, Chessie Systems
1981	R.G.CLEVENGER, Retired, General Electrical Foreman, Atchison, Topeka & Santa Fe Rwy

1982	N.A. BUSKEY (Deceased), Asst. General manager-Locomotive, Chessie Systems
1983	F.D. BRUNER (Deceased), Asst. Chief Mechanical Officer, R&D, Union Pacific RR
1984	R.R.HOLMES, Retired Director Chemical Labs & Environment, 600 Brookestone Meadows Place, Omaha, NE 68022
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, 10501 W. 153rd St, Overland Park, KS 66221
1987	D.L.WARD (Deceased), Coordinated-Quality Safety & Tech Trng, Burlington Northern RR
1988	D.G. GOEHRING, Retired, Supt. Locomotive Maintenance, National RR Passenger Corp, 1408 Monroe, Lewisburg, PA 17837
1989	W.A.BROWN, Retired, I&M Rail Link, 9047 NE 109th St. Kansas City, MO 64157
1990	P.F.HOERATH, Retired, Sr. Mech. Engr. Shop, Conrail 1534 Frankstown Rd, Hollidaysburg, PA 16648
1991	D.D.HUDGENS, Retired, Sr Mgr R&D, Union Pacific, 16711 Pine St., Omaha, NE 68130
1992	K.A.KELLER, Retired, Supt. Locomotive Maint, Reading RR, 241 E. Chestnut, Cleona, PA 17042
1993	W.R.DOYLE, Project Manager, Sound Transit, Seattle, WA 98104
1994	M.A.COLES, Sr. Mgr-Loco. Engineering & Quality, Union Pacific RR, Omaha, NE 68179
1995	C.A.MILLER, Retired Mgr-Loco. Engineering & Quality, Union Pacific RR, 17745 Doras Circle, Omaha, NE 68130
1996	G.J.BRUNO, Retired, Supt.-Mechanical, Amtrak 14142 S.E. 154th Pl, Renton, WA
1997	D.M.WETMORE, Retired-Genl Supt.-Fuel Opns, NJT Rail Opns, 2005 Acadia Greens Drive, Sun City Center, FL 33573
1998	H.H.PENNELL, Retired-Ellcon National, 1016 Williamsburg, Lanne, Keller, TX 76248
1999	JAKE VASQUEZ, Retired, Asst. Supt.-Terminal Services, Amtrak, 25531 NE 138th St., Salt Springs, FL 32134
2000	RON LODOWSKI, Retired Production Mgr, CSX Transportation, Selkirk, NY 12158
2001	LOU CALA, Retired, Duncansville, PA 16635
2002	BOB RUNYON, Engineering Consultant, Roanoke, VA 24019
2003	BRIAN HATHAWAY, Consultant, Port Orange, FL 32129
2004	BILL LECHNER, Retired, Sr Genl Foreman-Insourcing-Air Brakes, Governors & Injectors, Norfolk Southern Corp, Altoona, PA 16601
2005	TAD VOLKMANN, Director-Mech. Engrg., Union Pacific RR, Omaha, NE 68179
2006	BRUCE KEHE, CMO, CSS&SB, Michigan City, IN 46360
2007	LES WHITE, Applications Specialist, Bach-Simpson, London, Ontario N6A 4L6
2008	MIKE SCARINGE (Deceased), Director-Locomotives, Amtrak, Beech Grove, IN 46109
2009	DENNIS NOTT, Northwestern Consulting, Boise, ID 83703
2010	BOB REYNOLDS, Sales Manager, Amglo Kemlite Laboratories, Calgary, Alberta T24 2V8
2011	JACK KUHNS, V.P. Sales, Graham White, Salem, VA 24153
2012	RON BARTELS, Sr. Manager - Equipment Reliability and Electrical Engineering, Via Rail-Canada, Montreal, Quebec
2013	R. BRAD QUEEN, Manager of Locomotive Utilization - RCO, BNSF Railway, Fort Worth, TX
2014	DAVE RUTKOWSKI, CMO, Providence & Worcester RR, Worcester, MA
2015	MR. BOB HARVILLA, Asst. VP - Regional Sales, PowerRail Distribution, Duryea, PA

Our Past Presidents

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

MR. BRUCE KEHE
Chief Mech. Officer
Chgo, South Shore & South Bend RR
Michigan City, IN 46360

MR. JACK KUHNS
V.P. Sales
Graham White Manufacturing
Salem, VA 24153

Our Officers

President
STUART OLSON
Regional Sales Manager
Wabtec Corporation
Alpharetta, GA

1st Vice President
JEFF CUTRIGHT
Manager - Locomotive Engineering
Norfolk Southern
Roanoke, VA

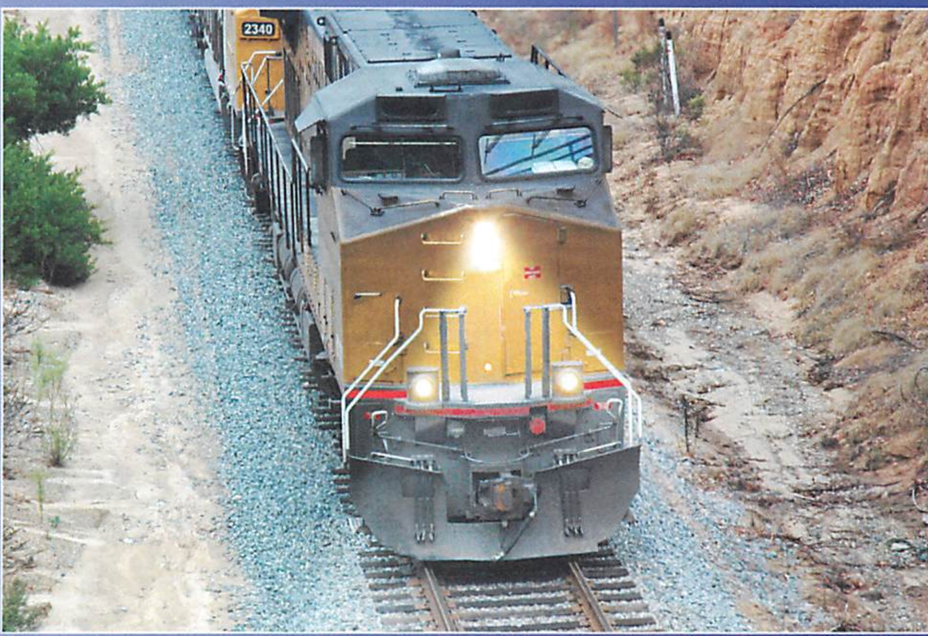
2nd Vice President
DWIGHT BEEBE
Vice President
Temple Engineering
Liberty, MO

3rd Vice President
MIKE DRYLIE
Director-Electrical Systems-Retired
CSX Transportation
Jacksonville, FL

Amglo Kemlite Laboratories

SPECIALTY LAMPS MANUFACTURER

LOCOMOTIVE RAILWAY LAMPS



Amglo Kemlite Labs. Inc.
8787 Enterprise Blvd.
Largo, Fl 33773

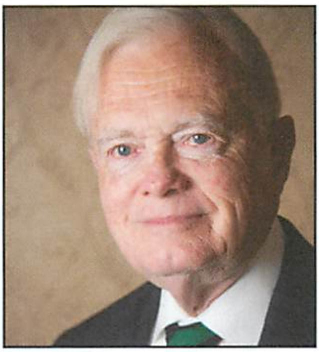
www.amglo.com

Ph: (727) 812-2000
Fax: (727) 812-2001
e-mail: amglo1@amglo.com

Our Past Presidents

MR. DENNIS NOTT
Sole Member
Northwestern Consulting, LLC
Boise, ID 83703

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



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

Our Past Presidents

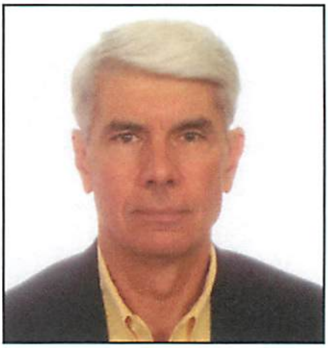
DAVE RUTKOWSKI
Chief Mechanical Officer
Providence & Worcester RR
Worcester, MA

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

MR. LES WHITE
Application Specialist
Bach Simpson
London, Ontario
N6A 4L6

Our Regional Executives

IAN BRADBURY
President & CEO
Peaker Services, Inc.
Brighton, MI



JIM CHRISTOFF
National Acct. Mgr.- Traction Sales
Morgan Advanced Materials/National
Cicero, NY

TOM GALLAGHER
Global RR Technical Liaison
Chevron Oronite
Commerce, MI

TOM NUDDS
Manager-Training & Development
ZTR Control Systems
London, Ontario

Our Regional Executives

BILL PETERMAN
Director-Rail Operations
B.P. Railway Services
Baie D'Urfe, Quebec

RON SULEWSKI
VP–Sales & Marketing
Rail Products International Inc
St. Louis, MO

2015 State of the Union Address

President Bob Harvilla
Monday, October 5, 2015
1:15 PM

Good afternoon ladies and gentlemen, and welcome to the 2015 Technical Papers presented by the Locomotive Maintenance Officers Association here in Minneapolis. I would like to welcome all of our Past Presidents, along with the Executive Board and all the members of the LMOA. Thank you all for your attendance today.

It has truly been an honor to serve as the President of the LMOA this past year. The LMOA is a prestigious and hallowed organization, and I am humbled to have had the opportunity to serve as the President.

The Technical Committees that make up the LMOA have put together a very strong roster of papers to be delivered this year. I would encourage all of you to attend as many of the presentations as possible. I think you will find they are well prepared, thoughtful, and informative. I can assure that a lot of work has been put into them by the presenters and their fellow committee members.

In all the LMOA has had a very good year in 2015. We have a very experienced and hard working Executive Board, dedicated Committee Chairmen, and generally well stocked committees.

We have 190 individuals who were pre-registered with the LMOA for the 2015 Railway Interchange, some from as far away as Spain, Germany and the United Kingdom. Welcome we're glad you're here. This number is more than the other four Coordinated Mechanical Associations put together. This number is also in line with the past few full conventions, in spite of the fact that due to slowing business conditions some of the Class 1 Railroads limited the number of employees they allowed to attend these proceedings as a cost cutting measure.

One topic brought up due to some LMOA members not being able to attend this year, is if we should offer either a live feed of the technical papers being presented, or record the presentations to be viewed at a later date. This topic has come up in the past with the concern being expressed that it might take away some of the incentive to attend the convention. I think this is a topic that should be reviewed again as the business climate and technology has changed over the years.

Another initiative we embarked on is to add copies of our yearly proceedings to the LMOA website. We currently have the last five years

PowerRail
205 Clark Road
Duryea PA 18642

"Uniting Innovation, Engineering, Manufacturing and Distribution"

PowerRail Electronics & Technology

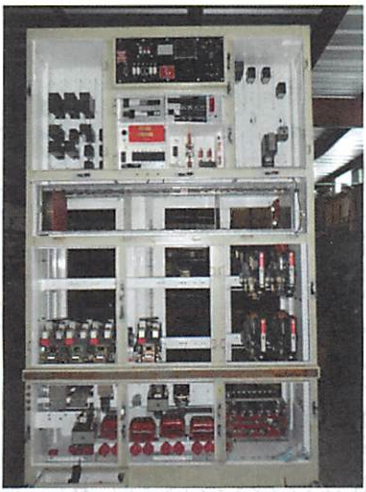
Controllers

New or Remanned

Control Stands EMD - GE

New or Remanned AAR Stands

Simulators



Electrical Products

New and Remmaned

Electrical Lockers

New and Remmaned

Sales@PowerRail.com   *WWW.EpowerRail.com* proceedings loaded onto the website, with plans to continue adding them. We are also looking at adding a search engine feature which would allow users to look for solutions and best practice for a particular issue.

In May this year we had our Joint Committee meetings hosted by the Burlington Northern Santa Fe in Fort Worth Texas. We had very good attendance, and the BNSF did a terrific job of providing the necessary meeting rooms and organization. We would like to thank Steve Harris from BNSF for hosting the meetings. We would also like to thank Past LMOA President Brad Queen, who did a great job of putting the meetings together, and we would like to thank Nancy Gandy from the BNSF for all the work she did in organizing the meetings. Also, thank you's go to PowerRail Distribution and Curry Rail Services for providing lunches during the meetings.

The LMOA is about people, it's about hard work and spirit. It's an organization of people who care about the Railroad Industry, and more specifically care passionately about locomotives. The LMOA is not made up of things. There is no LMOA building; we don't own any shops or equipment. We don't even have our own locomotive. What we do have is experienced Railroaders, and Railroad professionals who are willing to give of their time and skills to forward the operation and maintenance of locomotives to the betterment of our industry.

Our industry is constantly giving us challenges concerning the maintenance and operation of locomotives. Emissions regulations, PTC requirements, alternative fuels for locomotive engines are just a few of the issues LMOA Committees are working on. I feel confident that as we head into 2016 and beyond, the LMOA is positioned to continue to offer Best Practice and solutions to the Railroad Industry.

We would like to thank all of the Chief Mechanical Officers of the railroads. I see some of you in attendance today. We very much appreciate your support, and allowing your staff members to be involved with the LMOA. I would also encourage you to view us as a tool to be used for any locomotive issues you feel we can help with.

We would also like to thank all the Companies that support the LMOA through advertisements in our annual proceedings book.

I would like to thank our Secretary Ron Pondel for all he does to keep the LMOA on track and moving forward, thanks Ron. I would also like to thank my Executives this past year. 1st Vice President Stuart Olson, 2nd Vice president Jeff Cutright and 3rd Vice President Dwight Beebe.

I would also like to thank my beautiful wife Barb for all of your love and support over the years. Thank you dear.

Once again, it has been a great honor to serve as the President of the LMOA.

Enjoy the rest of the Technical Presentations, along with the indoor and outdoor exhibits. Safe travels home, and we look forward to seeing you in Omaha, Nebraska in 2016.

Thank You!

Acceptance speech

T. Stuart Olson
Tuesday, October 6, 2015
9:00 AM

Thanks Bob. I hope that I can live up to the standards you set this year.

Ladies and Gentlemen, members of the Executive Committee, Mr. Secretary, all committee members, and fellow LMOA members, I thank you for this privilege. To be elected President of this Association and to follow in the footsteps of so many is quite an honor.

To help us remember why we are here let me paraphrase from our constitution and by-laws: "The purpose of the Association shall be to improve the interest of its members through education, to supply locomotive maintenance information to employers, to exchange knowledge and information with members of the Association, and to make constructive recommendations on locomotive maintenance procedures through the technical committee reports for the benefit of the railroad Industry."

To do this it takes all of you. It is all of you that put your heads together to plan and host meetings. It is all of you that pool your ideas, provide suggestions to each other and offer coaching and wisdom. It is all of you that sacrifice evenings and weekends to research, review and write technical papers. It is all of you that make this organization what it is today. It is all of you that make up the companies we work for that have supported our travel, time and efforts during the year. Without your support and their support it would be difficult to continue the work of the Association. We offer our sincere thanks to each company supporting each of our members. In particular we thank those companies from the railroad and supply community that sponsored and hosted the various committee meetings during this past year. The time and effort you have afforded us is much appreciated and your support is priceless.
We want to thank Graham White for sponsoring the Audio Visual equipment for LMOA presentations. We thank PowerRail for maintaining our website. In case you have not looked at it recently, point your browser to www.lmoarail.com. We thank the BNSF and Brad Queen for arranging and hosting our joint meetings in Fort Worth this year. And last, but certainly not least, we thank the companies that take out ads in the annual LMOA book. Your ads help cover the costs of printing and publishing. As you all know, with your annual membership comes a copy of the LMOA book. It has been a mainstay or our Association since the beginning. In this book you will

TreadGuard® Brake Shoes cover a lot of ground.

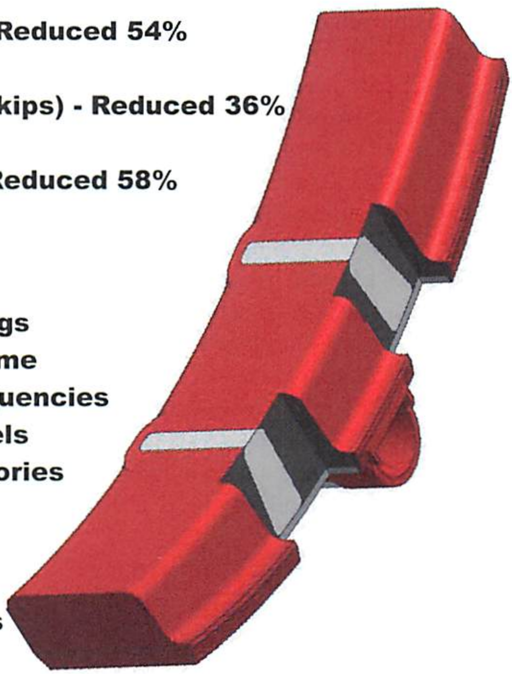
LOCOMOTIVE TREADGUARD® BRAKE SHOES

16 Month Field Test Results

Out of Service Time—Reduced 54%

High Impact Frequency (>90 kips) - Reduced 36%

Wheelset Turnings—Reduced 58%



BENEFITS:

- Reduces Wheel Set Turnings
- Reduces Out of Service Time
- Reduces High Impact Frequencies
- Prolong Life Cycle of Wheels
- Reduces Wheel Set Inventories
- Increased Shoe Life
- Direct Replacement for Standard High Friction Locomotive Brake Shoes

ailroad Friction Products Corporation
O Box 1349
aurinburg, NC 28353
10-844-9700
obrabrakeshoes@rfpc.com
ww.rfpc.com

Registered Firm: ISO 9001-2008
AAR M-1003

find most of the presentations made at the annual technical conference.

As information – there are more than 9000 registered for the overall combined convention this year. LMOA has about 230 registered attendees. This is comparable to 4 years ago when we had about that many at this same venue. In recent years in Montreal, Chicago and Indianapolis, we had attendance between 140 and 210. At this year's meetings we have registered participation from as far away as Chile, Spain, Germany, Switzerland and the United Kingdom. We welcome this diversity and hope we can all expand our mutual knowledge through traditional personal interaction and communication. When there is a break in the activities take a moment and seek out someone you do not know – introduce yourself and expand your horizons. You never know what you can learn until you take this step.

I want to take a few minutes to point out a good way to get the most value from this Association—Personal Networking. We are beginning the 77th year of working together in a friendly, but competitive, environment to further the maintenance practices and general knowledge of all members. When LMOA was formed in 1939 the main networking outlet was face to face, personal communication and regular postal service. Today the speed and accessibility of information is as close to us as a mobile device and an internet connection. We can research almost anything in an instant. We can become immediate experts on almost anything - BUT - we must be cautious with information and data we get from unknown sources. It is extremely important to make sure the information we plan to use is accurate, trustworthy and relevant. The best way to have confidence in the viability of the information is to have experience with the source. One of the best ways to do this is to network with others in this Association. After we have met our peers and built a personal relationship with others in the industry it becomes easy to pick up the phone and discuss various issues as though we are in the same room. We can send diagrams, pictures and commentary in an instant. With all of these conveniences it is still best to discuss in person if at all possible. This Association facilitates in-person, direct exchange of information and data and remains one of the best means of networking open to you today.

Each technical report presented every year, is the result of networking activities with committee members and with each members extended network of technicians, engineers and managers. Every member has their own unique perspective on a topic or issue. Each committee member brings their distinctive view to a friendly and open forum for discussion which allows an issue to be fully debated and deliberated with the benefit of having been reviewed by others, often others with a different perspective. I have seen members get inspired and motivated from what they learn while working with their peers in the industry. Just learning that others have met similar challenges head-on will empower and energize a member. Sometimes an important project can get stalled for any number of reasons. A fresh look by someone that has met a similar challenge before and that you know and trust, can frequently help you get that stalled project moving again. The interactions you have here support a focus on safety, true 'best practices', better design, and help advance a deeper understanding of issues as well as help you find and develop more efficient processes.

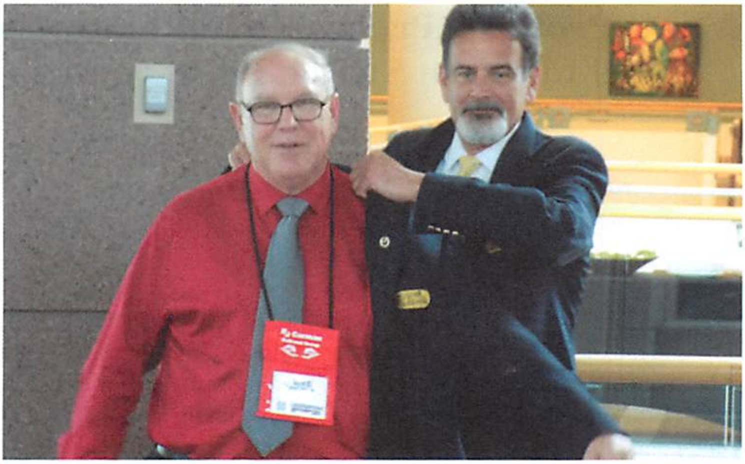
We have 6 working committees. Each meets several times during the year. Meetings are generally held at convenient railroad or supplier facilities. Members get to see the real deal through these visits. These visits expand the level of understanding and help both the railroad and supply communities gather an appreciation of the work required to service, maintain and overhaul locomotives. This allows members to take the information back to their work place and incorporate lessons learned into their own facilities and their own products. Frequent meetings and communication with others in the industry outside your normal workplace help broaden your understanding and appreciation for required locomotive work. LMOA can be a powerful tool in your toolbox to a better and more efficient workplace.

As we move into the coming year let's all strive to work together and use the relationships we develop here to improve our individual and collective locomotive knowledge. Let's work safely and efficiently. Enjoy the rest of the conference and plan to learn something new by listening to the rest of the technical presentations and seeing the indoor and outdoor exhibits. Thank you.

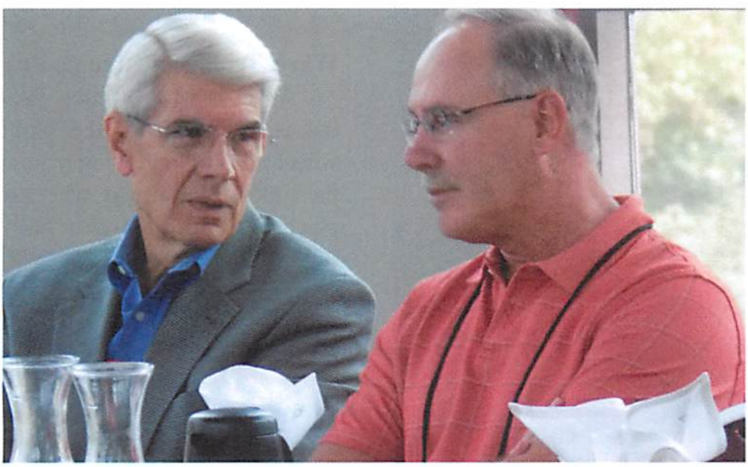
Newly Elected President Stuart Olson, Wabtec Corporation, pounding the gavel on the table as he begins Executive Board meeting immediately following the conclusion of the 2015 convention in Minneapolis.

Past President Dennis Nott, Northwestern Consulting, presenting the Past President's Watch to outgoing President Bob Harvilla, PowerRail Distribution.

Past President Tad Volkmann, Union Pacific RR, presenting the Past President's Pin to outgoing President Bob Harvilla, PowerRail Distribution.



Past President Dave Rutkowski, Providence & Worcester RR, helping newly elected 3rd Vice President, Mike Drylie, retired CSX, put on his LMOA blazer.



Regional Executive Jim Christoff, Morgan AM&T, discussing LMOA matters with New Technologies Vice Chairman, Jeff Clapper, Wheeling & Lake Erie RR during the Executive Board meeting held at the end of the 2015 convention in Minneapolis.

Wheel Profiling Processes in Relation to Wheel Climb in Switch Point Guards

Prepared by:
Prepared by: Roger Collen, Simmons Machine Tool
Presented at the Minneapolis Convention on October 5, 2015

Overview

Slow speed locomotive derailments in switches related to wheel climb on point guards has been of increasing concern as evidenced by the article in Technology Digest authored by Hui min Wu and Scott Cummings with the Transportation Technology Center (TTCI) in September 2014 titled *Causes of Locomotive Wheel Climb at Switch Point Protectors*.

This article documented an investigation by TTCI which lead to recommendations which included;

- additional training regarding optional locomotive wheel cutter head lateral positioning and its importance
- Industry wide standardization of locomotive wheel widths and locomotive wheel truing profiles including the possibility of using a radius instead of a chamfer
- Improve the lateral alignment method of cutter heads to minimize the chamfer size, and eliminate the sharp corners

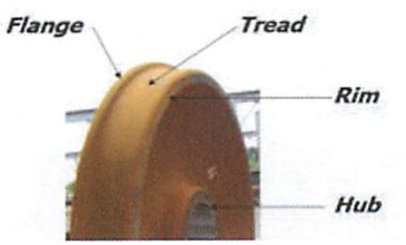
This paper reviews these recommendations with regards to wheel truing processes and machines.

Wheel Truing and Truing Processes

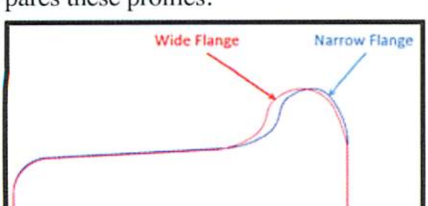
What is wheel truing? Wheel truing is restoration of the profile of a wheel tread by removing material from the rim of the railway wheel while in place on the locomotive or rail vehicle.



The running profile of a railway wheel is part of a guidance system that includes rail geometry and condition as well as vehicle type and suspension. There are a large variety of profiles in use across rail vehicles and systems. The selection of a system wheel profile takes into consideration many operating factors and can change when factors change or as system knowledge changes. Regardless of which profile is implemented in a particular system, wheel profiles have common features with varying dimensions across rail operating systems. Common features include; flange width and height, flange angle and shape, flange tread transition or throat, the gaging point, tread taper, the tape line, and the tread rim face transition also known as the field side relief.



The most commonly used locomotive tread profile currently in use in North America is the AAR 1B which has both wide and narrow flange versions. The following illustration compares these profiles.



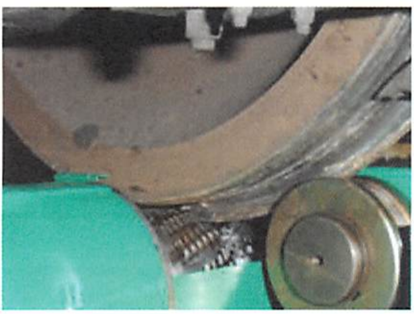
While the wide flange profile is the shape for new wheels, both wide flange and narrow flange profiles can be produced by wheel truing equipment. Which profile a particular machine is producing is an operating system's choice. Some operators elect to true worn wheels to a narrow flange profile because it reduces the depth of cut required and will result in a larger final wheel diameter. Some operators true wheels to the wide flange profile because the increased flange thickness can extend the operating period before the wheel has to be trued again or pulled from service because it has reached condemning limit.

The truing of mounted wheels may be required for a number of reasons. Steel wheels rolling on steel rails will cause wear as the surfaces run against each other. The replacement of wheels is a much simpler process than the replacement of rail so the wheel is produced with a softer material than the rails. For this reason the primary driver for wheel truing is due to wear on the flange and tread. Other reasons for wheel truing is to remove defects on the wheel including; flat spots, shelling or built up tread, cracks, roundness, and parity of wheel diameter on an axle, in a truck, and over the locomotive.

The most common process for wheel truing of freight locomotives is milling. The milling process uses many cutting tools called inserts placed on a rotating cutter.

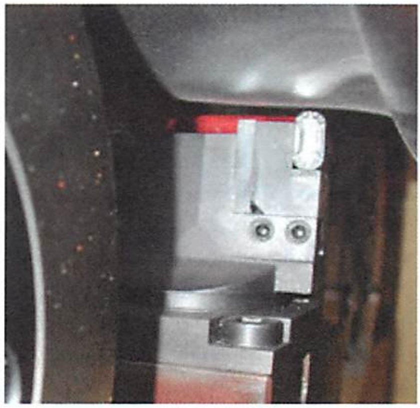
Installed Milling Cutter

The milling cutter engages the entire wheel tread so that the cutter produces the full wheel profile. The cutter is constructed of multiple blades each holding up to 13 inserts.



Advantages of the milling process is the generation of small chips and the slow rotation rate of the locomotive wheel during the process. The slow rotation rate, or feed rate, of the locomotive wheel is the consequence of the fast rotating speed of the milling cutter. A typical wheel truing cycle takes 3 rotations of the wheel in the machine at about 7 minutes a revolution for a total period of about 25 minutes.

Another process for truing of wheels in place on a rail vehicle is turning using a lathe. The turning process utilizes two carbide inserts mounted to a rigid tool that moves on a path across the surface of the wheel tread as it rotates.



Turning Tool in Lathe

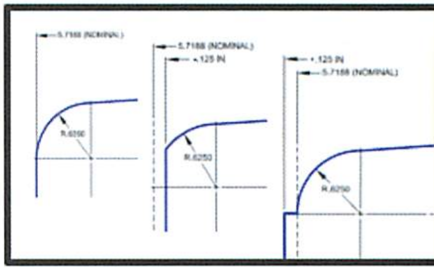
Turning a wheel requires a wheel rotation of about 22 RPM to obtain 185 surface feet per minute to generate the force required at the insert to cut the tread of the wheel. A modern lathe utilizes a computer (CNC) to control the path the tool moves however older machines remain in service that utilize hydraulic tracing systems for tool control. The advantage of the turning process for producing a wheel profile is that the tool path can easily be adjusted as required by wheel dimensional features such as width.

Alignment of Wheel Truing Processes

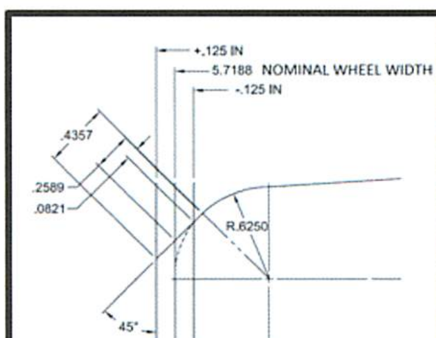
A critical part of a wheel truing process is the alignment of the cutter with the wheel. Correct alignment not only results in an accurate profile, it controls the space or gap between the running wheel and rail. Misalignment of cutter and wheel can result in issues such as; wide or narrow flange, out of gage, incorrect tread taper and flange angle, and field side transition out of specification. The effects of a wheel that is trued out of tolerance or specification can range from negligible to contribution to derailment or wheel failure.

Regardless of the wheel truing process (milling or turning), the cutter must be aligned with the inside face of the wheel rim. This alignment produces an accurate flange profile and positions the wheel gage point in the correct location. As noted by the TTCI Technology Digest Article, locomotive wheels do not have an industry standard wheel width. In the case of the milling process, the full profile cutter is not adjustable therefore the field side transition must accommodate the variation in wheel width.

If the milling cutter were to produce a radius on the field side of the wheel, the cutter would be designed to produce a full radius at the nominal width. If a wheel is under nominal width, only a portion of the radius would be produced when truing is completed. In this instance there would be a sharp transition between the radius and the rim face. If the wheel width exceeded the nominal width then the blades of the milling cutter would contact the wheel and result in damage to the cutter. The following diagram illustrates wheel width variation if a radius was produced by the milling cutter.



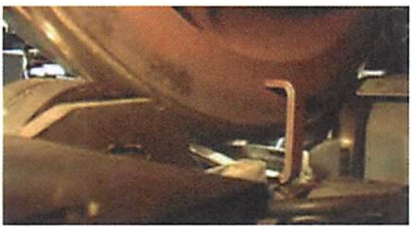
The application of the chamfer in the milling cutter on the field side of the profile accommodates width variance. When a narrow wheel is trued, the resulting chamfer is small. When a wide wheel is trued, the resulting chamfer produced is large. The wheel width variance impacts the chamfer length as illustrated in the following diagram.



Field Relief Chamfer Variance due to Wheel Width Variance

This variation of chamfer length is a direct result of variation in wheel rim width when the milling cutter is correctly aligned to the inside rim face. The field relief chamfer can also impacted by misalignment of the cutter to the wheel.

The milling cutter alignment process utilizes a device called a "J Gage". A J Gage is specific to a cutter and in the alignment process, is manually positioned by the machine operator against the inside wheel rim face.



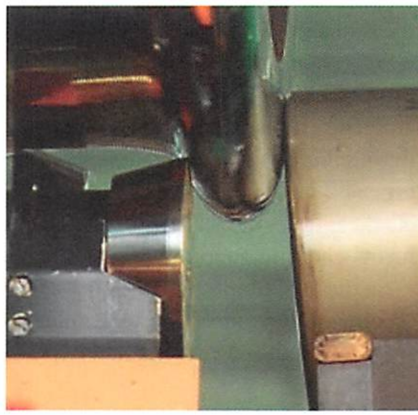
Once the J Gage in in the proper position, the operator will move the cutter laterally to align the cutter to the wheel.

This milling cutter alignment process is dependent on:

- Using the correct J Gage for the particular milling cutter
- Calibration of the J Gage
- Training, skill, and attention of the operator using the gage

The length of the chamfer on the field side transition of a trued wheel will be impacted by any deviation of alignment with the J Gage.

In the turning process on a lathe, the cutter alignment with the inside face of the wheel rim is done by an automatic probe system. The probe cycle is initiated by the operator and then automatically moves through a cycle contacting the wheel in multiple locations.



The dimensional data collected by contacting the wheel includes both the inside and outside rim surfaces. By contacting both surfaces, the lathe determines the wheel width and can automatically generate a tool path that will adjust for wheel width variation. The measured width of the wheel and the ability to modify the tool path gives the turning process the advantage to generate a radius on the field side relief of the wheel.

Good Intentions – Saving a Wheel

On occasion the depth of cut to restore a narrow flange profile of a worn wheel will reduce the wheel diameter to condemning limit or less. Using the turning process the tool path can be adjusted to reduce the flange to an acceptable thickness below full profile thus reducing the depth of cut and saving the wheel. Attempting to "save a wheel" by reducing the flange thickness in the milling process requires shifting the cutter towards the gage side of the wheel which will result in a larger chamfer on the field side and increasing the potential for a derailment in a switch point guard.

Summary

The recommendations identified during the TTCI investigation and documented in the Technology Digest article do address the wheel climb problem in switch point guards;

- additional training regarding optional locomotive wheel cutter head lateral positioning and its importance

Alignment of the cutter is paramount in controlling the size of the chamfer on the field side transition of a trued wheel. The machine operator must understand the importance of this alignment and how critically important it is.

- Industry wide standardization of locomotive wheel widths and locomotive wheel truing profiles including the possibility of using a radius instead of a chamfer

Standardization of the wheel width and restraining the allowable tolerance of the width will control the width of the chamfer. The milling cutter cannot produce a radius unless the allowable tolerance of the wheel width is tightly controlled. If a wheel width standard with tight tolerance was implemented, it would take many years until wheels already in operation are replaced and milling cutters with radius can be introduced without concern for cutter damage.

- Improve the lateral alignment method of cutter heads to minimize the chamfer size, and eliminate the sharp corners

Lateral alignment is operator dependent. Increasing training and the introduction of chamfer measuring devices will increase operator attentiveness.

A Key Note

It could be construed from this paper that the implementation of a wheel turning process in place of a milling process would provide the ability to generate radius on the field side of the wheel is the solution to the wheel climb issue in switch point guards however this singular ability is not sufficient to make a judgement about which process to utilize in a given system. There are many factors to be considered when selecting a wheel truing process some of which are equally if not more important than this ability.

Report on the Committee on New Technologies

Monday, October 3, 2016 at 8:00 A.M.

Chairman

Tom Mack
President & CTO, VeRail Technologies
Reno, NV/Cincinnati, OH

Vice Chairman

Jeff Clapper
Supt-Motive Power, Wheeling & Lake Erie Rwy
Brewster, OH

Commitee Members

Y. Abdel-Moty	Mgr-Mechanical Systems	CSX Transportation	Jacksonville, FL
S. Bakker	President	ARMS Inc	O'Fallon, MO
S. Beal	President	National Railway Equipment	Mt. Vernon, IL
A. Bennett	Gen. Mgr of Engineering	R.J. Corman Railpower Locos	Erie, PA
S. Biln	Dir-Community Relations & CMO	Southern Rwy of B.C.	New Westminster, BC
D. Brabb	AVP-R&D	Sharma & Associates	Countryside, IL
B. Calvert	Mech Engineer-New Prod Development	Motive Power	Boise, ID
D. Caron	Acct Mgr-Locomotive Application	ABB	Lachine, Quebec
K. Gilbert	Vice President-Sales	Miller Ingenuity Corp	Candiac, Quebec
V. Gvelesiani	Director-Product Development	ZTR	London, Ontario
P. Hess	Mech Engineer-Locomotive Design	Norfolk Southern Corp	Atlanta, GA
B. Kehe *(Past President)*	Chief Mech Officer	Chgo, South Shore & So Bend RR	Michigan City, IN
W. Klaric	Senior Project Engineer	Progress Rail-A Caterpillar Co	LaGrange, IL
J. Maher	Mechanical Engrg Manager	Brookville Equipment	Brookville, PA
R. Nelson	Marketing Director	Cummins, Inc	Columbus, OH
C. Nordhues	Business Develop Mgr	Relco Locomotive	Omaha, NE
J. Smith	Mgr-Mechanical Engineering	Union Pacific	Melrose Park, IL
G. Trillanes	NPI Product Leader	GE Transportation Systems	Erie, PA
K. Ulbick	Sales Manager	Peaker Services, Inc	Brighton, MI
B. Wolff	Sales Engineer-Rail	MTU	Detroit, MI
C. Wyka	Senior Reliability Specialist	Canadian National Rail	Edmonton, Alberta

PERSONAL HISTORY

Tom Mack

President & CTO, VeRail Technologies
Reno, NV/Cincinnati, OH

Tom Mack is the President and Chief Technology Officer of VeRail Technologies, Inc. VeRail was founded in 2013 to focus on bringing leading edge natural gas locomotives and technologies to railroads around the world.

Prior to VeRail, Tom worked for two years as Vice President of Sales and Business Development for a U.S. based locomotive rebuilder and manufacturer. Prior to that, he founded Alternative Hybrid Locomotive Technologies (AHL-TECH) in November 2005. Tom assembled a team of innovators from the locomotive, biofuels, software, and energy storage industries to design the world's first ethanol hybrid locomotive. While the AHL-TECH hybrid never became reality, the designs incorporated into the locomotive and the computer models developed, along with the experience gathered from the project, have given Tom a unique insight into alternative fuels use in locomotives, locomotive new technologies, and the locomotive market.

In addition to LMOA, Tom serves on the Mechanical Committee for the American Short Line and Regional Railroad Association (ASLRRA), is a member of the FRA's Natural Gas Locomotive Research Task Force, and as a supplier representative has been invited to meetings of the AAR Natural Gas Fuel Tender Technical Advisory Group (AAR NGFT TAG). He also served on the SAE TC-7 Biodiesel in Rail committee.

Tom currently resides in Cincinnati, Ohio with his wife, Mary.

The New Technology Committee would like to express their sincere appreciation to ABB, Inc and David Caron for hosting the committee's 2015 winter meeting at their Phoenix, Arizona facility.

The committee would also like to thank Southwest Research Institute for hosting their Spring 2016 meeting in San Antonio, TX.

ECP Beyond Train-Handling – How ECP System Development Can Enhance Other Locomotive Technologies

Prepared by:
P. L. Hess, Norfolk Southern Corporation

Electronically Controlled Pneumatic (ECP) braking systems have been around for many years and much has been written on the subject. The benefits of these systems, in particular as they relate to improved train handling, have been well documented. But the technology behind ECP braking systems opens up opportunities for additional benefits that don't always garner the bright spotlights. Along with the benefits are also challenges that need to be overcome. The focus of this paper is to highlight some of these lesser known benefits and challenges related to ECP braking systems.

Beyond a general discussion of the background of ECP implementation and operation, this paper will not focus on specifics of train handling, nor will it address costs and installation issues arising from said implementation and operation, unless needed to illustrate the finer details which are the focus of this presentation, and then from a high level.

The Basic System – What It Brings

Anytime a new technology is being developed there are a number of criteria that must be met in order for the new technology to unseat the incumbent, particularly when the current design has itself been proven and refined over many years. It must be able to do the new job in some combination of reduced cost, increased reliably, increased productivity, and increased safety. All these things are inter-related. Each generally affects the others and all must be considered when evaluating new technology. And, when evaluating an emerging technology one must consider not only the ability to perform the principal duty for which it is designed, but also the extraneous benefits that may become possible. That is the question being explored here, namely, what are the side benefits of an ECP implementation?

If knowledge (information) is power, ECP certainly has the advantage over conventional braking systems. From a technological standpoint, one of the biggest benefits ECP braking systems bring is a fully two-way communication path between the locomotives and cars. Along with that it becomes a smart communication path, where each car and locomotive has its own identity and its own voice. Access to this information enhances not only response to operational issues (failures on line-of-road) but helps expedite repair at terminals through self-diagnostics.

In a conventional pneumatic braking system the locomotive broadcasts a single basic control signal to the entire train. Each car sees that same signal and responds. How each individual car responds is determined by the specific combination of reservoirs, control valves, brake cylinders, and linkages on each car. Communication is one way, from locomotive to cars. The exception to this would be a trainline emergency, in which the locomotive would sense a rapid loss in brake pipe pressure and respond accordingly.

With ECP, the controlling locomotive can not only issue commands to all cars as a group, it can also issue commands to just a specific car. Further, the cars themselves can respond back to the locomotive with anything from command receipt acknowledgement to health status updates. The ECP system knows the complete train consist and order because each car is able to report in.

How is all this information useful? Suppose car 203456 suffers some form of brake failure en route. On a conventional train the crew would have to walk the train looking for the specific culprit, then make repairs if possible, apply a runaround hose, or set the car out. Finding the source of the trouble is often the biggest delay. On an ECP train, it is possible for the car with the brake failure to notify the controlling locomotive that it has a failure. The individual car control system may even automatically cut the brakes out on just this car so that the train can continue.

In practice, it doesn't work quite this smoothly, as it is generally still required of the crew that they walk to the site of the trouble unit in order to inspect and check out the defective car before proceeding, thus negating much of the benefit. However, it is not hard to imagine the potential benefits to be gained as systems are refined and operating rules changed, and scenarios such as the above become commonplace.

And, while a wealth of data is now capable of being collected and presented to be acted on, much of it is being underutilized. ECP trains currently in service are still, in reality, considered to be running in trial service, working out bugs and refining the technology. As such, the array of information available is really only available to technicians and service reps with specialized equipment needed to access and decipher it. And it will likely remain their domain until ECP trains enter more widespread mainstream service. But until maintenance and repair personnel across railroad systems really start to see ECP trains in widespread service on a regular basis, they have no need to access more detailed information. This is the so-called Catch-22.

Wired Trainline

In order to implement ECP a separate communication path is necessary, in addition to the standard train line on conventional trains. While it may be possible to implement a wireless version of ECP, to date in the United States all ECP implementations have utilized a wired communication path. A wired train line consists of a continuous electrical connection that runs the entire length of the train, from the lead locomotive to the End-Of-Train device on the rear. This connection is able to serve multiple needs: It supplies the power needed for operation of the electronic systems, through the charging of a battery on each individual car. It provides the communication network that not only passes control signals from the control unit on the lead locomotive to the equipment on each car, but also feeds back data from the cars to the locomotive.

One benefit that this new trainline is already being used for is as an additional communication path for Distributed Power, or DP, systems. In standard multiple unit configurations, all locomotives in a consist have to be physically coupled to each other and connected by a control jumper to pass control signals. In a wireless DP system a controlling locomotive at the head of a train is able to remotely control additional locomotives that are not physically coupled to the consist with radio signals providing the communication path between separate groups of locomotives.

However, many things affect the quality of this radio connection. Operating in terrain with mountains or valleys may make it difficult to establish and maintain a good radio link. Similarly, the length of the train may play a role. Radio systems may be subject to other external interference of various types. On an ECP train, it is possible to utilize the existing ECP trainline to pass DP signals to remote locomotives, thus circumventing many of the shortfalls of a radio based system outlined above.

Wired trainlines are not without their own shortcomings, however. Current issues being investigated involve an occurrence sometimes referred to as 'crosstalk', although that may not be an entirely accurate moniker. This condition has been observed to occur most often in cases where two ECP trains are in close proximity to each other, or sometimes in cases where an ECP train has been cut, for example to switch out a car. Anecdotal evidence also suggests that it has to do with the specific track arrangement in the area, i.e. it occurs in areas where trains are operating on or through turnouts, and it is thought that it is related to grounding issues in the ECP equipment and the train itself. This issue is still under investigation, having not yet had a satisfactory resolution. While this issue does not pose a safety risk in the form of one train randomly responding to control commands of another parallel train, it does cause train delays in the form of penalty stops and the time associated with recovering from that.

Other Limitations to ECP

Running ECP requires specific equipment on all cars in the train, including all locomotives in the consist. Locomotives can be equipped either as ECP leaders, or as trailing units with pass-through ECP cables only. Lead capable locomotives are equipped with a trainline power supply and a Train Control Computer. Trail-only units only have cabling to pass the ECP signals through the locomotive and on to the train. Since the functions of the locomotive brakes on trailing locomotives are still controlled via MU hose connections, trailing locomotives don't need any actual interface to the ECP braking signals on the ECP trainline.

It is possible to operate a locomotive consist in which all the units are lead-equipped. Obviously only one unit is functioning as the controlling unit at a time, however, the system is designed so that all power supplies on lead-equipped units in the consist should be on during operation regardless of whether or not the locomotive is acting as the controlling unit. While the system is designed for standard operation in this mode, in practice this has caused occasional problems with interference between power supplies. Again, this is an issue that is not fully understood, and may have its roots in other additional equipment on the locomotive unrelated to the ECP equipment. This issue also requires further investigation. To circumvent these issues when they arise it is possible to shut off the power supplies on trailing locomotives, however doing so imposes certain limitations on sequencing of cars and equipment in the train.

Because of the need to have all locomotives in the consist equipped for ECP operation, unforeseen situations. such as the failure of a locomotive en route, impose serious restrictions. If a locomotive fails on a train and the train does not have sufficient power to continue, it is not possible to simply add a conventional locomotive to the consist and continue. For this reason, ECP trains currently in operation either need to run with extra units as protection, or have appropriate units stationed somewhere near enough to be able to provide protection to the schedule. This is because all of the trainsets currently in operation run with a standalone ECP system, as opposed to overlay systems that maintain conventional brake equipment on each car in parallel with the ECP equipment.

Future Benefits—ECP as a LAN

If we step back and look at the wired ECP setup we realize that what we really have is just another local area network (LAN). In this manner ECP can be seen as a logical extension of the network infrastructure that already exists across the railroad in various implementations. Locomotives are being equipped with on board networks that collect data from the locomotive, from operational stats, event recorder data, and fault logs to fuel levels and GPS coordinates. These locomotives are connected to the larger railroad network, feeding their data to back office servers for dissemination to whoever needs it. It is not that difficult to imagine this new train-wide network as an extension of the network already being applied to locomotives.

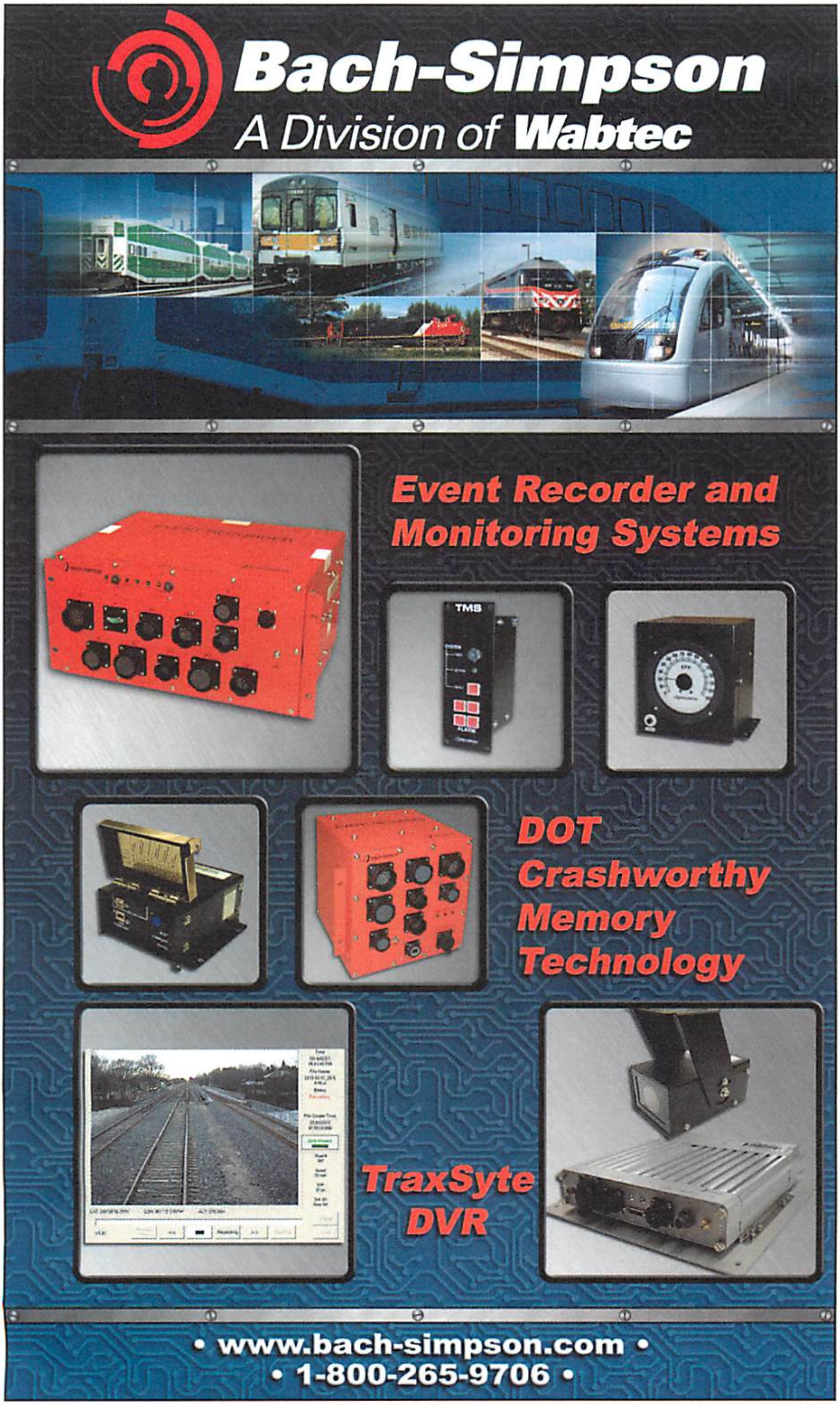
Once the basic network is put in place, freight cars would move from being 'dumb' equipment to "smart" equipment, capable of reporting just about anything by simply adding sensors and inputs. Consider what could be gained by adding sensors to determine the state of the handbrake. Locomotives already monitor parking brake status. This data is used to prevent flat spots and hot wheels.

Parking brake status also factors into AESS operation. Monitoring freight car handbrake status and feeding this information to the locomotive control system could reduce occurrences of slid-flat wheels on cars, which in turn would reduce potential for cracked wheels and even rail damage. It is beyond the scope of this paper to evaluate potential savings in these areas but it certainly is worthy of consideration. A similar case could be made for monitoring things such as bearing temperatures on cars and reporting back to the locomotive. Or perhaps monitoring in-train buff and draft forces in real time and integrating this information into locomotive control systems could be used to help engineers control their trains more efficiently.

Along with the increased functionality comes increased complexity and additional equipment to install and maintain. Care must be taken to mitigate things such as Electromagnetic Interference (EMI). [For a more detailed consideration of EMI please see the white paper entitled "The Ghost in the Machine: EMI on Your Locomotive" found in the 2015 LMOA Proceedings of the 77th Annual Meeting.] As we've already seen, one issue that has been seen on trains with multiple locomotives equipped with ECP control equipment is interference of sorts between power supplies on different locomotives. On an even more basic level, all the additional hardware that is being applied to locomotives also has to compete for a limited amount of space for installation. Equipment racks are filling up with PTC equipment, Onboard Network computers, Distributed Power equipment, voice and data radios, event recorders, crash-hardened memory and video storage.

One final thing to consider is network security. As devices become more and more interconnected, steps must be taken to guard against unauthorized access to the network. Most people are at least somewhat familiar with the concept of a computer virus – malicious computer code that is capable of copying itself and typically has a detrimental effect, such as corrupting the system or destroying data. At the least, something like a computer virus could cause onboard computer system crashes with associated train delays and locomotive out-of-service time for repairs. In a more extreme scenario an unsecured network could allow unauthorized entities to gain access to the network resources and either gather data not meant for distribution, or potentially take over control of the resources on the network. With the growing use of microprocessors and networks this is not out of the realm of possibility.

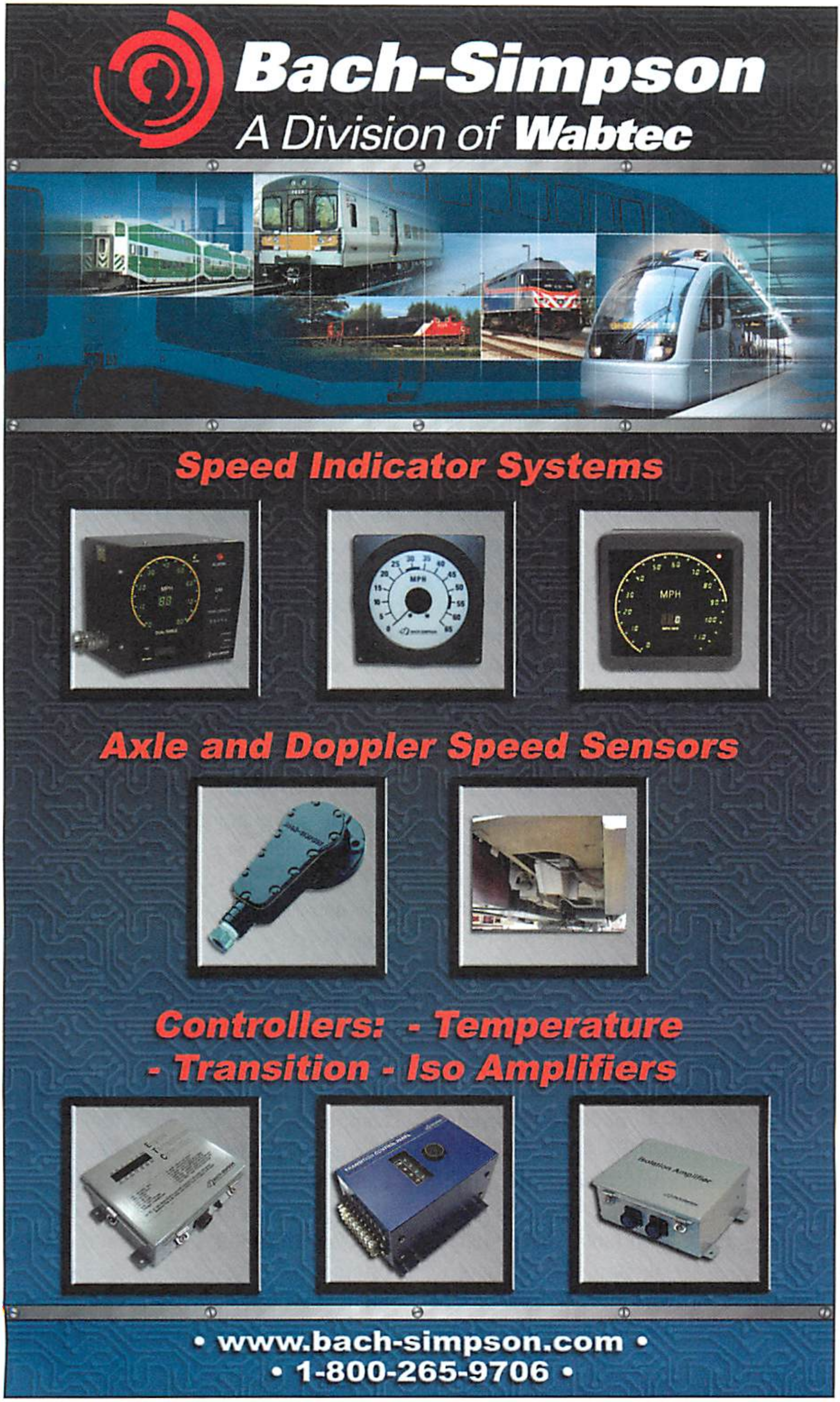
Consider the following: At a briefing presented at Black Hat USA 2015 (a large security conference), researchers Charlie Miller and Chris Valasek discussed the process by which they were able to remotely gain access to a Jeep Cherokee and ultimately take control and operate the vehicle. In his article titled 'Hackers Remotely Kill A Jeep On The Highway – With Me In It' in Wired magazine, senior writer Andy Greenburg describes his experience being "Miller and Valesek's digital


Bach-Simpson
A Division of Wabtec
Event Recorder and Monitoring Systems
TMS
DOT Crashworthy Memory Technology
TraxSyte DVR
• www.bach-simpson.com •
• 1-800-265-9706 •

crash-test dummy, a willing subject on whom they could test the car hacking research they'd been doing over the past year." He goes on to describe "an automaker's nightmare: software that lets hackers send commands through the Jeep's entertainment system to its dashboard functions, steering, brakes, and transmission, all from a laptop that may be across the country." In essence these two individuals found ways to exploit holes in the security of the interconnected, networked components of the vehicle. They connected to the vehicles entertainment system via its cellular connection. From there they were able to gain access to the vehicle's CAN bus , the network that connects the electronic control systems to the physical components such as accelerator and transmission, and actually send commands to control the vehicle hardware. This is no longer a theoretical scenario—it has actually been shown to be possible. Hacks like this can be prevented before they occur, but only through diligent research designed to identify and close any and all holes in security.

Conclusion

As railroads and locomotives move further into the wired world, security of new technologies will become an ever more important consideration, as will the way in which various technologies interact with and affect each other. There are a wealth of possibilities opening up to piggyback technologies together and integrate various components, but these possibilities are not all without a downside.


Bach-Simpson
A Division of Wabtec
Speed Indicator Systems
Axle and Doppler Speed Sensors
Controllers: - Temperature
- Transition - Iso Amplifiers
Isolation Amplifier
• www.bach-simpson.com •
• 1-800-265-9706 •

New Developments in Diesel-Electric Passenger Locomotives

Prepared by:
Brady Calvert, Motive Power, In and David Caron, ABB, Inc.

The market for US Diesel-Electric Passenger Locomotives is evolving as new technologies are brought to market and new regulations come into effect. This paper seeks to provide an overview of the recent history of Commuter and Intercity Passenger Locomotives, the new regulations and procurements that have affected the market, and an overview of the next generation of these locomotives. Information has been gathered from the market's major suppliers, where available, along with research on the latest procurements and regulations. Any reference to particular products or technologies should be considered as informed general assumptions (as many of the systems are proprietary to the given suppliers). For definitive, detailed information on a particular system, the supplier should be contacted directly.

1 Diesel Electric Passenger HEP Technology

Before 2014, passenger locomotives were extremely similar to their freight counterparts with one major exception. The requirement to keep passengers comfortable necessitated that passenger locomotives also provide some way of transferring power to the coach cars in the train consist for lighting, heating and air conditioning in the form of 3-phase 480 VAC power. Passenger locomotives contain an additional power generation system for this purpose. Generally referred to as "Head End Power (HEP)" or "Hotel Power," HEP systems have been implemented in many configuration types as shown below.

1.1 Shaft Driven HEP Systems

Shaft Driven HEP systems operate using a separate HEP alternator that is driven by an extended shaft from the Prime Mover. The Prime Mover operates at a higher operating notch than what is necessary for traction only, driving a gear box that drives the HEP alternator and provides power to the coach cars.

1.2 Separate Diesel HEP Systems

Separate Diesel-Electric HEP systems provide HEP power by operating independently of the Prime Mover. A completely separate genset (engine and alternator) is installed in the rear of the locomotive carbody. The separate genset requires its own system of cooling and air filtration. This configuration offers some advantages to the previous Shaft Driven system. If a failure renders the locomotive unable to motor, the

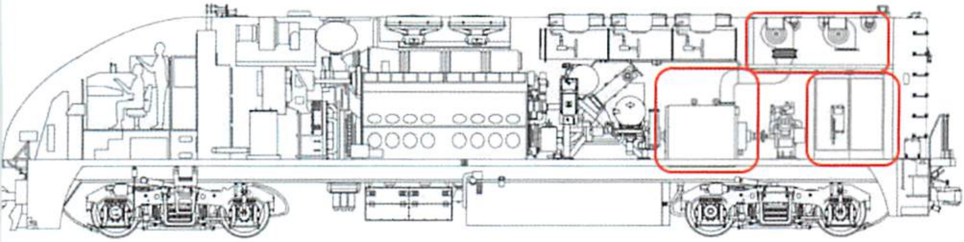


Figure 1. Shaft Driven HEP System

passengers can stay comfortable, still having lighting and HVAC provided to the coach cars from the HEP system while they await rescue. Alternatively, if the HEP genset fails, and the system is not able to provide power to the coach cars, operators can continue motoring using the Prime Mover to get to the next station and offload passengers if required.

1.3 Inverter HEP Systems

Inverter HEP systems take electrical power from a Main Alternator winding and convert it to HEP power. HEP Inverter systems have been around for quite some time but continue to evolve as power transforming technology gets smaller and more sophisticated.

Next Generation Passenger Locomotives primarily implement

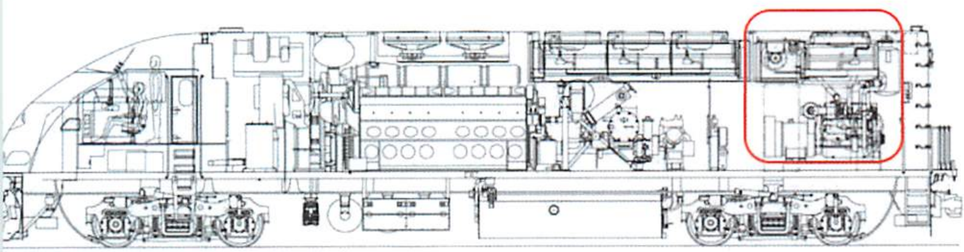


Figure 2. Separate Diesel-Electric HEP Plant

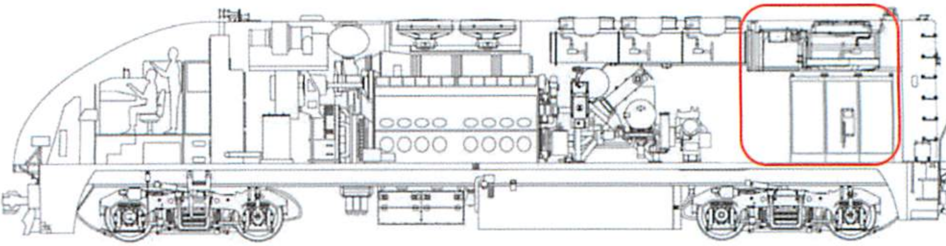


Figure 3. Inverter HEP System

Inverter HEP technology similar to that in ***Figure 3. Inverter HEP System*** and discussed further in ***Section 4.1 Inverter Technologies*** below.

2 Intercity vs. Commuter Transit Locomotives

An important distinction should be noted when discussing Diesel-Electric Passenger Locomotives. Throughout the US, different forms of passenger transportation require different needs, despite efforts at standardization, and can make a suitable solution for one instance not acceptable in another.

2.1 Intercity Passenger Locomotives

Intercity Diesel-Electric Passenger Transit is generally considered to be over longer distances, often 50 – 100 miles or more, transporting passengers from one major metropolitan area to another, sometimes even over state lines. Intercity Passenger Trains usually include a train set made up of two locomotives and passenger cars.

In two locomotive train sets, typically both locomotives provide tractive effort allowing for increased operating speed if the track allows. Only one locomotive in the train set will provide HEP power to the coach cars. Redundancy is provided in intercity train sets by having two locomotives. Because each locomotive has the capability to provide both traction and HEP power, in the event of one locomotive Prime Mover failure, the remaining locomotive can provide tractive effort and HEP power to get the train set to the next station, albeit at a slower operating speed and reduced HEP power.

Another consideration that is important for intercity travel is increased fuel capacity. Although difficult to implement, increased fuel capacity will allow long intercity treks between station stops without the additional inefficiencies of fueling stops in between destinations.


ABB
ABB

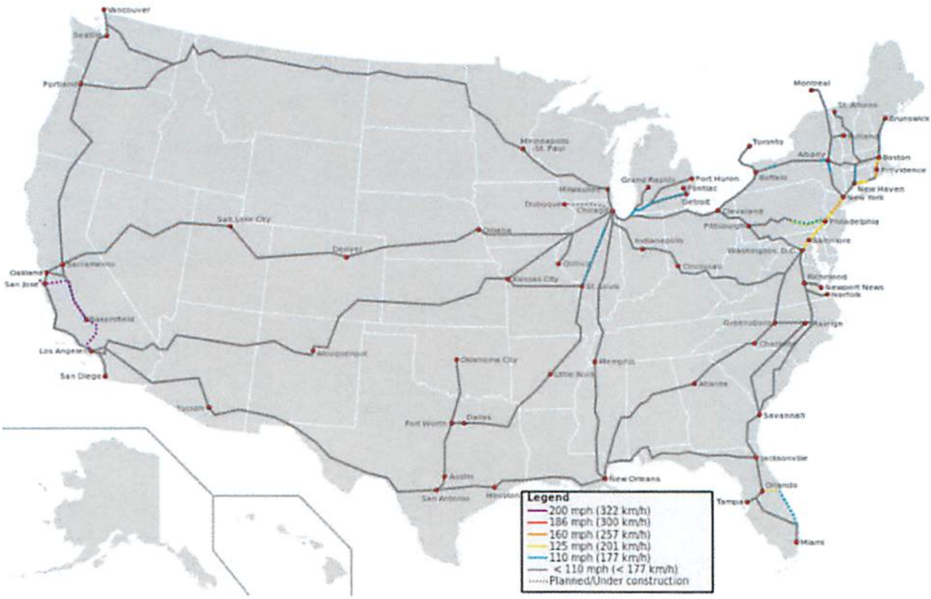


Figure 4. Intercity Passenger Service Map, Example
Source: https://commons.wikimedia.org/wiki/User:justthisonceokey
Source: https://commons.wikimedia.org/wiki/User:theshibboleth

2.2 Commuter Passenger Locomotives

Commuter Locomotives, in contrast, transport passengers from major metropolitan areas to the outlying suburbs, generally less than 50 miles from the city. Commuter railroads often operate in a "Hub and Spoke" type configuration and operate primarily on weekdays with limited or no weekend service. Commuter Passenger trains usually include a train set made up of a single locomotive, passenger cars, and an unpowered control car (Cab Car) on the opposite end of the train from the locomotive.

Traditionally, commuter train sets receive both tractive effort and HEP power from a single locomotive. This can create a redundancy issue for instances where the Prime Mover may fail, leaving passengers both stranded and uncomfortable. Separate HEP plants provide relief from this concern because passengers are able to either get to the next station and unload, or at least remain comfortable while being rescued from a non-moving train set. As emission requirements and inverter technologies drive increased use of inverter HEP systems, special redundancy considerations will necessitate continued development.

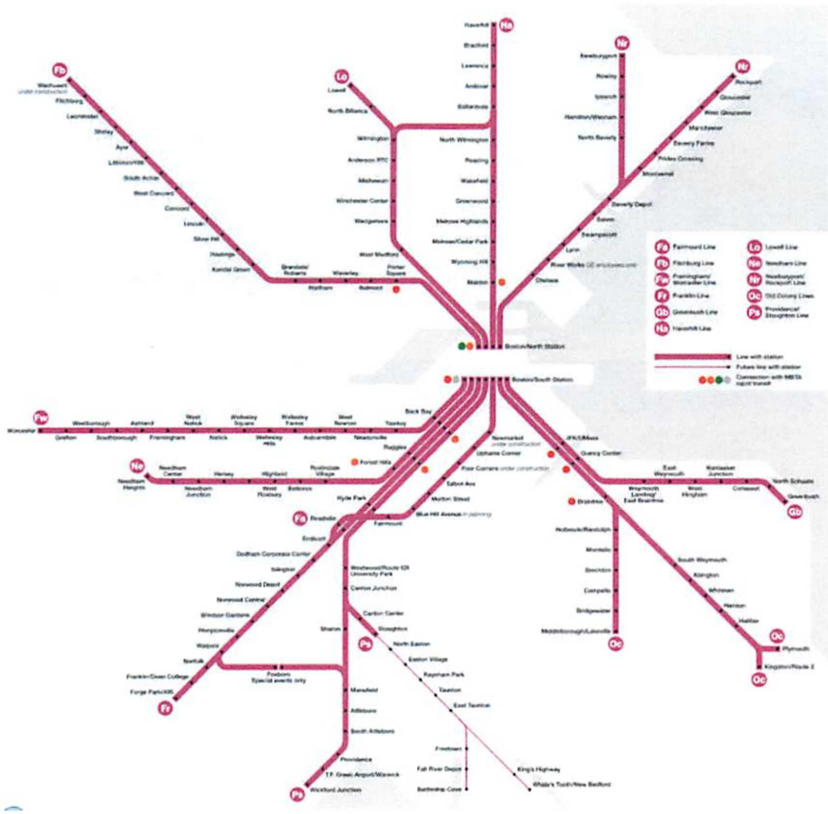


Figure 5. Commuter Passenger Service Map, Example
Source: https://commons.wikimedia.org/wiki/User:The_Port_of_Authority

3 Passenger Locomotive Recent History

Up until 2013, the design of Diesel-Electric Passenger Locomotives used many of the same propulsion systems as their EMD and GE freight locomotive counterparts, with added HEP systems for providing power to the passenger cars. The Prime Mover engines implemented on these passenger locomotives include the EMD 645 & 710 engines and the GE 7FDL engine.

Builder	Model	Year	Prime Mover	HEP System	Propulsion Type
EMD	F40PH	1975-1992	EMD 645	Shaft Driven Alternator	DC Traction
EMD	F59PH	1998-1994	EMD 710	Separate Diesel HEP	DC Traction
EMD	F59 PHI	1994-2001	EMD 710	Separate Diesel HEP	DC Traction
GE	P40DC	1993	GE 7FDL	Static Inverter	DC Traction
GE	P42DC	1996	GE 7FDL	Static Inverter	DC Traction
MPI	MP36	2004-2013	EMD 645	Separate Diesel HEP	DC Traction

Figure 6. Past EMD (F59PHI Shown) & GE (P42 Shown) Passenger Locomotives
Source: F59PHI Photo by M. Cottrell
Source: P42DC Photo by Don O'Brien

4 Passenger Market Changes That Have Driven Change

Many changing factors and regulations have affected the passenger locomotive market since the early 2000s. As the industry began to adapt, new technologies and locomotive configurations have become commonplace in the diesel-electric passenger locomotive markets including advanced inverter technologies, AC traction, and Tier 4 emissions.

4.1 Inverter Technologies

Power Electronics Semi-Conductors are responsible for turning on and off their internal switches to recreate a Sinusoidal Waveform, replicating an AC Power waveform.

The Power Electronics Semi-Conductor has been used in the industry for approximately 20 years. The designs are in constant evolution, from the first generation of Power Electronic Gate Turn-off Thyristor (GTO) inverters, to the current Insulated Gate Bipolar Transistor (IGBT) technology used in every new generation of passenger and freight locomotives, and to the future Silicon Carbide (SIC) inverter technology still in development.

The GTO was the first device enabling AC traction in modern locomotives. The GTO converters are primarily forced air cooled where cold air is needed to circulate through a series of fins to cool down the internal devices. The newer generation of Traction Converters utilize IGBTs where forced air cooling may still be used, but the latest generation IGBTs utilize liquid cooled heatsinks where a mix of water and glycol will circulate inside the heatsink, cooling the IGBT devices. The heat is then dissipated through a heat exchanger located somewhere in the locomotive. The main advantage of liquid cooled converters is the space the equipment requires inside the locomotive. The liquid-cooled inverters take up far less space than their air-cooled counterparts.

IGBT technology offers about 4x the switching frequency compared to its GTO predecessor. Higher switching frequency better defines the Sinusoidal Waveform needed to power the AC Traction motors and HEP trainline.

In the near future, SIC technology will be a part of every design where the compactness, heat losses and high switching frequency will be reduced to a level never reached before with GTO and IGBT semi-conductors.

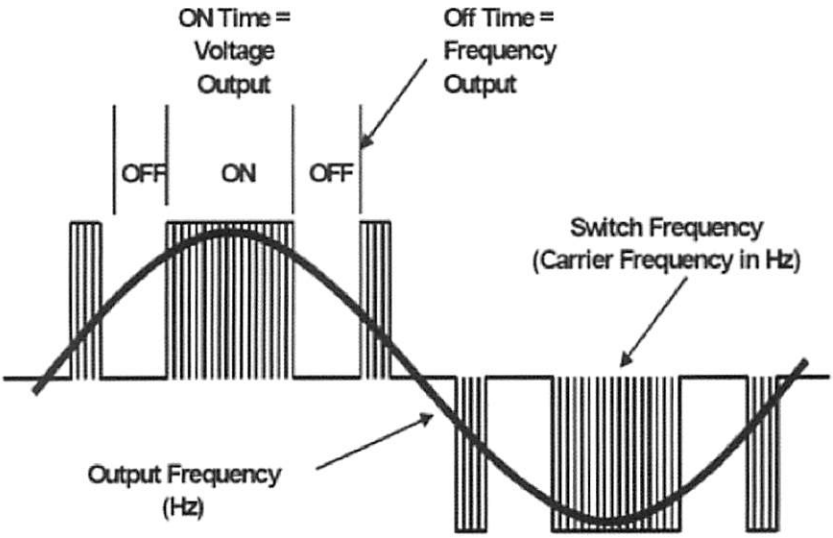
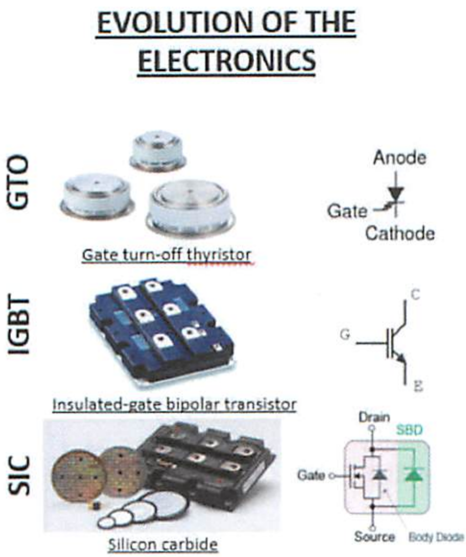


Figure 7. AC Sinusoidal Waveform



Losses	Switching Freq.	Power Density	Status	Integration Complexity
High	250 – 500 Hz	Low	Phase Out	High
Lower	1 – 2 kHz	Higher	Active	Mid.
Ultra Low	10-20 kHz	Ultra High	Future	Low

Figure 8. Evolution of the Power Electronics devices

4.2 AC Traction

Utilizing the Power Electronics devices, AC Traction has changed the way diesel locomotives provide power to their auxiliary systems. The traction converter is a power management system which, in a very efficient way, handles the power supplied from the main generator by controlling losses, thus actually increasing the total efficiency of the locomotive. AC traction offers an average total traction power transmission efficiency of around 87%, compared to only around 82% for DC traction. This 5% power transmission improvement provides direct savings to the operator by increasing fuel efficiency, allowing the power saved to be utilized in the traction or auxiliary power circuits. Integrated HEP and AUX power loads also reap the benefit of this increased efficiency.

During dynamic braking, the AC traction motor associated with the converter acts as a generator, feeding power back into the system for immediate use. This extra power will first be used internally for powering the HEP trainlines, powering cooling fans, battery charging or any other auxiliary power needed (as included in the converter design). For example, extra power could be used to power the coaches behind the locomotive via the HEP circuit during dynamic braking. Any additional power that remains will be sent directly to the dynamic braking resistors via a Voltage Limiting Unit (VLU). Therefore, an AC traction system can actually be regenerative, using the instantaneous power generated during braking to power auxiliary equipment on the locomotive and HEP on the coaches, the net result of this being fuel savings.

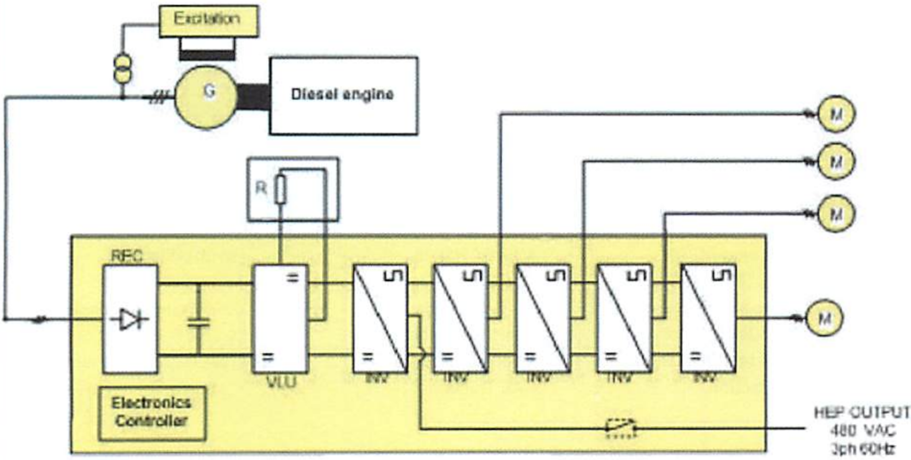


Figure 9. Typical AC Traction Electrical Layout

4.3 Emissions

4.3.1 Tier 0 - Tier 3

As the new emissions regulations first began to be implemented in the market, lower emissions locomotives began to be developed. The first of these started with low emissions kits and tuning techniques to the EMD 645 engine and followed the traditional passenger locomotive layouts.

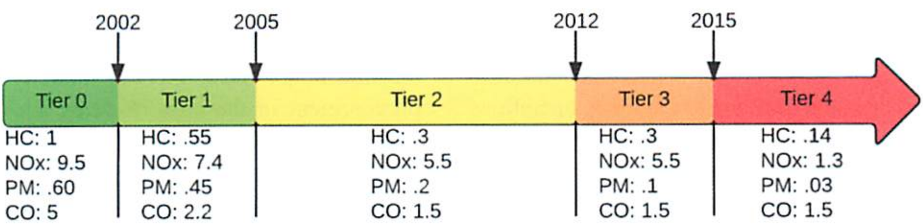


Figure 10. Emissions Regulations & Effective Dates

When EPA Tier 3 regulations became the requirement of the market, a couple of variations on the tried-and-true passenger solutions began to emerge to meet the more stringent requirements (Figure 11. US EPA Tier 3 Passenger Locomotives).

MPI MPXpress MP40	MPI/GE HSP46	Brookville BL36
2014	2014	2014
EMD 710 Engine and Emission Kit	GE EVO Engine	MTU 20V4000 Engine w/ DOC & DPF
Electronic Fuel Injection	Electronic Fuel Injection	Electronic Fuel Injection
Separate Diesel HEP Plant	IGBT Inverter HEP System	Separate Diesel HEP Plant
DC Traction	AC Traction	DC Traction

Figure 11. US EPA Tier 3 Passenger Locomotives
Source: Brookville Photo by Mike Cruz

4.3.2 Tier 4

To meet Tier 4 emissions, the passenger railroads have been more accommodating compared to the freight markets to adopt the use of high-speed diesel engines (1,800 RPM) and Selective Catalytic Reduction (SCR) technology. SCR technology requires the use of Diesel Emissions Fluid (DEF), a urea based liquid, to control NO_x emissions. A large part of this quick adoption has been because most passenger locomotive operations are "yard trapped" with defined fueling stations and defined fueling times. It is a much easier task to undertake the implementation of a DEF infrastructure at a couple of distinct points, rather than across the entire country's Class 1 rail lines. SCR technology has been proven by various engine manufacturers to meet US EPA Tier 4 emissions without any additional aftertreatment beyond SCR alone.

4.4 Multi-State PRIIA Intercity Procurement

The Multi-State Passenger Rail Investment and Improvement Act of 2008 (PRIIA) intercity procurement changed the diesel-electric passenger industry in a number of ways. It was the first major diesel-electric intercity procurement in the past 15 years and was the first intercity procurement to bring together all of the latest technology integrations (AC Traction, Inverter HEP, Tier 4 Emissions and Crash Energy Management (CEM)). EMD, who had been absent from new passenger locomotive delivery for the last 15 years, re-entered the market with a

PRIIA compliant commuter procurement win at SCRRA, presumably also in preparation for the PRIIA procurement. Siemens, who had been absent from the North American diesel-electric market completely, also entered the market for the procurement with what was eventually the PRIIA winning SC-44 Charger locomotive.

5 Next Generation Diesel-Electric Passenger Locomotives

Based on the latest public tenders, such as PRIIA, future procurements will most likely be based on similar new technology integration. AC traction, integrated HEP, Individual Axle Control (IAC) and Tier 4 emissions will be the minimal requirements for new passenger locomotives. Figure 12 shows the locomotives that are being produced today that meet these requirements.

MPI MP54AC
2016
Twin Cummins QSK60
ABB IGBT AC Traction & HEP
Customer: GO Transit

EMD F125
2016
Caterpillar C175
Melco IGBT AC Traction & HEP
Customer: SCRRA

Siemens SC-44 Charger
2016
Cummins QSK95
Siemens IGBT AC Traction & H
Customer: IDOT/Multi-State

Figure 12. Current Next Generation Tier 4 Passenger Locomotives
Source: EMD F125 Photo from metrolinktrains.com
Source: Siemens Charger Photo by Siemens USA from railjournal.com

Transit authorities will have the choice of purchasing new equipment, utilizing their existing assets and converting them to latest technology, or remanufacturing them in-kind. As difficult as it can be to predict future regulations and procurements, there are a few conclusions that can be made regarding diesel-electric passenger locomotive technology evolution beyond today.

It is likely that further emissions reduction regulations will eventually affect the passenger locomotive market. To meet these demands, engine manufactures will continue to develop further emissions reduction technology. This technology very likely may be a combination of existing technologies to continue to drive down the regulated pollutants. Combinations of SCR, Exhaust Gas Recirculation (EGR), Diesel Particulate Filters (DPF) and Diesel Oxidation Catalysts (DOC) may all be major players in the emissions reduction, depending on the requirements.

Another future consideration is onboard energy storage. As described in this paper, AC traction systems allow for energy generated during braking to be used to power the locomotive appurtenances at a point-of-generation. As battery and super capacitor technology progresses, and the technology becomes more cost effective, implementation of onboard energy storage will become a consideration.; Onboard energy storage will allow the locomotive to use regenerated energy as demanded, rather than just during braking.

6 Conclusion

Historically, diesel-electric passenger locomotive equipment has been conservative and slow to embrace new technology, opting more for proven performance rather than the latest technological advancements. However, in the last two years, the diesel-electric passenger locomotive market has changed significantly with the introduction of new emission regulations and inverter/AC Traction technology. As these technologies permeate the markets and gain more service time, the market will continue to adapt with new competitors and new technologies. OEMs will focus on the next logical step of integrations such as safety improvements, dual mode configurations, onboard energy storage and further emissions reductions.

Diesel Emissions Control Technologies – A Post-Tier 4 Review

Prepared by:
Tom Mack, President & CTO, VeRail Technologies

Prolog: In 2011 the LMOA New Technologies Committee published a white paper by Bruce Wolff of MTU and Randy Nelson of Cummins entitled "EPA Tier 4 Locomotive Development Status Update". This white paper is an updated continuation of that paper that will discuss the actual current implementation by the various diesel locomotive engine manufacturers and how they have applied these technologies. Some of the information in this paper is taken verbatim from the 2011 LMOA white paper by Wolff and Nelson, but there are many additions, including a cross reference table showing how these technologies have now been applied to today's Tier 4 locomotive engines, and also actual maintenance considerations for some of these after-treatment systems.

A special thank you is given to Bruce Wolff of MTU, David Bugert of Cummins, and Adam Bennett of RJ Corman / Railpower for their assistance in the updates to this paper.

While individual companies may utilize proprietary or unique emissions control technologies on their engines (please consult individual manufacturers for details), diesel emissions control technologies fall predominately into four categories. Depending on the engine design and emissions requirements, it is not necessary to use all four of these technologies together to control emissions on today's Tier 4 locomotive engines (see the chart in Table 1 for details on which specific individual technologies are applied to current diesel locomotive engines). The four major control technologies are as follows:

EGR – Exhaust Gas Recirculation – NOx

Exhaust gas recirculation (EGR) is a technique used to reduce NOx emissions by reducing peak cylinder temperatures. (High cylinder temperatures along with high pressure produce NOx.) With EGR, a controlled amount of exhaust gas from one or more "donor" cylinders are diverted from the exhaust stream, cooled in an EGR cooler, and mixed with the intake air before entering the cylinders. The

higher specific heat capacity of the water and carbon dioxide in the exhaust gas limits the temperature rise during combustion.

There are a few drawbacks to EGR. Presence of exhaust gas in the cylinder leads to increased PM emissions, often requiring a diesel particulate filter (see below). An EGR-equipped engine can have less power and lower fuel efficiency than an equivalent non-EGR engine. Also, EGR can significantly increase coolant heat rejection which can prove difficult when packaging the larger cooling systems within the locomotive. The higher heat rejection will in turn reduce traction power because of the additional parasitic fan loads.

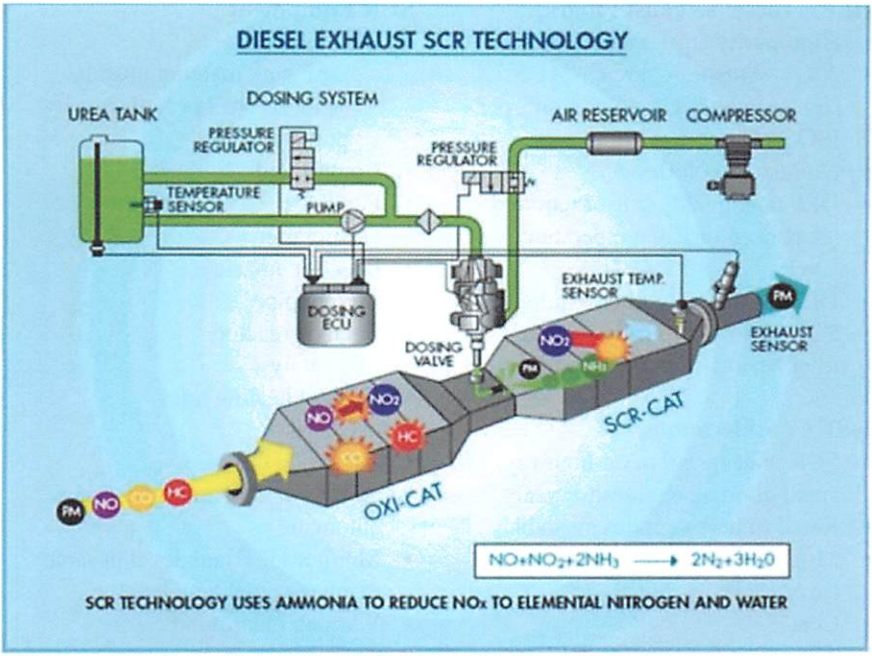
SCR – Selective Catalytic Reduction – NOx

Not all engines are capable of reducing NOx sufficiently through the use of EGR alone and subsequently some manufacturers may choose to add SCR in addition to EGR to meet EPA Tier 4 requirements. Some manufacturers may choose to use SCR in place of EGR. In these engines an additional catalytic process must be introduced to reduce the NOx to low enough levels to meet the EPA Tier 4 requirements. While HC, CO and ultimately PM are removed through an oxidation reaction, a reduction reaction is needed to convert NOx back to harmless nitrogen (N_2) gas. In the oxygen-poor exhaust from a spark-ignition engine, this can be accomplished by a passive "three way" catalyst. However, in the relatively oxygen-rich exhaust of a diesel engine, another strategy is used: Selective Catalytic Reduction (SCR).

In SCR, an additional fluid is added to the exhaust as a "reductant". This reductant is then mixed with the exhaust, before entering the SCR's catalyst chamber. There, the reductant reacts with the NOx to convert it to N_2. In existing mobile diesel engine applications, an aqueous solution of urea (commonly known as diesel emission fluid, or DEF, or in Europe as "AdBlue") is used as the reductant. While mixing with the hot exhaust, the DEF breaks down into ammonia, which in turn reacts in the SCR chamber to reduce the NOx. The amount of DEF injected must be carefully controlled based on the engine's operation (load, speed, temperature, etc.) to maximize the reduction of NOx, and to minimize the release of unreacted ammonia from the SCR. This "ammonia slip" is also prevented by using a "slip catalyst" to convert any remaining ammonia into harmless N_2 and H_2O.

The use of DEF in SCR requires procuring, storing, dispensing and carrying onboard the locomotive another fluid besides those already used. Typically, an SCR-equipped locomotive can expect to use between 5% and 10% as much DEF as it does diesel fuel. An alternative being developed uses hydrocarbons such as diesel fuel as the reductant, rather than DEF. This avoids the infrastructure needed to support a separate fluid, though it increases the consumption of diesel fuel aboard the locomotive.

As with some other catalyst-based systems, SCR can be "poisoned" by



sulfur in the fuel. This means that sulfur compounds in the exhaust attach permanently to the catalyst, eliminating its ability to reduce NOx. This is another reason why only ULSD (Ultra-Low Sulfur Diesel) can be used in most if not all locomotives designed to meet the Tier 4 emission standards.

SCR Overview

- Exhaust aftertreatment system
- Used to reduce NOx emissions
- Inject urea solution into exhaust
  - o Hydrocarbon SCR uses diesel fuel, but less effective NOx reduction
- Urea dissociates into ammonia
- Ammonia reacts with NOx in catalyst chamber to produce N_2, H_2O
- "Slip Catalyst" removes remaining ammonia from exhaust stream

SCR Considerations

- NOx sensors will be damaged with moisture, so typically have mounting requirements to keep from getting condensate
- DEF injectors typically cannot be mounted with the injectors facing upward
- Exhaust before SCR devices is typically wrapped with insulation, helps keep exhaust hot. SCR does not catalyze at lower temperatures, so DEF injection an issue at idle typically
- Vibration/shock limits of SCR device, transfer pumps, and injectors vary depending on engine OEM

DEF = Diesel Exhaust Fluid
- High-purity aqueous urea solution
- AKA "AdBlue", "urea", "AUS 32" (for "Aqueous Urea Solution", per ISO 2241)
- Non-toxic, colorless
- DEF tank quality sensor required (% concentration, temperature, level)
- DEF fluid pickup filter required
- SCR systems typically include DEF filter besides tank pick-up filter

DEF Considerations
- SCR widespread in on-highway, small nonroad engines for years
- Retail to bulk supplies available
- Mobile diesel refueling trucks now carry DEF
- Cost
- Anywhere from 3-10% DEF usage predicted, it depends on technology (if have EGR) and duty cycle
- If DEF costs same as diesel, this effectively adds 3-10% to fuel cost of locomotive
- On 300,000 gallon line haul fuel usage DEF cost is like using 9,000 to 30,000 more gallons of fuel

DEF Handling
- Compatibility with container, piping etc. materials
- EPA mandates type of DEF line connection
- Shelf Life
- Ensuring cleanliness / purity / concentration
- Crystallization at leaks
- DEF tank cap typically blue and clearly identified

SCR Equipment
- DEF tank
  - o DEF tank material must be stainless steel or high density polyethylene
- Control unit
- Pump
- Dosing unit
- Injection nozzle
- Mixing pipe
- Catalyst reactor
- Slip catalyst
- Coolant heating lines

Crew Tasks
- SCR system operation entirely automatic
- Monitor DEF tank level in same manner as fuel tank level
- Warning / alarm indicators
  - Inducement

Maintenance Tasks
- Replenish DEF tank – but how frequently?
- Recommended to align this with the locomotive refueling interval
- Scheduled SCR system maintenance
- SCR alarm troubleshooting – corrective maintenance

Temperature Effects on DEF

Cold Conditions:
- Freezing / slushing below 12°F / -11°C
- DEF tank, lines aboard locomotive heated with engine coolant
- DEF lines are heated to keep from freezing
- DEF lines must not have water traps

- Tanks required to thaw in 70 min typically, can be done with engine coolant or electrical submersion heater
- DEF tanks must account for freeze expansion volume and reserve DEF volume for cooling of injectors
- Emission regulations allow warm-up period before SCR begins to operate

Hot Conditions:

- Negative affect on shelf life
- DEF freezes at 12 deg F, but also must be stored less than 86 deg F or it will start to degrade

Additional Adam Bennett comments:

1:1 volume for diesel usage, EPA mandated typically.

Tank pickup (head) typically has engine coolant to keep from freezing

DEF injectors are cooled with engine coolant.

DOC – Diesel Oxy-Catalyst – PM

A diesel oxidation catalyst (DOC) is a passive catalyst chamber inserted into the exhaust stream. It can be used downstream of the turbocharger, or in some engines, in the exhaust manifold between the cylinder heads and the turbocharger. As exhaust passes over the catalyst, CO and HC react with remaining oxygen to form CO_2 and H_2O. DOC can be very effective at reducing CO and HC. It also has a small effect at reducing PM, but is generally not effective at reducing NOx.

DOC can be used to condition the exhaust to enhance the function of further downstream aftertreatment. Because the oxidation reactions increase the exhaust temperature, controlled amounts of fuel can be injected into the exhaust upstream of the DOC (or added through post-injection in an electronically-controlled common-rail fuel system) for the specific purpose of raising the exhaust temperature to a level that maximizes the reaction rate in other aftertreatment devices further along the exhaust system.

DPF – Diesel Particulate Filter – PM

As its name implies, a diesel particulate filter (DPF) acts as a filter to remove particulate matter from the exhaust stream. Based on its design, a DPF can remove anywhere from 50% to 85% or more of the PM from the exhaust. However, the higher PM removal comes with an increased backpressure, leading to increased fuel consumption in the engine.

As the PM builds up in the DPF the backpressure increases. If allowed to accumulate, the backpressure would soon reach a level where the engine could no longer operate. In order to keep the backpressure within limits, the DPF must be "regenerated" by burning off the PM and turning it into CO_2.

To regenerate, the DPF must reach relatively high temperature and remain there for several minutes (depending on the amount of PM to be burned off). The use of a catalyst "washcoat" on the filter medium can reduce the temperature needed for regeneration. If the engine's load profile is high enough

- for example, a locomotive in line-haul service - the engine's exhaust temperature is often high enough to cause DPF regeneration. On the other hand, an engine whose exhaust temperature is mostly too cold for regeneration – for example, a switcher - must use other means to raise the exhaust temperature. This could involve injecting diesel fuel upstream of a DOC. However, if the exhaust is too cold, even this will not be effective, as the liquid fuel would pass through the DOC without reacting. In this case, a fuel-fired burner upstream of the DPF, or an electric heating element within the DPF, may be required.

Generally, a DPF that can regenerate strictly from the high temperature of the exhaust is called a "passive DPF", while a DPF with a burner or electric heater is an "active DPF". The choice of the type and size of DPF depends not only on the emission characteristics of the engine, but also on a good understanding of how the engine will be used and what exhaust temperature can be expected.

A DPF can be plugged not only by PM, but also by ash coming from engine lubricating oil burned in the cylinder. Minimizing oil consumption and selecting a low-ash oil can help prolong the filter element life. Even so, periodic removal and cleaning of the filter element will be required. Depending on many factors, this cleaning interval may be semi-annual, annual or biennial.

Manufacturer Engine Offerings (alphabetical)

Caterpillar

Caterpillar introduced the 4,700 horsepower C175-20 as its first Tier 4 locomotive engine. This engine is being used in the new EMD F125 passenger locomotives. F125's are currently being built for Metrolink in Los Angeles, California.

Cummins

As of the writing of this paper, only Cummins offers an engine actually certified to the Tier 4 switcher locomotive standard. This engine is the Cummins QSX15 and is a 600 horsepower engine designed for multi-genset locomotive application. The QSX15 is unique in Cummins locomotive product offering in that it does not require SCR to achieve Tier 4 NOx levels. It is not certified, however, for line haul.

Cummins offers higher horsepower engines for line haul or passenger rail applications. The QSK60 is a 60 liter V-16 engine rated at either 2,310 BHP or 2,700 BHP. The QSK60 can be used as a single engine for a medium horsepower line haul or passenger rail locomotive or in a twin-engine configuration as a high horsepower line haul or passenger rail locomotive. The MPI MP54AC commuter locomotive uses twin Cummins QSK60 engines to create a 5,400 HP commuter locomotive.

The Cummins QSK95 is a high horsepower V-16 engine rated from 4,000 BHP to 4,400 BHP. The engine is designed for use in single engine high horsepower line haul or passenger rail

Manufacturer	Caterpillar	Cummins	Cummins	Cummins	Cummins	EMD	GE	MTU
Model	C175-20	QSX15	QSK19R	QSK60	QSK95	1010-T4	EVO	S4000R54
Horsepower	4,700	600	760	2,310-2,700	4,000-4,400	4,300	4,400	2400 / 3200
RPM	1,800	1,800	1,800-2,000	1,800	1,800	1,050	1,050	1,800
Type	V20	Inline 6	Inline 6	V-16	V-16	V-12	V-12	V-12 / V-16
Displacement	105.8 liter	15 liter	19 liter	60 liter	95 liter	1010 ci/cyl		4.78 l/cyl
Emissions	Tier 4 Line Haul	Tier 4 Switcher	Tier 4 Nonroad	Tier 4 Line Haul	Tier 4 Line Haul	Tier 4 Line Haul	Tier 4 Line Haul	Tier 3 Line Haul
EGR	X	X				X	X	X
SCR	X		X	X	X			(X for Tier 4)
DOC	X	X						(X for Tier 4)
DPF		X						
Locomotives	EMD F125	Brookville BL12CG NRE 2GS12B Railpower RP20BD	Nippon Sharyo Metrolinx and SMART commuter railcars	MPI MP54AC	Siemens SC-44 "Charger"	EMD SD70ACe-T4	GE ET44AC ET44C4	KLW SE24B, SE32C

Table 1: Alphabetical List of Tier 4 Locomotive Engine Offerings

applications. The first application of the Cummins QSK95 is in the Siemens SC-44 "Charger" passenger locomotive. The engine has also been installed and is testing in a demonstration freight locomotive rebuilt from an EMD SD90MAC.

Lastly, Cummins offers their QSK19R horizontal engine for use in T4 Final Diesel Multiple Unit (DMU's a.k.a. railcar) applications. This engine is classified within the EPA's Nonroad category because it falls below their 1,006 BHP classification limit for locomotives. The engine is a horizontal design which suits it well for low profile installations under passenger cars. This engine is used in Nippon Sharyo's T4 DMU passenger trains operating in Metrolinx (Toronto) and SMART (California).

EMD

EMD has moved from two-cycle engine technology for its Tier 2 and Tier 3 locomotive engines, to four-cycle technology for its new 1010 engine. While the displacement per cylinder is the same as the earlier 6,300 horsepower 265H engine used in the EMD SD90MAC, this is a brand new engine from EMD designed and built for the Tier 4 standard. The engine is still a medium speed design in order to operate with existing EMD traction alternator technology. Like its GE Tier 4 counterpart, the EMD engine does not require SCR to meet the Tier 4 NOx levels. Instead the EMD 1010 engine uses cooled EGR to control NOx. The engine has moved from a single large turbocharger design to using three smaller turbochargers in a two-stage layout. A single low pressure turbocharger drives two (one per cylinder bank) high-pressure turbochargers to supply the engine air. The higher pressure is necessary for the advanced EGR system and lower emissions. The EMD 1010 engine is currently installed on a small fleet of demonstrator SD70ACe-T4 locomotives currently undergoing road testing.

GE

GE began manufacturing and production on locomotives that achieve Tier 4 standards directly in 2015. GE utilized its four-cycle Tier 2/3 EVO engine as the basis for its new Tier 4 engine. Like the EMD 1010, the GE EVO T4 does not require SCR for NOx control, but utilizes cooled EGR. The new design now uses a two-stage turbocharger instead of the single-stage turbocharger of the earlier Tier 2/3 EVO engine. The reduction in particulate matter is managed by a high pressure Common Rail fuel delivery system combined with an updated power assembly. In 2014, GE received over 1,355 Evolution Series Tier 4 locomotive orders for fulfillment over the next three years.

MTU

MTU has certified two models of its current-generation Series 4000 engine, the 12V4000R54 at 2400 hp and the 16V4000R54 at 3200 hp, to the Tier 3 Line Haul locomotive emission standards. These models use common-rail fuel injection, controlled two-stage turbocharging and cooled EGR. They have emissions well below both the Tier 3 Line Haul and Tier 3 Switch locomotive emission limits without aftertreatment, while providing excellent throttle response and fuel efficiency.

MTU also works with OEMS to achieve the appropriate EPA locomotive emission certification for their locomotives powered by a variety of other MTU engines from 1050 hp through 4000 hp.

Report on the Committee on Diesel Electrical Maintenance

Monday, October 3, 2016 at 9:30 A.M.

Chairman

Keith Mellin
Sales Manager, Peaker Services, Inc
Brighton, MI

Vice Chairman

Amarjit Soora
Mgr of Engineering, ZTR Systems
London, Ontario

Commitee Members

M. Ablett	Product Development Engr	Central Railway	Jacksonville, FL
C. Adams	Sales Rep	TPSC	Buffalo, NY
S. Alessandrini	Senior Rel Specialist	CN Rwy	Concord, Ontario
S. Bakker	President	ARMS	O'Fallon, MO
D. Becker	Design Engineer	Progress Rail-A Caterpillar Co	LaGrange, IL
S. Bendriss	Electrical Engr	Amtrak	Wilmington, DE
J. Brodkin	Senior Engineer-Loco Systems	CP Rail	Calgary, Alberta
J. Fox	Dir-Loco Engrg	Union Pacific RR	Omaha, NE
I. Gaudet	AVP-Engineering and Quality	PowerRail Distribution	Duryea, PA
E. Grecu	Senior Electrical Engineer	ViaRail-Canada	Montreal, Quebec
R. Honc	Senior Research Engineer	Southwest Research Institute	San Antonio, TX
B. Locklear	Manager-Electrical Systems	CSX Transportation	Huntington, WV
G. Lozowski	Senior Applications Engr	Morgan Advanced Materials	Greenville, SC
S. Mueting	Field Service Engineer	Siemens	Aurora, CO
C. Muir	Sales Rep	East Penn Mfg	Lyon Station, PA
B. Reynolds *(Past President)*	Sales Manager	Amglo Kemlite	Calgary, Alberta
P. Scholtens	Customer Relations Mgr	TMV Control Systems	Cambridge, Ontario
S. Sledge	Fleet Mgr	Norfolk Southern Corp	Atlanta, GA
C. Taylor	Product Specialist	Bach Simpson	London, Ontario
T. Weidemann	VP-Loco Maint & Opns	CIT Rail	Chicago, IL
L. White *(Past President)*	Applications Specialist	Bach Simpson	London, Ontario
J. Whitmer	Electrical Specialist	Dakota, Missouri Valley & West	Bismarck, ND
B. Wilds	Senior Mgr-Loco Opns	BNSF Rwy	Fort Worth, TX

Note: Current LMOA President Stuart Olson is a contributor to committee

PERSONAL HISTORY

Keith Mellin

Sales Manager
Peaker Services, Inc, Brighton, MI

Keith Mellin was born in and raised in the Detroit area and has worked for Peaker Services since 1982.

Keith works primarily with the railroads but also works with the marine and power generation industries. His extensive work experience at Peaker includes: mechanical EMD & GE engine and component overhauls and repairs; truck assembly overhauls; electrical rewires and control system upgrades of diesel locomotives, ships and generator sets. His engineering experience includes: control system design; on site testing and customer training for diesel and gas engines and, steam and gas turbines.

He has worked in all departments at PSI, with a majority of time spent working Field Service assignments, including overseas work. Keith has two degrees from Ferris State College in Automotive and Industrial Engineering. Keith has been participating in the Electrical Committee since 2007. He and his family reside in Brighton, Michigan with his wife Teresa, son Robert & daughter Andria and 2 grandchildren Haylee and Jacob. Keith enjoys traveling, photography and collecting rare and unique industrial engine and locomotive related items.

The Diesel Electrical Committee would like to thank Southwest Research Institute for hosting their winter meeting Feb 24-25, 2016 in San Antonio TX. Special thanks to Randy Honc & Steve Fritz for arranging the meeting and hospitality.

Special thanks to Norfolk Southern for hosting the Joint Meeting at their Roanoke Facility.

We would also like to thank Chad Muir for arranging our July meeting at East Penn Manufacturing and the tour of their facility in Lyon Station PA.

Stuck in the Middle With You: PTC and Short Line Railroads

Prepared by:
Joe Whitmer, Dakota Missouri Valley and Western RR and
Peter Scholtens, TMV

Introduction to PTC

What is Positive Train Control (PTC)? According to the FRA, PTC systems are "integrated command, control, communications, and information systems for controlling train movements with safety, security, precision, and efficiency."[1] PTC is a set of technologies intended to make freight rail safer by automatically stopping a train before certain types of accidents take place.[2] Mandated by the Rail Safety Improvement Act of 2008 (RSIA), and originally to be implemented by December 31, 2015, Congress passed H.R.38 19 - Surface Transportation Extension Act of 2015, which provided a three-year extension to 2018 for the installation of PTC.[3]

Positive Train Control (PTC) has existed in some form for many years previous to the government mandated the Rail Safety Improvement Act of 2008. However, in 2008 a serious collision between a passenger train and a freight train that resulted in the death of 25 people and injuries to more than 135 influenced the adoption of this act, requiring railroads to implement an interoperable system allowing railroads to share equipment.

PTC is a mission critical, fault tolerant, vital signaling system. Using GPS-based locations and various radio technologies, it monitors many items including switch positions, signal indications, track restrictions, and many other inputs. The purpose of all of these inputs is to prevent train-to-train collisions, overspeed conditions, violations of work zone limits, and to prevent a train from entering a wrong track by way of an incorrect switch position.

This process is performed by the PTC system by continuously monitoring and identifying potential conflicts between the trains current operation and signal aspect, switch position, maximum authorized speeds, and any work zones. If potential conflicts are realized by the system, this information is communicated visually to the crew to act upon. If the crew does not act within the specified window, then the system will provide enforcement, stopping the train short of the obstruction or violation.

Onboard equipment consists of a Train Management Computer (TMC). The TMC is the heart of the locomotive system with inputs from GPS, operator controls, and locomotive feedback systems. Operational data such as train configuration, operator information, track profile, track status, etc., is downloaded via external communications,

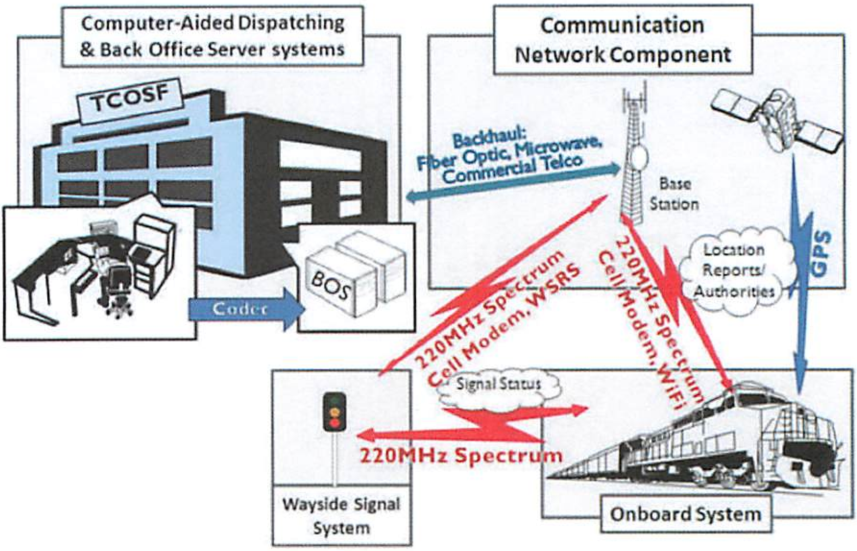


Figure 1 – PTC Infrastructure
(Image – Metrolink)

including 220 MHz radio, Wi-Fi (802.11), and cellular.

Although the locomotive equipment is a large part, what makes up the PTC system is more than just what is on the locomotive. An even larger component is the installation of the wayside infrastructure required to support the operation. On the main line, every switch, signal, or crossing, needs to be monitored for status. Changes in the status of any of this equipment modify the current operation of a train operating near that zone. Various technologies are utilized to communicate these changes in status, though most are via radio or wireless link. The requirement of these radio links makes it necessary to install many communications towers that were formerly not required.

The final portion required is the Back Office Server or BOS. The BOS as its name implies, carries the information for the PTC system to operate. This is the storage bank or database for the track restrictions, signal information, and track profiles. The wireless resources on the locomotive are used to access this information when initializing the train and during operation.

PTC and Class I Railroads

The Class I railroads have the staffing and expertise in their various departments to deal with PTC implementation. They often have a team delegated to handle the various duties required, including Signals and Communications (S&C) bringing in the signaling and track detection, Information Technology staff that handle bringing in BOS operations, and staff from the mechanical departments to install equipment as required on locomotives.

PTC and Class II and III Railroads

For the most part, regionals and short lines are not required to be equipped with PTC for their day to day operations. However, when they enter Class I lines, the fun begins. As long as short line equipment is operated for less than 20 miles on the Class I, at 4 or less trains per day, PTC is not required (CFR 49, Subtitle B, Chapter II, Subpart I, 236.1006(b)(4)(ii) and (iii)). If there are more than 4 Class II or Class III trains per day, or if they short line is operating in excess of this 20 mile limit, then the short line needs to furnish its locomotives with PTC equipment. With this being said, the short of it is if the host railroad says you need to have it, then you have to apply the equipment.

Equipment Issues

If a short line railroad finds itself in the unenviable position of needing to implement PTC, what are the issues that they need to consider? While many of the concerns are common knowledge today at Class I railroads with current implementations of PTC at Class I's, it is far more complex at the short line for the following three reasons

First, many short lines do not have a dedicated IT department. If their IT work is contracted out, the contractor may have no clue what is required for a BOS for PTC.

Second, depending on the size of the short line, S&C may or may not be able to handle the installation of the required wayside equipment. These short lines may have just basic signaling such as grade crossings, nor

Figure 2 – Older Locomotive Models Present Unique Challenges
(Picture – DMVW)

is the S&C department necessarily capable of handling all of the installations required. In some cases where passenger transportation is using the short lines rails, wayside equipment will have to be installed. In many cases this will be funded by the passenger rail company, but this may not always be true. But, then of course this also leads to the routine maintenance and testing that will be needed going forward.

Third, and finally, the mechanical team also may not have the necessary expertise in communication to deal with the radio and wireless equipment required. As previously mentioned, most short line operations do not have the engineering expertise required to implement the locomotive portion. This is the more simple portion of the operation since equipment purchased from vendors comes with support, though the level is not going to be the same as an application where there may be 100 of a given type of locomotive, but instead for this type operation there may be several types or vintages of locomotives giving a unique status for each application. This causes a lot of work to be involved in research, fabrication, and installation. It goes without saying that some short lines have unusual locomotive builds that are not necessarily conducive to the application of PTC. Even if they are, since this equipment is unique and the install base is small, will support remain for the life of the locomotive? For one short line, the solution was to research lease power and pursue that route. However, that may not be economically feasible for some roads to do this.

Short Line Frustrations with PTC

During investigation of this project a few more obscure, yet important items have come to light.

First, (and it goes without saying) technology is ever changing. One of the frustrations of the short line is that if they install today's technology, it may be obsolete by the time implementation actually happens. As a result, many have opted to 'wait it out'. This has been the approach of many that we spoke to while doing the research for this paper.

Thankfully, when it comes to wayside equipment, the Class III railroad likely is not on the hook, since the majority of their track will not require any. Although they may need to install Wi-Fi access points as initialization points for their trains, depending on where they enter the Class I trackage, otherwise, the majority of these issues falls on the Class I railroads.

Then comes the dirty word, the BOS, or Back Office Server. Class I's all have an IT department that can handle this type of work. With the short line however, this likely is not the case. Going to a third party to set up and support the BOS and slot 10 imaging is a tough item. The slot 10 image is effectively the operating system that handles the communications on board the locomotive, without this the system cannot operate. To do this individually can be cost prohibitive. Searching for another provider for these services cost effectively also takes time and effort. Fortunately, the American Short Line and Regional Railroad Association (ASLRRA), has taken an initiative to sponsor a hosted back office server for crew initialization. This will assist the short line and regional railroads in their need to acquire these services. The expected operation is expected to be available Q2 of 2017.

Most Class I's do not want to share any of this with the tenant railroads leaving some wondering how to handle it. This requirement is to hold the track databases, train information, and crew information to log in. To this end, ASLRRA has since requested a plan be developed that will provide for development of a BOS provider for short lines to help attack this plague that confronts us. But, a question that has not been firmly answered and subject to disagreement is this: What if the short line crews never operate in the PTC territory?

For example, what happens if the short line brings the train with their locomotives, equipped with PTC, to a point short of entering the Class I's main. The short line crew gets off and the Class I's crew boards before entering the main line. In this case, does the short line need to maintain a BOS? None of their crew persons will be operating the train in PTC territory. None of them would be in a crew database for this reason, and the Class I already would have the train make up prior to their crew boarding.

Paperwork

Along with all the infrastructure requirements, there is also paperwork. Each railroad involved with PTC needs to have a PTC Implementation Plan and a Safety Plan. Here also the short lines don't have the workforce like a Class I. Perhaps they don't need to develop a 1000 page plan, but who's to say? What's the starting point? What needs to be included? Since a short line is not, in many cases responsible for wayside equipment, is this something they need to cover in their plan? Who do they ask? This might be able to be contracted out, but cost again is a stumbling block. Again the ASLRRA has stepped in to assist in providing a draft safety plan for members, but this is still in process.

Training and Reporting

And along with infrastructure and equipment comes training and time reporting. While vendors offer some training, with a small workforce, who needs to get the training? In some cases only one individual may be impacted on a particular short line. What happens if they have worked their full day and an issue with PTC comes up? How does the short line railroad handle that issue? Stop the operation until the individual has met their rest requirements?

Legal Issues

And finally, the most daunting issue in all of this is the legal ramification. In discussions, the subject of liability has arisen, some of the contracts required by providers expects a level of insurance liability that is not realistic for most short lines. A number to be in the range of $200M has been noted, highly unrealistic for the small operation. This will continue to a long term stumbling block in getting agreements completed unless some better agreement can be made.

It can be noted from these points that when PTC was envisioned, that the Class I was obviously in the forefront. The regulatory agencies were not considering the short line railroad that would need to be a part-time tenant to the Class I railroads. There is still time to move forward on this, and if we all put our heads together to make a reasonable solution, it will benefit everyone.

1. https://www.fra.dot.gov/Page/P0152 (Accessed June 24, 2016).
2. https://www.aar.org/policy/positive-train-control (Accessed June 24, 2016)
3. Ibid.

Troubleshooting Multiplexer Faults on EMD Locomotives Using EM2000

Prepared by:
Randell L. Honc – Southwest Research Institute (SwRI), and
Stephen Alessandrini – Canadian National Railway (CN)

Introduction

With the addition of Automatic Engine Start Stop, Event Recorders, Smart Train, and other digital devices, the need for more computer processing power on board locomotives grows. One area that is strained to the limit is the number of digital IO parameters that need to be monitored. Locomotives equipped with the EMD EM2000 computer system have found a way around this problem by multiplexing several digital inputs to one digital input channel. However, troubleshooting errors in such circuits can be more difficult than a non-multiplexed input channel that can only sense the status of one device or circuit.

DIO Module Basics

The DIO modules interface digital input and output signal lines between the 74V control system and the 5V computer system. Electrical isolation on the modules prevents either system from interfering with the other. Each DIO module has 24 input channels and 26 output channels. There can be three or four identical DIO (digital input/ output) modules, which are designated DIO-1 through -4.

A typical non-multiplexed DIO input channel monitors contacts of an external device (circuit breaker, relay, contactor, switch, etc.). When the external contacts close, they complete a circuit to 74 V common through the DIO input channel circuit.

Each DIO Module includes a faceplate FAULT indicator light.
If this red indicator lights then the DIO module must be changed out.

74 VDC current flow through a DIO module input channel signals the computer that the input channel status is ON (Logic 1). When the set of contacts connected to the input channel is open, no current flows through the input channel circuit. Circuitry on the DIO module senses that the input channel status is OFF (Logic 0).

DIO module output channels can be used to control high power devices using a 5V control signal. When OFF (Logic 0), the DIO output channel power transistors are open circuit (they do not conduct). When ON (Logic 1), each DIO output channel can provide 3A of continuous current, and has its own short circuit protection circuit. The protection circuit trips at approximately 14A. When tripped, the short circuit protection circuit switches the output power transistor OFF.

Figure 1. Locomotive Computer Chassis with 3 DIO Modules

To enable the channel to turn ON again, computer operating power must cycle (OFF, then ON).

Multiplexer Theory of Operation

On module DIO-1 and DIO-2, input channels 1 through 8 are multiplexed. Each DIO multiplexed input channel monitors up to 6 lines, including one diagnostic line. Figure 2 illustrates the connection of six inputs to DIO-1 input channel 1.

Below each INPUT channel is a Computer Multiplexing (CMU) Plug. All multiplexed inputs, contacts, interlocks and switches are connected to the CMU Plug. The CMU base, to which the CMU Plug connects, acts as a shorting connector so that up to five (5) individual interlock of switches can be connected to one (1) input channel. A CMU Plug connected to a CMU Base is shown in Figure 3.

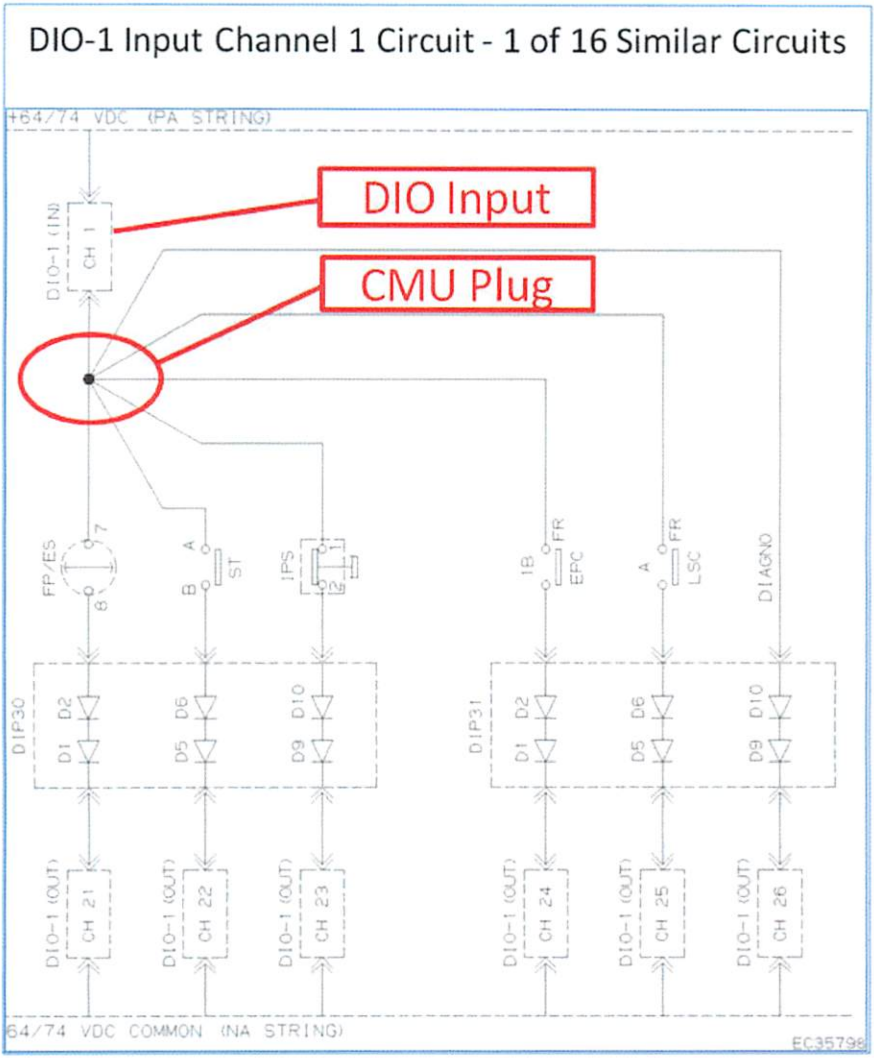


Figure 2. Multiplexing Six Inputs to One Input Channel

Figure 3. CMU Plug with CMU Base

DIO-1 output channels 21 through 26 provide the multiplex outputs for the six multiplexed circuits monitored by DIO-1 input channel 1. When the computer turns a multiplex DIO output channel ON, the channel completes a path to common for up to 16 DIO input channels simultaneously (DIO-1 and DIO-2 input channels 1 through 8 are multiplexed). Remember, each DIO output channel can only provide 3A of continuous current, and has a short circuit protection circuit that trips at 14A. Figure 4 illustrates the connection of sixteen inputs to DIO-1 output channel 21.

Several DIPs (diode input panels) are used in DIO input channel multiplexing. Diode pairs on the DIPs keep one circuit from energizing the other circuits within the multiplexer group. Remember, current flow through a DIO module input channel signals the computer that the input channel status is ON. The diode pairs allow current flow in one direction only. A diode input panel is shown in Figure 5.

In a 100 millisecond cycle that runs like a clock while the computer is in operation, the six DIO-1 multiplexing outputs turn ON, then OFF, in sequence. During the last part of the cycle (see Figure 6), all six outputs are OFF. In this manner, the computer monitors and records the status of up to 80 external devices or circuits (up to 16 at a time), and updates their recorded status every 100 milliseconds.

Troubleshooting Digital Input System Failures

It is during the last part of the cycle that the status of the multiplexer circuit is tested. If the test fails, the computer will log a DIGITAL INPUT SYSTEM FAILURE fault. This fault will cause a "no start" and must be fixed first. We can use the Locomotive Computer Display to help isolate the problem.

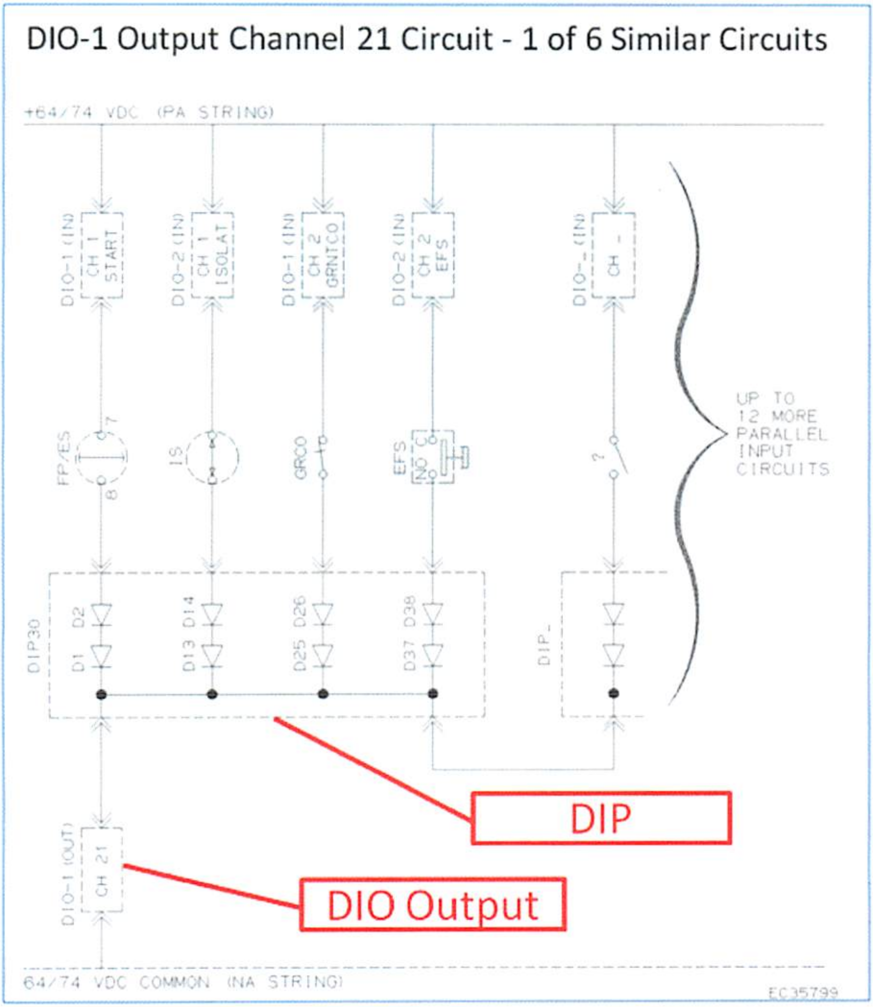


Figure 4. Simultaneously Enabling 16 Input Channels

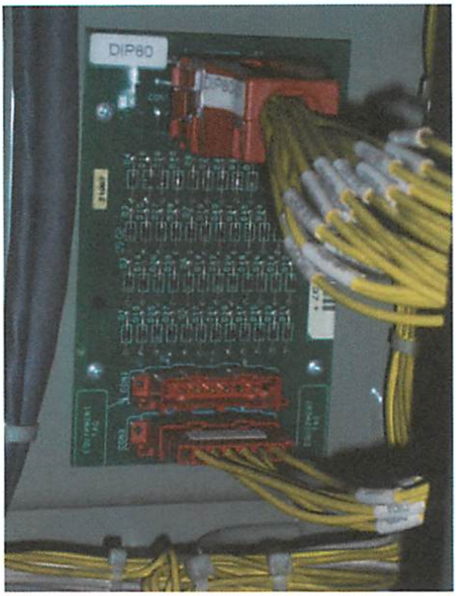


Figure 5. Diode Input Panel

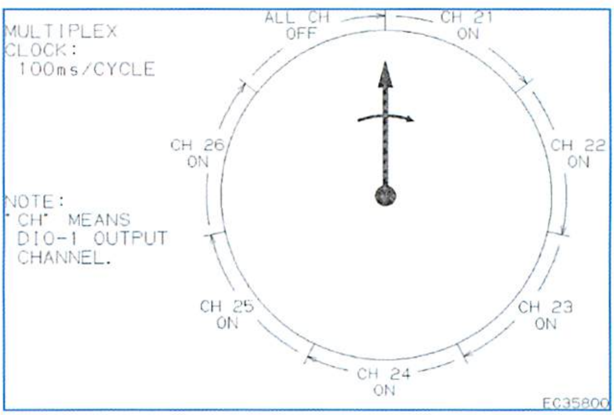
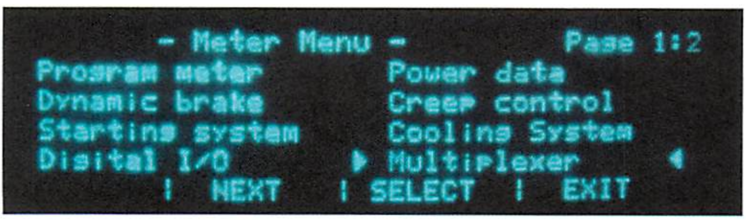


Figure 6. Multiplex Cycle

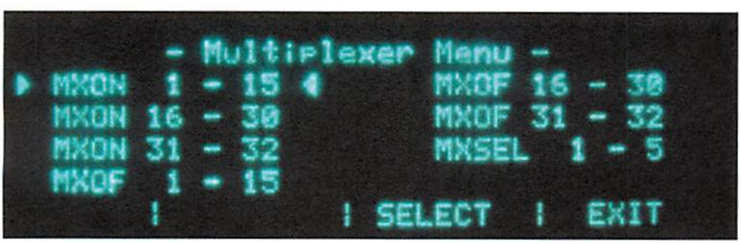
- **Check that the battery voltage is 65V or better prior to testing.**
- **If a circuit breaker for one of the multiplex feedbacks is dropped with the Computer Control circuit still closed, a false annunciation of MUX problems can occur**
- **Always close the Computer Control circuit breaker last**

From the Main Menu: Select Data Meters

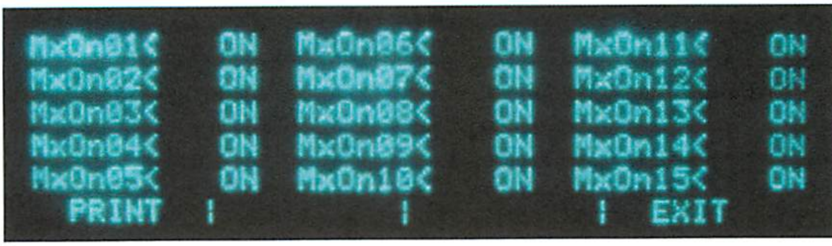
From the Meter Menu: Select Multiplexer



From the Multiplexer Menu: Select MXON 1-15

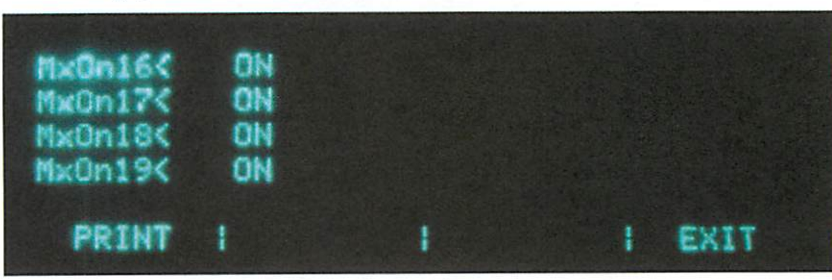


Note any parameters that are OFF



Select EXIT to return to the Multiplexer Menu
From the Multiplexer Menu: Select MXON 16-30

Note any parameters that are OFF.



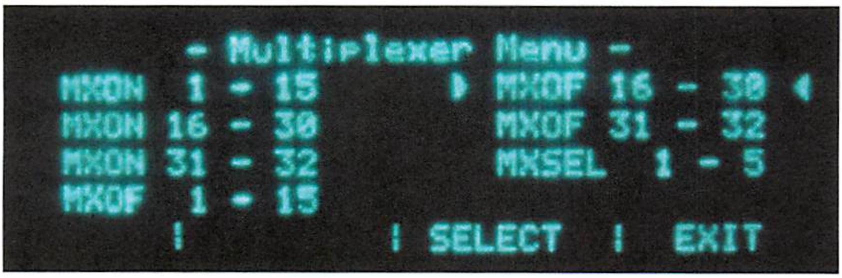
Select EXIT to return to the Multiplexer Menu
Since only MxOn 16 through 19 were displayed in MXON 16-30, we can skip MXON 31-32

From the Multiplexer Menu: Select MXOF 1-15

Note any parameters that are ON.

Select EXIT to return to the Multiplexer Menu

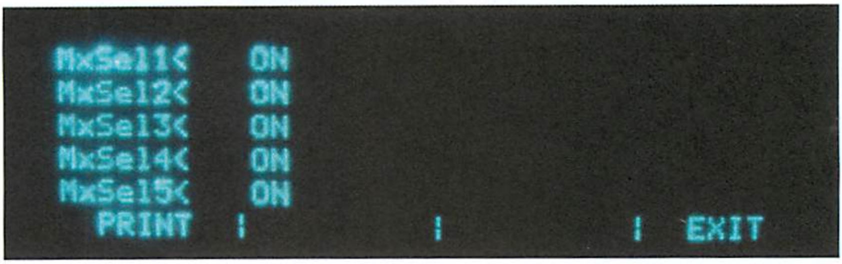
From the Multiplexer Menu: Select MXOF 16-30



Note any parameters that are ON.

Select EXIT to return to the Multiplexer Menu
From the Multiplexer Menu: Select MXSEL 1-5

Note any parameters that are OFF.



If any Parameters were different than expected, we can isolate the problem further by swapping the DIO cards.

- **Only swap DIO cards that have the same part numbers.**
- **Open the Computer Control circuit breaker first**
- **Open all the circuit breakers and open the knife switch**
- **Swap any two DIO cards**
- **Close the knife switch and all the other circuit breakers**
- **Always close the Computer Control circuit breaker last**

Repeat the previous steps and note any changes.

If the parameters change then the problem is with one of the DIO cards that were swapped. Return the DIO cards to their original positions. Swap one of the previous DIO cards with a different DIO card. If the "odd" parameters return to their initial positions then the problem is with the DIO card that was not swapped.

- **Only module DIO-1 and DIO-2, input channels 1 through 8 are multiplexed**
- **Only module DIO-1 output channels 21 through 26 are multiplexed**
- **A good strategy would be to focus on DIO-1 and DIO-2**
- **Swap DIO-1 and DIO-3**
- **If the problem is resolved then DIO-1 (now DIO-3) is bad**
- **If the problem changes then do not discount that DIO-3 was also bad**
- **If we swap DIO-1 and DIO-2 and the problem is resolved then one or more of the output channels 21 through 26 on DIO-1 (now DIO-2) are bad**

An EMD DIO Bench Tester is available that can be used to confirm that a suspect DIO card is bad.

Figure 7. EMD DIO Bench Tester

If all the DIO cards have been swapped and the "odd" parameter never changes then the problem is in the circuit itself. Use the electrical schematic to determine which circuit has the problem. Inspect all plugs, pins, sockets, fastons, and wires within that circuit for loose connections or damage. Correct any defects and retest.

- **Open all the circuit breakers and open the knife switch before removing any plugs**
- **Always open the Computer Control circuit breaker first**

Troubleshooting Failed to Pick Up Faults

Failed to pick up faults are the result of an open circuit and are usually caused by intermittent connections. Use the electrical schematic to determine which circuit has the problem. Inspect all plugs, pins, sockets, and wires within that circuit for loose connections.

If there are multiple failed to pick up faults, look at the circuits for commonalties such as the affected devices using the same CMU plug. The CMU bases *can* be swapped to eliminate them as the source of the problem and noting any changes.

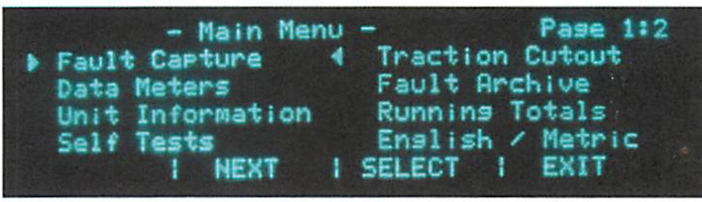
If there are only faults for one individual contactor, troubleshoot that circuit specifically.

The Diode Input Panel (DIP) can be eliminated as the source of the problem by swapping the suspect DIP with any other and noting any changes. Look for any burnt or open diodes or traces on the circuit boards.

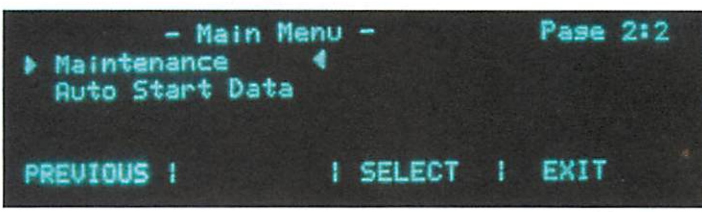
We can use the Locomotive Computer Display to freeze a single digital output channel on and then the circuit can be treated as a non-multiplexed DIO input channel.

Figure 8. CMU Base with a Compromised Solder Joint

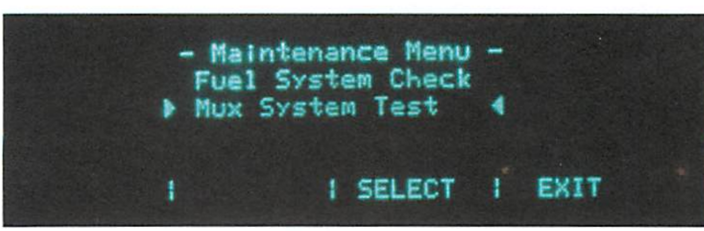
From the Main Menu: Select Next



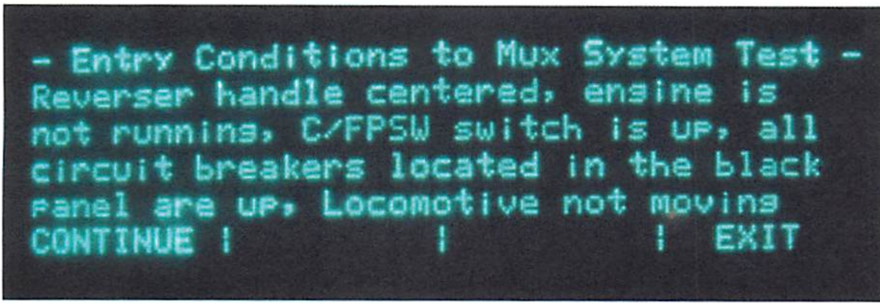
From the Main Menu: Select Maintenance



From the Maintenance Menu: Select Mux System Test



Confirm the Entry Conditions and Select Continue



From the DIO Mux Menu: Select Mux 1

You can now check voltage readings along the schematic to determine where the circuit is open.

You can select next to go the next page or end test to unfreeze MUX 1. The other digital output channels can be frozen similarly.

Troubleshooting Failed to Drop Out Faults

Relay or contactor faults that indicate failed to drop out are the result from either a short circuit or a low voltage ground on the locomotive. Use the electrical schematic to determine which circuit has the problem. Inspect all plugs, pins, sockets, fastons, and wires within that circuit for bare connections.

If there are multiple failed to drop out faults, look at the circuits for commonalties and investigate the circuits these faults all share. If there are only faults for one individual contactor, troubleshoot that circuit specifically.

- **Review the event recorder download in order to determine if there is an event (e.g. bell, horn, etc.) that coincides with the faults. Any event that coincides is a clue to possible grounds on the locomotive and helps narrow down the problem circuit.**
- **Examine the quantity and duration of the faults logged in the archive.**
- **A "failed to drop out" fault that is active once for a significant length of time is most likely a hard ground.**
- **A "failed to drop out" fault that is logged a quantity of times for a shorter duration may be a spike or short time event. For example if the fault is logged 60 times and shows a duration of 10 minutes, you should be looking for an event that has a duration of 10 seconds. Failed suppression diodes on magnet valves (horn, bell, sanding, radar blow down, radiator shutters, etc.) can cause spikes into the circuit. Activate all of these types of valves during testing.**
- **Usually a number of "failed to drop out" faults are logged together. Look for commonality across the faults. Investigate the circuits these faults all share.**

A MUX fault always requires at least two paths to ground in order to create the fault.

1. A ground in the MUX circuit to allow a DIO Input Channel to sense current flow
2. A ground in a circuit to provide a return current path

Be sure to locate both grounded paths, correcting only 1 ground only fixes half of the problem.

One ground will not affect the operation of the locomotive circuitry. When two grounds are present, a new circuit path is created from ground #1 to ground #2. The resulting performance will depend upon the resulting new connection. Figure 9 shows how two grounds would cause the multiplexer DIO input channel to always be ON. If one ground is at the headlight N wire and another ground is at a wire of

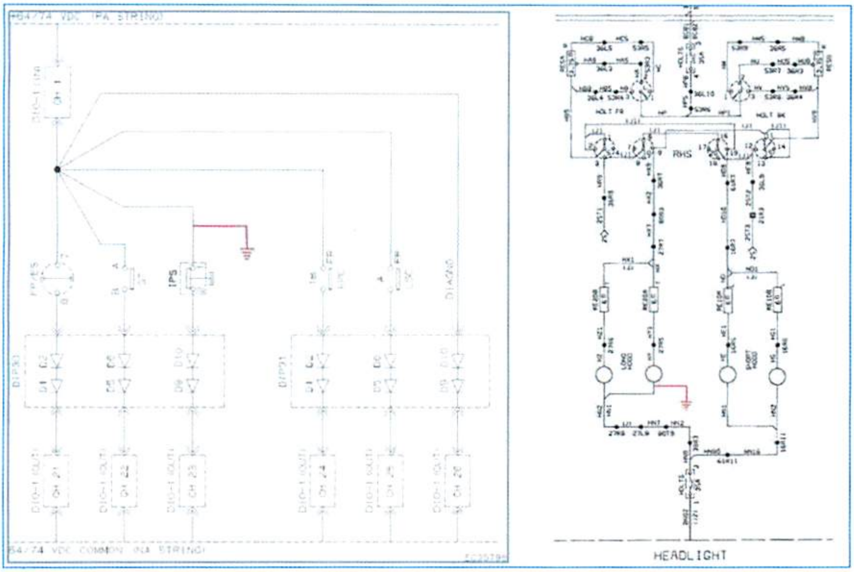


Figure 9. Failed to Drop Out Multiplexer Fault Illustrating Two Ground Paths

the IPS, the IPS wire is tied directly to negative, which creates a continuous current flow through the DIO input channel.

Low Voltage Ground Inspection Procedure:

1. Verify a 15-Watt test light illuminates when connected across battery knife switch.

2. Make sure the locomotive is completely isolated and is not connected to any other locomotives via the MU cable.

- **This indicates that there is a battery negative to car body ground condition.**
- **The ground path will bypass the digital output channel.**
- **The digital input channel will see a steady current flow (ON /Logic 1) since the digital output is bypassed.**

3. Ensure all circuit breakers are closed, and turn on all the lights (cab lights, front and rear headlights, engine room lights, ground and step lights).

> - **This indicates that there is a battery positive to car body ground condition.**
> - **The ground path will bypass the digital input channel.**
> - **The digital input channel will never see any current flow (OFF /Logic 0).**

4. Apply one of the test light leads to the positive side of the battery knife switch and the other lead to anywhere convenient on the car body that is paint free and makes adequate contact. Note if the light illuminates. If it illuminates, go to step 6 otherwise go to step 5.
5. Now apply one of the test light leads to negative side of the battery knife switch and other lead to car body ground. Note if the light illuminates. If it illuminates, go to step 6 otherwise go to step 10.
6. If the light illuminates in step 4 or 5 above, it indicates that there is a low voltage constant ground present in either the negative side or the positive side. Note that a pulsating light bulb indicates a ground in the MUX circuit. If the light is steady and not pulsating, go to the next step otherwise go to step 11.

7. Now connect the test light to the side of the battery knife switch that lit the light above and the other lead to the car body ground.

8. Open one (1) circuit breaker at a time until the test light extinguishes. If the ground clears when a particular circuit breaker is opened, that circuit needs to be inspected in order to find and repair the ground.

9. If ground is still present after opening all the circuit breakers, check all the battery connections for problems.

10. If the light did not illuminate in step 4 or 5 above, it may indicate that there is a low voltage intermittent ground present in either the negative side or the positive side. With one lead connected to battery knife switch and the other to car body ground, perform each of the following tests in order to identify and narrow down the source of the possible intermittent grounds:
    a. Check the turbo lube pump circuit by shutting down the locomotive engine
    b. Operate the horn, bell, sanders, heated windshield etc.
    c. Perform the contactor/relay self test. During the test, keep an eye on the contactor/relay that causes the light to illuminate.

d. Perform throttle 8 load test
e. Perform all the other EM2000 self tests
f.Perform throttle 1 stall test

11. If the test light was flickering in the previous steps, we are troubleshooting a mux circuit ground. View the MUXOFF data meter screens to determine which MUXOFF input is showing ON or flickering between OFF and ON.

12. In the locomotive electrical schematic, identify the circuits that are associated with the affected channel.
13. Once the circuits are identified, the ground can be isolated by disconnecting the D1 plug on the DIP panels one by one until the ground goes away. As you go through the process of disconnecting the D1 plugs that belongs to the affected channel, leave the plugs disconnected. Once the ground is isolated to a DIP panel; leave that panel isolated and start reconnecting the removed plugs to ensure that there are not additional grounds on the mux circuit.

14. After identifying the affected DIP panel, plug the D1 connector back in, ensure the ground is still present. Follow the electrical schematic and start to isolate the ground by removing pins from the D2 and D3 plugs on the DIP panel that was isolated in step 13.

15. After determining the mux channel that has the ground, start isolating the components until the failed component is identified.

16. If no car body grounds was discovered previously then go to step 10 and look for an intermittent ground or proceed with an AC ground inspection. Correcting only 1 ground only fixes half of the problem.

AC Ground Inspection Procedure:

1. Verify the 15-Watt test light illuminates when connected across battery knife switch.
2. Check for grounds with the test light connected between each of the six (1-6) Companion Alternator test points and car body ground under following conditions:
   a. Perform throttle 2 stall test
   b. Perform throttle 1-8 load test. Throttle out slowly and stop at a throttle position at which the light illuminates.
   c. Perform all the blower self tests
   d. Perform Cooling fan self test

3. On SD70ACe and SD70M-2 models, don't use the test light to check for grounds on the APC winding of the companion alternator (APC winding test points are 7, 8 and 9). Follow Service Advisory 05-050: Troubleshooting APC Low Voltage Grounds; check for grounds across each of the test points 7-9 and car body ground with the use of a megger.

Conclusion

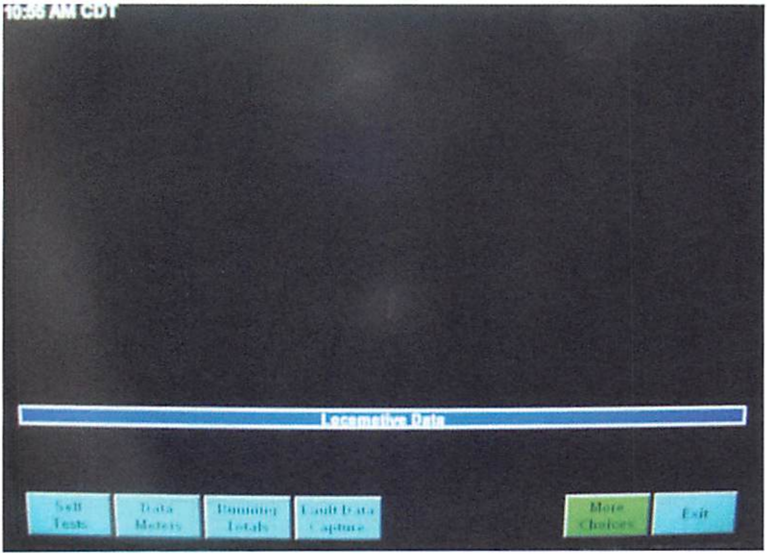
This paper is intended to help locomotive electricians troubleshoot common multiplexer problems on locomotives using EM2000. This document should be used as a guide and should only be used in accordance with local shop safety rules and practices.

Appendix A – Troubleshooting with the FIRE GEN II Display

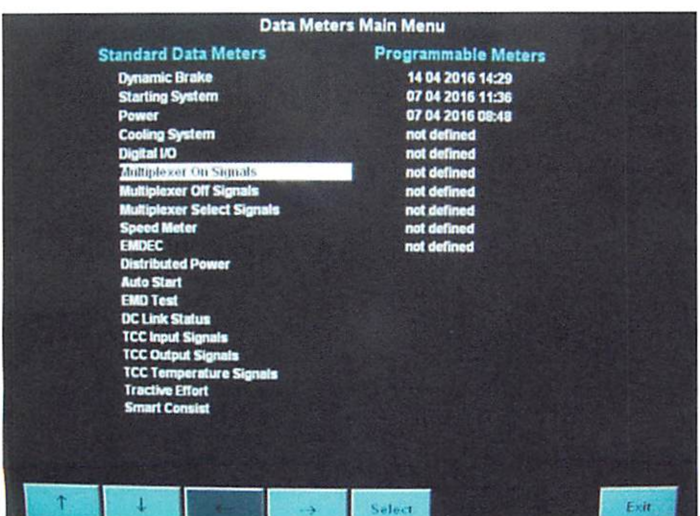
Newer locomotives use the Functionally Integrated Rail Electronics Generation 2 (FIRE GEN II) display. We can use the Locomotive Computer Display to troubleshoot DIGITAL INPUT SYSTEM FAILURE faults as discussed previously.

From the Main Menu: Select Locomotive Data

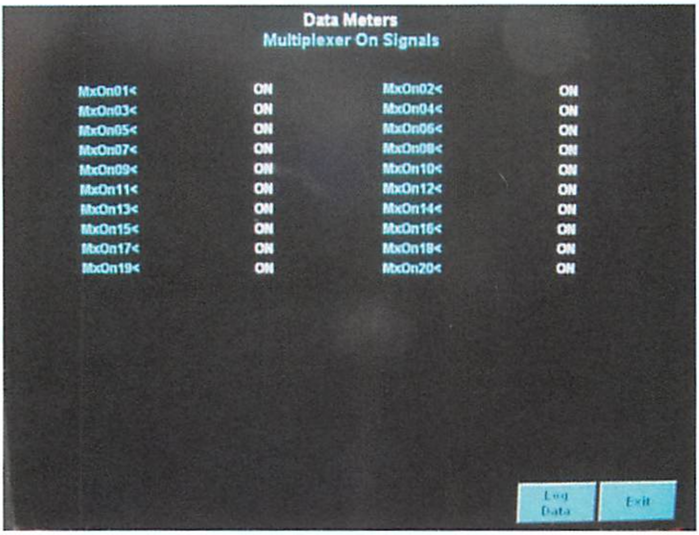
From the Locomotive Data Menu: Select Data Meters



From the Data Meters Menu: Select Multiplexer On Signals



Note any parameters that are OFF.



Select EXIT to return to the Data Meters Menu

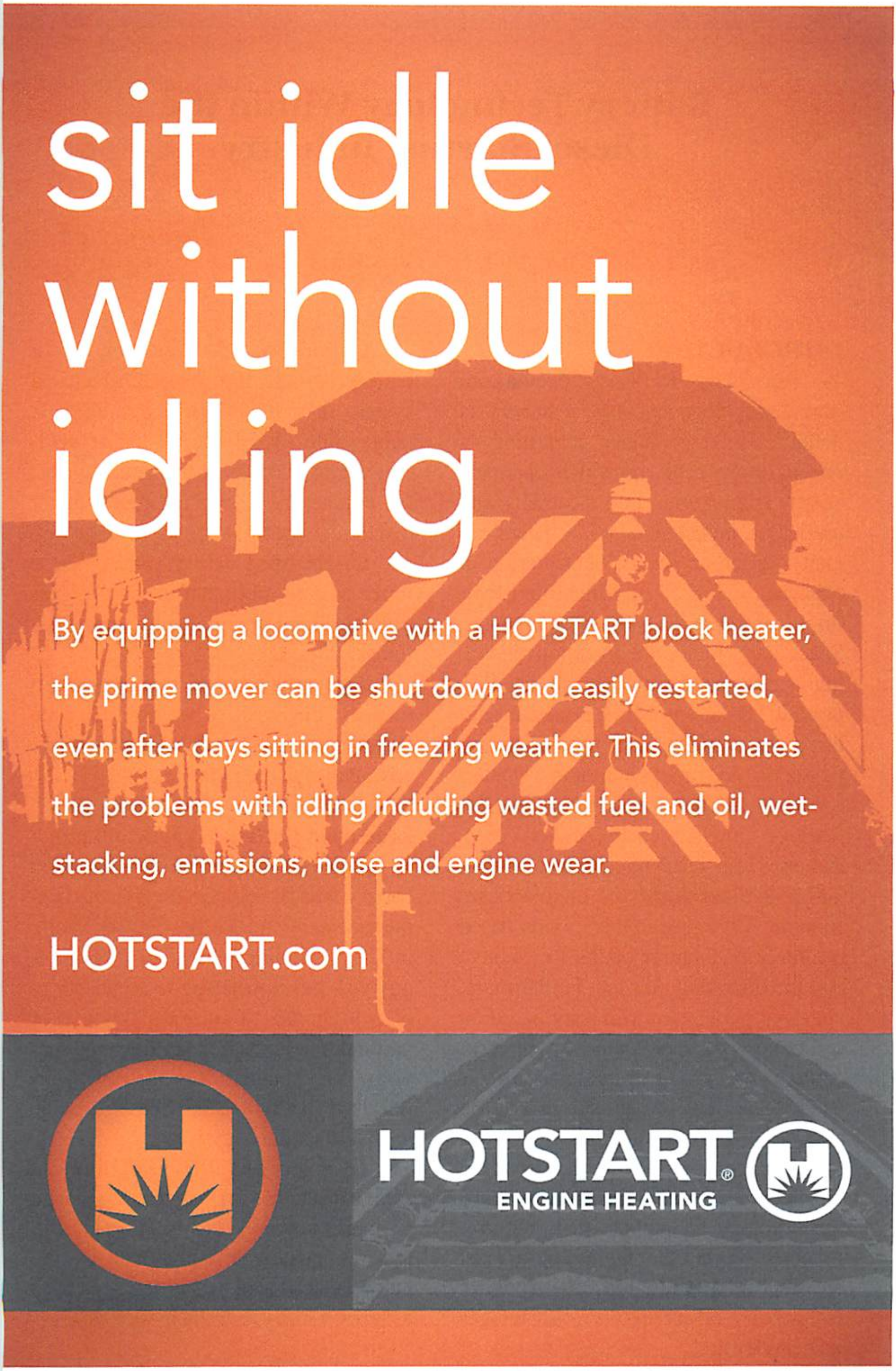
The Multiplexer Off and Select Signals can be viewed similarly. Any DIGITAL INPUT SYSTEM FAILURE faults can be cleared as discussed previously.

References

1. *Electro-Motive Diesel Trouble Shooting Guide 07-012 "Multiplexing Faults"*

2. *Electro-Motive Diesel BP07-041 "MUX Fault Troubleshooting"*

3. *Electro-Motive Diesel "SD70 Series (DC) Locomotive Service Manual"*


sit idle without idling
By equipping a locomotive with a HOTSTART block heater, the prime mover can be shut down and easily restarted, even after days sitting in freezing weather. This eliminates the problems with idling including wasted fuel and oil, wet-stacking, emissions, noise and engine wear.
HOTSTART.com
HOTSTART®
ENGINE HEATING

Battery Technology Within the Diesel Starting Industry

Prepared by:
Chad Muir, East Penn Mfg. Co.

INTRODUCTION

According to Encyclopedia.com (www.encyclopedia.com), a battery is defined as "a container consisting of one or more cells, in which chemical energy is converted into electricity and used as a power source". There are many different forms of batteries in existence today, all of which offer their own advantages and disadvantages. Specifically within the locomotive starting application, batteries are used to provide DC energy which is used to start large diesel engines, in turn providing power to AC traction motors, smaller onboard controls, and crew comfort features (lights, heaters, radios, etc.). Batteries are discharged when in use, and recharged while the engine(s) are running. Charging strategies vary based on the manufacturer of the locomotive and the operating railroad. Furthermore, charging parameters will vary based on the battery technology used. In most cases, if the wrong charging strategy is used, there will be adverse effects on battery performance and life.

The majority of Class I railroads in North America utilize lead acid battery technologies to support their requirements however other technologies exist such as NiCd and Li-Ion. Each battery technology offers its own advantages and challenges.

Considering the function of a battery within the overall electrical system of a locomotive, reliability is paramount. Very similar to the vehicles we drive, if the battery fails to start the engine(s), there is the potential for lost time, expensive, timely change out, and unscheduled maintenance. These repercussions ultimately result in less efficient locomotives, and can be a financial burden.

The remainder of this paper will identify the basic operation of each battery technology and its' respective advantages and challenges.

Lead Acid Battery / Application(s):

The first rechargeable lead acid battery was developed for use in commercial applications by Gaston Plante in 1859. Traditional lead acid technology was developed due to its ability to offer high rates of current. This was of particular interest for starting applications. The abundance of the raw material used (lead), and its' low cost made lead acid technology very attractive.

Over the past 157 years the lead acid battery has undergone significant changes; however the basic chemistry remains unchanged. Throughout its' evolution the lead acid battery has been used to support many industries, such as:

- Automotive / Commercial / Marine
- Airline ground support vehicles
- Underground mining
- Hybrid electric vehicle
- Telecommunications / Datacenters
- Switch gear railroad signal
- Industrial lift trucks
- Solar power
- Military power
- Diesel starting

As industries have demanded a more robust, dependable and cost effective power solution, the traditional lead acid technology has evolved into the current product offerings / technologies we see in today's market place. This can easily be seen in the following battery designs that support the corresponding applications:

- Flooded maintenance free automotive batteries
- Dual purpose marine
- Sealed valve regulated lead acid:
  - o Absorbed glass mat
  - o Gel
- High energy technology
- High temperature stationary technology
- The list goes on . . .

Lead Acid Battery Technology:

A lead acid battery consists of three major components; grid, active material, and electrolyte. Each of these three components plays an essential role in converting chemical energy to electrical energy.

- **Grid**: consisting of primarily lead, a grid serves as the skeleton structure of every battery. In addition to lead the grid consists of various alloys, each of which offers their own advantages in various applications. Grids are cast from molten lead into various sizes, shapes, and constructions to carry the current generated by the battery's active material.

- **Active Material**: consisting of PbO2 known as lead dioxide, the positive active material, and lead, the negative active material, this active material has a similar consistency of wet cement. During the manufacturing process, the cement like material is adhered or "pasted" to the grid and then cured or dried. This process bonds the active material to the grid structure and may vary based on battery manufacturer. Various active materials used are manufactured specifically for the battery application, and may contain elements which provide advantages in very specific operation environments

- **Electrolyte**: consisting of sulfuric acid (H2SO4), and water, the electrolyte interacts with the active material to generate electricity. As the chemical reaction is generated the sulfuric ions will migrate toward the positive and negative active materials, creating current. The electricity is carried through the grid structure to the top of the battery terminal. When submersed in the electrolyte (H2SO4), the active materials react and have the ability to produce and absorb electrical energy. During use, a chemical reaction between the active material and the electrolyte occurs, which is a basic chemical reaction.

These components serve as the basic structure of any lead acid battery. Each manufacturer may have specific processes or alloys that offer a competitive edge.

EVOLUTION OF THE LEAD ACID BATTERIES WITHIN THE RAILROAD

Lead acid batteries have been the predominant means of starting locomotives since diesel fuel became the primary fuel source. The railroad application has evolved over time and there have been several key enhancements to batteries. While the original lead acid product offering was effective as a power source, it required detailed maintenance on regular basis. Battery manufacturer's recommended watering on 30 – 184 day intervals, depending on operating temperature. This was often a difficult and time consuming task. If the maintenance was not complete, the battery could become less reliable, and battery life could be reduced.

Early 1980's

The original diesel starting battery was designed in hard rubber containers, also known as jars, covers, and trays. These components enclosed the internal battery components and liquid electrolyte. This container material became brittle over time and often lead to cracking, and damage. This increased the risk of spillage, and lost electrolyte. In the early 1980's battery manufacturers introduced polyethylene trays, and polypropylene jars and covers. The evolution from hard rubber to plastic materials offered a more robust enclosure. In addition, this change reduced the amount of battery damage in locomotive shops, leading to easier storage, and installation of batteries.

Early 1990's

Historically lack of battery maintenance has been the leading cause of failures in the field. In order to help alleviate the maintenance of the batteries, manufacturers began designing "low maintenance" batteries. This was achieved by reducing the amount of antimony alloy in the grid structure and replacing with calcium. By modifying the grid alloy manufacturers were able to lower the amount of hydrogen and oxygen produced during recharge. This allowed the battery to "use" less water, and require less frequent maintenance. By extending battery maintenance (watering) intervals, the railroads were able to align battery maintenance with their standard locomotive maintenance schedules. This change was effective, however maintenance was still required

Early 2000's

A major product development occurred in the early 2000's when battery manufacturers began offering maintenance free sealed valve regulated lead acid batteries. These batteries were manufactured using absorbed glass mat material (AGM). The SVRLA technology does not require regular watering, or maintenance. Challenges to this technology can be:

- Susceptible to heat
- Susceptible to damage by over discharging and undercharging
- More difficult to recondition if subject to abuse

Considering the railroad application is exposed to all of the above, these are factors that should be closely monitored.

Other Applications

The railroad industry is able to share in the advantages of lead acid batteries in applications such as signal huts, stand by power, and auxiliary power units. Each application requires a very specific design, and offers very specific energy requirements.

Summary of lead acid batteries

As mentioned by the International Lead Association, "Lead acid batteries are the mainstay of storage technologies for renewable energy sources, such as solar cell and wind turbines and are used to power cars, trucks, buses, motorbikes, electric vehicles and hybrid vehicles. Furthermore, lead acid batteries are vital as a back-up emergency power supply in case of main power failure in hospitals, telephone exchanges, mobile phone networks, public buildings and for the emergency services."

With this in mind, the technology offers safe and reliable energy that has been proven over its existence. In addition, lead acid technology offers a sustainable future through a very economical, reliable, and regulated recycling process. According to International Lead Association's article titled "Environmental and Social Responsibility for the 21st Century",

"Lead is one of the most effectively recycled materials in the world and today more lead is produced by recycling than is mined. Recycling lead is relatively simple and in most of the applications where lead is used, such as lead-acid batteries, it is possible to recover it for use over and over again. In fact the quality of recycled lead is often similar to that of metal obtained from mining."

Specifically, lead is able to be recycled over and over again in the new production of batteries. By creating a "closed loop" market, the lead acid battery industry is able to offer customers a responsible, economical, and sustainable means of storing energy.

Furthermore, when considering the robust technology of a standard lead acid railroad battery, the operating railroads are able to take advantage of reconditioning programs offered by various manufacturers, and battery repair companies. This allows a lead acid battery to be "reconditioned" numerous times throughout its life. Due to an economical recycling program, end users are able to offer residual value for the battery at the end of life. This value is typically recognized as a per pound credit, or can be used to offset the cost of reconditioning.

NICKEL CADMIUM

Prior to the evolution of lithium ion batteries, nickel cadmium technology was most commonly used in small footprint power tool applications. Also known as NiCd batteries, they offer a lower energy density than standard lead acid technology. Advantages include their ability to operate in a wide temperature range, in addition to offering a longer cycle life, when the batteries are maintained and cycled in accordance with the manufacturer's recommendations. The basic operation of a NiCd battery is very similar to lead acid batteries, however different metals are used to store and generate electrical energy. Considering different metals are used in the construction, there is a lower cell voltage, making "direct replacement" to lead acid technology difficult.

In addition to smaller foot print applications, NiCd technology is used to support two key functions within the railroad industry, stand by power, and in some cases diesel starting. These two applications, signal huts and starting, have very different requirements.

Signal Huts:

Historically a large number of signal huts seen at track crossings used NiCd batteries as backup power if power was disrupted to the hut. If a power outage were to occur, the signal functions would be powered by a bank of NiCd cells. NiCd batteries operate well in this application due to extreme temperature differences experienced in this application, as well as the low to moderate current required for system functionality. Their long design life of 10 + years and low to no maintenance option for remote locations is also attractive for signal applications.

Starting:

In some cases where locomotives operate in extreme weather conditions NiCd technology has been used for locomotive starting. Where lead acid batteries lose a portion of their capacity in cold environments, NiCd batteries perform as consistently as they would in warmer climates. However, NiCd offers a lower ability to provide high rates of current, in a short amount of time. This typically requires the customer to oversize the battery, and makes charging more difficult.

Operationally NiCd technology works very similar to lead acid technology, but the metals used to create and store chemical energy however are much different. As result of different metals, and alloy composition, the battery offers a lower voltage. In addition, NiCd battery charges differently than standard lead acid batteries. For battery users exploring new battery technologies, proper charging must be evaluated.

NiCd batteries are offered in the market at a very high price point when compared to lead acid. Furthermore, recycling NiCd batteries can be a challenge. The main metal, Cadmium, is difficult to recycle, and presents many environmental hazards. In addition the market for secondary Cadmium is very small, which leads to a low demand. Most recyclers of NiCd batteries charge a disposal fee. Comparing the NiCd challenges, vs. the value of a spent lead acid battery, these factors must be a consideration for companies who are exploring NiCd battery technologies.

LITHIUM ION

Initially, Lithium ion (Li-Ion) batteries have been used as the primary power source for cell phones and laptops as well as hybrid electric vehicles. Over the past 10 years Li-Ion technology has become more refined and has entered into larger scale applications, such as industrial forklift batteries, fully electric vehicles, and stationary backup power. Li-Ion technology can utilize a large variety of different alloy, metal, and chemistries. The combinations below have been used in various applications, and all excel in their own specific area:

- Lithium cobalt oxide
- Lithium manganese oxide
- Lithium nickel manganese cobalt oxide
- Lithium iron phosphate
- Lithium titanate

For example, lithium cobalt oxide excels in long discharge capacity, which is ideal for cell phone, and computer laptop applications, where lithium nickel manganese cobalt may excel in providing high energy peaks, and extended cycle life. However, each chemistry presents shortfalls, and potential hazards. Typically, Li-Ion chemistries that present the highest levels of available energy are the most unstable presenting greater risks for fire and explosion.

As a whole, Li-Ion technology provides a very high energy density product with low to no maintenance. As attractive as this may be, Li- Ion battery technology presents risks and concerns which must be addressed prior to committing to a large scale market shift.

Safety:

The higher the energy potential of a Li-Ion battery the more volatile the battery can become. This can potentially lead to fire, and possible explosion.

Li-Ion batteries also require battery management systems which control the battery to be operated within a specific window which primarily serves as a safety system. If a Li-Ion battery is operated outside of the recommended parameters, the risk of fire and explosion greatly increase.

Recyclability:

Today, a sustainable recycling plan does not exist for Li-Ion batteries. At the end of life, batteries are often disposed of in landfills, or incinerated and then disposed of in landfills. Much like NiCd batteries, there is very little value and use for secondary lithium. In order to ensure a sustainable model of storing energy for the railroads, it is critical to understand how the products being used will be disposed. Unless a sustainable means of disposal is developed, the industry must proceed with caution.

Economics:

Li-Ion technology presents a very high initial cost when compared to the incumbent technologies (Starting applications.....Lead acid; Signal applications....NiCd). In order to justify the higher initial cost, manufacturers/distributors of Li-Ion could potentially could offer a attractive cost per cycle, or cost per ampere. However one must keep in mind, Li-Ion does not currently have a large representation in the locomotive starting industry and demonstrations of real world life test are currently rare.

In addition, onboard charging strategies would have to be modified in order to accommodate Li-Ion's requirements. This may present a financial obstacle for railroads operating a large number of locomotives.

SUMMARY

Lead acid batteries are a reliable and sustainable power option for the rail industry for both starting and signaling. While it is important to consider new technologies, prior to implementation, it is important to consider multiple factors including: safety, sustainability, recyclability, and economics. The current lead acid batteries supplied to the locomotive industry excel in all areas, and manufacturers continue to look to the future to expand upon their success. Future technologies may offer low or no maintenance, scheduled repair intervals, or enhanced communications with AESS controls. As with all industries, we all strive to offer improved and enhanced products to our customers.

Supercapacitor Safety

Prepared by:
Amarjit Soora, ZTR Control Systems

Introduction

Industry demands for reliability, efficiency and performance improvements have utilized technological advancements made with capacitors. While used in early locomotives, the last few decades have seen capacitors become an increasingly critical piece of technology used for traction control, engine cranking and cranking assist technologies. In these cases the locomotive may not operate without these components. Engine, generators, compressors and motors are all main locomotive components, now high energy capacitors must be added to the list of components required for a locomotive to work.

With the benefits of these high energy sources also comes the usual and important questions regarding safety. What are the existing practices and how can the industry improve on them?

What are Capacitors?

Capacitors are an electric device that store electrical energy in an electric field. They typically contain at least two electrical plates (conductors) that are separated by a dielectric. Unlike batteries there are no chemical reactions and they are capable of operating at high voltages.

Super Capacitors (SC) do not have the type of dielectric used by other common capacitors; rather the plates are soaked in an electrolyte and separated by a thin layer. They are typically of high capacitance (ability to store charge), but at much lower voltages (~ 2.8VDC per capacitor).

COMMON USES ON LOCOMOTIVES

Early Locomotives – Low Energy Use

Excitation circuits:

Capacitors are often employed to ramp or "smooth out" the response from excitation circuits. As an example, the locomotive crew will throttle up and down for train handling. Common excitation response circuits correlate a voltage for each throttle position, which is fed as a target to the excitation system. Step change voltage targets to the excitation system will result in choppy response and engine overload, so capacitors are employed to delay or ramp the voltage changes, resulting in smoother train handling.

Time delay circuits for relay:

Relays actuate based on the voltage applied to the coil. When the voltage is removed the coil collapses and the relay (or contactor) deactivates rapidly. In contactor sequencing it may be important to delay the drop out of a relay, so a time delay circuit, utilizing a capacitor, is applied across the coil.

Filter Circuits

Capacitors are commonly used in wide array of electronics to filter unwanted frequencies often referred to as noise. Examples include filter circuits for speedometers, where the desired low frequency signal from the axle alternator is allowed through, but high frequency ripples are blocked.

Modernized Locomotives – High Energy Use

Traction Alternator Crank:

On some locomotive models the traction alternator is used as a synchronous motor for diesel engine starting purposes. During a starting operation a high voltage (~700 V) is applied to a capacitor using the traction alternator stator windings and electrical resonance. The capacitor voltage is then used for forced commutation of the SCRs in the cranking thyristor panels allowing for the generation of a rotating magnetic field using a DC power source (batteries).

DC Link Capacitors:

DC Link Capacitors take the rectified output from the Traction Alternator and applies it to the Inverters. The inverters drive AC Traction Motors with each of the phases produced by the inverter. The locomotive control system provides signals to each phase module to determine how much tractive or braking effort is generated.

Regenerative Circuits:

As opposed to dynamic braking where the kinetic energy is dissipated in the form of heat, regenerative braking systems convert the energy into a form where it can be used immediately or stored until it is required. Super Capacitors are commonly used in this application.

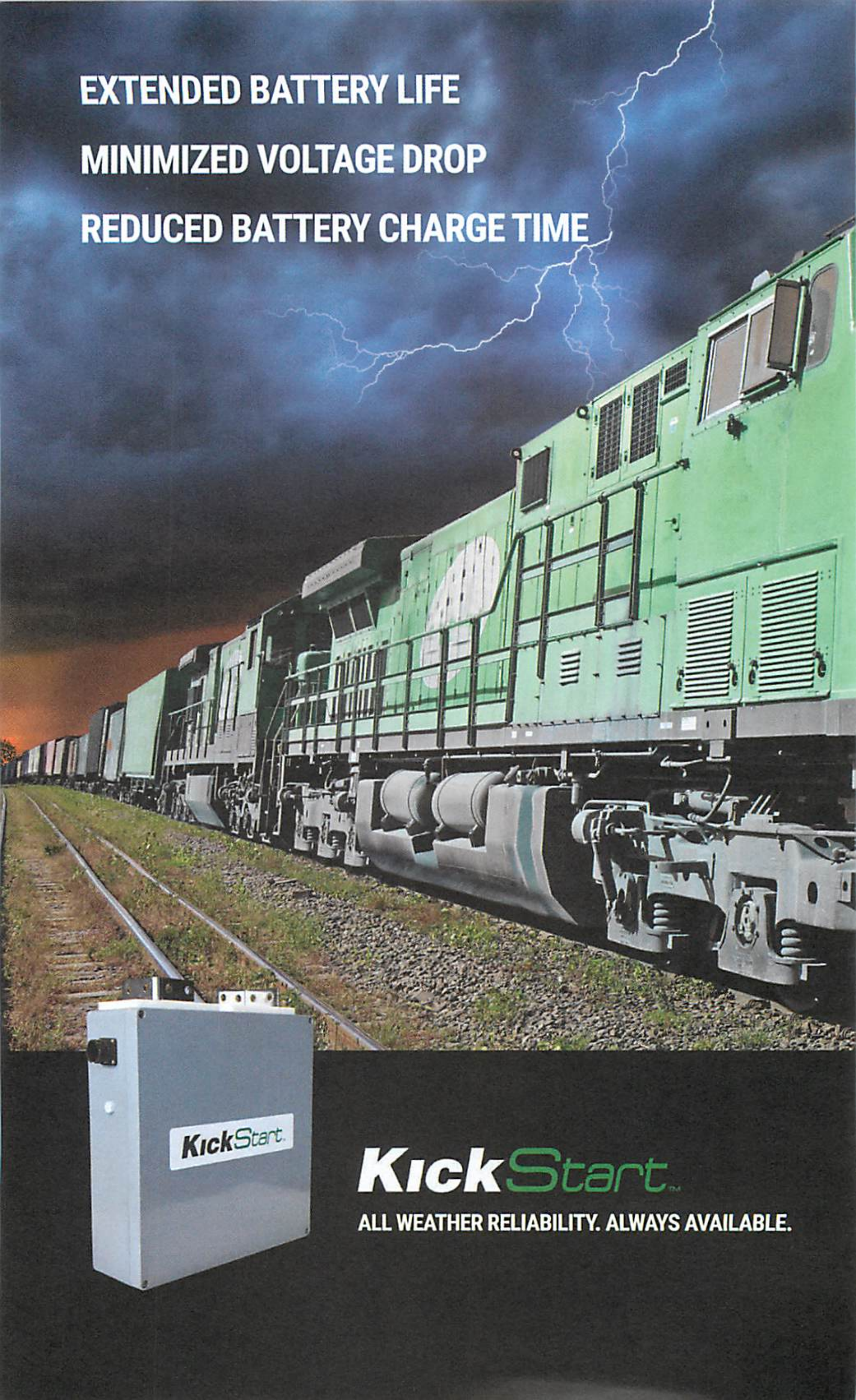
Cranking Assist Circuits:

Lead Acid Batteries have been the primary energy source to crank the engine. Other battery technologies have been sampled in the industry but the lead acid batteries have the capability to discharge energy at a high rate – a requirement to get the diesel prime mover rotating.

Lead acid batteries also suffer from noticeable drawbacks. Performance is affected by several factors, such as demands of AESS usage and lack of adequate voltage regulation and charging systems. Any discussion with a locomotive reliability officer will turn to the headaches they have with batteries, specifically reliability with respect to cranking.

Super capacitors offer advantages over lead acid batteries:

- Faster charge and discharge rates
- Thousands of cycles can be performed without degradation
- Ability to maintain charge for long durations (months)
- Tolerant of temperature extremes
- Able to handle high current discharge without degradation:


EXTENDED BATTERY LIFE
MINIMIZED VOLTAGE DROP
REDUCED BATTERY CHARGE TIME
KickStart
KickStart
ALL WEATHER RELIABILITY. ALWAYS AVAILABLE.


STARTS IN COLD WEATHER
EASY INSTALLATION
LOCOMOTIVE AVAILABILITY
ZTR™
FOR MORE INFORMATION CALL 1-952-233-4340
VISIT US ONLINE AT WWW.ZTR.COM

o The deep cycling of the batteries during crank (peak current demands) is decreased, therefore smaller lower capacity batteries may now be used on locomotives

For these reasons several industries have turned to super capacitors as a source of energy to assist with engine cranking. In some cases the capacitors are used as the prime source of energy for the cranking process, while the battery is used to power onboard systems when the engine is shutdown.

With another high energy system added to locomotive, along with the noted benefits comes the usual (and necessary) question: what do our operators and maintenance personnel need to do in order to ensure safety?

SAFETY PRACTICES TODAY

DC Link Capacitors

Locomotives are designed so that discharge circuits are connected across the capacitors on the DC Link when a locomotive is isolated. However, technicians should not rely on these discharge circuits to keep them safe. These circuits can fail and may not fully discharge the capacitors. Technicians should always verify that the capacitors have fully been discharged as designed prior to performing work on the locomotive.

Always assume a circuit is energized. It is a best practice for a technician to use a Voltmeter and a High Voltage probe to make sure that the capacitors are fully discharged. If the circuit is found to be fully discharged then the technician can proceed with work as planned.

If the capacitor is found to still be charged, then the technician should follow the manufacturer's recommendation to manually discharge the capacitor. Many times this involves connecting a resistive load across the capacitor to short it. After the resistive load is connected then removed, the technician should again verify that the capacitor is fully discharged using the voltmeter and high voltage probe. Some of the more advanced resistive loads have an integrated voltmeter so that the technician can watch the voltage decay as the load is applied across the capacitors.

It is also important to follow all manufacturer's recommendations regarding removing and transporting capacitors. After removing capacitors from locomotives it is a good practice to install a shorting strap across the capacitor after verifying that it is completely discharged. A shorting strap will prevent the capacitor from becoming inadvertently charged from an unexpected source or even static electricity. Consult the manufacturer's recommendations on how to size a shorting strap.

Super Capacitors in Cranking Circuits

Functionally speaking, there are typically two common methods in which they are applied:

1. The capacitors are charged from the battery prior to the engine crank, typically during the prime cycle.

The energy is then discharged into the starting circuit during crank. At all other times there is a mechanism in place to ensure the capacitors are discharged.

2. The capacitors are charged when the engine is running and maintain their charge when the engine is off, always ready to provide cranking energy. One could climb aboard a locomotive that has been inactive for months, and find the capacitors with enough charge to turn the engine. This may be the preferred option since, as opposed to option one, the energy for the capacitors comes from the auxiliary generator instead of the battery, reducing overall Ah draw on the batteries.

Electrically speaking, there are two ways the capacitors will be integrated into the starting circuit, on the battery side of the knife switch or on the load side.

Technicians tend to open the battery knife switch thinking the circuits are dead – with the above, this is not always the case.

There is something to keep in mind: getting people to do something different than they do today is one of the most challenging things in our industry. So perhaps the best approach is to have the supercapacitors integrated in ways that will minimize altering existing practices.

With that in mind one of the simpler things is to integrate the super capacitors on the battery side of the knife switch. Technicians are well aware of the batteries on the battery side of the switch and treat it as "live". In this case, the smartest and easiest thing to do is to treat them like batteries during operation, maintenance and troubleshooting. By adding some safety labels around the capacitors and electrical cubical, we reinforce something the technicians already know.

What if the cranking technology exists on the load side of the knife switch? It was earlier stated that technicians generally treat these circuits as dead once the knife switch is open. Reinforcing the "treat them like batteries approach" may not be enough. Instruments as simple as voltmeters should be used to verify absence of voltage before diving into troubleshooting, but time constraints and years of familiarity may lead to human error – people don't always check everything they are supposed to.

In this case, the best approach is to provide isolation circuits around the super capacitors themselves. For example, the capacitors are connected across the starting circuit during engine cranking or across the auxiliary generator when charging. In all other instances circuits isolate the capacitors from exposed bus bars and connections. This will be in line with systems they are used to dealing with i.e. if power is pulled, the terminals should be dead.

In the event the supercapacitors need to be removed or replaced, the safest practice is to ensure they are properly discharged prior to removal. As with DC Link Capacitors there are different ways to safely discharge capacitors, including automated devices,

ZTR™ AXLE GEN


PERFORMANCE FOR THE FUTURE
FIELD-CONFIGURABLE OPTIONS
UP TO 8 OUTPUTS
PTC COMPATIBLE
ZERO MAINTENANCE
ACTIVE, SELF-POWERED TECHNOLOGY
LOW PROFILE DESIGN
EASY INSTALLATION
ZTR™
FOR MORE INFORMATION CALL 1-952-233-4340
VISIT US ONLINE AT WWW.ZTR.COM

down to using a resistor to discharge the device.

Special attention should be paid to the OEM or manufacturer's guidelines. As previously mentioned some supercapacitor based products will provide isolation circuits such that when the system is not in use or powered down, the capacitors are isolated in the enclosure. Even then special attention must be paid to ensure there isn't a malfunction with the isolation circuits. Again, absence of voltage tests are recommended before beginning any work.

Once the device has been safely discharged, a good practice is to place and leave a grounding strap across the positive and negative terminals. This indicates to the handlers that the device is in discharged state.

SHIPPING CONSIDERATIONS

Per guidelines from manufacturers of supercapacitors, these devices should be shipped in a discharged state with a ground strap across the terminals.

If the device is not enclosed in a control housing and being shipped on its own, there should be a strong outer packing for shipment. If the device is enclosed as part of a control system, consult the manufacturer of the system to obtain and follow recommended shipping & packing practices.

EVERYBODY CALM DOWN

So now that we have put enough fear into everyone over these new monstrous energy sources, let's go over some simple facts:

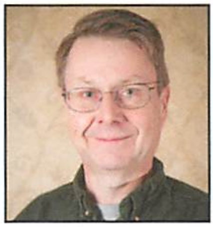
- Supercapacitors are similar to batteries - both should be treated with care and handled to avoid contact with the main terminals
- Super Capacitors and batteries serve a common purpose in that both provide energy – the battery stores energy in a chemical reaction and designed to provide steady power for long term loads, whereas the supercapacitor stores its energy in an electrical field and is designed for rapid high power releases.
- Although the supercapacitor provides a quick high power release and energy for the crank, the battery itself actually stores much more energy. Most supercapacitor based systems are designed to only assist at crank, so while they are capable of greater power delivery they store much less energy than the batteries which need to provide long term energy for locomotive subcomponents.
- The voltage out of the capacitors will not be higher than the source voltage, in this case a nominal 72VDC. Further to this, if a supercapacitor crank assist system is designed correctly there should be protection circuits in place to prevent exposure to overvoltage. This will extend the life of the capacitors and ensure charge voltages are maintained at expected levels.
- Supercapacitors are maintenance free
- They are more environmentally friendly, as they do not contain lead and other potentially harmful substances.

References

1. *https://en.wikipedia.org/wiki/Supercapacitor*
2. *http://www.maxwell.com/products/ultracapacitors/*
3. *http://news.nationalgeographic.com/news/energy/2013/08/130821-supercapacitors/*
4. *http://berc.berkeley.edu/storage-wars-batteries-vs-supercapacitors/*
5. *http://energyandcarbon.com/lithium-ion-batteries-versus-supercapacitor/*
6. *SD70Ace Locomotive Running Maintenance Manual; Feb 2008*

Report on the Committee on Diesel Mechanical Maintenance

Tuesday, October 4, 2016 at 8:45 A.M.



Chairman

Tom Kennedy

Mgr-Loco. Engineering-Mech. Loco. Dept., Union Pacific RR
Omaha, NE

Vice Chairman

Tim Standish

Quality Manager, Progress Rail-A Caterpillar Company
LaGrange, IL

Commitee Members

M. Abbott	Product Development Mgr	HotStart	Spokane, WA
J. Bink	National Sales Manager	JMA Rwy Supply	Carol Stream, IL
J. Brunson	Program/Product Mgr	Graham White Mfg	Burleson, TX
S. Bumra	Asst. Supt.	Amtrak	Chicago, IL
D. Cannon	PTC Project Manager	BNSF Rwy	Fort Worth, TX
T. Casper	AVP-Product & Marketing	PowerRail Distribution	Duryea, PA
S. Cronin	Sr. Mgr Equipt Engrg	Amtrak	Chicago, IL
E. Dillen	Dual Fuel Eng Platform Leader	GE Transportation	Erie, PA
M. Duve	Syst. Mgr. Loco Rel.	Norfolk Southern Corp	Atlanta, GA
T. Frederick	Dir-Engine & Emissions Syst	CSX Transportation	Huntington, WV
D. Freestone	Chief Mech. Officer	Alaska RR	Anchorage, AK
J. Hedrick	Principal Scientist	Southwest Research Institute	San Antonio, TX
F. Jalili	President	Chromium Corp	Dallas, TX
J. Kincaid	AVP Mechanical-Midwest Reg	Genesee & Wyoming	Springfield, IL
D. Nott *(Past Pres)*	Sole Member	Northwestern Consulting	Boise, ID
A. Reid	CMO Locomotives	Iowa Interstate RR	Cedar Rapids, IA
M. Ritchey	President	Curry Supply	Hollidaysburg, PA
C. Shepherd	CMO	Arkansas & Missouri RR	Springdale, AR
J. Sherbrook	VP & GM	Sherpower	Trussville, AL
B. Singleton	VP-Sales	Transpar Corp	Cohoes, NY
G. Sumpter	Sales Rep	Casey & Associates	Ponte Vedra, FL
S. Wiegel	Locomotive Tech Supt	Wabtec Coporation	Park Ridge, IL
G. Wilson	Superintendent of Cars	Iowa Interstate RR	Cedar Rapids, IA
R. Wullschleger	CMO	New York & Atlantic Rwy	Glendale, NY

PERSONAL HISTORY

Tom Kennedy

Mgr-Loco. Engineering-Mech. Loco. Dept., Union Pacific RR
Omaha, NE

Tom was born in Kansas City Missouri and obtained a Bachelor of Science degree in Mechanical Engineering from the University of Kansas, Lawrence Kansas Campus. He joined Boeing Aircraft Company in Wichita Kansas in 1980 as a Systems Engineer covering the areas of reliability, maintainability, life cycle costing, and safety for multiple military projects. In 1990 Tom transitioned to the commercial side of the business where he was a Structural Design Engineer on the 737 aircraft. In 1995 Tom joined Case corporation as a reliability project engineer and became the corporate manager for reliability in 1996. In 2000 Tom joined Electromotive Diesel as the corporate reliability Manager. In 2005 Tom joined Union Pacific Railroad where he manages multiple projects and new technology in the Mechanical Department. Tom is also a member of the Society of Automotive Engineers.

Tom and his wife of 34 years, Joan, live in Omaha Nebraska. Their three sons (Zack, Mike, and Joe) also live in Omaha. Tom and Joan enjoy outdoor activities such as bicycle riding, BBQ's, and playing with their German Shepherd, Nikki.

The Diesel Mechanical Maintenance Committee would like to thank Iowa Interstate Railroad (Greg Wilson and Butch Reid) and Wabtec (Steve Wiegel) for hosting our winter meeting in Cedar Rapids, IA.

Also thanks to the Union Pacific for hosting our teleconferences.

Locomotive Horsepower

Prepared by:
Mark Duve, Norfolk Southern Corporation

Introduction

The term horsepower has been used to rate diesel-electric locomotives since the very first success diesel locomotive the FT 103. There are also many derivatives of the term horsepower used to describe various attributes of a locomotive such as brake, gross, auxiliary, parasitic and traction horsepower. But, what does the term horsepower actually mean when applied to a locomotive? One might think that in general we don't have to precisely know the amount of horsepower a locomotive produces, which in daily operation may be true; but, for the purposes of fuel economy and emissions testing it is important to understand the true locomotive horsepower. In addition, a locomotive's horsepower rating is used in the trading of locomotives for on the basis of horsepower hours. The American Association of Railroads has Recommended Practice RP-589 "Rating for Specific Fuel Consumption of Diesel Electric Locomotives. However, RP-589 has multiple definitions for brake and auxiliary horsepower and does not provide sufficient details for the definitions, and leads to many questions about horsepower rating. This paper will describe the various horsepower terms as they apply to a locomotive and how the terms were developed.

The Rudimentary Definition of Power and Horsepower

In physics the term power means the time rate at which work is done. For instance we know in railroading that the time it takes to move a train over a specific distance depends upon how much power the locomotives have. The more power a train has, the faster the time, and conversely less power means greater time.

In the International System, the unit of power is the Watt which is 1 Joule per second (1 W = 1 J/s). The Watt is named for James Watt who made major improvements to steam engines. In the British engineering system the unit of power is 1 foot times a pound per second (ft * lb. / s). However, 1 ft * lb/s is fairly small and it was suggested by James Watt to rate an engine's power in a quantity that was equivalent to the power delivered by an average horse. Ultimately, one horsepower (with the abbreviation hp) was chosen to be 550 ft *lbs/s. In the International System of units 1 horsepower is approximately equal to 745.7 Watts.

1 Horsepower (hp) = 550 ft * lb /s

1 Horsepower (hp) = 745.7 Watts

Rating Conditions

Per the American Association of Railroads (AAR) RP-589, the ambient conditions for rating locomotives are as follows:

Barometric Pressure:	28.86 in Hg (corresponds to roughly 1000 feet in elevation)
Ambient Air Temperature:	60°F
Fuel Temperature:	60°F
Specific Gravity of Fuel:	0.845
Fuel Higher Heating Value:	19,350 Btu/lb.

To correct the overall horsepower ratio divide the observed fuel higher heating value by the AAR higher heating value (19,350 but/lb and multiply this figure times the horsepower observed. To correct for the Barometric Pressure and the Ambient Air Temperature see the formula in the Auxiliary Horsepower section of this document.

With governor controlled engines, as the ambient conditions varies from the standard conditions the horsepower would vary. Colder temperatures would allow more horsepower to be made; whereas, hotter temperatures would produces lower horsepower. The same is true for barometric pressure and fuel heating value, which will cause lower horsepower numbers with lower barometric pressure and lower fuel heating value.

On today's microprocessor controlled engines, where fuel injection is better regulated, the horsepower will stay relatively the same; the difference is the amount of fuel. At temperatures greater than the ambient conditions, the fuel rate will increase. Conversely at temperatures lower than ambient the fuel rate will typically go down (note, this may not occur with some emissions controls.)

Horsepower Definitions

Brake or Gross Horsepower

Both EMD and GE have different terms for the total engine horsepower. GE uses the term Gross Horsepower, and EMD uses the term Brake Horsepower. These two terms are the same. The brake horsepower is the useable horsepower delivered to the load. Brake (Gross) Horsepower is the total output (usable) horsepower for an engine.

For calculations of brake/gross horsepower the power provided by the engine for engine mounted water pumps, water pumps and either fuel injector pumps or unitized fuel injection systems is not considered part of the output power of the engine.

Brake Horsepower (EMD)

On an EMD engine the brake horsepower includes all the engine output to the flywheel (or coupling disk) which is connected to the alternator (generator)/companion alternator, and the power supplied by the auxiliary drive shaft which is used to turn the auxiliary generator and in most EMD models the combination traction motor blower and alternator (generator) blower). The power supplied to engine driven air compressors through the crankshaft stub shaft is also considered in the brake horsepower

Gross Horsepower

On a GE locomotive, the gross power is all the power the engine uses to turn the main alternator and auxiliary alternator.

Net Traction Horsepower

The Net Traction Horsepower is the rectified output power from the main generator (alternator).

To determine the Net Traction Horsepower (NTHP), the following formula is used:

$$NTHP = \frac{\text{Volts X Amps}}{\text{745.6 watts/amp}}$$

On the GE EVO Tier 4 locomotive, there is no auxiliary alternator, which in this case, the output from the rectifiers to the main inverter system should be measured.

Auxiliary Horsepower

The auxiliary horsepower otherwise known as parasitic loads are those loads which are necessary for the locomotive operate. The locomotive builder will provide the auxiliary horsepower loads at AAR conditions. The typical locomotive accessory loads are as follows:

- Engine Cooling Fans
- Traction Motor Blower(s)
- Inertial (Spin) Filter Blowers
- Control System Power* (Auxiliary Generator)
- Air to Air Cooling Fans (if equipped)
- Inverter Blower (for AC locomotives, if equipped)
- Air Compressor – Engine Driven, unloaded**

*The Control System Power required for the control system and/ or the computer. This power does not include the power required to lights, cab heat or air conditioning

** The unloaded engine driven air compressor is not necessary required to run the locomotive, but it can 't be stopped without running the engine.

These loads must be rated for the AAR conditions. To correct the auxiliary for the conditions use the following formula:

$$\text{Rated Auxiliary HP}_{AAR} \times \frac{(\text{Baro}_{obs})}{(\text{Baro}_{AAR})} \times \frac{(491.67 + 60^\circ F)}{(491.67 + \text{Temp } ^\circ F_{Obs})} \times \frac{(\text{Engine Speed}_{Obs})^3}{(\text{Engine Speed}_{Rated})^3}$$

(The "Observed" subscript designates the test conditions, and the AAR subscript designates AAR conditions)

In correcting to AAR conditions, the absolute temperature must be used (Rankine Scale) and the engine speed must be corrected to the engine speed at which the auxiliary horsepower was rated at AAR conditions. An example of the correction is listed shown below:

Auxiliary Horsepower Correction Example:
Given:
Cooling Fan at AAR conditions, throttle notch 8 (900 rpm): 37 HP

Tested Conditions:
Ambient Temperature: 90°F
Barometric Pressure: 32.2 in Hg
Engine Speed: 950 rpm

$$37 \text{ HP}_{AAR} \times \frac{(29.92_{obs})}{(28.86 \text{ Baro}_{AAR})} \times \frac{(491.67 + 60^\circ F)}{(491.67 + 90\ ^\circ F_{Obs})} \times \frac{(950 \text{ rpm})^3}{(900 \text{ rpm}_{Rated})^3} = \mathbf{42.78 \text{ HP}}$$

Traction Horsepower
The horsepower that is delivered from the engine to the main generator (alternator) that will be used to power the traction motors. To calculate the Traction Horsepower, the Net Traction Horsepower must be divided by the main alternator efficiency. The alternator efficiency should be obtained from the locomotive builder. The equation for Traction Horsepower (THP) is as follows:

$$\text{THP} = \frac{\text{Volts X Amps}}{745.6 \text{ (watts/amps) X Alternator Efficiency}}$$

Hotel Loads
Hotel Loads are those loads used for the cab features such as cab heat and or air conditioning, lights refrigerators, radios and any other non-essential loads such that if turned off will not affect the ability of the locomotive to provide traction power.

Example Calculation (SD40-2)

From Load Test:
Main Generator Volts: 1140
Main Generator Amps: 1870 AAR Conditions

From EMD Manual (Loads) at throttle notch at AAR loads (note, if test is run at conditions not specified by AAR conditions, the auxiliary loads must be corrected to AAR Conditions.

Aux Gen HP:	4.0 (Control System Horsepower)
Cooling Fans:	111.0 (3 Fans on High)
Inertial Filter Blower:	12.0
WBO Air Compressor:	15 (Unloaded)

Parameter	Formula	Calculation
Net Traction Horsepower (NTHP)	Volts X Amps / 745.6	1140 Volts X 1870 Amps / 745.6 = **2859 NTP**
Traction Horsepower (THP)	THP / Generator Efficiency	2859 / 93.9% = **3045 THP**
Brake (Gross) Horsepower (BHP)	THP + Auxiliary Loads	3045 THP + 4 Aux Gen HP + 111 Cooling Fan HP + 12 Inertial Filter Blower 15 WBO Air Compressor (Unloaded) **3187 Brake Horsepower**

Note on the EMD SD40-2, the main generator efficiency incudes the traction motor and generator blower horsepower.

Locomotive Rating Horsepower

Generally both EMD and GE rate the locomotive horsepower based upon the traction horsepower. But, in reality both have differing definitions of locomotive rating horsepower. These definitions are based upon how the auxiliary loads vary with ambient conditions.

Today, both EMD and GE build locomotives in which the engine control system allow a maximum brake horsepower load of 4500 brake (gross) horsepower at

all times if the engine is healthy. This control scheme is referred to as Brake Horsepower Control where the amount of traction horsepower available is the 4500 BHP minus the auxiliary and hotel loads. As the auxiliary loads decrease the traction horsepower increases and conversely as the loads increase, the traction horsepower decreases. Since the engine cooling fans often cycle from high to low during AAR conditions, the amount of traction horsepower can vary at AAR. Both GE and EMD differ on rating their locomotives on the variations of the traction horsepower at AAR conditions.

GE Locomotive Rating Definition

GE rates the Traction Horsepower based upon the maximum horsepower that can be available during AAR conditions rounded to the nearest hundred horsepower. The maximum traction horsepower an ES44AC can make at AAR conditions is 4365 THP, which rounded makes 4400 THP.

EMD Locomotive Rating Definition

EMD rates traction horsepower based upon the traction horsepower that can be made at all times during AAR conditions; in other words the minimum traction horsepower and it is rounded down to the nearest 100 horsepower. The SD70ACe can deliver 4350 traction horsepower, but is rated at 4300 THP.

Prior to the 2005 Tier 2 EMD locomotives with a few exceptions, EMD utilized Traction Horsepower control logic. Under the THP control scheme, the main generator output is regulated to deliver a maximum of 101% (One Hundred and One Percent) of the rated locomotive Traction Horsepower. As the auxiliary loads increase and decrease, the maximum allowable traction horsepower remains constant. Only under extreme conditions, will the locomotive derate. The drawback to THP control is that when operating at conditions below AAR conditions, there is more available engine horsepower that could be utilized.

Conclusion

There are many variations of the term horsepower that describe a locomotive. These terms include Brake (Gross) Horsepower, Auxiliary Horsepower, Hotel Horsepower, and Traction Horsepower. These horsepower numbers will vary with deviations from the stated AAR conditions and sometimes at AAR conditions. Both major locomotive builders rate their locomotives based upon Traction Horsepower. But, due to the nature that even at AAR conditions the loads are not constant; this leads to a dilemma of what is the real definition of Traction Horsepower. As the AAR Recommend Practice reads today, there is no clear definition on how to rate a locomotive, and thus the definition of rated locomotive horsepower is determined by each locomotive builder.

Best Practices Locomotive Fuel Spill Prevention

Prepared by:
Steve Wiegel, Wabtec and
Greg Wilson, Iowa Interstate Railroad, Ltd.

The focus of this paper will be centered on the Best Practices to prevent fuel spills while fueling locomotives. As such we will apply our focus towards the onboard equipment as opposed to the wayside equipment.

Whether you are fueling your lawn mower, putting gas in your fishing boat, or filling your locomotive with 4,000 gallons of Ultra Low Sulfur Diesel (ULSD), it's a fairly unchanging task that takes place many times a day. Because the operation is so mundane, it is also one task that will allow for complacency amongst our team members working the service tracks. When complacency sets in, problems occur; when they take place fueling locomotives, other problems such as fuel spills are inevitable. Throughout the paper we will explain what to look for and how to avoid potential problems.

The most widely used system in the industry is manufactured by Snyder Equipment Company. This system delivers over 8 billion gallons of diesel fuel annually through over 7000 nozzles in service worldwide. Because of this, our paper will focus around the Snyder system.

Due to the importance of a properly working fueling nozzle as it relates to overall performance of the system, the nozzle is the one piece of the wayside equipment we will discuss.

Snyder II Automatic Nozzle operation

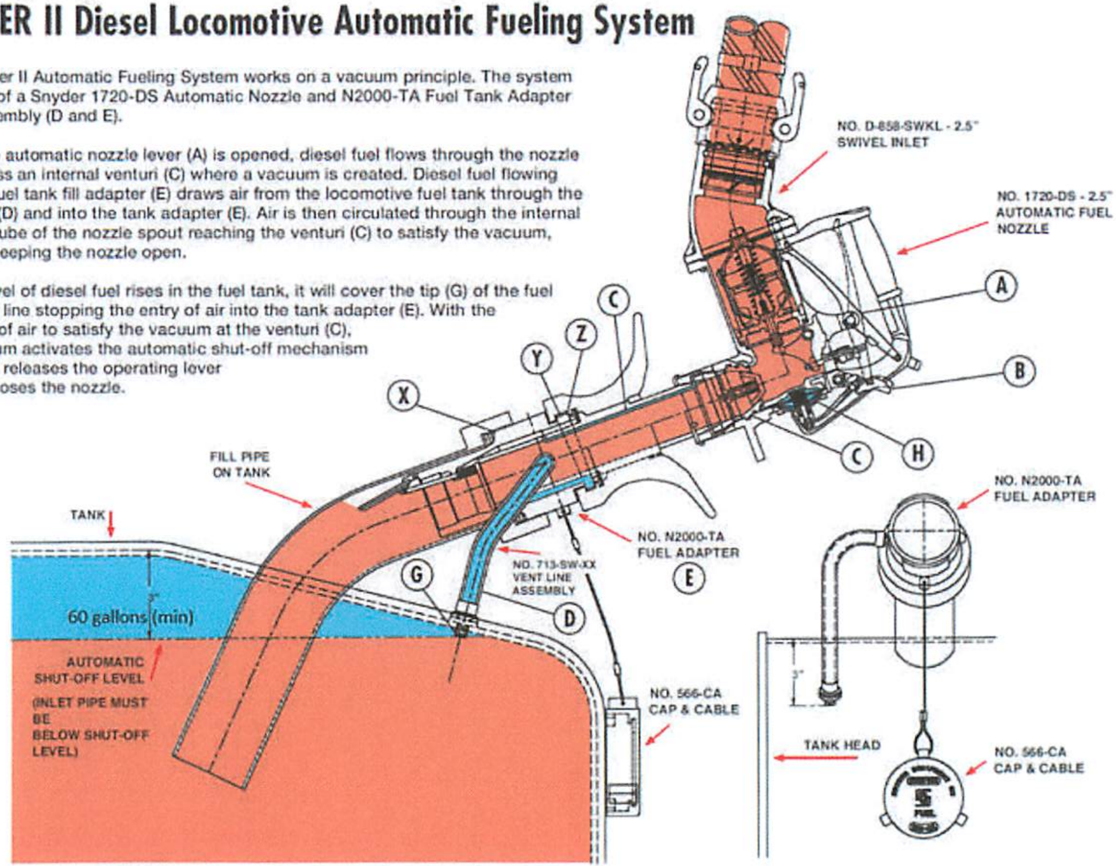
When the automatic nozzle lever is opened, diesel fuel flows through the nozzle and across an internal venturi where a vacuum is created. Diesel fuel flowing into the fuel tank fill adapter draws air from the locomotive fuel tank through the vent line and into the tank adapter. Air is then circulated through the internal vacuum tube of the nozzle spout reaching the venturi to satisfy the vacuum, thereby keeping the nozzle open. As the level of diesel fuel rises in the fuel tank, it will cover the tip of the fuel tank vent line stopping the entry of air into the tank adapter. With the absence of air to satisfy the vacuum at the venturi, the vacuum activates the automatic shut-off mechanism which releases the operating lever and closes the nozzle. See the figure on next page for details.

SNYDER II Diesel Locomotive Automatic Fueling System

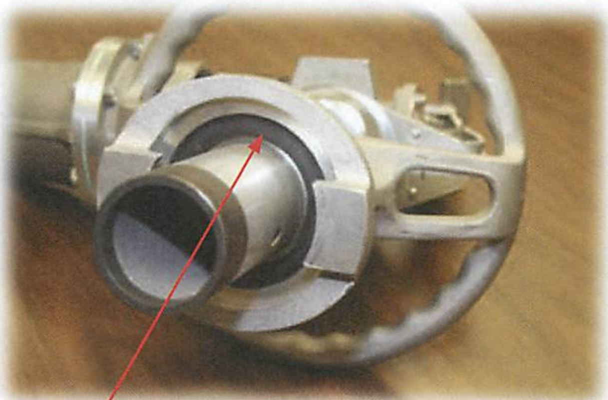
The Snyder II Automatic Fueling System works on a vacuum principle. The system consists of a Snyder 1720-DS Automatic Nozzle and N2000-TA Fuel Tank Adapter Vent Assembly (D and E).

When the automatic nozzle lever (A) is opened, diesel fuel flows through the nozzle and across an internal venturi (C) where a vacuum is created. Diesel fuel flowing into the fuel tank fill adapter (E) draws air from the locomotive fuel tank through the vent line (D) and into the tank adapter (E). Air is then circulated through the internal vacuum tube of the nozzle spout reaching the venturi (C) to satisfy the vacuum, thereby keeping the nozzle open.

As the level of diesel fuel rises in the fuel tank, it will cover the tip (G) of the fuel tank vent line stopping the entry of air into the tank adapter (E). With the absence of air to satisfy the vacuum at the venturi (C), the vacuum activates the automatic shut-off mechanism (H) which releases the operating lever (A) and closes the nozzle.

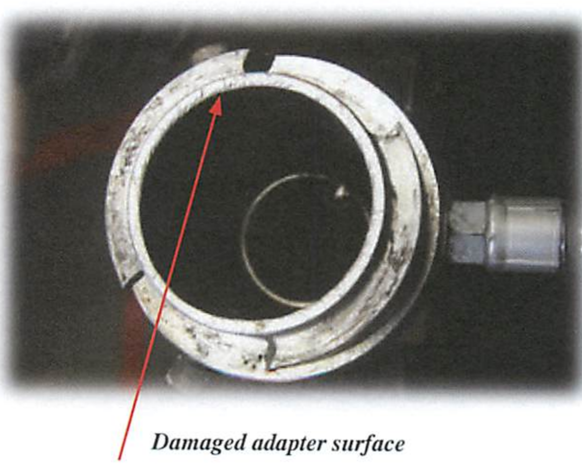


System checks



a) Gaskets

The coupling gasket between the nozzle and the tank adapter is vital to preventing leaks. The gasket surface must be intact and free of obstructions. To check the gasket, turn the nozzle assembly ¼ turn and pull away from the adapter. Remove any foreign objects in the sealing area that could prevent a proper seal between the nozzle and adapter. Inspect the coupling gasket and replace the gasket if it is nicked or damaged. Also check the surface of the tank adapter for any damage that would prevent a seal; replace the tank adapter if necessary.



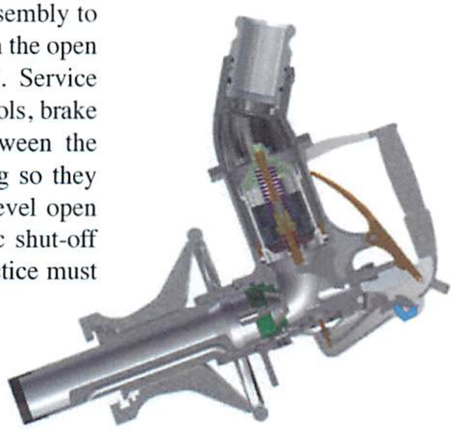
Damaged adapter surface

b) Fuel Hoses

Be sure to check the main fuel hose for damage or excessive wear that may cause it to burst under pressure. Inspect swivel fittings to ensure they do not leak.

c) Nozzle Latches

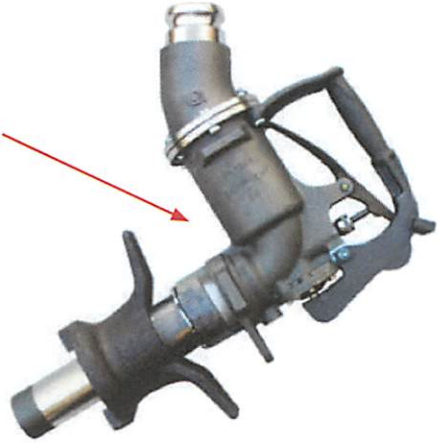
Check the nozzle lever latch assembly to make sure it holds the nozzle lever in the open position with the latch inoperative. Service Track personnel will often wedge tools, brake shoes or other foreign objects between the lever handle and the nozzle housing so they can do other work. Propping the level open defeats the purpose of an automatic shut-off and can lead to fuel spills. This practice must be avoided.



Never wedge the handle open with foreign objects!

d) **Nozzle Bodies**

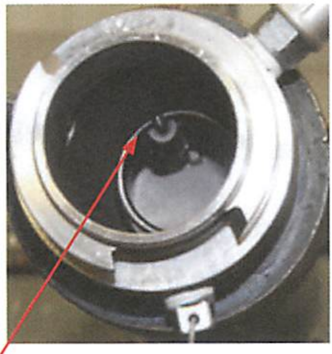
Check for fuel leakage from the body of the nozzle. If nozzle body leaks are discovered at the fueling station, replace the nozzle and send the leaking nozzle in for repair.



e) **Tank Adapters**

Improvements in tank adapter technology have decreased the chances for fuel spills. The flapper design in newer tank adapters prevents sloshing of fuel and fuel spills on uneven tracks, and it is essential to newer generation roll-over tank designs. However, the adapter must be installed properly. The hinge of the flapper should be installed as close to the 12 o'clock position as possible, and must be between the 11 o'clock and 1 o'clock positions to operate properly.

Older Design, No flapper



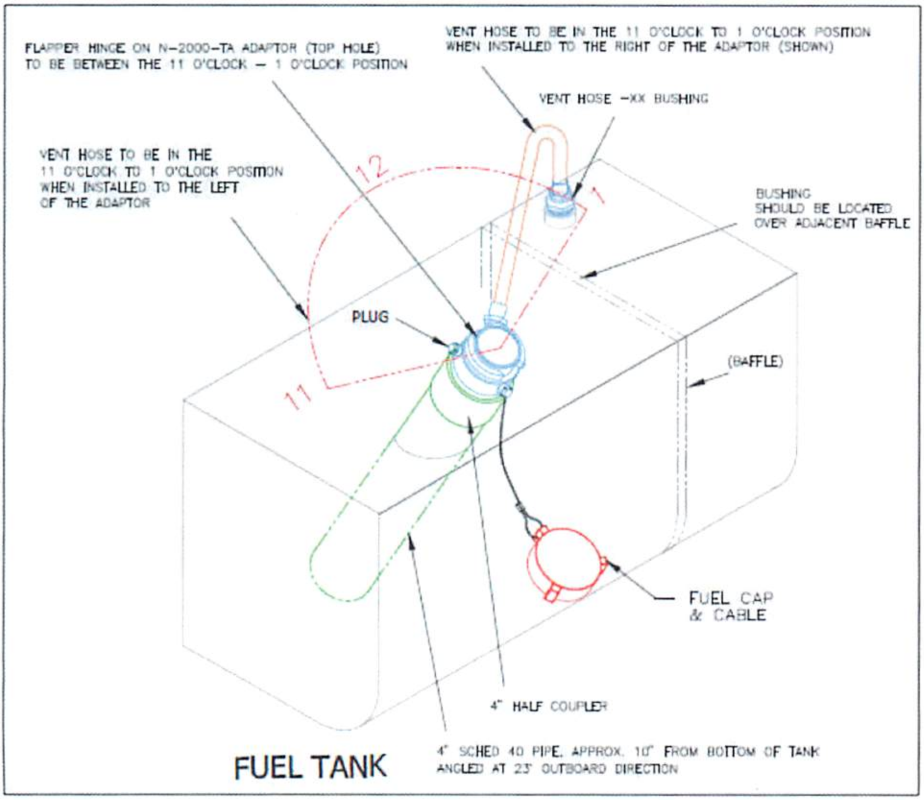
Latest Design, Flapper hinge (correctly applied hinge between 11 and 1 o'clock positions)

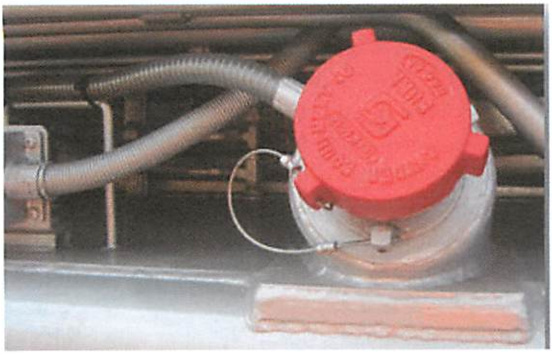
f) Vent Hoses

The vent hose may be the one of the most overlooked and improperly applied components of the onboard fueling system. A lack of understanding of vent hose operation causes problems to periodically resurface. In our view, this should be a topic of focus for every operator throughout the industry

In order for the system to work as designed, the vent hose must be installed between the 11 o'clock and 1 o'clock positions (toward 12 o'clock) as shown in the drawing below.

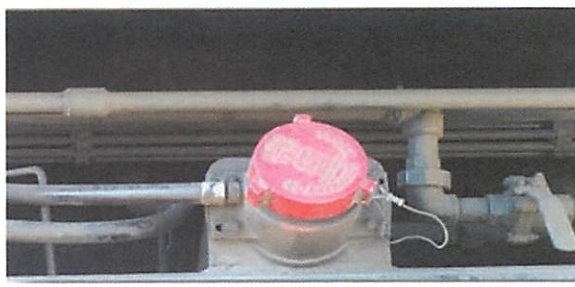
Once you have installed the vent hose in either upper location, install a plug in the unused hole in the other upper position. Finally, install the plug with cable and cap at the 6 o'clock position.





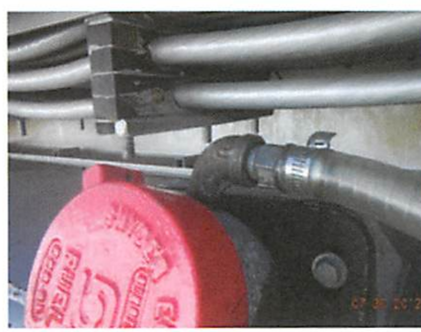
Vent hose correctly applied

Neither the vent hose nor the flapper is applied correctly



Vent hoses on older systems without the flapper design must still be installed between 9'o'clock and 3 o'clock (on the 12 o'clock side) to keep fuel from collecting in low spots and creating premature vacuum.

It is also important to use the fittings supplied with (and designed for) the vent hose. A correct installation is shown (above). Elbows, reducing bushings, hose clamps, and other restrictions and modifications (including the examples as depicted in photos) should not be used.



Incorrect hose and fittings

In short, anything that blocks, restricts, or changes the airflow through the vent hose will affect the proper operation of the nozzle. This includes fuel collecting in sagging vacuum lines and additional fittings that restrict the intended airflow.

g) Fuel Tanks

Fuel tank inspection must be performed prior to fueling. Fuel tank inspections should be performed whether it is a railroad employee or contractor. Look for obvious defects, damage from side swipes, derailment damage, grade crossing incidents and tank construction defects.

Fuel tank damage

A majority of spills can be associated with human error, either by improperly applied tank adapters, vent hose, flapper or even the most obvious using foreign material to wedge open the nozzle. A review of current training procedures and what to look for in regards to improperly applied, damaged or faulty equipment would be our first recommendation for corrective action. A second recommendation would be to further educate front-line workers as to how the equipment is designed to work and potential risks involved. As a final thought to consider as a risk mitigation practice, keep fueling personnel present and attentive during fueling operations.

Are there better ways to educate and reinforce the importance of properly working system to prevent fuel spills? Some operators have decals with pictures just above the tank adapter, but as you can see this decal suggests only that we need to check during winter operations. Why not check every time we fuel?

In conclusion, by surveying random locomotives operated by different railroads, we find that a vast majority do not have the equipment applied correctly. By correcting application issues and keeping training practices up-to-date, the chance of fuel spills can be greatly reduced.

Cleaning up fuel spills is costly and the reporting of spilled fuel varies by state. Some states want it reported if any amount is spilled while others have a weight requirement. In any case, fuel spills are preventable. Train your fueling personnel to take the extra time to prevent spills that can save thousands. Take the time and do it right and minimize your risk.

References:

Maintenance of Locomotive Fueling Systems for a Spill Free Operation. (1987). Locomotive Maintenance Officers Association, 200-210.

Snyder Equipment Co., Inc. http://www.snyderequip.com/

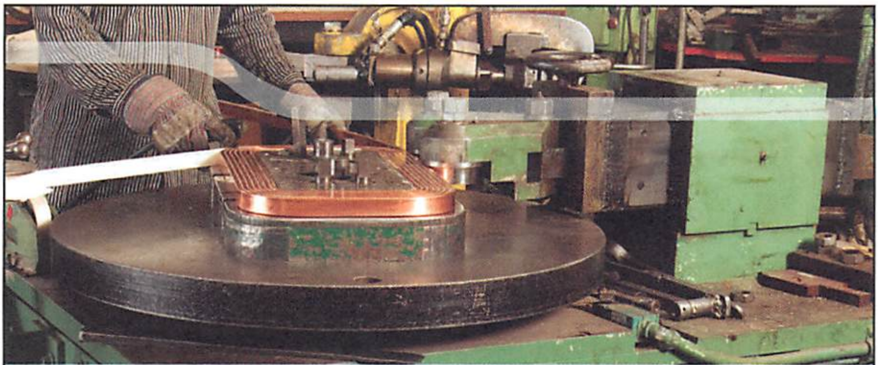
Acknowledgments:

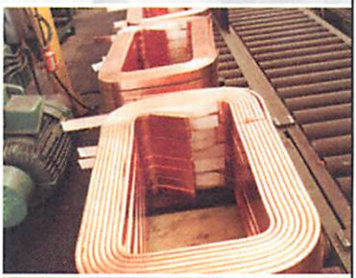
Mr. Thomas Kennedy, Manager Locomotive Engineering, Union Pacific Railroad

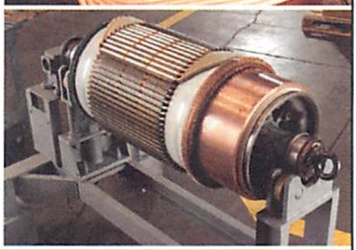
Mr. James Sherbrook, Vice President and General Manager, SHERPOWER, LLC.

Mr. Sam Benson, President, Snyder Equipment Co., Inc.

Mr. Mike Stroder, Technical Writer, Snyder Equipment Co., Inc.





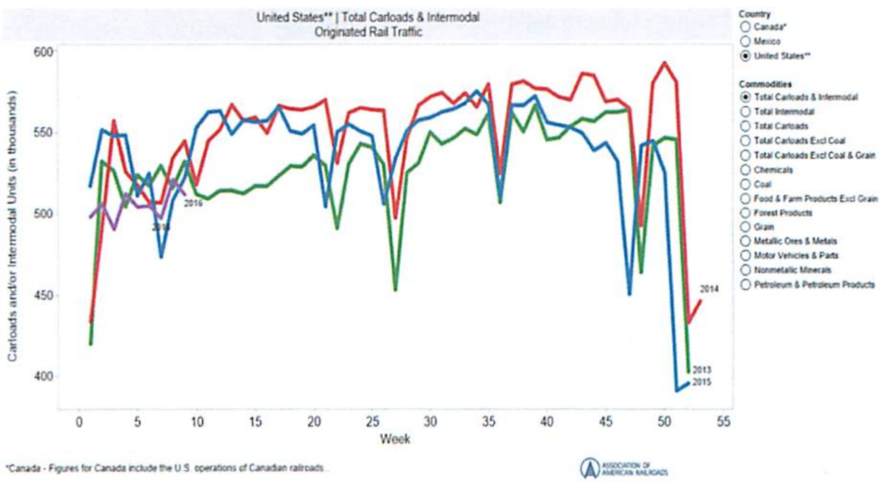


LOCOMOTIVE METRICS
Reliability/Availability
Is there a need for a Standard Definition?

Prepared by:
Bob Singleton, Transpar, Inc.

The ability by any company to measure their past performance is crucial to their future success. Like every company, railroads track performance data and use that data to measure their progress and improve performance. It also helps them maximize the use of expensive capital equipment.

On a weekly basis, the major North American railroads report their traffic for the previous week to the AAR. The data is published in AAR's Weekly Railroad Traffic report the following Wednesday. Carload traffic is classified into 20 major commodity categories such as; coal, chemicals, grain, and primary metal products. Rail intermodal is reported separately. They also report Cars-on-Line, Train Speed and Terminal Dwell Hours which the AAR publishes. *Below is AAR Total Carloads and Intermodal example.*



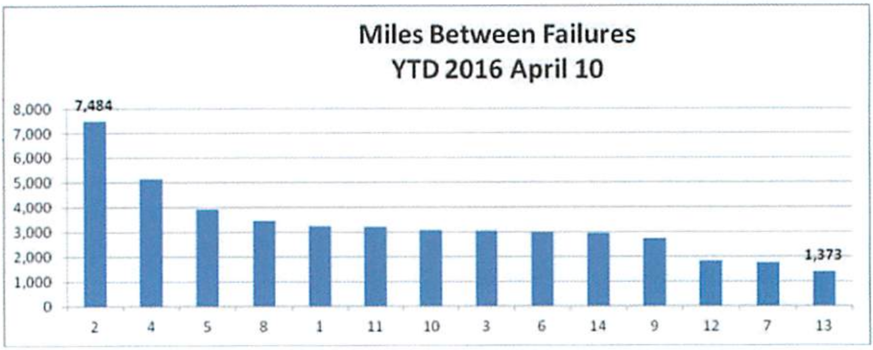
In addition, although not an AAR requirement, all railroads use a variety of measurements (metrics) to track their performance. This includes measuring their performance in all aspects of their business in order to improve performance and ultimately increase shareholder equity. Anything that can be measured, usually is: On-Time Originations, On-Time Arrivals, Trains Holding for Power, Train Crew delays, etc. Some of the railroads report this data online or in monthly/annual reports.

Railroads also have several metrics to measure their locomotive performance and locomotive reliability/availability. These measurements can vary from railroad to railroad depending on what data is most important to a specific railroad. However, much of the desired data is very similar and some of the methods used to extract the data are also similar.

Tracking locomotive reliability/availability can involve multiple measurements, but the basic question is the same: How reliable is a given locomotive or fleet of locomotives? The answers to this question can help railroads determine the best allocation of maintenance dollars and will aid in determining their locomotive acquisition decisions. There are literally scores of metrics used to track locomotive performance with many of them having slight variations.

Some of the more common locomotive metrics used are:

1. Out of Service—locomotives not available to pull freight; appears straight forward but there are different definitions. Some don't include past due FRA, some require CMO to verify issue, other minor differences, etc.
2. Reliability/Availability—inverse relationship; a 5% failure rate is a 95% availability
3. FLY (Failures of Locomotive per Year)—some railroads may prefer Failures per Locomotive Service Days or Impaired FLY which is locomotives that cannot be used as intended or some other variation of FLY. Fly may or may not include units not in service, units due FRA, etc.
4. MMBF (Mean Miles Between Road Failures)—or similar versions such as Mean Time Between Unscheduled Shoppings, which is a locomotive malfunction that degrades power output or worse.
5. AISD—Active In-service Days. In-Service also has definition issues
6. Road Failures – several different measurements. For example, Road Failures After Shopping, Road Failures that require major repairs, Road Failures that diminish horsepower, etc .
7. THFP—Trains holding for power; appears simple enough but some railroads include time frames around this metric.
8. CCPL—Component Changes per locomotive; this can also be bracketed with qualifiers such as dollar



The above chart is an example of one locomotive metric from a Class I railroad. The numbers on the X axis represent different locomotive fleets.

amounts or component categories.

Currently, there isn't one formula that everyone uses. So, railroads can't compare their locomotive fleet performance to other fleets within their railroad and/or to other railroads. The question this paper was written around is: Is there a need for a "standard" definition of locomotive reliability/availability?

It appears there is growing support among Class I railroads for a standard definition of locomotive reliability/availability which they can use in a variety of ways to improve their railroad's performance. The following were the main reasons given to support a standard definition:

- Railroads need for equal comparison of a fleet or class of locomotives so they can make the best use of those fleets.
- The desire to implement an equal comparison between locomotive models so the use of and procurement of the most efficient ones can be maximized.
- A standard definition can help railroads look to "best practices" in terms of locomotive maintenance which could help them maximize their maintenance dollars.
- Ability to use a standard metric that cannot be "gamed" so the results are meaningful
- A true railroad to railroad comparison of locomotive performance may help determine which models are best suited for specific duties.

Therefore, while there is ample interest in the use of a standard definition of locomotive reliability/availability, the natural question is why haven't the railroads been using one? The answer is...they have and they haven't.

As noted in the eight locomotive metrics listed above, railroads tend to utilize very similar locomotive performance measurements, but it seems they are all slightly different. Some Out-of-Service numbers include all locomotives not able to pull freight and others add qualifiers to this metric. For example: not including units that are Past Due FRA, partial power units, trail only units, and units headed to shop for repair. Some railroads require a mechanical officer to verify the locomotive issue before it can be classified. Almost every metric has different qualifiers on different railroads.

Often times, these qualifiers were implemented because they take into consideration what is most important to a specific railroad and/or they weed out inputs that would unnecessarily distort the metric. While this may be useful for a particular railroad, it does not allow for cross-metrics comparisons.

Another obstacle preventing the railroads from developing a standard locomotive performance metric is that even if the metric is absolutely the same, locomotive use may not be. The use of a metric to compare a GP40 in local service to one in road service may not yield meaningful data. Similarly, when comparing specific locomotive models operating on different railroads with vastly different terrains, traffic mix and network designs, the data may be so diverse it may not yield much useful information.

The good news is, with the increasing use of automated and even wireless locomotive performance feedback, metrics will become easier to collect and much more reliable. As systems are upgraded and newer technology is utilized, the availability and veracity of this data will enable operators to make much quicker and more informed decisions. This data should in turn enhance the use locomotive metrics for all those concerned.

In summary, railroads and other operators have expressed ample interest in a "standard" definition (metric) of locomotive reliability/availability that can be utilized by their company to make the best decisions concerning their locomotive fleets. These decisions include, but are not limited to, locomotive utilization, maintenance, and procurement.

This metric, or possibly multiple metrics, need to be clearly defined so every railroad's locomotive fleet can be measured accurately and equally. Technology will increase the reliability of this data. Even when this metric is defined and agreed upon, a perfect comparison may never be achieved between fleets and railroads. However, the industry will have a much more reliable source of data from which to make important fleet management decisions.

SD59MX EGR Performance Reports

Prepared by:
Tim Standish, Progress Rail, A Caterpillar Company

Electro-Motive and Union Pacific worked together on a small group of 9 locomotives that are identified as SD59MX that are currently in service inside the South Coast Non-attainment Area in regional "hauler" service between LA basin rail yards. These locomotives were originally SD60M line-haul locomotives delivered around 1992 that had 16 cylinder 710G3A tier 0 engines (3800 hp) that were converted to 12 cylinder 710G3B-EXP engines (3000 hp) with Exhaust Gas Recirculation (EGR) to lower the NO_x emissions. These locomotives had other upgrades that included EM2000, split cooling and new high-impact crashworthy fuel tanks. The locomotive road numbers for these units are 9901- 9909. Another locomotive, UP 9900, was also fitted with the same engine configuration but added an engine aftertreatment system (ATS) which will not be covered in this paper. There are also another 18 SD59MX's, 9910-9927, delivered with the 12 cyl engine but with a provision for EGR.

THE EGR DESIGN

Discussions began back in 2008 between EMD and Union Pacific to investigate EGR as a potential solution to meeting tier 4 emission requirements in particular to see if it is a viable alternative to Selective Catalytic Reduction (SCR). SCR's are not a desirable option due to infrastructure requirements for urea and on board space requirements among other reasons. In order to reduce NO_x emissions, Exhaust Gas Recirculation (EGR) has been incorporated into the air handling system of the SD59MX locomotive. This system will recover cylinder exhaust gas, filter and cool the gas, and then re-introduce it into the engine's air box. Cooled exhaust gas dilutes the oxygen content that is introduced into the cylinder on each power-stroke in which less oxygen and inert combustion gases translates into lower combustion temperatures that in turn reduce NO_x emissions.

Much engineering research was conducted to develop the final design of the EGR system in which a generic example is shown in figure 1. The EGR system that was designed recycles around 10 percent of the exhaust which passes first through a diesel oxidation catalyst then a diesel particulate filter and then through the EGR cooler before sending the gases back into the engine air intake. The DOC and DPF work together to remove particulate matter from the exhaust to prevent fouling of the EGR cooler and

the engine aftercoolers. In order to accommodate the EGR system, a 12 cylinder 710 engine was selected in place of the 16 cylinder engine. The EGR application goal was to reduce NO_x to below Tier 2 standards and with further tuning to drive NO_x closer to Tier 4 levels. To optimize performance, much attention was given to the design of the turbo blades and nozzle through various iterations since the EGR system is diverting some of the exhaust gases from the turbo. Also, as can be seen in figure 1, there is a pump (blower) in the EGR loop to push the exhaust gases since a 2-stroke engine intake pressure must be higher than the exhaust pressure. The flow of the EGR gas is controlled by the blower speed and the EGR valve. When the system is activated the valve will open and the blower will start to pump exhaust gas from the manifold to the rear of the engine via the return pipe and introduced into the aftercooler duct where it is further cooled before entering the air box of the engine.

Note: The EGR system requires the usage of Ultra-Low Sulfur Diesel (ULSD) fuel (15 ppm or less sulfur). Using higher sulfur content fuel will damage the DOC in the EGR system along with the potential for creation of sulfuric acid which will cause corrosion. It should also be noted that trans-mix is not ULSD.

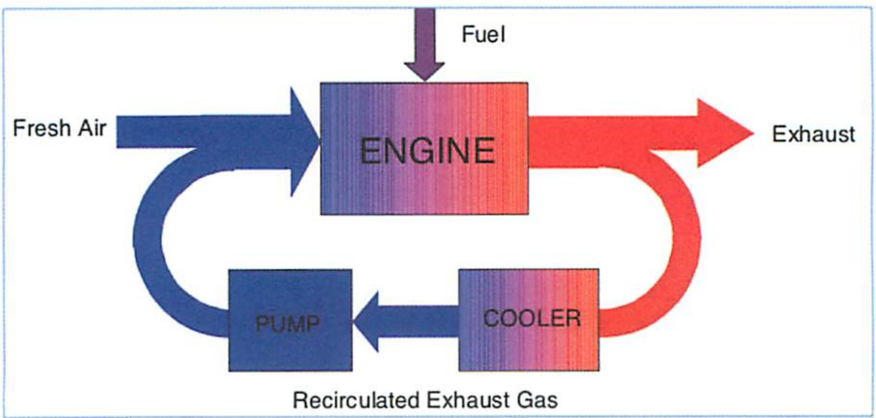


Figure 1: Example of an EGR System

THE DPF/DOC SYSTEM

As mentioned, the DOC and DPF work together to remove particulate matter from the exhaust to prevent fouling of the EGR cooler and Aftercooler. Diesel engine particulate matter is mostly soot – carbon particles with other organic chemicals attached. The wall flow DPF traps the soot so it can react with oxygen to create carbon dioxide. The soot in the DPF is passively regenerated "burnt off" with the help of the DOC in the system. The catalyst in the DOC allows continuous regeneration of the soot by reducing the temperature that regeneration would normally occur. The DOC also helps to burn off any un-burnt fuel and convert carbon monoxide to carbon dioxide. The SD59MX EGR system has been designed to ensure that continuous regeneration occurs at all operating conditions. The regeneration process cleans the filter of soot, but not ash which is a by-product of combustion of engine oil additives. The only way to remove the ash is by mechanical cleaning. Over time the ash will begin to plug the filter increasing the pressure drop. A "delta P" sensor in the system measures the pressure drop across the filter. If the pressure drop is too large the control system will issue a warning that the filter needs to be cleaned. When the delta P exceeds the max allowable limit the EGR system will be deactivated until the DPF is cleaned. When the warning is issued the DOC/DPF should be removed for service. The estimated ash cleaning cycle is 6 months which in freight service for a 12 cylinder engine would be around 1,400 - 1,700 Mwhrs.

MAINTAINABILITY OF SD59MX WITH EGR

The nine SD59MX locomotives with the EGR system (UP 9901-through-9909) were designed with ease of maintenance in mind utilizing input from UP shop safety and craft people. Manufacturing techniques and design considerations for EGR reliability have resulted in a unit that is not readily disassembled or repaired without the proper tools and facilities. It is not recommended that any attempts be made at disassembly or repair without the necessary special tools and fixtures required. Caution must be taken prior to servicing as EGR components can be extremely hot after use and care needs to be taken to ensure all components are cooled off prior to servicing. An infrared temperature sensor is useful to ensure components are cooled to an acceptable level prior to maintenance. Personnel should have a thorough understanding of the equipment before attempting to perform any maintenance. As noted, the maintenance required is to remove the DOC/DPF from the EGR system and de-ash the DPF and therefore the chamber was designed as a removable set that is accessible from the left-hand walkway of the locomotive. Lifters were adapted to existing shop tooling such as the power assembly lifter. See figure 2. Four jacking screws and their corresponding holes on the flange closest to the cooler are used to separate the EGR DOC/DPF chamber from the EGR Cooler. Guide rods at the bottom of the DOC/DPF chamber horizontally to slide it past the guide rods at the bottom of the cooler. The chamber is removed as a complete package and is not to be further disassembled by shop personnel at this time but sent back to EMD for analysis and cleaning. Replaceable gaskets and captive high-temperature fasteners for the chamber were designed to ensure joint integrity and minimize the risk of exhaust leaks which is an FRA defect; therefore the proper components must be used upon servicing.

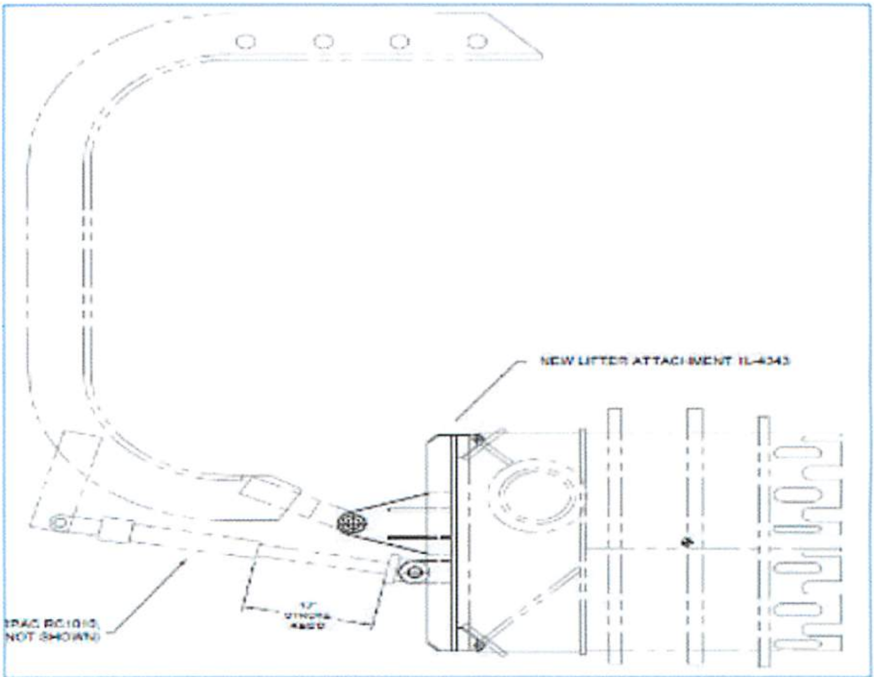
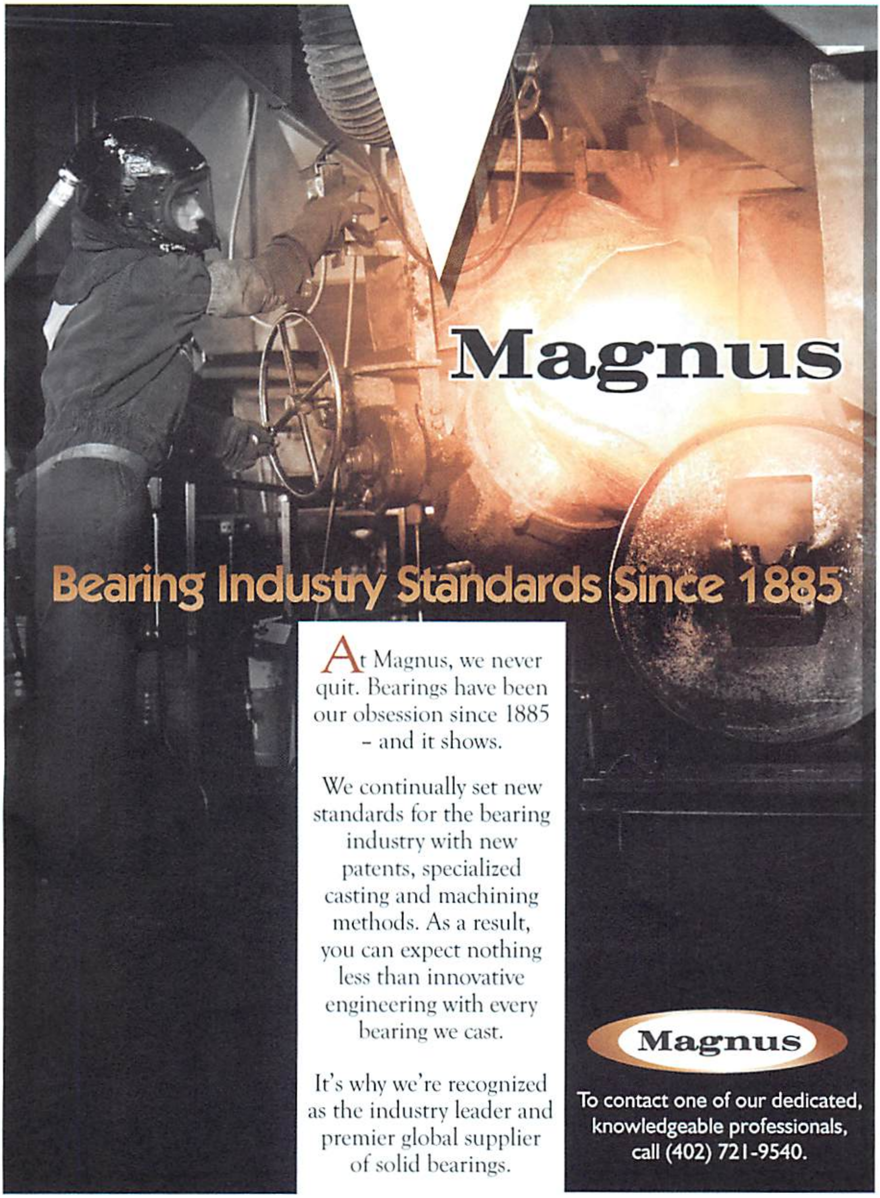


Figure 2: EGR Lifter

IN SERVICE HISTORY

The 9 locomotives went into service around January 2012 and are each averaging around 13,000 miles and 225,000 kwhrs per year. Locomotive 9902 had a high delta P reading in June 2015 when it was noted during load test and was also verified through other signals in EMDEC. Unit logged (FC-4992) EGR System Warning – DOC/DPF Pressure above normal – DPF Service Required, during shopping on 6/8/15. The DPF/DOC chamber was removed and sent back to EMD for analysis. This locomotive accumulated around 1,000 Mwhrs and 50,000 miles since early 2012. Upon teardown inspection, the DOCs and DPFs were found to be very clean. See figure 3 and 4. The DOC in pictures may look like they have soot on the front, but it is catalyst coating and the angle of the photo. The flow channels were clean. The high delta P reading was found to be the tube fitting for DeltaP sensor which was found broken. The leak at this location is most likely reason for high reading. The DOC/DPF was rebuilt with used elements and put back into service.


Magnus
Bearing Industry Standards Since 1885
At Magnus, we never quit. Bearings have been our obsession since 1885 – and it shows.
We continually set new standards for the bearing industry with new patents, specialized casting and machining methods. As a result, you can expect nothing less than innovative engineering with every bearing we cast.
It's why we're recognized as the industry leader and premier global supplier of solid bearings.
Magnus
To contact one of our dedicated, knowledgeable professionals, call (402) 721-9540.

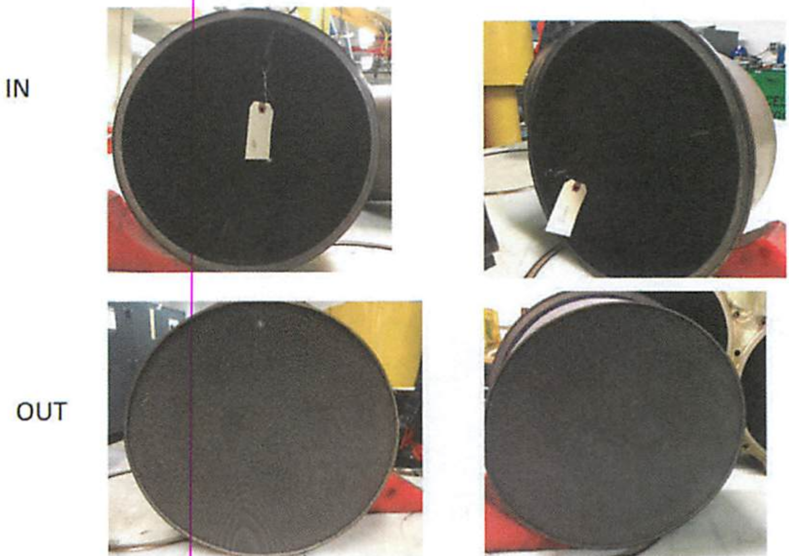


Figure 3: DOC inspection

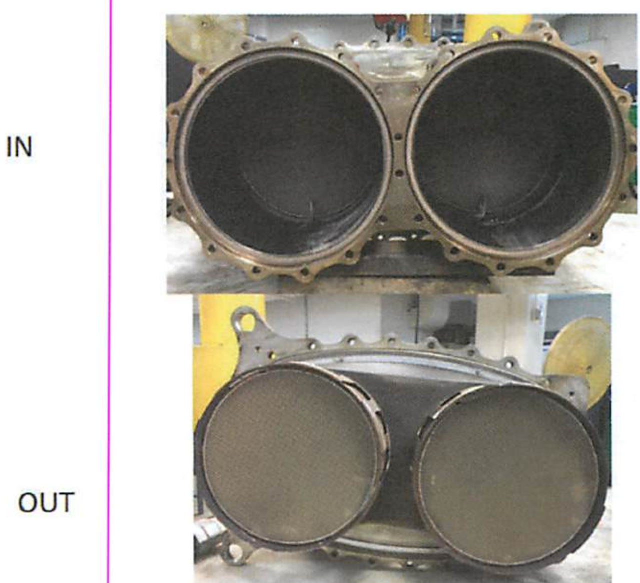


Figure 4: DPF Inspection

SUMMARY

EGR application to the EMD 2-stroke engine is a viable option to reducing NO_x and has been successful on the 9 locomotives that have been running over 4 years of service to date. The one locomotive that had faults for high pressure differential was found to have a broken fitting and based on the inspections of the DOC and DPF there were no issues noted. Further data and teardown analysis will be needed to better understand the expected DOC/ DPF de ash cycle. Close collaboration between UP and EMD has made these EGR equipped locomotives reliable, maintainable and has shown that EGR on EMD's 2-stroke engine can lower NO_x emissions. Input to this paper was much appreciated and provided by Tom Kennedy, UP, Steve Johnson, EMD, Rafael Rodriguez, EMD, and Deep Bandyopadhyay, EMD.

Reference Sources:

1. *Iden, M., Goetzke, M. and Bandyopadhyay, D., Experimental Exhaust Gas Recirculation (EGR) on EMD SD59MX 2.238 Megawatt Diesel-Electric Freight Locomotives, ASME ICEF2012-92167*

2. *EMD internal documents, SA-11-035 SD59MX EGR System*

High Pressure Common Rail Fuel Injection System and Potential Issues

Prepared by:
John C. Hedrick and Steven G. Fritz,
Medium-Speed Diesel Engines - Design and Development Dept.
Southwest Research Institute

Introduction

High pressure common rail (HPCR) fuel injection systems are becoming commonplace in modern rail applications and in many locomotive engine rebuilds or retrofits. The HPCR systems are also found in essentially all modern diesel powered service trucks and heavy duty (HD) On- and Off-highway engines. The HPCR system is used to reduce emissions and engine noise and to prepare the engine exhaust to maximize the aftertreatment systems performance.

This paper reviews components that make up a HPCR system, helps explain why HPCR systems are needed for modern diesel engines, discusses some of the potential issues and failure modes, and covers some basic safety information.

Background

HPCR fuel systems are used in modern automotive, and HD On- and Off-highway diesel engines. Additionally, the HPCR fuel systems are currently being used by locomotive OEM's in the following applications:

- GE's
  - o Tier 2+
  - o Tier 3
  - o Tier 4
- EMD's Tier 4
- Progress Rail locomotives powered by Off-Highway Tier 4 Caterpillar engines
- GENSET locomotives
- Locomotive conversions fitted with MTU S-4000 / S-2000 engines

HPCR is not a new concept; a patent was issued to Thomas T. Gaff, of Washington, DC in 1913 for an engine built around a mechanical common rail system. One of the drawings from Gaff's Patent (Patent 1059604) is shown in Figure 1[A] This concept used a mechanical common rail fuel injection system that could not generate the high injection pressures or provide the injection control that a modern HPCR is capable of providing. However, this patent shows that the concept and need for a common rail injection system has been around for over 100 years. In 1995, Denso Corporation of Japan claims to be the first company to offer a commercial version of an electronically controlled HPCR system. This Denso system is the predecessor to the HPCR systems found in today's low emissions diesel engines.

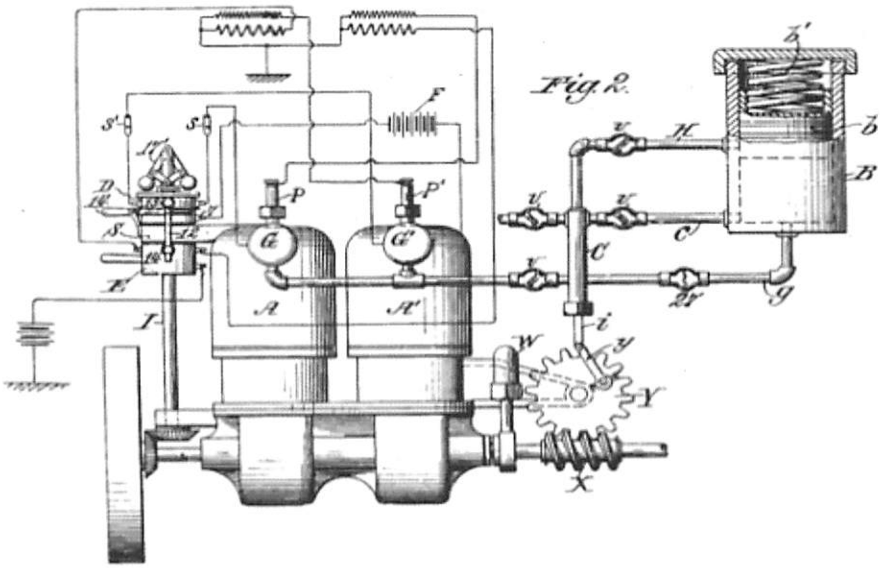


Figure #1 Patent Drawing of Original Mechanical Common Rail System (A)

The components of typical HPCR fuel system are:

- Low pressure fuel pump
- Fuel filters
- High pressure fuel pump
- High pressure manifold (manifold is built into the larger injectors)
- Engine ECU
- Wiring harness
- Fuel pressure control valve

Many of these components are shown in Figures 2, 3, and 4.

While many of these components are common to what is used in a standard diesel fuel injection system (ECU, Wiring harness, low pressure pump, filters, …), these common components are typically upgraded or improved to meet increased demands of a HPCR system. For example: the fuel filter used with a HPCR system will typically require a higher level of filtration and the addition of a water separator.

1. *High Pressure Pump*
2. *Metering Unit (Injection Pressure Control)*
3. *Injector (with high pressure manifold built into injector)*
4. *ECU*
5. *Sidepipe*

Figure #2 High Pressure Common Rail System Components (B)

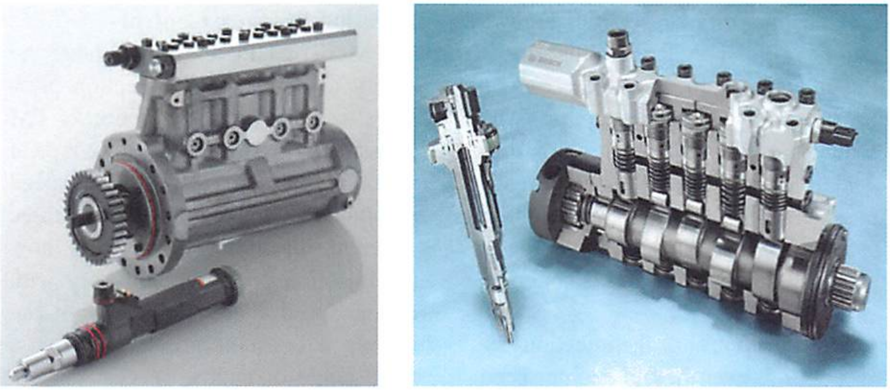


Figure #3 Examples of Other High Pressure Common Rail Pumps (B) (D)

Figure #4 Examples of Other High Pressure Common Rail Injectors (D)

Automotive, HD On-highway, and the majority of HD Off-highway engines use HPCR systems due to the demands on the diesel engine to improve fuel consumption while reducing engine-out exhaust emissions. The modern HPCR system can reduce engine out emissions by providing:

- Multiple injection events per engine cycle.
- Precise control of the injection pressure over the full engine speed range.
- Accurate injection timing.

Additionally, an HPCR system can activate some types of exhaust after-treatment systems that require the addition of hydrocarbons in the exhaust. Each of these topics will be discussed in the following subsections.

High Injection Pressures and Injection Pressure Control

Modern HPCR systems have the ability to deliver high injection pressures to assist in the reduction of PM emissions. Figure 5 shows the typical injection pressures for a high speed automotive application with three different injection systems and how the injection pressures will vary with engine speed. The HPCR system can deliver a constant pressure across a wide range of engine speeds, but the pump-line-nozzle fuel injection systems, similar to the injection system on GE's FDL and GE Tier 2 EVO engines, the injection pressure is very engine speed dependent. The Electronic Unit Injector's (EUI), similar to what is used in an EMD 710 engines that meet Tier 1, 1 Plus, 2, 2 Plus, and Tier 3, have injection pressure that is less speed dependent above a mid-engine speed but is still engine speed dependent at less than mid operating engine speeds.

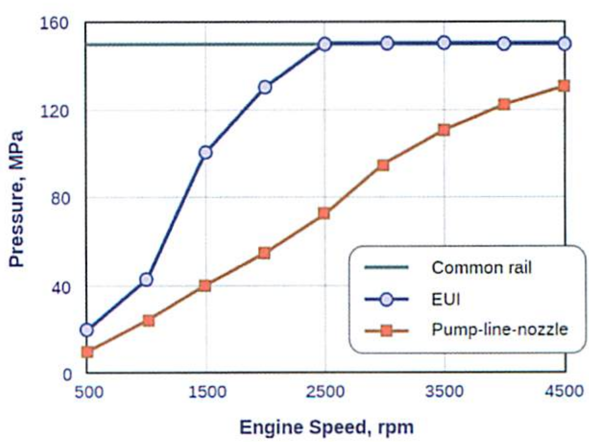


Figure #5 Examples of Injection Pressure vs Engine Speed for Automotive Applications (E)

With an HPCR system, the engine's Engine Control Unit (ECU) commands a target injection pressure based on the engine speed, engine load, intake manifold air pressure, and other engine and atmospheric conditions. The ECU's pressure command signal is sent to the HPCR metering unit, which controls the injection pressure. The HPCR pressure will have some pressure variations, outside of the commanded pressure, as injection events occur.(F) However, the variations are minor compared to the pressure variations seen with an EUI or pump-line-nozzle injection system. Figure 6 shows the variation in an automotive sized HPCR system; the commanded injection pressure in Figure 6 was 100 MPa (~14,500 PSI) with pressure variations on the order of +/- 10%. For comparison, Figure 7 shows the variation in injection pressure for an EMD 710 EUI over the injection event at Idle and Notch 8. Figure 7 also shows the relative difference in maximum injection pressure between the two notch conditions.

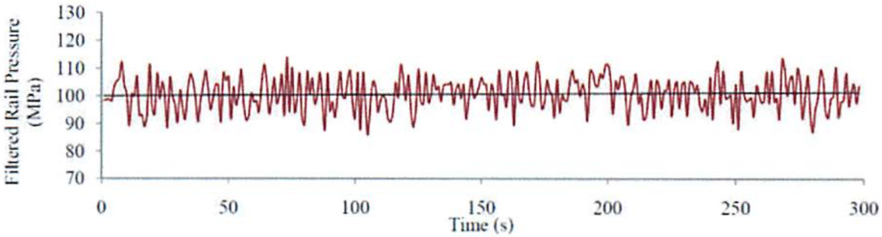


Figure #6 Example of HPCR Pressure Variation With 100 Mpa (14,500 PSI) Commanded Pressure (F)

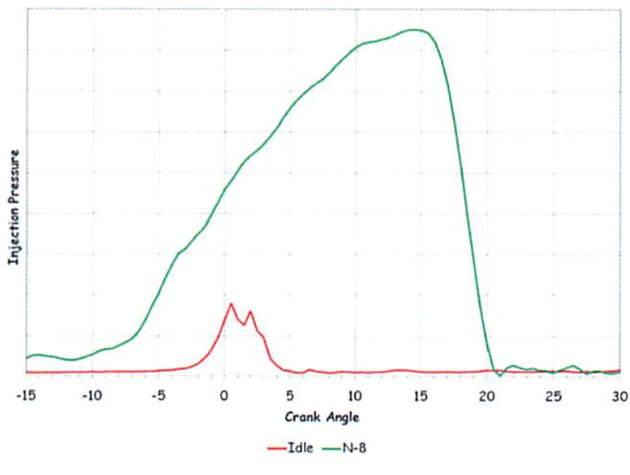


Figure #7 Example of Injection Pressure of EMD EUI at Idle and Notch 8

Modern HPCR systems can provide multiple injections per engine cycle to reduce combustion noise, engine out NO_x emissions, and PM emissions. Some automotive HPCR systems can provide up to 7 injection events, but a typical HD engine will use five or less injection events. An example of these injection events are shown in Figure 8 and are:

Pre Injection - Reduces NO_x emissions and combustion noise.
Pilot Injection - Reduces NO_x and noise.
Main Injection – Provides the majority of the fuel to produce power.
Post Injection – Reduces PM emissions.
Second Post Injection – Provides hydrocarbons to aftertreatment (if needed).

By reducing NO_x emissions with the Pre and Pilot injection events, the injection timing of the main injection event does not need to be as retarded to maintain the same NO_x emissions level. By allowing the main injection event to be more advanced the engine out PM emissions are reduced and the engine's fuel economy is improved. Additionally, the initial Post injection further assists with the reduction of PM emissions, which can reduce the size or eliminate the need for PM reducing aftertreatment, depending on the target PM emissions level. The ability of the HPCR system to generate high injection pressures over a wide range of engine speeds also assists reduce engine out PM emissions and maximize the fuel efficiency of the engine.

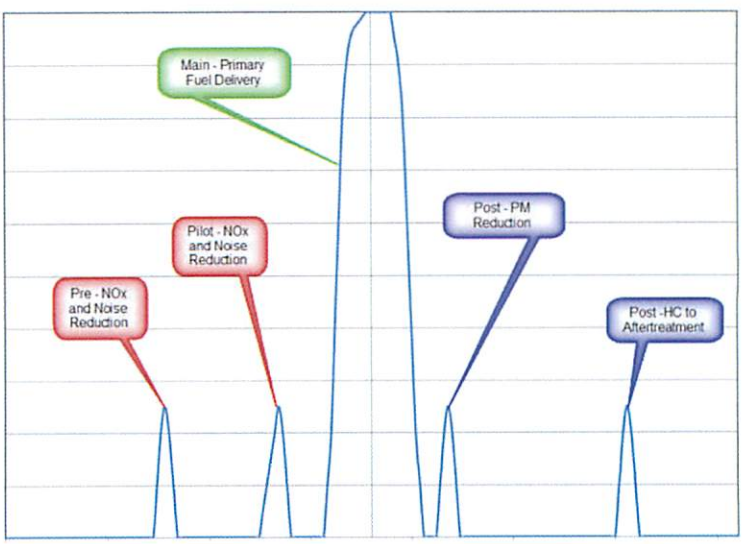


Figure #8 Example of Potential Multiple Injection Events by a HPCR

Discussion

From an OEM's "Guide to Potential Causes of Common Rail Injector Failures",(B) the main reasons for HPCR failures are typically:

- Fuel contamination
- Poor fuel filtration
- Incorrect installation
- Non-OEM approved products

Dirty fuel and or poor filtration are possibly the largest causes of HPCR failures. Abrasive contaminants in the fuel can damage pressure control valve, high pressure pump, injectors, and other HPCR parts. When HPCR components wear due to dirty fuel and or poor filtration, the engine can exhibit:

- Excessive smoke
- Starting / idling problems
- Injector / pump / engine failure

If the fuel filtration system is adequate, fuel contamination can exacerbate fuel filtration issues. Typically, HPCR filters requires a filtration efficiencies of 99% at 4 microns. However, some HPCR systems require 2 micron filtration compared to the 5 to 12 micron fuel filter used on older locomotive applications. For a sense of scale:

- I Micron = 1/1,000,000 of a meter.
- Approximately 0.00004".
- Human red blood cell is about 5 microns across.
- Human hair has a diameter of approximately 75 microns.

Because of the high filtration requirements of an HPCR system, contaminated fuel will greatly accelerate plugging rate of the fuel filters. Additionally, water contamination in the fuel can cause poor performance of fuel filter system and can cause microbial growth in the fuel. These in turn cause rapid fuel filter plugging and degradation of fuel. Both can cause damage to the HPCR system. Figure 9 shows an example of water contamination and microbial growth in the fuel filter systems sight glass of a GenSet locomotive.

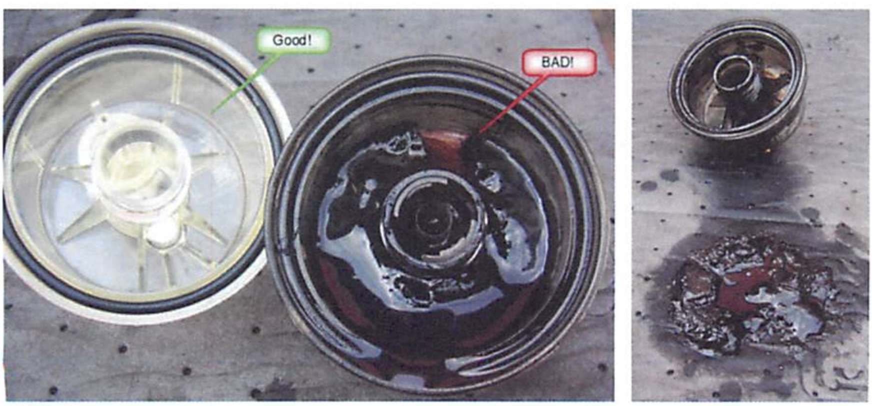


Figure #9 HPCR Filtration Plugging Due to Water in Fuel and Microbial Growth

For the safety of maintenance staff and durability of the HPCR system, it is very important to read and follow the HPCR OEMs' installation / maintenance procedures. Some of the critical aspects are:

- Assuring that the HPCR system is no longer charged with high pressure fuel before the system is repaired or maintained.
- Cleanliness of all the components and mounting surfaces during their installation.
- Installation process, including hardware orientation and torque procedures.
- Dings, dents, or dirt on high pressure sealing surfaces.

Additionally, HPCR system failures can be minimized by following OEM recommendations. This includes the use of OEM approved, or equivalent, HPCR injectors, pumps, control valves, and filters. It is also critical that the diesel fuel used in the engine meets the OEM's specifications.

Another potential cause of failures in HPCR systems is deposits within and on the injector. Many of these deposits can be attributed to the fact that the HPCR system has elevated fuel pressures and temperatures in the injectors. The typical automotive or HD HPCR system will operate at a maximum pressure of ~40,000 PSI. On top of these elevated pressures, the fuel temperatures internal to the HPCR system can exceed 180°F. These pressures and temperatures are much higher than previous injection systems.

For many years, the railroad industry has seen carbon deposits on injector tips, as shown in Figure 10. These tip deposits are typically associated with the use of off specification fuels or excessive oil consumption in the cylinder. However, the HPCR injectors can generate these types of tip deposits even when operated with fuel that meets OEM specifications and normal levels of oil consumption.

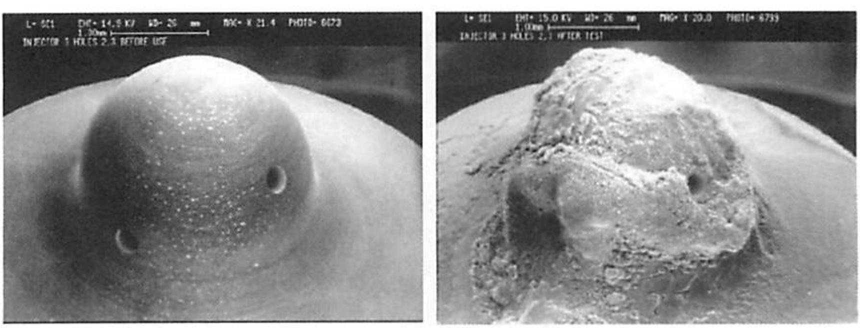


Figure #10 HPCR Tip Deposits (G)

HPCR injectors are unique in that they can fail due to internal deposits. These internal deposits can fill passages and crevices inside the injector and the injector control valve. The deposits can become significant and cause parts to stick and injector to fail. Why is this a "new" problem? Some technical literature suggests that:

- The fuel is being worked harder by HPCR compared to other injection systems.
  - o Fuel experiencing higher temperatures and pressures.
- The injectors have tighter tolerances in the injector compared to many standard injectors.
- Diesel fuel specifications have changed.
  - o Bio-diesel
  - o Low Sulfur content
  - o New catalysts types used to make the diesel fuel

Figure 11 and Figure 12 shows an example of internal deposits on an HPCR injector control valves and Figure 13 shows deposits that developed on an HPCR injector needle. The deposits shown in Figures 11 and Figure 12 were significant and ultimately would prevent the HPCR injectors from operating correctly. The deposits shown in Figure 13 were not significant enough to prevent the injector from operating but it shows that the deposits can form on almost any of the internal injector components.

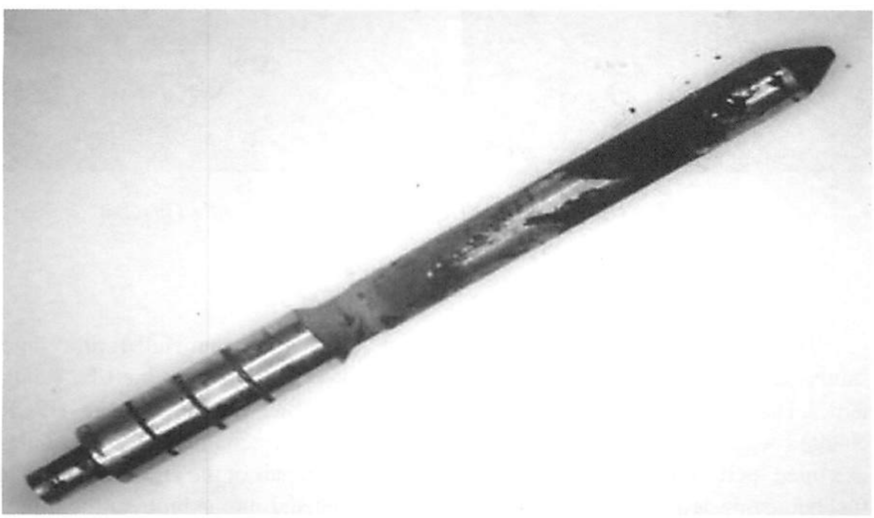


Figure #11 HPCR Internal Injector Deposits (G)

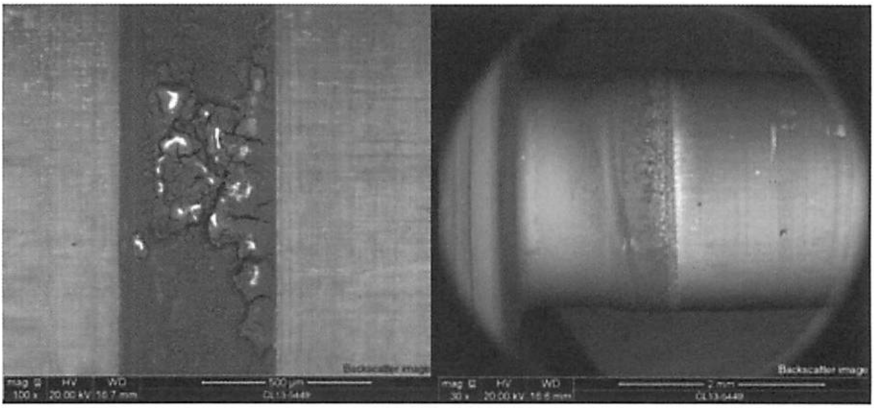


Figure #12 HPCR Internal Deposits on Control Valve (G)

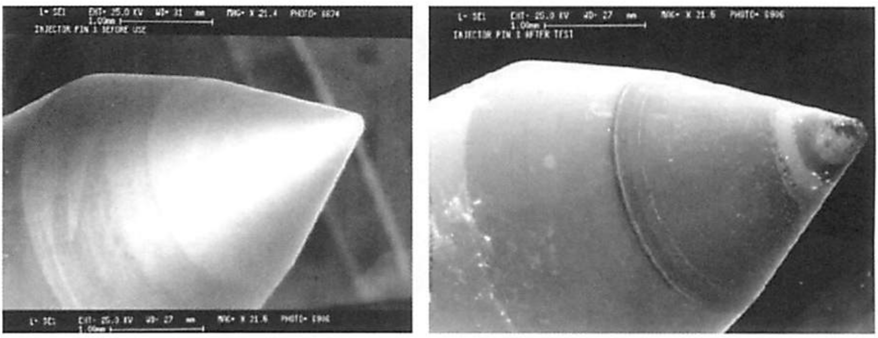


Figure #13 HPCR Internal Deposits on Injector Needle Tip (G)

There are some unique points of safety associated with an HPCR system. The HPCR system can remain charged with high pressure fuel for an extended period time. High pressure fuel being injected into human body can cause injury and possibly death. Make sure that staff are trained and follow the OEM's recommended procedure to make HPCR system inert by safely releasing fuel pressure in the HPCR system before conducting any maintenance or repair of the HPCR system. If fluid injected into skin, treat the injury immediately by a doctor familiar with this injury type.

Conclusions

HPCR are used on modern diesel engines to reduce emissions. While this is not a new concept, it is new to the locomotive industry. The HPCR system provides high injection pressure, multiple injection events, and has the ability to provide hydrocarbons to aftertreatment systems.

HPCR systems are offered in large number of locomotives today. Some of these are:

- GE Tier 2 Plus
- GE Tier 3
- GE Tier 4
- EMD Tier 4
- Any recent Progress Rail loco fitted with CAT engines.
- All GENSET locomotives
- Conversions fitted with MTU S-4000 / S-2000 engines.
- HPCR in majority of diesel powered service trucks and HD on- and off-highway engines.

Fuel quality and proper filtration is critical. Additionally an HPCR system can have issues with internal deposits that can cause the injector to fail. Like any new technology, there is a learning curve for the staff working with the system. Training is needed to maximize system reliability and staff safety.

References:

A) US Patent 1059604 A – "Explosion-engine".

B) BOSCH Brochure "Diesel Systems - Modular Common Rail System MCRS-T for large diesel engines"

C) http://de.bosch-automotive.com/en/parts_and_accessories/motor_and_sytems/diesel/large_diesel/large_diesel_3

D) http://www.lorange.com/fileadmin/fm-dam/lorange/lorange/publications/LO_4-SEITER_COMMON-RAIL_GB_DRUCK_NEU.pdf

E) https://www.dieselnet.com/tech/diesel_fi_common-rail.php

F) Phan, A., Iowa State University, "Development of a Rate of Injection Bench and Constant Volume Combustion Chamber for Diesel Spray Diagnostics"

G) JSAE 20119126 Diesel Injector Deposits – An Issues That Has Evolved with Engine Technology.

H) Jeyashekar, Yost, and Westbrook; SwRI Topical Report #2 to FRA. "Locomotive Engine Fuel Injector Deposit Characterization Using FTIR"

GE Dual Fuel Locomotive Development

Prepared by:
Eric Dillen, GE Transportation; Dan Yerace, GE Transportation; Les Trask, GE Transportation; Adam Klingbeil, GE Global Research; and Scott Ellis, Southwest Research Institute

INTRODUCTION

The onset of efficient and cost effective shale gas drilling in North America in the late 2000's drove natural gas prices down while crude oil prices continued to rise (Figure 1) [1]. In early 2012, interest in dual fuel technology for locomotives began to increase due to the favorable difference in price between natural gas and diesel fuel and the projection that the difference would remain for years to come. In mid-2012 GE started a program to develop a dual fuel locomotive that would maximize the substitution rate (SR) while still being able to operate on 100% diesel.

CONCEPT SELECTION

GE worked with multiple Class 1 railroads to develop the key requirements for a dual fuel locomotive:

- Maximize SR while still being 100% diesel capable.
- Maximize market penetration.
- Minimize cost
- Must meet applicable EPA emission regulations

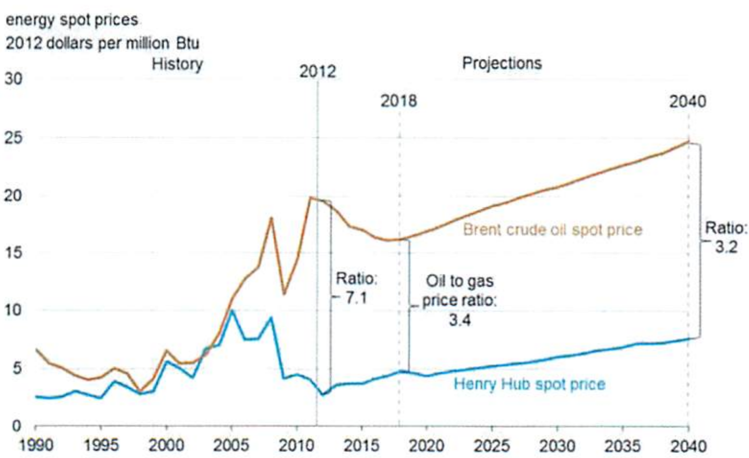


Figure 1 – Crude Oil vs. Natural Gas Spot Prices

- Demonstrate the technology quickly

Each one of these requirements drove concept and design decisions. Being able to maximize the SR while still being 100% diesel capable defined the technology that was eventually selected. The four main dual fuel technologies that were considered are; fumigation, port injection, micro-pilot, and high pressure direct injection (HPDI). Table 1 highlights the four technologies and their pros and cons. Micro-pilot and HPDI are both capable of very high substitution rates but neither is capable of running on 100% diesel. Fumigation on a medium speed diesel engine can yield comparable substitution rates as port injection but will lead to excessive methane slip during valve overlap and reduced thermal efficiency. Timed port injection is the most efficient method to introduce gas into the combustion chamber and was chosen as the concept to proceed with.

	Fumigation	Port Injection	Micro-pilot	Direct Injection
Description	Single point gas injection upstream of intake manifold. Standard diesel injector.	Timed gas injection at each intake port. Standard diesel injector	Timed gas injection at each intake port. Micro-pilot diesel injector.	High pressure gas injected during diesel injection event.
Pros	Low complexity. High SR, >60%. Low pressure gas.	Med complexity High SR,>75%. Low press gas. Max efficiency Min slip	Med/High complexity. Very high SR, >95%. Potential to meet Tier 4 NOx w/o EGR.	High complexity Very high SR, >95%. DOC not needed. "Diesel-like" combustion.
Cons	DOC for HC and CO. High methane slip. Knock control required.	DOC for HC and CO. Knock control required.	DOC for HC and CO. Knock control required. Not 100% diesel capable.	Very high gas pressure. Not 100% diesel capable.

Table 1 – Technology Comparison

The need to maximize market penetration and minimize cost drove the requirement for the dual fuel package to be a retrofit kit applied to existing EVO locomotives at time of engine overhaul. Cost is minimized since many of the components that need to change to support dual fuel operation are components that get replaced or re-qualified at overhaul. Performing the upgrade during overhaul also minimizes locomotive out of service time which is a direct cost savings to the customer. Market penetration is maximized since there are many more engine overhauls performed each year versus the number of new locomotives built.

The locomotives must also meet the applicable EPA emission regulations [2] which are Tier 3 for the target locomotive population. See Table 2 for EPA Tier 3 locomotive emission limits.

	g/kW-hr			
	CO	HC	NO_x	PM
Tier 3	2.0	0.40	7.4	0.13

Table 2 – EPA Locomotive emission levels

The final requirement was to demonstrate the technology quickly so the railroads could quantify real life cost savings and to explore the infrastructure and logistic concerns associated with fueling and maintaining LNG tender cars.

Development Approach – To meet the requirement of demonstrating the technology quickly, an approach was used that focused on testing and validating with customers early, learning, and iterating to develop a practical solution quickly. Figure 2 shows the development timeline that was followed for the design, build, ship, and test of two demonstrator (demo) locomotives.

Figure 2 – Dual Fuel Development Timeline

Other Factors Impacting Timing – In addition to engine and locomotive design considerations, there were other factors that impacted the timing of field trials. The specification of the tender required to carry the LNG is regulated by the Federal Railroad Administration (FRA) and at the time of the build of the first two demo locomotives there was no specification in place. Special approvals called Letters of Concurrence were needed from the FRA every time a railroad wanted to perform a test on a section of their track.

Also, due to absence of a tender specification, there were no new tenders being built. A few tenders that were used in the late 90's during an earlier round of dual fuel investigation were brought out of storage and refurbished to be used for the field trials.

The refueling of the tenders was done with tankers hauled by trucks since there was no infrastructure in place at the railroads to handle tender refueling.

SINGLE CYLINDER ENGINE DEVELOPMENT

Experimental Setup – The dual fuel development program was centered on a GE Tier 3 Evolution engine. The general specifications of the engine are listed in table 3. A single-cylinder engine (SCE) was fitted with dual fuel capability to understand the performance characteristics for this engine. The production compression ratio was reduced to enable increased substitution rate of natural gas, but the original geometry of the piston bowl was maintained for this modified piston. A natural gas port injection fuel system was installed on the engine to enable proper phasing of the gas injection event with the engine breathing events, thereby reducing hydrocarbon emissions exhausted during the scavenging process.

Max Speed	1050 RPM
Max Power	375hp/cyl
Rated BMEP	20.3bar
Bore	250mm
Stroke	320mm
Con Rod Length	590mm
Displacement	15.7L/cyl
Fuel System	Common Rail

Table 3. Characteristics of the Engine as tested

The test cell was equipped with a California Analytical emissions bench capable of measuring NO_x, CO, CO_2, O_2 and unburned hydrocarbons. The engine was also fitted with an AVL water-cooled flush mounted pressure transducer to provide online diagnostics of the combustion event. The tests on the single cylinder engine focused on understanding the combustion and performance across a broad range of operating conditions.

Knocking On Sce And Max Sr – One key challenge for a dual fuel engine was to maximize the SR while avoiding knock or misfire conditions. The SCE was thus used to explore high substitution operation. At low to moderate substitution rates, the pressure trace and heat release rate resembled that of a diesel engine (Fig 3A). In this particular case, there was little evidence of a premixed burn, although it has been observed at other conditions.

As substitution rate was increased further, the heat release rate began to exhibit a characteristic of accelerating combustion late in the cycle as illustrated by Fig 3B. In this case, the maximum limit was being approached and this particular accelerating heat release was not caused by deliberate increase in the substitution rate, but was rather caused by natural variation of the fueling and combustion events at a nominally fixed operating condition. The increase in late-cycle heat release profile was indicative that the knock-limited maximum substitution rate was being approached. Small increases in substitution rate from this condition (or in this case, variations in fueling at a fixed conditions) could lead to a late-cycle knocking condition where the heat release would begin as normal, but later in the combustion event, the remainder of the natural gas would combust very rapidly, as shown in Fig 3C. Increasing substitution rate beyond this point very quickly led to heavy knock and excessive peak cylinder pressures.

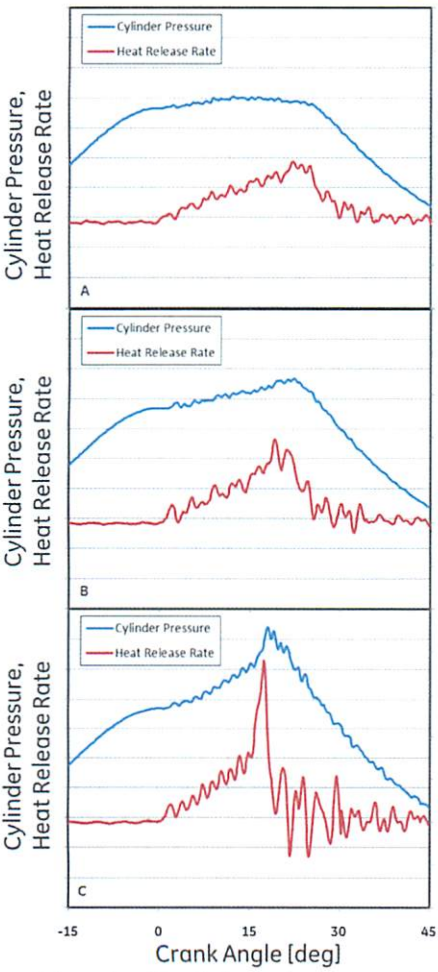


Figure 3 – Knock-limited pressure and heat release traces

SR Versus MAT – Using a process similar to that illustrated in Figures 3, the maximum SR of the engine was explored on the SCE at notch 8 (N8) operation as a function of the manifold air temperature (MAT). At low MAT, high substitution rates could be met. However, as the MAT was increased, a point was reached where the maximum SR was reduced due to the onset of knock, as shown in Figure 4. At the highest MAT levels tested, the max SR was reduced by approximately 35% of the maximum SR at the lower MAT levels.

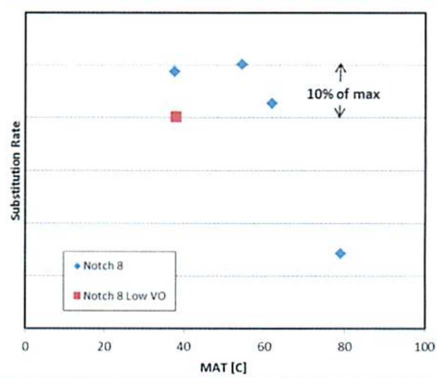


Figure 4 – SR vs. MAT

Combustion Optimization – Limited experiments were performed with a low valve overlap cam where the valve overlap was reduced 30 degrees to evaluate the effectiveness of reducing unburned hydrocarbons. While the hydrocarbons were substantially reduced, the low valve overlap cam had a significant impact on the maximum substitution rate, also shown in Figure 4, pushing the engine much closer to knock. With the low valve overlap cam, additional exhaust residuals were retained in cylinder resulting in higher gas temperatures for otherwise identical operating conditions. It is likely that the higher in-cylinder temperatures caused by these residuals led to improved hydrocarbon oxidation during the expansion stroke, and even as the gases moved through the exhaust system there was evidence that the hydrocarbons were still oxidizing. This increase in gas temperature also led to a higher likelihood of knock, thereby reducing the maximum substitution rate.

Two of the key metrics for dual fuel engine performance are NOx emissions and total unburned hydrocarbons (THC). NOx emissions are a common parameter of interest in all diesel engines and this concern translates to dual fuel engines as well. The total unburned hydrocarbons are dominated by methane and are prevalent because some of the premixed gas is trapped in the crevice volumes of the combustion chamber during the combustion event and are thus not oxidized.

The SCE was used to investigate the impact of the air to fuel ratio (AFR) in an effort to provide strategies for reducing such emissions. Figure 5 shows NOx/THC tradeoff curves for a high and low AFR set of experiments. The diesel injection timing was adjusted while the other parameters were held fixed in order to provide the tradeoff curves. The data reveal that for lower AFR, the HC/NOx tradeoff was improved; however this improvement was seen more in the retarded timing points than the advanced timing points. Furthermore, exhaust temperatures were higher due to the lower air dilution which can impact the useful life of exhaust system components.

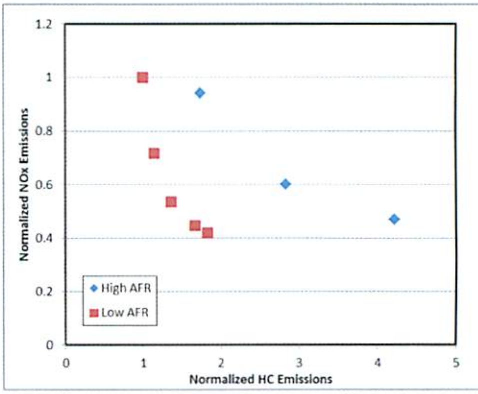


Figure 5 – NOx vs THC for a high and low AFR

MULTI-CYLINDER ENGINE DEVELOPMENT

Due to test cell availability, multi-cylinder engine (MCE) testing was conducted at Southwest Research Institute in San Antonio, TX. The test engine was a V12 version of the SCE described in Table 3. Figure 6 shows the engine in the test cell.

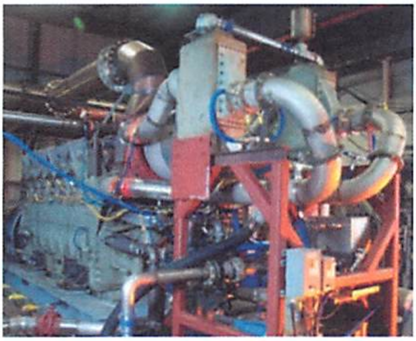


Figure 6 – EVO V12 Dual Fuel Engine

Test Cell Configuration – The test cell was configured to use as much locomotive hardware as possible to maximize the amount of data transferable from the test cell to the demo locomotives described later in this paper.

Two eddy current dynamometers in series were used to control load in the test cell compared to a single engine mounted alternator used in a locomotive. A combustion air system that maintained constant inlet air temperature and humidity was used in the test cell to enable consistent test conditions on a day to day basis. The test cell also had the ability to control the AFR within a limited range. Finally, city gas was used in the test cell instead of the LNG used in the demo locomotives.

To achieve the maximum benefit of the tests conducted, the engine was very heavily instrumented. Test cell specific instrumentation included the following:

- In-cylinder high speed pressure measurement.
- Individual cylinder air/fuel ratio measurement.
- Provisions for high speed intake and exhaust pressure measurements.
- Exhaust gas emission measurements (THC, CO, NO_x, NO plus CO_2 EGR, CO_2, O_2, CH_4).
- Gravimetric and AVL smoke based PM measurement.
- Opacity Measurement.
- Separate NG and diesel fuel rate measurements.
- A gas chromatograph to monitor the composition of the natural gas supply.

The test cell control system consisted of 4 modules communicating over CAN with the T3-ECU having supervisory function over the other modules. A diagram of the test cell engine control system is shown in Figure 7.

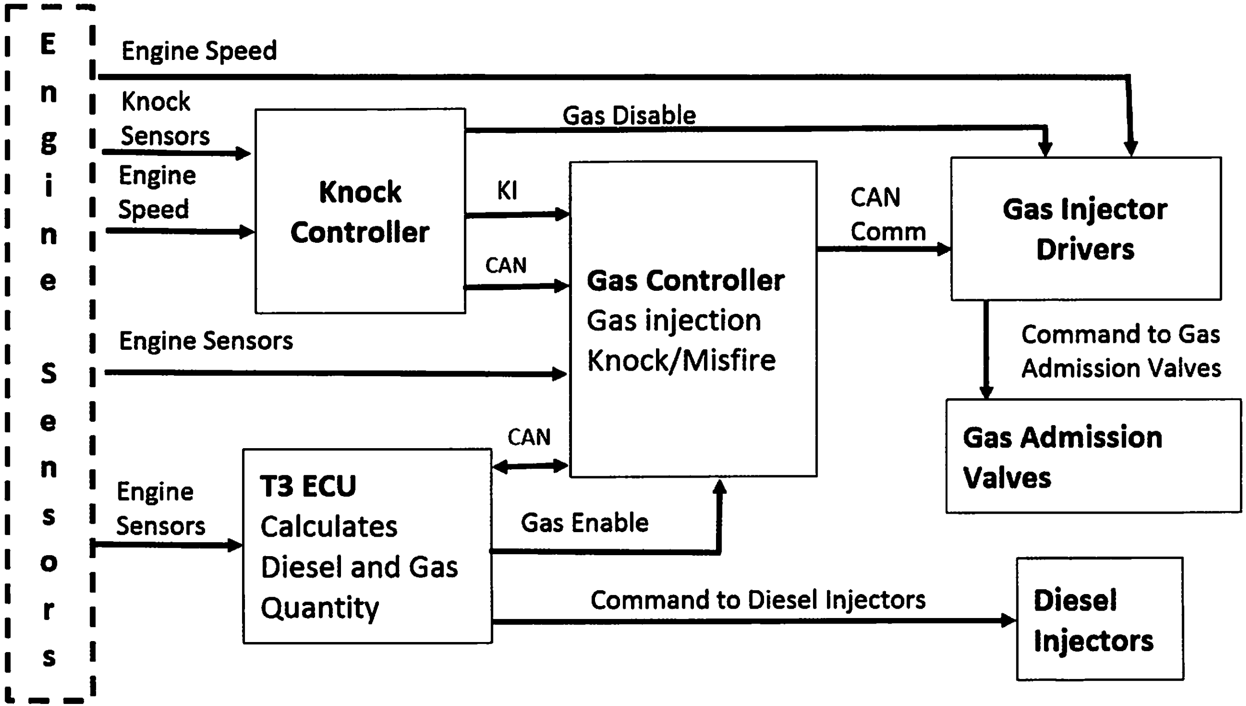


Figure 7 – Test Cell Engine Control Diagram

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
LOWER LINER INSERT
PULLER/INSTALLER
EMD Engines
CYLINDER HEAD AND LINER
WATER TEST MACHINES
EMD Engines
EXHAUST VALVE SPRING
DEAD WEIGHT TESTER
EMD Engines
and other
SPECIAL TOOLS & MACHINES
designed to
SAVE YOU MONEY
TAME, INC.
Tools and Maintenance Equipment Co., Inc
2523 Chattanooga Valley Drive • P.O. Box 250
Flintstone, Georgia 30725 • U.S.A.
Telephone (706) 820-0397
Fax (706) 820-9802
TAME INC

Dual Fuel Specific Terminology – With the introduction of dual fuel there was a need to come up with some standards which we agreed to use throughout our testing and reporting. These terms included energy-based substitution ratio, diesel equivalent brake specific fuel consumption (BSFCe) and percent of unburned methane.

The energy-based substation ratio is defined as the natural gas energy to total fuel energy (diesel and natural gas).

$$SR = (\dot{m}_{gas} * LHV_{gas})/(\dot{m}_{gas} * LHV_{gas} + \dot{m}_{diesel} * LHV_{diesel})$$

Diesel equivalent BSFC allows direct comparison to historic diesel BSFC by normalizing with the diesel LHV.

$$BSFCe = (\dot{m}_{gas} * LHV_{gas} + \dot{m}_{diesel} * LHV_{diesel})/(LHV_{diesel} * BHP)$$

The percentage of unburned methane calculation is the ratio of the methane measured in the exhaust stream to the total NG supplied to the engine. For this calculation, the supplied NG is assumed to be 100% methane.

$$\%UCH_4 = (Mass\ CH_4\ Exhaust)/(Mas\ Gas\ to\ Engine)$$

Development – While many different development tasks were undertaken to support Demo Loco calibration, two specific activities will be addressed in this paper. The first is the effect of diesel timing on engine performance and emissions while the second is the effect of gas admission valve timing.

The impact of diesel timing on engine performance, while operating in dual fuel mode, has very similar characteristics to diesel only operation. Figures 8 shows the impact of varying diesel injection on emissions while holding engine speed,

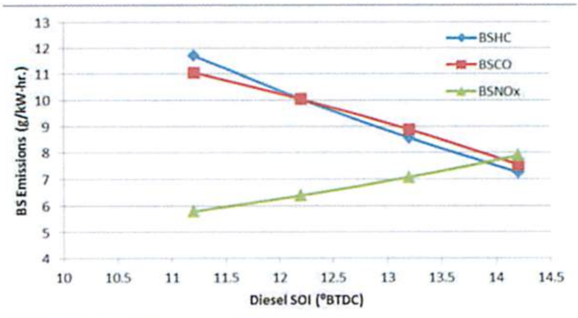


Figure 8 – Emissions vs. Diesel SOI

load, gas valve timing, substitution ratio, diesel rail pressure and intake manifold temperature constant for all points.

As the graph in Figure 8 shows, BSHC and BSCO decrease as diesel timing is advanced while $BSNO_x$ increases. During these runs, the AFR wasn't controlled so the engine experienced approximately a 1 AFR richening of the mixture from the most retarded to most advanced timing as the turbocharger responded to the change in operating conditions. The SCE results suggest that this AFR reduction likely aided in improving combustion of the natural gas, reducing BSHC and BSCO.

Gas admission timing tests were conducted in a similar manner to the diesel timing study outlined above except that diesel timing was held constant while gas admission timing was swept around TDC during the overlap period (between the exhaust and intake strokes). Timing was advanced and retarded by A° as well with a maximum advance of A°+30° BTDC. This was conducted at 3 levels of gas substitution (baseline, baseline +10% and baseline +20%).

Figure 9 shows the impact of varying the gas admission SOI on BSHC with the data normalized to the baseline substitution ratio average. As illustrated in the graph, at the baseline substitution rate, gas admission timing effects are minimal for BSHC. As the substitution rate is increased, the gas admission timing demonstrates a preferred timing and shows a stronger effect on BSHC. One can also see the challenges of increasing the substitution ratio since the increase in BSHC is proportional to gas fueling.

Figure 10 is a plot of BSCH4 emissions from the same data set from Figure 11 and shows a similar trend to the BSHC trends. This suggests that a very high percentage of BSHC is BSCH4.

Figure 11 again uses the same data set as the previous plots and focuses on BSCO. There is a minimal gas admission timing effect on BSCO. We do see an overall increase in the BSCO level as substitution rate increases, similar to the BSHC, but the baseline +20% substitution ratio has lower BSCO than the baseline +10% data. At this point it isn't clear why the higher SR has lower BSCO but one theory is that the baseline +20% points may demonstrate more premixed combustion compared to the lower points resulting in lower BSCO. Another theory is that the higher substitute points may have better in-cylinder air and fuel mixing. Yet another theory is that as the SR is increased, the stoichiometry of the natural gas/air mixture allows for more complete combustion of the premixed fuel, thereby reducing CO emissions.

Figure 12 shows that there is minimal variation of $BSNO_x$ (corrected for humidity) as substitution rate and gas admission timing vary.

Figure 13 shows the expected decrease in BSPM with increasing substitution rate and minimal impact from gas admission timing variation.

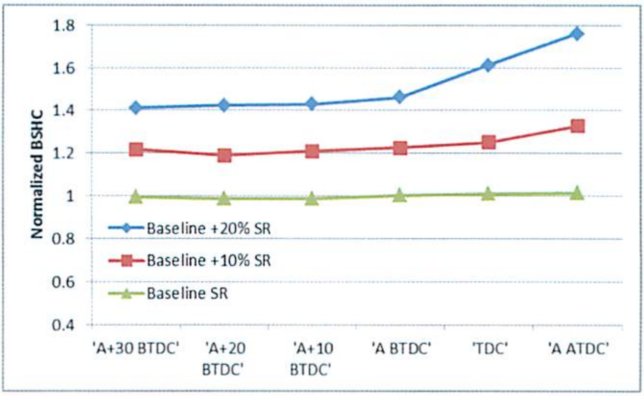


Figure 9 – BSHC vs. Gas SOI

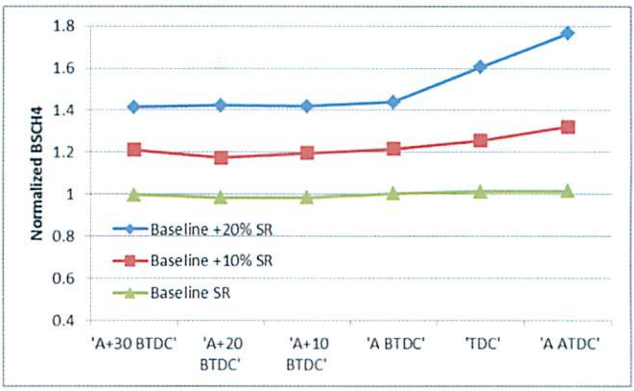


Figure 10 – BSCH4 vs. Gas SOI

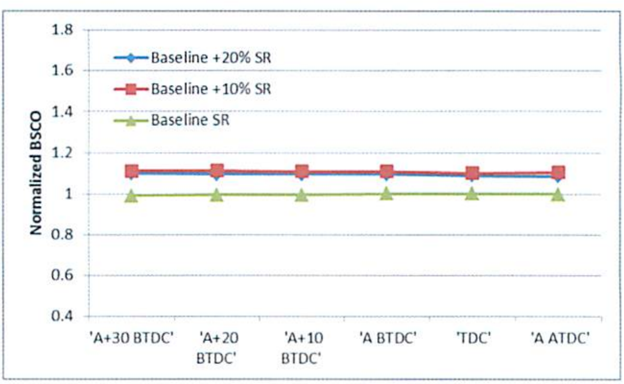


Figure 11 – BSCO vs. Gas SOI

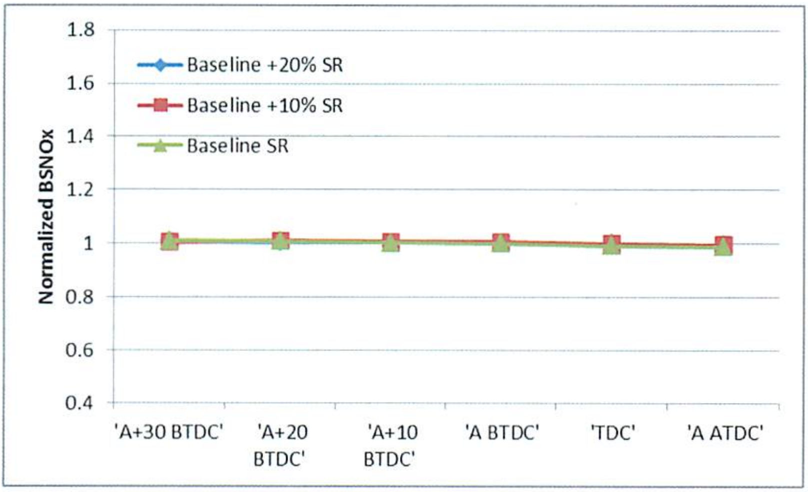


Figure 12 – BSNO$_x$ vs. Gas SOI

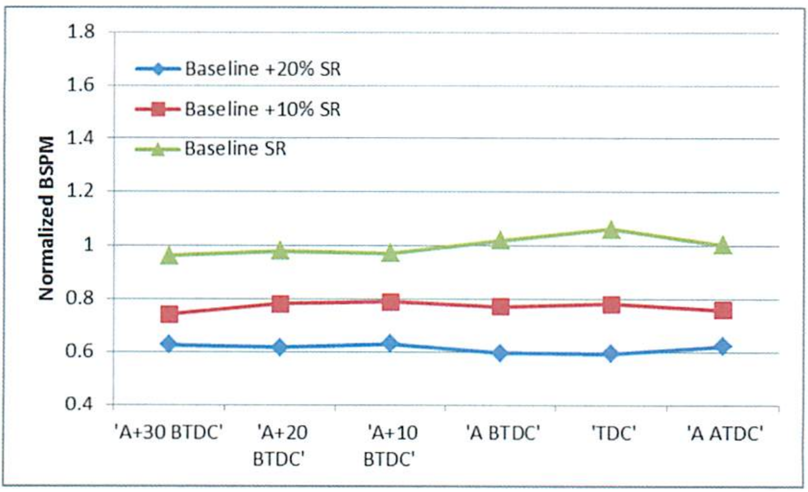


Figure 13 – BSPM vs. Gas SOI

DEMO ENGINE BUILD AND LOCO TEST

The goal of the initial dual fuel engine configuration was to provide a prototype for the NextFuel® demonstrator locomotive program as quickly as possible with the understanding that the dual fuel prototype engine would not be representative of the final product, but instead would serve the purpose of the technology demonstration. The overall program requirements, in order of importance, were safety, speed, functionality, and durability. The dual fuel prototype engine needed to be capable of operating with at least 50% natural gas substitution and provide 1 to 2 years of limited duty service compared to a typical North American Freight locomotive. Given the second priority of speed (i.e., time required to have the locomotive operational), using an existing GEVO12 Tier 3 diesel engine with mostly 'bolt-on' modifications was the preferred option.

The majority of the engine gas admission design effort surrounded packaging of gas rails and delivery of the gas to the intake ports. Conceptual design began in late 2012 with the detailed design occurring the first month of 2013. The NextFuel® demonstration loco's schedule was very aggressive with the first locomotive build and upgrade being completed by May of 2013. Complex concepts requiring extensive analyses were weighed against more straightforward approaches that could meet the highest priorities without compromising minimum performance.

Engine Design – Figure 14 shows a cross section of the power assembly air intake, indicating the location of gas admission. This position was chosen primarily due to cylinder head geometry and adequate gas mixing. It also allowed close proximity mounting of the gas admission valve to minimize transport distance to the intake port.

Moving upstream, routing gas to each cylinder head was the next challenge. By utilizing existing holes in the engine frame, gas rails were mounted along each bank with branches extended to each head. Packaging was the most restricting factor especially between the locomotive engine cab walls and high pressure diesel fuel lines. Additionally, exhaust heat shields were applied to protect the gas admission valves from elevated engine cab temperature. Figure 15 shows the demo loco's engine gas delivery design.

Gas Supply – Supplying gaseous fuel to the engine from the LNG tender required a heating source to vaporize the cryogenic liquid. Engine cooling water was utilized to heat a propylene glycol mixture. The warm glycol was pumped to a vaporizer heat exchanger on the tender, which then flowed back to the locomotive to complete the cycle.

The tender supplied natural gas to the locomotive at a higher pressure than needed so it could be regulated against intake manifold pressure. A natural gas regulator on board the locomotive used an intake air pressure sensing line to modulate the downstream gas pressure to a consistent value greater than intake air. The gas admission valves for this configuration required a range of gas pressure of 1 to 2 bar greater than intake air. During transient engine load operation it was possible to create pressure differentials greater than 2 bar. A back-pressure regulator was added to relieve excess gas pressure in these situations.

The gas train consisted of a series of pneumatic control valves to allow gas flow to separate stages. Gas pressure and temperature were monitored to actuate the valves when desired. An automated vent valve was installed in the most downstream end of the gas train that opened whenever the engine was shut down. Manual vent valves were incorporated to enable gas pressure relief prior to maintenance in the event of a control valve failure. A gas filter was also included to protect the gas admission valves from potential debris. Figure 16 shows a schematic of the GECX3000 NextFuel® demo loco gas train. Later in 2013 another NextFuel® demonstrator locomotive was built in similar engine configuration from a T2 Burlington Northern Santa Fe (BNSF) locomotive going through overhaul.

Field Trials – Functional testing of the demonstrator locomotives was conducted in Erie, Pennsylvania throughout 2013 and into 2014. On-site testing consisted mainly of stationary dual fuel controls verification with limited track time. The control system used on the demonstrator locomotives was similar to the engine control system used in the test cell, outlined in Figure 7, with extra functionality to control the gas supply system and other auxiliary systems. Figure 17 shows the GECX3000 connected to the tender at the GE test facility in Erie, PA. In May of 2014 GECX3000, along with the BNSF NextFuel® demo loco, was moved to the Association of American Railroads' Transportation Technology Center Inc (TTCI), in Pueblo, Colorado. At TTCI both locomotives and the tender accumulated over 5000 test track miles in dual fuel operation. This allowed the Federal Railroad Administration to evaluate the prototypes under controlled conditions before allowing revenue service on a Class 1 railroad.

Later in 2014 the NextFuel® locos traveled to Barstow, California under BNSF railroad operation. In route to California, the locomotives were operated in dual fuel mode at elevations as high as 7000 feet above sea level. Throughout 2015, demonstration testing continued with BNSF accumulating an additional 18,500 track miles while operating in dual fuel mode. Most recently, GECX3000 was removed from dual fuel demonstration testing and upgraded to production intent dual fuel engine configuration.

CONCLUSIONS

GE Transportation used an accelerated design approach for the dual fuel demonstrator locomotive program. The first demo locomotive was designed, manufactured, and functional within 10 months of the beginning of the program. The SCE and MCE engine development were completed in a very condensed timeframe in parallel with the engine and gas train component and engine control system design.

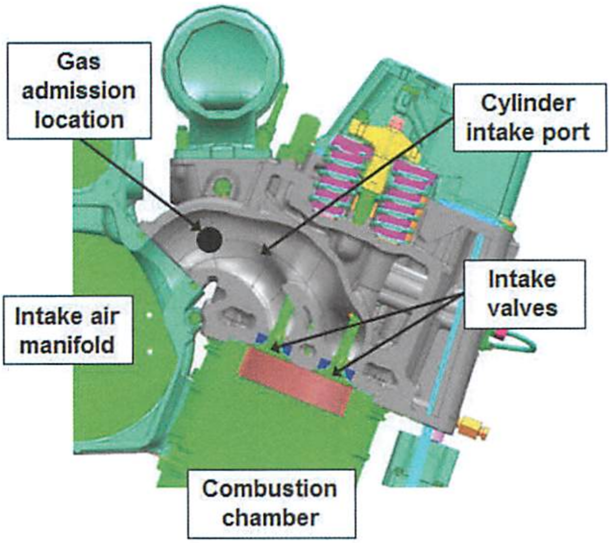


Figure 14 – EVO Intake Cross Section

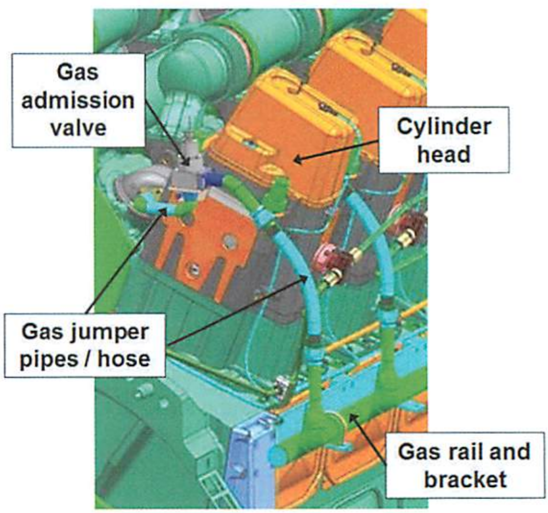


Figure 15 – Engine Gas Admission Architecture

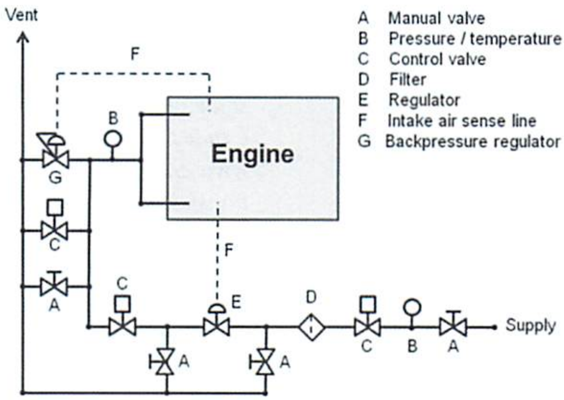


Figure 16 – Locomotive Gas Piping Schematic

Figure 17 – GECX3000 and LNG tender

The dual fuel demonstrator locomotives were delivered to the customer within 9 months of completion of the second locomotive, where they were used to quantify real life cost savings and to explore the infrastructure and logistic concerns associated with fueling and maintaining LNG tender cars.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

Dual Fuel: Capable of running on 100% diesel or a combination of diesel and natural gas.

Substitution Rate: The amount of gas burned vs. total fuel burned.

Notch: Locomotives operate in discrete power settings called notches. In North America, locomotive power levels vary from minimum power at notch 1 (N1) to maximum power at notch 8 (N8).

ACKNOWLEDGMENTS

The authors would like to thank the General Electric Company and Southwest Research Institute for permission to publish this work.

This paper was originally published and presented at the 2016 CIMAC Congress in Helsinki, Finland. The authors would like to acknowledge CIMAC for giving permission to republish this paper in the LMOA technical session Fall 2016.

REFERENCES AND BIBLIOGRAPHY

[1] SIEMINSKI, A. "Outlook for U.S. shale oil and gas" Argus Americas Crude Summit, 14 Jan. 2014, http://www.eia.gov/pressroom/presentations/sieminski 01042014.pdf

[2] EPA Federal Register, CFR, Title 40, Subchapter U, Part 1033, Subpart B, Part 1033 "Exhaust Emission Standards"

Report on the Committee on Fuel, Lubricants and Environmental

Tuesday, October 4, 2016 at 10:30 A.M.

Chairman

Virginia Wiszniewski

Researcher, Exxon Mobil Research & Engineering

Paulsboro, NY

Vice Chairman

Pete Whallon

Director of Railroad Sales, Clark Filter

Lancaster, PA

Commitee Members

D. Bills	Vice President	Red Giant Oils	Council Bluffs, IA
R. Chapman	Industry Liaison Mgr	Innospec Fuel Specialties	Englewood, CO
S. Fenwick	Technical Director Chief	National Biodiesel Board	Jefferson City, MO
S. Fritz, P.E.	Manager-Research & Develop	Southwest Research Institute	San Antonio, TX
J. George	R&D Director	Camfil-Farr	Laval, Quebec
F. Girshick	Technologist	Infineum USA, L.P.	Linden, NJ
B. Graver	Acct. Manager	Clark Filter	Lancaster, PA
L. Haley	Chief Chemist	Norfolk Southern	Chattanooga, TN
B. Hoogland		Union Pacific RR	Fort Worth, TX
S. Koshy	Mechanical Engineer	Amtrak	Wilmington, DE
N. Kuzhiyil	Sr. Lube & Fuel Technician	GE Transportation	Erie, PA
C. Leftwich	CTS Technologist-Engine Oils	Afton Chemical	Richmond, VA
M. Lefebvre	Supply Mgr-Loco & Marine Diesel	Canadian National RR	Edmonton, AB
D. McAndrew		Dennis McAndrew, Inc.	Waterford, PA
H. Parker	Dir-Fuel Infrastructure	Union Pacific RR	Omaha, NE
C. Ruch	Asst. Director–Tech. R&D	BNSF	Topeka, KS
M. Stanfill	Dir-Environmental Engrg & Program Development	BNSF	Topeka, KS
D. Tuttle	Mgr-RR&Marine Sales	American Refining	Atlanta, GA
J. Walkup	Technical Business Development	Dingo Maintenance Systems	Centennial, CO
K. Wazney	Chemist/Testing Specialist	Canadian Pacific	Winnipeg, Manitoba

PERSONAL HISTORY

Virginia Wiszniewski

Researcher, Exxon Mobil Research & Engineering
Paulsboro, NY

Virginia was born and raised in Montreal, Quebec Canada, and received a BSc in Chemistry from McGill University in Montreal, and a PhD in Chemistry from University of Alberta in Edmonton, Alberta, Canada, before coming to the U.S. Virginia started with Mobil Oil in 1989 in Princeton, New Jersey, as a synthetic chemist. In 1990 Virginia moved to Mobil Oil's Paulsboro, New Jersey Research Laboratory, working on passenger car engine oil lubricant development. Since that time Virginia has worked in Products Coordination, Base Stocks, Technical Service before current work on lubricants development for marine, railroad and environmental applications. Virginia is a member of American Society for Testing and Materials (ASTM International), Society of Tribologists and Lubrication Engineers (STLE) , American Chemical Society (ACS), and joined the LMOA Fuel, Lubricants and Environmental Committee in 2010. Virginia enjoys skiing, cycling, hiking, tennis and swimming, and currently resides in Deptford, New Jersey.

The LMOA FL&E committee would like to express their sincere appreciation to Southwest Research Institute for hosting the winter committee meeting in San Antonio, TX on February 25, 2016. Special thanks to Steve Fritz for making all the necessary arrangements.

The committee would like to thank Norfolk Southern for hosting the joint technical committee meeting in Roanoke, VA on April 25-26, 2016.

Special thanks to Exxon Mobile for sponsoring the committee's monthly teleconferences.

Honorable mention is given to Don Mattey of Alfa Laval for arranging the acquisition of LMOA FL&E committee shirts. Thank you Don.

Defining LMOA Generation 7 Engine Oil Performance Category

Prepared by:
Tom Gallagher, Chevron Oronite Company LLC; David Bills, Red Giant Oil; Fred Girshick, Infineum USA, L.P; Leighton Haley, Norfolk Southern Corporation; Najeeb Kuzhiyil, General Electric; George Lau, Canadian National Railroad (retired); Conner Leftwich, Afton Chemical; Dennis McAndrew, DM, Inc.; Virginia Wiszniewski, ExxonMobil Research & Engineering

Abstract

In March 2008, the Environmental Protection Agency (EPA) finalized stringent emission standards (Tier 3 and Tier 4) for locomotive and marine engines. Locomotive fuel sulfur levels also decreased from 5000 ppm maximum on June 1, 2007 to 500 ppm and then down to 15 ppm maximum on June 1, 2012. Locomotive engine manufacturers have enacted a number of modifications to meet these regulations.

The Locomotive Maintenance Officers Association (LMOA) Fuels, Lubricants and Environmental (FL&E) committee issued the definition of LMOA Generation 6 performance category for locomotive engine oils in September 2012 with an effective date of 2009. Generation 6 addressed decreasing fuel sulfur levels along with Tier 3 and earlier emission requirements and has been in use for over 7 years. During this same period, railroad operations have increased locomotive efficiency and utilization which have further influenced engine oil stress and rate of oil degradation.

The Tier 4 emission standard effective January 1, 2015 resulted in additional engine modifications and the introduction of exhaust after- treatment in some engines. The significant engine and system changes implemented on Tier 4 locomotives provided the basis for defining the performance requirements for LMOA Generation 7 locomotive engine oils.

Introduction

The LMOA FL&E Committee established the generation performance categories to define lubricant performance in line with advancements in lubrication technology. Traditionally, advancements in locomotive engine oil performance were associated with alkalinity as measured by the ASTM International D2896 method. However, improved performance and technology innovation are not limited to alkalinity alone. This paper provides the background of LMOA Generation performance categories and factors that established the basis for defining LMOA GEN 7 oils

Non-Road Diesel Fuel Standards										
Who	Covered Fuel	2006	2007	2008	2009	2010	2011	2012	2013	2014
Large Refiners and Importers	Non-Road	500+ ppm	500 ppm	500 ppm	500 ppm	15 ppm	15 ppm	15 ppm	15 ppm	15 ppm
Large Refiners and Importers	Locomotive and Marine	500+ ppm	500 ppm	500 ppm	500 ppm	500 ppm	500 ppm	15 ppm	15 ppm	15 ppm
Small Refiners and Other Exceptions	Non-Road, Locomotive and 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 transitions to ULSD in 2006. Locomotive and Marine diesel fuels were required to transition to 15 ppm ULSD effective January 1, 2007.										

Table 1. Non-road diesel fuel sulfur levels

Recent History

The 2012 issuance of the LMOA Generation 6 definition for locomotive engine oils broke from the historic alkalinity basis and served to effectively address transitional fuel sulfur levels between 2007 and 2012 for diesel fuel consumed by the locomotive fleets in North America. The information in Table 1 is sourced from the EPA and summarizes fuel sulfur changes.

An exception allowing use of transmix fuel containing up to 500 ppm sulfur in older technology locomotives past 2014 remains in effect. This exception was to permit continued, efficient operation of the petroleum distribution system by providing an outlet for pipelines to reasonably dispose of comingled product separating two different fuels.

In general, North American railroads have transitioned away from transmix in preparation for receiving Tier 4 locomotives that require use of 15 ppm maximum sulfur fuel. However, instances may remain where specific locations still accept and consume transmix in non-Tier 4 engines.

Recently, there has also been an increased emphasis on considerations for dual fueled (e.g., diesel & Liquefied Natural Gas) consumption locomotives. Though there will be some similarities in the demands on oil performance, additional parameters will need to be considered. LMOA Generation 7 definition does not address the consumption of alternative fuels.

As defined in Table 2, LMOA Generation 6 locomotive engine oils were researched, developed and field tested to lubricate engines in modern tier compliant locomotives consuming low (≤500 ppm) and ultra-low (≤15 ppm) sulfur diesel.

LMOA Generation	Effective Year	Typica l BN	Performance Milestones of Locomotive Engine Oil Advancements	Formulation Issues
1	1940	<7	Straight mineral oils	Lost alkalinity, lead corrosion, bearing failures
2	1964	7	Ashless dispersants, improved alkalinity with Calcium detergents	Reduced sludge and 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 and dispersants	Increased protection for adverse engine operating conditions
5 *	1989	13 /17 /18	Improved drain intervals in low oil consumption engines	Longer life oils that meet LMOA definitions and requirements
6	2009	9 / 10	Optimized dispersant & detergent system for low sulfur diesel (≤500 ppm) & ultra low sulfur diesel fuel (≤15 ppm) for low oil consumption engines	Proper balance of lube oil alkalinity in consideration of fuel sulfur levels while maintaining established oil drain intervals; concurrent with reduction in sulfated ash in the oil

* GE 4 Long Life (GE 4LL). General Electric recognized the performance improvement but not the guaranteed 184 drain cycle.

Table 2. Locomotive Engine Oil Generations

Current emission standards for locomotive service (line-haul & switch) are summarized in Table 3 per the March 2016 document in EPA's "Non-road Engines and Vehicles Emission Standards" section. Please reference the Code of Federal Regulations (CFR) for a thorough review of the material and applicability.

	Duty-Cycle[b]	Tier	Year[c]	HC[l] (g/hp-hr)	NOx (g/hp-hr)	PM (g/hp-hr)	CO (g/hp-hr)	Smoke (percentage)[m]	Minimum Useful Life (hours / years / miles)[n]	Warranty Period (hours / years / miles)[n]
Federal	Line-haul	Tier 0	1973 - 1992[d, e]	1.00	9.5 (ABT)	0.22 (ABT)	5.0	30 /40 /50	(7.5x hp)/10/750,000[o]	1/3 * Useful Life
		Tier 1	1993 - 2004[d, e]	0.55	7.4 (ABT)	0.22 (ABT)	2.2	25 /40 /50	(7.5x hp)/10/750,000[o] (7.5xhp) /10 /-	
		Tier 2	2005 - 2011[d]	0.30	5.5 (ABT)	0.10 (ABT)	1.5	20 /40 /50	(7.5xhp)/ 10/-	
		Tier 3	2012 - 2014[f]	0.30	5.5 (ABT)	0.10 (ABT)	1.5	20 /40 /50	(7.5xhp)/ 10/-	
		Tier 4	2015 +[g]	0.14	1.3(ABT)	0.03 (ABT)	1.5	-	(7.5xhp)/ 10/-	
	Switch	Tier 0	1973 - 2001	2.10	11.8 (ABT)	0.26 (ABT)	8.0	30 /40 /50	(7.5x hp)/10/750,000[o]	
		Tier 1	2002 - 2004[h]	1.20	11.0 (ABT)	0.26 (ABT)	2.5	25 /40 /50	(7.5xhp)/ 10/-	
		Tier 2	2005 - 2010[h]	0.60	8.1 (ABT)	0.13[i] (ABT)	2.4	20/40 /50	(7.5xhp)/ 10/-	
		Tier 3	2011 - 2014	0.60	5.0 (ABT)	0.10 (ABT)	2.4	20 /40 /50	(7.5xhp)/ 10/-	
		Tier 4	2015 +	0.14[j]	1.3[j] (ABT)	0.03 (ABT)	2.4	-	(7.5xhp)/ 10/-	

Table 3. Locomotives Exhaust Emission Standards

Notes:

a. These standards apply to locomotives that are propelled by engines with total rated horsepower (hp) of 750 kilowatts (kW) (1006 hp) or more, unless the owner chooses to have the equipment certified to meet the requirements of locomotives. This does not include vehicles propelled by engines with total rated horsepower of less than 750 kW (1006 hp); see the requirements in 40 Code of Federal Regulations (CFR) Parts 86, 89 and 1039. The test procedures specify chassis-based testing of locomotives. These test procedures include certification testing, production line testing, and in-use testing using the Federal Test Procedure (FTP) when the locomotive has reached between 50-70 percent of its useful life.

b. Line-haul locomotives are powered by an engine with a maximum rated power (or a combination of engines having a total rated power) greater than 2300 hp. Switch locomotives are powered by an engine with a maximum rated power (or a combination of engines having a total rated power) of 2300 hp or less.

c. The Tier 0 standards apply to locomotives manufactured after 1972 when they are manufactured or remanufactured. Note that interim standards may apply for Tier 0 or Tier 1 locomotives remanufactured in 2008 or 2009, or for Tier 2 locomotives manufactured or remanufactured in 2008-2012.

d. Line-haul locomotives subject to the Tier 0 through Tier 2 emission standards must also meet switch standards of the same tier.

e. The Tier 0 standards apply for 1993-2001 locomotives not originally manufactured with a separate loop intake air cooling system

f. Tier 3 line-haul locomotives must also meet Tier 2 switch standards.

g. Manufacturers using credits may elect to meet a combined nitrogen oxides (NO_x) plus hydrocarbon (HC) standard of 1.4 grams per brakehorsepower-hour (g/bhp-hr) instead of the otherwise applicable Tier 4 NO_x and HC standards.

h. Tier 1 and Tier 2 switch locomotives must also meet line-haul standards of the same tier.

i. The numerical emission standards for HC must be met based on the following types of hydrocarbon emissions for locomotives powered by the following fuels: (1) alcohol: total hydrocarbon equivalent (THCE) emissions for Tier 3 and earlier locomotives, and non-methane hydrocarbon equivalent (NMHCE) for Tier 4; (2) natural gas and liquefied petroleum gas: non- methane hydrocarbon (NMHC) emissions; and (3) diesel: total hydrocarbon (THC) emissions for Tier 3 and earlier locomotives, and NMHC for Tier 4.

j. Manufacturers may elect to meet a combined NO_x+HC standard of 1.4 g/bhp-hr instead of the otherwise applicable Tier 4 NO_x and HC standards.

k. The line-haul particulate matter (PM) standard for newly remanufactured Tier 2 locomotives is 0.20 g/bhp-hr until January 1, 2013, except as specified in 40 CFR Part 1033.150(a).

l. The switch PM standard for new Tier 2 locomotives is 0.24 g/bhp-hr until January 1, 2013, except as specified in 40 CFR Part 1033.150(a).

m. The smoke opacity standards apply only for locomotives certified to one or more PM standards or Family Emission Limits (FEL) greater than 0.05 g/bhp-hr. Percentages apply to smoke opacity at steady state/30-second peak/3-second peak, as measured continuously during testing.

n. Useful life and warranty period are expressed in megawatt-hours (mw-hr), years, or miles, whichever comes first. Manufacturers are required to certify to longer useful lives if their locomotives are designed to last longer between overhauls than the minimum useful life value.

o. For locomotives originally manufactured before January 1, 2000, and not equipped with mw- hr meters.

Code of Federal Regulations (CFR) Citations:

- 40 CFR 1033.101 = Emission Standards and Useful Life
- 40 CFR 1033.120 = Warranty Requirements

Potential Engine Technologies to Meet Tier 4 Emission Levels

To meet the Tier 4 emission levels OEMs have been introducing new technologies to the railroad industry. One OEM started commercial production of a Tier 4 engine in 2015 which was developed from the ground up. From the experience so far with on-highway trucks and the railroads, potential technologies to meet Tier 4 emission levels include Exhaust Gas Recirculation (EGR), Exhaust After-Treatment System (ATS), Reduction in Oil Consumption and Combustion Optimization. The final solution may include all of these techniques or a combination of some of them.

Exhaust Gas Recirculation (EGR)

Exhaust Gas Recirculation (EGR) is a NOx reduction technique. Most of the NOx formation in internal combustion engine is due to "Thermal NOx" which is dependent on flame temperature and concentration of oxygen in the combustion mixture. By recirculating a portion of the cooled exhaust gas (10-40%) into the combustion chamber, the flame temperature and concentration of oxygen can be reduced thereby reducing the NOx formation (Fig 1). However, EGR tends to increase the formation of particulates during combustion. Hence, there always is an optimum amount of EGR that balances NOx and particulate emissions for an engine at given operating conditions.

EGR requires the addition of new components to the engine such as EGR cooler, EGR control valves and extra piping. For the railroad industry, these components are new requiring additional workforce training and different maintenance practices. On the other hand, EGR puts additional stress on engine oil. While cooling the exhaust gas the sulfuric and nitric acid vapors

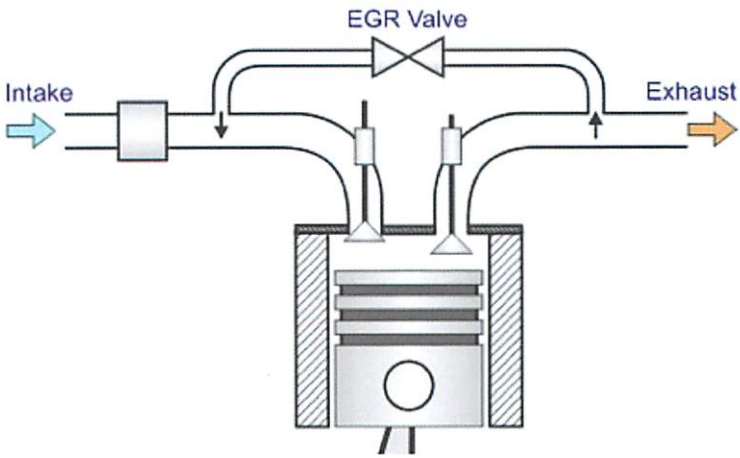


Figure 1. Schematic of EGR

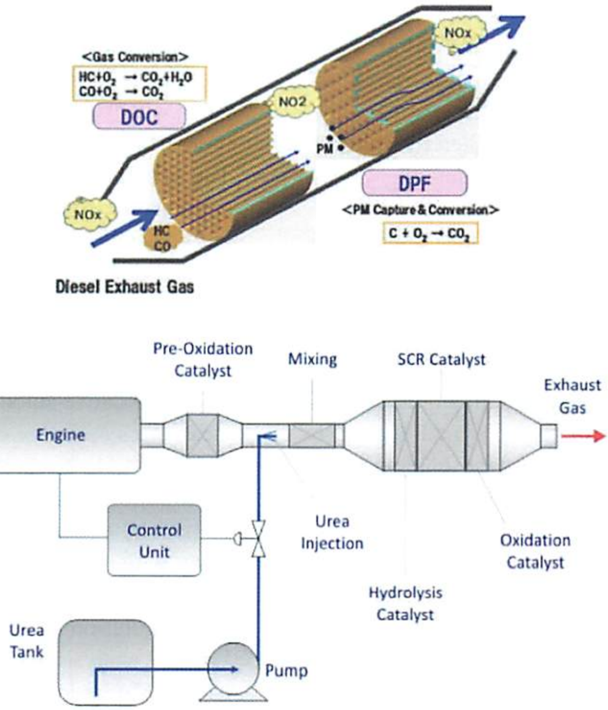


Figure 2. Examples of DOC-DPF and SCR

contained in it tend to condense and increase the acidity of the intake air.

This increase in acidity causes faster depletion of the bases (BN) in the engine oil.

Exhaust After-Treatment System (ATS)

Generally, there are two types of ATS used in diesel engine applications. One is a Diesel Oxidation Catalyst-Diesel Particulate Filter (DOC-DPF) combination and the other is Selective Catalytic Reduction (SCR). The DOC-DPF burns most of the carbon particulates and aerosols in the exhaust and captures most of the remaining particulates. The SCR system on the other hand, converts NOx into nitrogen and oxygen with the help of ammonia/urea and a catalyst. The on-highway industry has been using one or the combination of both for exhaust after-treatment on diesel engines since 2010. For emissions compliance, Tier 4 locomotives may use After-Treatment Systems.

Tier 4 freight locomotives commercially available in North America from one OEM do not use any after-treatment technology.

Reduction in Oil Consumption

Most of the oil consumed in an engine burns or forms aerosols in the combustion chamber thereby causing the emission of particulates.

Reduced oil consumption is a technique used by engine builders to reduce the particulate emission which is a potential technique to help meet the Tier 4 emission standards. Such reduced levels of oil consumption increase the stress on engine oil as the amount of fresh oil additions also called "top off", to the engine sump during normal operations is reduced.

Combustion Optimization

In order to reduce NOx and particulates, permutations and combinations of combustion conditions are used in diesel engine design. These include high pressure common rail fuel injection system (HPCR), optimized air intake systems and optimized valve timings. Some of the combustion optimization techniques such as higher peak firing pressure and related temperature rise influences engine oil degradation.

LMOA GENERATION 7
Performance Category Definition

LMOA Generation 7 locomotive engine oils must be capable of maintaining current performance expectations while operating in locomotives meeting 2015 EPA Tier 4 Emission Standards as well as in legacy fleet locomotives. The FL&E committee defines Generation 7 diesel locomotive engine oil performance attributes and qualities *per* the following:

- The finished oil formulation must be suitable for use in locomotive fleets with Tier 4 and earlier locomotive engine models.
- The finished oil formulation must demonstrate equivalent or improved performance over the previous generation oil. These performance characteristics include deposit and wear control, alkalinity retention, acid control, viscosity control, thermal & oxidative stability, engine cleanliness & sludge control.
- The locomotive engine oil formulation must be tested to demonstrate acceptable compatibility with existing original engine manufacturers (OEMs) approved oil formulations.
- Used oil analysis trending of the finished oil formulation must demonstrate the ability to maintain and/or exceed established locomotive maintenance intervals without breaching OEMs used oil condemning limits.
- The finished oil formulations must pass all OEM test requirements which may include laboratory and field testing.
- Issuance of finished oil formulation approval letters by the OEMs is a prerequisite for claiming LMOA GEN 7 performance.

Field testing to demonstrate LMOA Generation 7 performance must adhere to the following:

- Field testing must be conducted in accordance with the procedures prescribed in the LMOA FL&E paper titled "Engine Lubricating Oil

LMOA Generation	Effective Year	Typical BN	Performance Milestones of Locomotive Engine Oil Advancements	Formulation Issues
1	1940	<7	Straight mineral oils	Lost alkalinity, lead corrosion, bearing failures
2	1964	7	Ashless dispersants, improved alkalinity with Calcium	Reduced sludge and 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 and dispersants	Increased protection for adverse engine operating conditions
5 *	1989	13 /17 /18	Improved drain intervals in low oil consumption engines	Longer life oils that meet LMOA definitions and requirements
6	2009	9 / 10	Optimized dispersant & detergent system for low sulfur diesel (≤500 ppm) & ultra low sulfur diesel fuel (≤15 ppm) for low oil consumption engines	Proper balance of lube oil alkalinity in consideration of fuel sulfur levels while maintaining established oil drain intervals; concurrent with reduction in sulfated ash in the oil
7	2016	10 / 11	Improved weak acid control and alkalinity retention for low oil consumption engines while maintaining /enhancing established maintenance intervals	Emission Regulations, Compatibility with EGR & Exhaust After-treatment technologies, SAPS (sulfated ash, phosphorous, sulfur) content in locomotive engine oil

* GE 4 Long Life (GE 4LL). General Electric recognized the performance improvement but not the guaranteed 184 drain cycle.

Table 4. Updated Locomotive Engine Oil Generations

Evaluation Field Test Procedure" published in the year 2000

- The field test protocol must be reviewed and approved by the OEMs and the additive company
- Performance must be demonstrated in EPA Tier 4 compliant locomotives (and not in Tier 4 credit locomotives,T4C)
- The selected locomotives must be operated in a service having a severity level meeting the respective OEM's requirements
- Resultant field test data must be reviewed by the individual OEMs for issuance of written approval and recognition
- Acceptance by the particular OEMs

As defined in Table 4, LMOA Generation 7 locomotive engine oil specification denotes performance attributes for Tier 4 locomotives while maintaining the expected performance in legacy fleet locomotives.

SUMMARY

The evolution of crankcase oil requirements concurrent with advancements in engine design introduced a new LMOA lubricant category: LMOA Generation 7.

REFERENCES:

Environmental Protection Agency, Office of Transportation and Air Quality, EPA-420-B-16-024, March 2016 (www.EPA.gov)

Fuel, Lubricant and Environmental Committee of LMOA, Definition of LMOA Generation 6, 2012

Fuel, Lubricant and Environmental Committee of LMOA, Engine Lubricating Evaluation Field Test Procedure, 2000

Fuel, Lubricant and Environmental Committee of LMOA, History of the LMOA Lubricating Oil Classification System, 1987

Natural Gas for Rail Applications: LNG Fuel Quality Considerations

Prepared by:
J. Soles (Ferus Natural Gas Fuels), Mathieu Lefebvre (CN), Corey Ruch (BNSF), Najeeb Kuzhiyil (GE), Shaji Koshy (Amtrak), Steven Fritz (SWRI) Union Pacific Railroad, and Bruce Thomson, CSX Transportation

Abstract

Over the past few years, the rail industry has been advancing the use of natural gas fuels for rail applications. As the price spread between natural gas and diesel widened over the past decade, natural gas locomotive technology has developed and grown. There is an increasing interest in the use of natural gas for rail applications and other industries that consume significant amounts of diesel fuel. Variations in natural gas quality can have an impact on engine performance and emissions profiles. Due to these variations, currently there is a push to develop unified fuel quality expectations and standards throughout the natural gas industry, engine manufacturers and railroads.

This paper will review the basic properties of natural gas fuel and the fundamentals of its quality. The differences and similarities between natural gas and diesel as fuels for the rail industry are discussed. Recommendations on a path forward for standardizing fuel quality measurements are put forth for wider consideration.

Introduction

As of 2016, there is currently no fuel quality specification for natural gas consumed as a fuel in locomotive applications. The LMOA FL&E Committee recommends the development of railroad-specific fuel specifications to meet proposed engine OEM requirements and ensure consistency and reliability of natural gas as a locomotive fuel across North America. The focus of this paper is the composition of the gas delivered to the inlet of the locomotive engine, whether the original product is Liquefied Natural Gas (LNG) or Compressed Natural Gas (CNG). However, since most natural gas trials in service today are utilizing LNG for its higher energy density, the major discussion of this paper will center on LNG fuel. As a practical matter, the proposed locomotive fuel specification will need to be a procurement specification, but this will be addressed in future papers.

A collaboration of engine manufacturers, gas suppliers, and railroads will be required to optimize a blend of natural gas fuel quality, cost, and performance. Most natural gas specifications are geared toward boiler and external combustion use (for example: power plants, water heaters, and home use), but internal combustion engines have different quality requirements to prevent issues such as pre-ignition/ detonation.

Methane Number is the most commonly used natural gas engine fuel quality metric, but it is complicated by the various (sometimes proprietary) calculation methods and lack of overarching standard.

A Brief History of Natural Gas for Rail

Historically, natural gas has found a variety of uses in residential, commercial, and industrial applications. A shift towards the use of what has been called "the cleanest fossil fuel" has been investigated in the rail industry over the past several decades, dating back to an early Burlington Northern trial in 1976 with CNG, and the more-publicized LNG trials of Burlington Northern and Union Pacific in the early 1990s[1]. Beginning in 2013, there has been a resurgence of natural gas trials, with five Class I railroads investigating various technologies to make natural gas a viable alternative fuel for the rail industry.

Why Fuel Quality is Important to the Railroads

In the view of railroads, fuel quality has a direct impact on:

- Fuel Efficiency (Gross Ton Miles (GTM) per Gallon)
- Substitution Rate
- Methane Slip
- Emissions Profile
- Engine Durability and Maintenance
- Oil Life

While some of the above impacts are well-understood from a railroad performance viewpoint, others require further explanation.

- Substitution rate is the ratio of natural gas displacement of diesel. The higher the substitution rate, the more natural gas is consumed and the lower the diesel requirement of the engine. Dedicated (100%) natural gas engines will be impacted differently than dual-fuel solutions, and hence may have different fuel quality impacts.

- Methane slip refers to unburned methane that is carried over in the combustion cycle through the engine exhaust and into the environment. This is an undesirable effect of dual-fuel units, and the impact of methane slip is under investigation.

Natural gas fuel quality has a direct impact on emission and engine performance. The fuel properties required to keep a boiler running are different from those required to power a locomotive. The natural gas fuel quality affects propensity for engine knock and misfire, emissions, engine oil degradation, engine durability and maintenance.

LNG is made up of almost pure methane. During the cryogenic production process, most non-methane components and contaminants are removed. This provides a very pure composition, as the other constituents are only present in trace amounts. The high methane content LNG results in less chance of detonation and pre-ignition issues, where this abnormal combustion can be a severe issue due to the high potential for damage.

Railroads have to be in compliance with the changing emission regulations, and there is pressure for lowering carbon footprint and greenhouse gas emission levels. Sulfur is absent or present only in very minor amounts in natural gas fuels (a key advantage over Ultra-Low Sulfur Diesel) and hence natural gas does not emit sulfur oxides (SOx).

The lubricating oil in a natural gas engine does not need to be changed frequently as it burns cleaner than diesel, producing less ash and soot deposit in the oil. In addition, cleaner burning characteristics of natural gas and the absence of particulates often reduce engine wear and tear, thereby extending the engine life.

Natural gas fueled vehicles can run on 100% gas using spark ignition engines or dual fuel engines that use ignition by a small diesel portion in the fuel. Dual fuel engines can alternatively run on diesel fuel oil alone. Most locomotive dual fuel engines require CNG or LNG delivered from the fuel tender as a low-pressure dry gas at 100-150 psi to be burned in the engine combustion chamber. In dual fuel engines, the natural gas is injected into the intake air at low pressure, although there are some high pressure systems in development that inject the fuel at 5,000+ psi into the combustion chamber. This air-gas mixture is compressed in the engine to attain high pressure and temperature. Thereafter the diesel fuel is injected, which auto ignites and in turn ignites the natural gas. The power is generated by burning the mixture of natural gas and diesel. This substitution rate varies according to the load and is controlled by the dual fuel control computer. At lower loads, use of diesel fuel tends to be higher, whereas at higher load the gas proportion is higher.

Natural Gas Fuel Properties

Natural gas by definition is comprised of mostly methane (CH_4, also known as "C1" because the molecule contains one carbon atom) with diminishing amounts of ethane (C_2), propane (C_3), butanes (C_4), pentanes (C_5), as well as trace amounts of inert gases (CO_2 and N_2) and heavier hydrocarbons.

As a transportation fuel, natural gas is delivered in two phases:

- Cryogenic (Liquefied Natural Gas; LNG)
- Compressed (Compressed Natural Gas; CNG)

In comparison to diesel, natural gas is a greatly simplified molecule, but presents unique storage, handling, operational, and quality issues compared to diesel and other fuels.

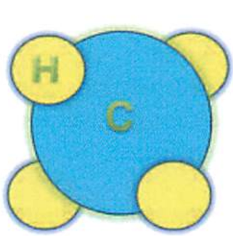


Figure 1 - Simplified Methane Molecule

Component	Typical Range (mol%)
C1 Methane	85-99%
C2 Ethane	5-10%
C3 Propane	2-5%
C4+ Butane and Heavier Hydrocarbons	< 3%
N2 Nitrogen	< 5 %
Other Inerts	< 1 %

Table 1 - Typical Constituents of LNG and CNG

There are key differences between natural gas and diesel in terms of fuel properties. The incumbent fuel, diesel, is fully-established within the industry and there is a high level of familiarization around handling, dispensing, and spill response. Diesel fuel is stored at ambient pressures and temperatures and is relatively stable over time.

In contrast, LNG is a cryogenic liquid fuel, stored at approximately -260°F and 0-150 psi. Since insulation can only offer so much protection towards the fuel warming up (cryogenic storage tanks are best thought of as insulated Thermos bottles), the composition changes over time in two different phenomena:

1) Weathering – whereby lighter molecules (C_1, C_2, N_2) boil off and create vapor in the head space, leaving more concentrated and denser molecules (C3, C4,...) in liquid form in the tank
2) Stratification – whereby the density difference of the various constituents in the tank separate into "layers" within the storage tank

Methane is lighter than air therefore LNG spills will not remain in contact with the ground for a long period of time, as the methane dissipates into the atmosphere rapidly. LNG leaves no trace other than temporarily frozen ground. This property is one of the reasons why LNG can offer substantial environmental benefits over diesel, as spills result in a venting of methane and require no ground remediation.

CNG is natural gas stored at high pressure (typically over 3600 psi) and at ambient temperatures. The fuel is essentially stable in storage over time without change in composition, but the product itself can be of lower quality as less pretreatment is required for the production of CNG.

LNG and CNG Production Processes

To better understand natural gas fuel properties, an overview of the production processes is included in this section.

Both liquefaction and compression require forms of pretreatment to clean up the gas and remove contaminants. The amount of pretreatment required is a direct function of the quality of the source gas, as well as the desired fuel quality at the outlet of the facility.

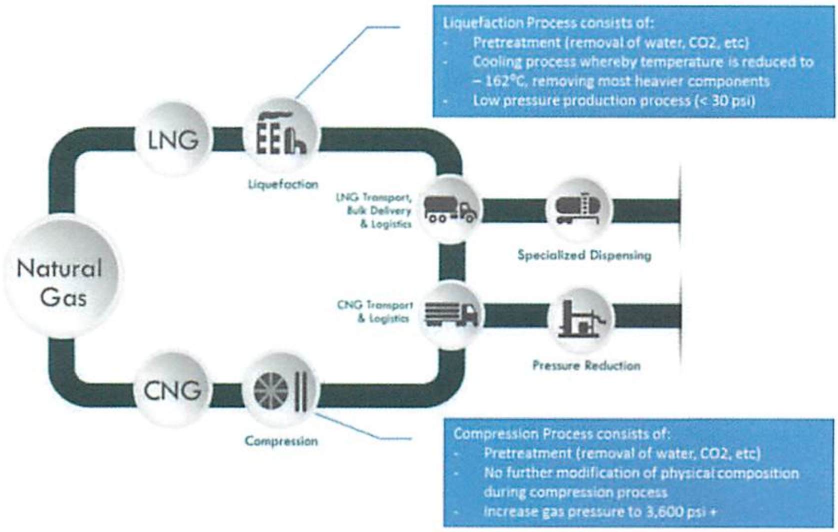


Figure 2 - Comparison of LNG and CNG Production Processes

Much like gasoline, a variety of fuel qualities can be produced by LNG and CNG facilities, and engine OEMs have standards and optimal ranges of quality for operation of their equipment.

Across North America, gas pipeline composition can vary greatly with location. Demand for ethane has fallen dramatically with the rise of shale plays and increased production of natural gas and oil. As such, ethane is often added into the existing natural gas pipelines, which is leading to the ethanization of pipelines in North America pushing the traditional typical 10% ethane limit.

With both LNG and CNG, higher methane purity content can be achieved through the removal of heavier hydrocarbon products, which complicates and adds cost to production process by requiring additional distillation columns and other equipment for treatment. LNG is generally comprised of mostly methane as many contaminants are removed in the production process, but ethane, other heavier hydrocarbons, and inerts can still be present in LNG. Pre-treatment of gas, such as ethane extraction can be costly, but may be necessary to meet methane content requirements.

Pretreatment components can include options such as Amine Units (which absorbs CO_2 and H_2S), or Molecular Sieves (which remove water, CO_2 and H_2S via adsorption). Other options include siting liquefaction and compression facilities near deep cut ethane extraction facilities, where many of the non-methane components are removed for other purposes upstream of the LNG plant, providing a much higher methane content.

The key difference between production of natural gas as LNG or CNG involves the use of pressure and

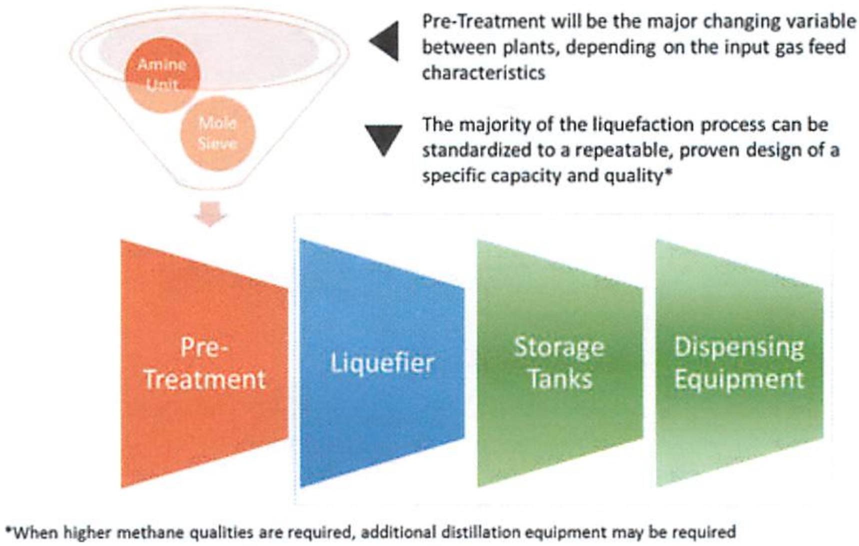


Figure 3 - Liquefaction Process Flow

temperature. Production of LNG cools the natural gas to a cryogenic state, which removes many non-methane components by design. With CNG, after pretreatment, the gas is compressed to high pressures for storage and transport, without further refinement. Fuel quality issues have been known to arise with CNG that is produced off of municipal gas supply lines without sufficient pretreatment.

The liquefaction process is largely scalable and repeatable, with the feed gas and pre-treatment being the main changing variable between facilities.

Methane Number

One commonly used term in the natural gas engine industry is "methane number". Similar to Octane Number for gasoline and Cetane Number for diesel fuel, a higher methane number generally means better ignition properties (less chance of knocking).

A major challenge with methane number calculation is that there are many different calculation methods, some of which are proprietary, and all give different results for a given fuel composition. Existing accepted methane number calculation methods include:

- AVL
- California Air Resource Board (CARB)
- CAT
- Cummins-Westport
- GRI
- ISO (TR 22302; Natural Gas Calculation of Methane Number)
- MWM
- Waukesha

To illustrate this point, Table 2 shows the LNG composition from a selection of LNG production facilities in North America. The compositions are listed in the upper portion of the table, and three different methane numbers (specifically, Cummins-Westport, CARB, and CAT, ISO, and MWM) are calculated below.

It is evident, there is notable discrepancy between the calculated methane number, as each method treats the different components in a unique way. Some may penalize heavier hydrocarbons more than others, and inerts receive different treatment across the methods.

With that in mind, the largest discrepancy in Table 2 is contained in the CARB methane number, which is based on the GRI method. In one paper, it was noted by SWRI and GRI that the conversion equation used by CARB tended to overestimate the methane number[2].

There is a good opportunity for the international standard organizations to develop a common methane number calculation method. To this end, ASTM has recently started a new work group to develop a methane number standard using the MWM method (WK 40094).

The key point in this discussion is that when methane number is reported, it should be accompanied by the applicable calculation method.

mponents	1	2	3	4	5	6
ethane	96.483	96.459	96.829	93.130	99.000	99.450
hane	3.317	3.318	2.640	6.250	0.055	0.150
opane C3H8	0.108	0.140	0.078	0.370	0.001	0.010
utane C4H10	0.011	0.028	0.002	0.060		0.020
Butane C4H10	0.011		0.001			
entane C5H12	0.002		0.001	0.010		
Pentane C5H12	0.001					
Hexane C6H14	0.001			0.010		
Heptane C7H16						
Octane C8H18						
Nonane C8H18						
Decane C10H22						
drogen H2						0.010
S ppm						
rbon Monoxide CO						
rbon Dioxide CO2	0.022	0.021			0.003	
trogen N2	0.044	0.034	0.449	0.170	0.550	0.360
ygen O2		0.000			0.010	
tal Composition	100.000	100.000	100.000	100.000	99.619	100.000
mmins Westport ethane Values	88.10	88.00	89.00	82.60	89.90	93.70
RB Equation Methane mber	99.00	98.84	100.92	91.05	108.26	107.77
T Methane Number	90.20	90.20	92.20	82.60	99.80	99.40
O Linear Coefficient	90.10	90.00	90.60	84.50	93.90	94.70
O Hydrogen/Carbon tio	90.60	90.50	92.40	83.60	98.90	98.50
WM	88.00	88.00	90.00	81.00	100.00	99.00

Table 2 – Comparison of Methane Number Calculations for a Selection of LNG Facilities

Engine Performance Impacts

The methane number requirement of natural gas engines highly depends on the actual engine design. Maximum substitution rate and exhaust gas recirculation rate, for example, can be influenced by the methane number. Some designs do exist that do not rely on a methane number requirement (such as the MAN ME-GI dual fuel engine).

In general, while there may be some discrepancies in the calculation methods, the impact of methane number is consistent. For diesel-natural gas dual fuel engines, the methane number of the LNG influences the maximum substitution rate and impacts the knock. For spark ignition engines, methane number can limit the operating range.

Energy content is another consideration for engines. The energy content of the fuel determines in part the maximum power of the engine. Although some natural gas fuels have high inert contents and high methane number they have low energy content, and can reduce the power available. There is a large push in the industry to maintain power between diesel and natural gas locomotives, so it is critical that natural gas meets the energy content criteria of the specific engine application to prevent any loss of power.

Increased ethane content reduces the methane number. The presence of ethane increases Non-Methane Hydrocarbon (NMHC) emission. Ethane oxidation using an Oxidation Catalyst is not very efficient today as it does not oxidize ethane very well, and is even less efficient in converting methane. Currently, the EPA mandates a limit on the emissions of NMHC.

The heavier hydrocarbons (such as propane or butane) also increase energy density (desirable for boiler fuels) but reduce methane number (undesirable for internal combustion engines). The higher the NMHC content of the fuel, the more NMHC will be in the exhaust – which has a direct impact on emissions profiles.

Fuel Tender Overview

While fuel tender standards are still under development[3], a generic LNG fuel tender is shown in Figure 4 for illustration purposes.

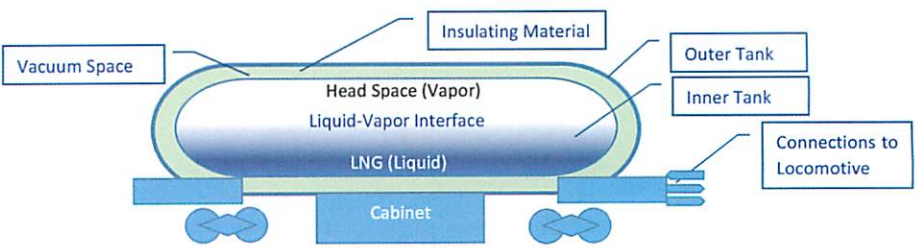


Figure 4 - Fuel Tender Sketch

It is important to note the cabinet contains the fill valves and instrumentation in crashworthy cabinet to protect sensitive components (such as valves, pipes, gauges, sensors, and emergency response features) in the event of an incident.

Methods of Measuring Natural Gas Quality and Parameters

The current industry-accepted practice for analyzing natural gas composition is ASTM D1945-14 - Standard Test Method for Analysis of Natural Gas by Gas Chromatography.

Gas chromatographs analyze gas compositions only, not liquid, so any analysis of LNG samples requires LNG to be collected from sample ports at production facilities, storage tanks, on-road transports, or fuel tenders. These LNG samples must then be vaporized to be analyzed in the gas chromatograph.

One location that gas samples can be collected from is on the locomotive natural gas fuel system, as shown in Figure 5.

Figure 5 - Gas Sample Bottle Collection on Locomotive

The source of natural gas samples is critical, as sampling from different locations in a storage vessel (such as the vapor space versus the actual liquid natural gas) can produce different results. Sampling gas from the head space of the fuel tender may not be representative of the liquid product as methane is most prone to boiling off, and therefore the gas analysis could show a disproportionately high methane content. Conversely, sampling gas that has been vaporized in the fuel tender off of a bottom port (liquid) may contain the heaviest of the components in the fuel tender, and analysis could show higher volumes of heavier hydrocarbons. The gas analysis provides constituents on a mole percentage basis, so no additional methane or ethane is "created" in the tender; rather, the composition will be representative of the volume of constituents in that region of the tender from which the sample was taken.

Ideally, the fuel tenders will draw a blend of products from both vaporized LNG and head space gas, and the composition of the overall gas supply will be a more representative sample of the quality within the fuel tender.

An example of a gas chromatography analysis system in place at one particular laboratory is shown in Figure 6. This system utilizes a 3000 Micro GC Gas Analyzer, with a filtration system to keep contaminants out of system. Calibration intervals are key for proper results from gas chromatographs.

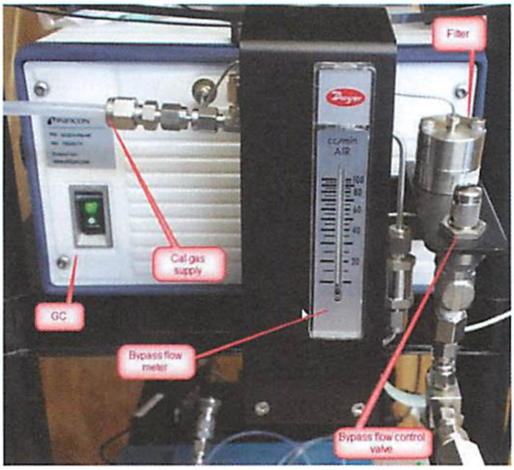


Figure 6 - Sample Gas Chromatograph Setup

Fuel Aging, Weathering and Stratification

LNG is a perishable product; if left unmanaged, pressure will build as external heat sources warm LNG in a storage tank. The typical pressure rise in a fuel tender or storage tank of similar design is around 1-6 psi/day; considering most product is delivered into storage at 0-50 psi, and the AAR Natural Gas Fuel Tender Specification (draft) suggests pressure relief valve settings of 200 psi, substantial hold time is allowed before any venting would occur.

The tender pressure rise fluctuates with different head space volumes as well. Pressure will rise faster in the event there is a large liquid volume with small headspace, and conversely pressure rise is more gradual with a small liquid volume and large head space. Non-condensable gases (such as nitrogen) increase pressure rise as they effectively reduce headspace volume.

As LNG is consumed (or as new, cold product is added), the pressure drops in tender, acting to "reset the clock" to some degree and extend hold time.

As product weathers, gas in vapor space will develop a higher methane content relative to the remaining liquid as nitrogen (as the lightest component) and then methane will boil off first. Conversely, ethane (C2) will condense out of the headspace vapor. It is important to note, none of these components are "created" or "destroyed" over time, but they do change phase and tend to assume gaseous or liquid states based on the respective boiling points.

Operational situations can also increase pressure rise; for example, LNG remaining in uninsulated pipes or heat exchangers after NG flow shut down will boil off and cause pressure rise, especially if starts and stops are rather intermittent. Onboard pumps can also add heat to the LNG.

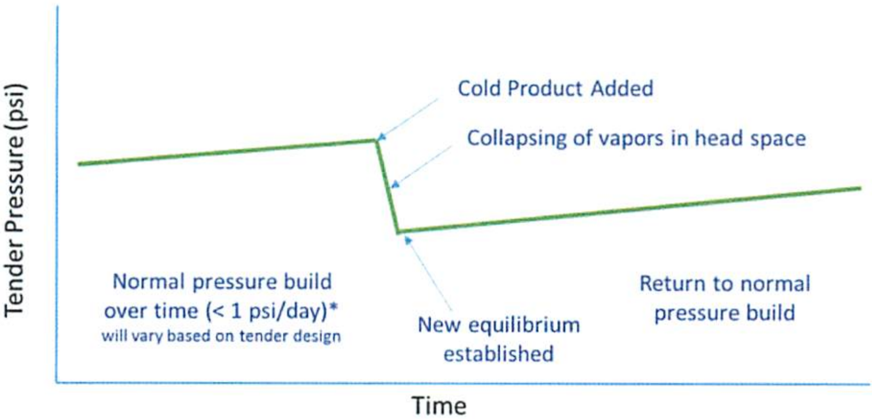


Figure 7 - Impact of Adding Cold Product to Storage Tank

A stationary tender can pressure up condition where head pressure is several PSI over saturation pressure. Moving can cause sloshing and collapse this situation temporarily.

Stratification of LNG involves the separation of the different LNG constituents into layers. This is more of an issue with large volume storage that sits over time, and is more likely to be a problem with peak shavers and other LNG produced that contains higher non-methane components. The process of stratifying takes time (longer than water/oil separation), and the issue can be addressed using top and bottom fill connections to cycle the tank.

Natural Gas Fuel Quality Standards in Other Industries

Various groups across other industries are developing natural gas fuel quality standards, but most of the focus has been on relatively small engines – although progress is being made, specifically on the marine side. ISO TC-28 has a new working group with a focus of developing LNG engine fuel standards for marine applications. Further participation by all parties, including the rail industry, will be beneficial as natural gas fueling develops. Due to the nature of high horsepower engines, the rail and marine industries may have to consider their own specifications.

A quick summary of other current natural gas fuel standards are listed below:

- Society of Automotive Engineers (SAE)
  - o SAE TC7-Fuels Committee
  - o SAE J2699 for LNG
  - o SAE J1616 for CNG (newly revised; published May 2016
- ISO - Natural Gas for Use as Compressed Fuel for Vehicles
  - o ISO 15403-1: Designation of Quality

  - ISO 15403-2: Specification of Quality
- CARB – Natural Gas Vehicle Specification
- ASTM International
  - Task force working on LNG for automotive consumption
  - ASTM Committee D03 on Gaseous Fuels
  - WK40094: Specification for Compressed and Liquefied Natural Gas as Motor Vehicle Fuel (under development)
- European Committee for Standardization (CEN)
  - EN 16726 Gas Infrastructure for pipeline natural gas
  - EN 16723 Natural Gas and Biodiesel for use in transport and biomethane for injection in the natural gas network (planned for ballot June 2016)

Individual OEMs may have their own unique natural gas fuel specifications for the fuel quality. Currently rail-specific manufacturers of note with fuel specifications include GE, CAT/EMD, and Cummins. Outside of the rail industry, MAN, Wartsila, and Westport are also developing their own fuel quality specifications. This variety of specifications is a key driver for the LMOA FL&E's recommendation for the rail industry to standardize early in the development of natural gas fuels.

Overview of Differences in LNG Composition

When discussing LNG fuel quality, it is imperative to understand the purpose of the LNG facilities in existence today. LNG is produced in the utility world as a method of storing natural gas during periods of low natural gas pricing (i.e. summer months) for later consumption. This practice is known as "peak shaving". LNG produced for the heating markets may not have been pre-treated sufficiently, as the requirements for this natural gas are largely centered around heat content per unit volume. Consumers such as railroads looking to peak shavers for LNG fuel for engine applications must be cautious about the fuel quality when using LNG produced for this purpose, to ensure the non-methane hydrocarbon content is not too high for the engine specifications.

Merchant facilities are LNG production sites built to supply a specific grade of LNG. These sites often use layers of pre-treatment to ensure that fuel quality meets a certain guaranteed level. Engine-grade merchant plants are already in operation and more are under development across North America as the natural gas fueling markets are establishing.

A sample of LNG compositions from typical merchant and peak shaving facilities is included in Figure 8 below.

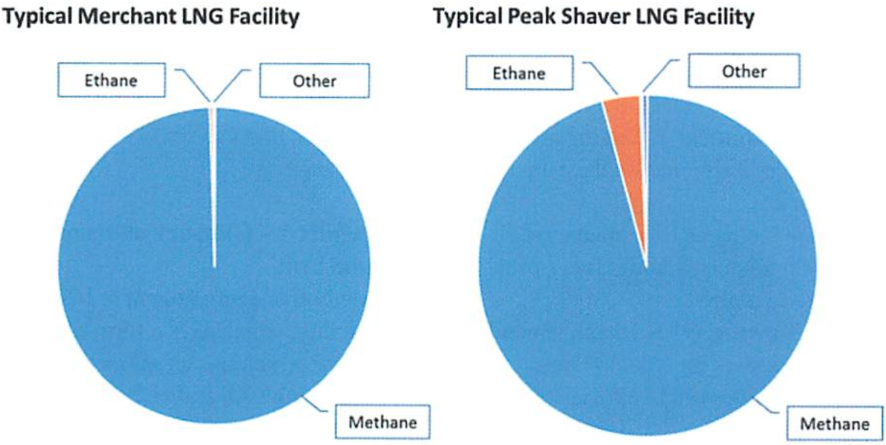


Figure 8 - Comparison of LNG Compositions for Merchant and Peak Shavers

Fuel Availability

With an understanding that fuel quality is important and high methane content is desirable from an engine performance point of view, one must also consider the impact of pricing as it relates to the fuel spread between natural gas and diesel, a common economic consideration for rail projects. The cost to produce higher quality fuel increases approximately exponentially when a methane content of 95 mol% or greater is required, as illustrated in Figure 9.

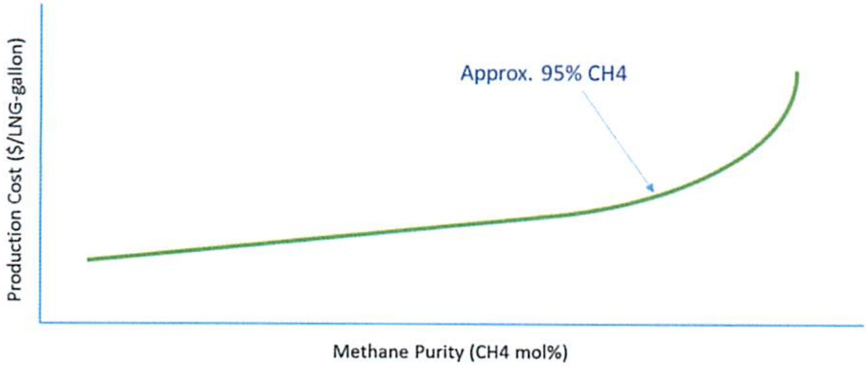


Figure 9 - Impact of Methane Purity on Production Cost

Another challenge presented by the current marketplace is the availability of LNG decreases as the required quality of product increases. As a general comment regarding availability in the 2016 marketplace in North America:

- 90% methane/10% ethane readily available as boiler fuel / peak shaver plants
- 95% methane/5% ethane generally available at merchant plants
- 99% methane/1% ethane sparingly available
- 99%+ methane – specialty gas available in small quantities

During the LNG locomotive trials in the 1990s, the term "Refrigerated Liquid Methane"TM (RLMTM) was introduced relating to very high quality LNG consisting of nearly-pure methane. RLM is a trademark of Air Products and Chemicals, Inc.

Recommendations

As natural gas rail projects continue to develop, a need will arise for a basic railroad fuel specification (with limits on ethane, water, inerts, and NMHC content). There are trade-offs in cost versus performance across the spectrum of quality and differences in ideal qualities across the industry for railroads, OEMs, and fuel suppliers. A unified and standardized method of measurement (for both individual components, and also a measurement standard such as methane number) will need to be defined to ensure consistency across industries.

In the absence of other standards specific to the rail industry, the LMOA FL&E Committee can develop an industry consensus recommendation while monitoring the other committees. We suggest that this could be a topic for a 2017 paper.

Appendix 1 – Glossary of Terms

Amine Unit
Method of Pretreatment at LNG Facility, which uses a form of liquid amine which has an affinity for absorbing CO_2 and H_2S

British Thermal Unit
Imperial measurement of energy, in this instance energy content of a fuel. 1 BTU = the energy required to raise 1lb of water by 1°F. (see also joule)

CARB
California Air Resources Board – established in 1967 with the stated goals of attaining and maintaining healthy air quality; protecting the public from exposure to toxic air contaminants; and providing innovative approaches for complying with air pollution rules and regulations.

CNG
Compressed Natural Gas – Natural gas which is placed under high pressure (typically 3,000 psi or greater, though typically at ambient temperature) for storage or transport.

DGE/DLE
Diesel US Gallon Equivalent / Diesel Liter Equivalent - the amount of alternative fuel (natural gas, in this instance) required to equal the energy content of one

liquid gallon (liter) of diesel fuel. DGE/DLE allows the consumer to more easily compare the cost of alternative fuels against the commonly known diesel fuel by accounting for the fact different quantities of alternative fuel may be required to produce the same energy as diesel fuel, though the alternative fuel may also have a different price.

External Combustion Engine
An engine which derives power from an external combustion source and uses a heat transfer medium to extract heat for the engine. (Example: Steam Engine, Steam Turbine Power Plant). Because fuel is usually combusted at low pressure in a continuous cycle, ECE generally do not have strict requirements for ignition properties of the fuel.

Gross Ton Miles ("GTM")
The product of total train weight multiplied by the distance traveled

Head Pressure
The pressure exerted by natural gas on the storage container. Typically expressed as gauge pressure (vs absolute pressure), this pressure could be simply due to the liquid column height of liquid natural gas if the container is vented to atmosphere, or could be a combination of liquid column height plus vapor pressure if the container is sealed.

Hold Time
he length of time a storage vessel will contain LNG before requiring pressure relief.

Internal Combustion Engine (ICE)
An engine which derives power directly from heat created from combustion of fuel within a cylinder. (Example: Gasoline Engine, Diesel Engine) Because fuel is usually combusted at high pressure in a short time, an ICE will often have specific requirements for the ignition properties (Octane, AKI, MN, Cetane) of the fuel.

Joule
SI unit of energy, in this instance energy content of a fuel. 1 Joule = the work done by a force of one newton when its point of application moves one meter (see also BTU)

LNG
Liquefied Natural Gas – Natural gas which has been converted to liquid form by cooling to approximately -260°F (-162°C). Typically stored at pressure ranging from atmospheric to ~150psi)

Merchant LNG Facility
LNG production sites built to produce a specific grade of LNG. These sites often use layers of pre-treatment to ensure fuel quality meets a certain guaranteed level.

Methane Number (MN)
Measurement of the knock resistance of natural gas fuel. MN is analogous to 'Octane' or Anti Knock Index (AKI) of gasoline, and somewhat similar to 'Cetane' or ignition quality of diesel fuel. Suitably high MN is required to prevent knocking / detonation in an ICE, though MN can be affected by weathering of the LNG.

Methane Slip
Methane (natural gas) which enters the cylinder of the engine, but is not burned during the combustion cycle. This unburned methane is expelled in the engine exhaust stream.

Mole Sieve
(also known as Molecular Sieve) Method of pretreatment at LNG Facility; removes water, H_2S, CO_2 via adsorption.

NMHC
Non Methane Hydrocarbons – the components of natural gas that are heavier than methane; for example, ethane, propane, butane

Peak Shaver
LNG production sites built for utility-grade LNG, often used to smooth demand cycles and provide backup supply to natural gas distribution systems

Substitution Rate
The amount of diesel fuel replaced by natural gas fuel in an engine. Usually expressed as a percentage based on DGE/DLE. Ie "70% substitution rate" means the diesel fuel consumption was reduced to 30% of the original value and the remainder of the fuel energy was comprised of natural gas.

Weathering
Refers to the change in composition of natural gas liquid remaining in a storage tank. As ambient heat causes the liquid to vaporize, lower boiling point fractions (methane, nitrogen) tend to vaporize preferentially to higher boiling point fractions (ethane, propane, butanes and beyond). This can lead to the vapor space becoming enriched in methane while the remaining liquid becomes depleted in methane / enriched in ethane, propane, butanes, etc.

Endnotes:

1. For further reading, please consider the 2007 report produced by the California Air Resources Board (CARB), "An Evaluation of Natural Gas-Fueled Locomotives" (www.arb.ca.gov/railyard/ryagreement/112807lngqa.pdf)
2. Society of Automotive Engineers Technical Paper (SAE 922359, 1992): http://papers.sae.org/922359/
3. The AAR Natural Gas Fuel Tender TAG is responsible for a dedicated tank car style fuel tender standard, which has been under development since 2013.

Appendix 2 – Energy Conversion Factors

Fuel Type	DGE	BTU/unit
Diesel	1.00 US gallon	141,000 BTU/gal
Gasoline	1.12 US gallon	115,000 BTU/gal
LNG	1.71 US gallons	82,000 BTU/gal
CNG	3.98 m3	35,000 BTU/m3

Appendix 3 - Recommendations for Future Papers

As natural gas as an alternative fuel for the rail industry grows in popularity and implementation, there are some recommended studies that the FL&E recommends:

Impacts of Fuel quality on:

1. Substitution Rates
2. Methane Slip
3. Emissions
4. Fuel Efficiency
5. Engine Longevity
6. Oil Life

Acknowledgements

The authors would like to thank the following individuals for their support in the preparation of this paper and presentation:

- Zac Stashko, Ferus Natural Gas Fuels (zacstashko@ferus.com)
- Kenneth Kar, Exxon Mobil (Kenneth.kar@exxonmobil.com)

Effects of Fuel Composition on In-Service Engine Oil Properties

Prepared by:
Dennis W. McAndrew (Consultant), Mathieu Lefebvre (Canadian National Railway), Scott Fenwick (National Biodiesel Board), Fred W. Girshick (Infineum, USA), George Lau (Canadian National Railway, retired)

OBJECTIVE: Attempt to discover if there are statistically detectable changes – of practical significance – in the crankcase oil's condition, due to variations in diesel fuel composition, and temperature differences across seasons.

ABSTRACT: To comply with government requirements to use fuel components derived from renewable sources a railroad blends either Fatty Acid Methyl Ester (FAME) or Hydrogenation-Derived Renewable Diesel (HDRD) into their diesel fuel. To avoid possible low-temperature handling problems, the railroad uses twice as much as mandated in the summer and none in the winter. This creates a natural experiment to examine whether – or how – the renewable fuels affect in-service lubricating oil condition and, by extension, engine condition (after accounting for any effects of seasonal temperature). A locomotive crankcase oil evaluation was conducted to discover these effects. These variables, along with regulated mandate about biomass fuel usage, are evaluated in this paper.

INTRODUCTION: The Canadian Government (the "Government") is committed to expanding the production of renewable fuels such as ethanol and biodiesel and their use in Canadian transportation fuel. As such, the Government has required gasoline fuel producers and importers to have an average renewable fuel content of at least 5% based on the volume of gasoline they produce or import commencing December 15, 2010. In addition the Government imposed a 2% biodiesel and/or renewable (biomass based diesel fuel) content requirement based on the volume of diesel fuel and heating distillate oil they produce or import commencing July 1, 2011. Canadian provinces also have their own mandates. However railroads travel between provinces; therefore the two major Canadian railroads are only complying with the Federal mandate, which has a 2% requirement at the moment. Both (gasoline and distillate) are integrated in the same Federal Renewable Fuels Regulation.

The colder climate in Canada coupled with renewable fuel regulations, are requiring fuel oil producers to supply biomass fuels only in warmer months almost everywhere in Canada.

The fuel oil producers believed there was a need to mitigate potential winter operation issues when biomass fuels are used. The mitigation plan was not to use biomass fuels seasonally and geographically in colder months. Therefore, in order to comply and still continue ensuring an adequate supply at the optimal price possible, the industry is producing and supplying a higher concentration of biomass fuels in warmer months.

The Locomotive Maintenance Officers Association's (LMOA) Fuels, Lubricants and Environmental Committee (FL&E) presented a paper in 2012 titled "*LMOA FL&E Locomotive Durability Test Protocol for Alternate Fuels and Biodiesel*". They recommended this protocol be used in the evaluation of biomass fuels (alternative fuels and biodiesel fuels). This protocol requires a two year controlled field evaluation with test and control locomotives. Because of the length of the test, difficulties in controlling fueling, cost, and complexities in managing test and control units, it has become difficult to find a location willing to conduct such an evaluation. However there still exists a need to understand if biomass fuels affect the locomotives' engine lubricating and fuel systems, and ultimately the locomotives' systems' reliability, durability, and availability.

Being that oil quality and oil conditions are important factors in determining a locomotive's engine reliability, durability, and availability, this study was undertaken.

Looking for an alternative method to the FL&E protocol, it was suggested that obtaining existing used crankcase oil laboratory test results from a railroad where the blend of biomass fuel concentrations were greater than five percent, some insight to the locomotive's condition might be achieved. A feasible alternative was to evaluate used oil test results from one of the railroads where the seasonal temperatures dictated a variation in diesel fuel composition, i.e., no alternative fuel in the cold winter months and concentrations greater than the Government mandate in the warm summer months such that the yearly total consumed is equal to or greater than the government yearly mandate.

OIL ANALYSIS (instrumentation and analytical methodology): The goal of the railroad is to have oil specimens collected from the locomotives once every 10 to 15 days. Those specimens are sent to a central laboratory for analysis. The analyses consist of the following:

1. Determination of the concentration of 18 elements using Inductively Coupled Plasmas Spectrometer (ICP)
2. Change in the oil's oxidation, nitration, sulfation, and soot using spectra from an Infrared (IR) Spectrometer
3. Percent of fuel and/or water contamination using spectra from an IR
   a. Fuel is by IR, verified/quantified by gas chromatograph if greater than 1%

4. Viscosity at 100 ° C, ASTM D445
5. Base number (BN), acid number (AN), and pentane insoluble (PI) calculated from IR spectra via a surrogate method, i.e., Principle Component Regression of over 1000 samples

EVALUATION METHODOLGY: The analytical evaluation of the used crankcase oil results were comprised of oil test data collected from locomotives with up to three years of oil specimen history. The original data set included 39,433 oil results collected from 1,170 locomotives. The locomotives oil specimens' history was divided into two seasons, i.e., winter or summer for the study. In addition it was believed there was a need to allow for a transition period between the seasons. Therefore, in addition to eliminating data from locomotives with oil specimens only in winter or summer, the oil results from the months of March, April, September, and October were excluded. The final number of oil specimens included in the first phase of the evaluation was reduced to 26,525 oil specimens.

Table 1 is a summary of the blended amount of biofuel in the locomotive diesel fuel at all of the railroad's fueling locations. It is important to note that the test laboratory determines the concentration of biodiesel fuel blended into the diesel fuel using ASTM D7371. The test laboratory did not measure the concentration of the renewable fuel (Hydrogenation Derived Renewal Diesel or HDRD) being blended into the diesel fuel; this was determined using fuel purchasing and delivery records.

The concentration of the HDRD blended into the diesel fuel was not determined because of the difficulties and cost of the determination, and in part because of lack of a standard definition of HDRD fuels. However, because of HDRD concentration being known in a specific region, the effect of HDRD in the fuel could be evaluated.

There could be seasonal differences in the composition of the base diesel fuel, but these were not investigated, and would be confounded with the broad seasonal effect.

To the first analytical approach, a second approach or method was employed. Two analytical approaches were used in the evaluation with each method having advantages and disadvantages. Within the second analytical evaluation methods, the data was divided first according to locomotive manufacturer, then by Tier level. The two methods are:

1. Macro high level comparison of averages, maxima, minima, and standard deviations for two data sets which differed by only one factor (for example, locomotives that used only diesel fuel in both summer and winter). (Note: the two months at each end of the seasons were removed.) The advantages and disadvantages of this method are:
   a. It is conceptually and computationally easy.
   b. It is easy to understand and explain.
   c. It is not mathematically rigorous

Table 1 – Amount of Biomass Fuel by Location by Month													
		Amount of Biomass Fuel Blended into Diesel											
Location	Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
3	FAME	0%	0%	0%	3%	3%	3%	3%	3%	3%	0%	0%	0%
4	FAME	0%	0%	0%	4%	4%	4%	4%	4%	5%	0%	0%	0%
5		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
6		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
7		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
8		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
9		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
10		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
11	HDRD	0%	0%	0%	5%	5%	5%	5%	5%	5%	0%	0%	0%
12		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
13		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
14		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
15	FAME	0%	0%	0%	4%	4%	4%	4%	4%	5%	0%	0%	0%
16		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
17	HDRD	0%	0%	0%	5%	5%	5%	5%	5%	5%	0%	0%	0%
18		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
19		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
20		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
		Winter		Transition		Summer				Transition		Winter	

Note: Data from the transition periods were excluded from analysis

and requires several unverified assumptions.

2. Non-linear least-squares regression analysis with indicator variables to fit all effects in the same mathematical model (explained in Appendix 1). The advantages and disadvantages of this method are:
   a. It is mathematically rigorous, requires fewer assumptions, and separates each variable.
   b. It is computationally difficult and requires specialized statistical software (and the expertise to use it).
   c. It is more difficult to explain.

METHOD 1: Tables 2 and 3 are, respectively, the summer and winter calculated values, and Table 4 shows the differences between the two seasons for locomotives that use no biomass fuel in either season. Of the18 elemental concentrations measured the tables list the 12 with significant variation. These results suggest there are no practical differences between the two seasonal data sets when no biomass is used. See appendix Table A for definitions of the properties tested and abbreviations used.

TABLE 2, Subset 2 Summer

2023	Total Specimens																					
	FE	PB	CU	SN	AL	SI	B	NA	CA	P	ZN	MO	OXI	NIT	SUL	FUEL	WATER	SOOT	VISC100	TAN	TBN	PI
Avg-->	6	0	1	0	2	3	1	4	3141	59	0	70	7.06	7.18	7.44	8.16	0.16	21.12	15.67	1.72	7.45	1.20
Min-->	1	0	0	0	0	0	0	0	2543	34	0	42	0.40	1.80	0.02	4.61	0.01	1.58	9.75	0.03	3.70	0.10
Max-->	26	25	76	13	15	22	74	209	3761	81	5	94	19.80	92.13	21.81	18.55	5.23	62.35	18.39	3.36	9.41	2.91
Std-->	4	1	3	1	1	2	2	8	191	4	1	5	2.89	4.06	3.59	6.00	0.65	11.66	0.56	0.63	0.99	0.51
115	Total Units																					

TABLE 3, Subset 2 Winter

1111	Total Specimens																					
	FE	PB	CU	SN	AL	SI	B	NA	CA	P	ZN	MO	OXI	NIT	SUL	FUEL	WATER	SOOT	VISC100	TAN	TBN	PI
Avg-->	7	0	1	0	2	3	1	4	3158	60	0	70	7.50	6.82	7.34	7.39	0.03	17.65	15.46	1.80	7.50	1.20
Min-->	1	0	0	0	0	0	0	0	2711	6	0	50	1.01	1.28	0.02	3.52	0.01	0.76	10.60	0.49	4.37	-0.03
Max-->	30	14	38	10	7	56	28	107	3916	72	5	87	17.00	18.64	20.02	17.35	0.05	76.51	17.19	3.41	9.19	2.84
Std-->	4	1	3	1	1	3	2	6	198	5	1	5	2.75	3.41	3.44	4.86	0.01	10.05	0.56	0.60	0.91	0.44
115	Total Units																					

TABLE 4, Subset 2 Delta

	FE	PB	CU	SN	AL	SI	B	NA	CA	P	ZN	MO	OXI	NIT	SUL	FUEL	WATER	SOOT	VISC100	TAN	TBN	PI
Avg-->	0	0	0	0	0	-1	0	0	-17	0	0	0	-0.44	0.36	0.10	0.77	0.13	3.47	0.21	-0.09	-0.05	0.01
Min-->	0	0	0	0	0	0	0	0	-168	28	0	-8	-0.61	0.52	0.00	1.09	0.00	0.82	-0.85	-0.46	-0.67	0.13
Max-->	-4	11	38	3	8	-34	46	102	-155	9	0	7	2.80	73.49	1.79	1.20	5.18	-14.16	1.20	-0.05	0.22	0.07
Std-->	0	0	0	0	0	-1	1	2	-7	0	0	0	0.13	0.66	0.15	1.14	0.64	1.61	0.01	0.03	0.08	0.07

Table 5
Comparison of Effects from Non-Linear Fitting[1,2]

Property	Units	r[3]	95% CI[4]	Winter[5]	FAME[6]	HDRD[7]	Significant?[8]
Base Number	mgKOH/g	0.54	0.16	0.03	0.09	0.07	None
Acid Number	mgKOH/g	0.21	0.07	-0.03	-0.03	-0.02	None
Viscosity Increase	mm²/s	0.13	0.07	-0.11	0.06	0.01	None
Soot	A/cm	3	1.93	-2.32	0.26	0.87	None
Insolubles	mass %	0.2	0.08	0.00	-0.01	0.02	None
Oxidation	A/cm	N/A	0.54	0.07	0.34	0.34	None
Nitration	A/cm	N/A	0.73	-0.33	0.05	0.26	None
Iron	ppm	1	0.95	0.07	0.33	0.87	None
Copper	ppm	1	0.87	-0.84	-0.11	0.05	None
Lead	ppm	0.3	0.87	0.15	-0.03	0.11	None

Comparable results for the other subsets were obtained (for example, locomotives from the same manufacturer and emission design using different fuels in the two seasons.), i.e., no practical differences between the seasons.

METHOD 2: The additional analysis is described in Appendix A1, with the results shown in Table 5.

---

1. Details of the non-linear fitting procedure are in Appendix 1
2. Columns Winter, FAME, and HDRD are the differences due to that effect.
3. Approximate repeatability of test method
4. 95% Confidence Interval of difference estimate
5. Property value in Winter minus value in Summer
6. Property value with FAME minus value without FAME
7. Property value with HDRD minus value without HDRD
8. Statistically significant if difference is greater than 95% CI

None of these properties is significantly affected by season, FAME, or HDRD for this data set.

The only combination close to statistical significance – and just barely – is the seasonal effect on Soot, which is shown graphically in Figure A2, compared to the approximate alarm limit for this property. The seasonal effect on viscosity is near to statistical significance, probably due to the higher soot content.

Despite crossing the threshold for statistical significance, neither difference (soot or viscosity) has practical significance for this railroad.

DISCUSSION: The authors would have preferred data from a controlled field test as described in the LMOA 2012 field test protocol. However, as noted earlier in the introduction section, "Because of the length of the test, difficulties in controlling fueling, cost, and complexities in managing test and control units, it has become difficult to find a location willing to conduct such an evaluation." The substitution of used crankcase oil data were utilized to determine if there were any effects on the oil's condition due to the fuel and seasonal variations.

Looking for a relative high differences/separation in fuel types, early in the evaluation it was believed some fueling locations had concentrations of biodiesel greater than the ASTM D975 allowable limit of 5% or HDRD fuels. Concentration as high as 20% for either biodiesel or HDRD could not be verified, therefore the authors only used information and data that was documented and reported that information in this paper.

With the limitations, the approach taken to evaluate the engines' oil condition and ultimately concerns on the engines' condition proved to be informative. The first method using a relative simple approach showed there was no practical difference in the oil data sets. The addition detail evaluation leveraged the following equation $Y = A + B * [1 - e^{(-time/C)}]$. By expanding "B" multiple different inputs (variables) were evaluated. Details on the analysis and the use of the equation can found in the appendix in the mathematical modeling function section.

CONCLUSIONS: Method 1 showed there were no practical differences in the crankcase oils' condition seasonal (summer vs. winter) where fuel supply varied with the seasons. The additional detailed analysis looking at several properties showed that "none of these properties is significantly affected by season, FAME, or HDRD for this data set. The only combination close to statistical significance – and just barely – is the seasonal effect on Soot, which is shown graphically in Figure A2, compared to the approximate alarm limit for this property. The seasonal effect on viscosity is near to statistical significance, probably due to the higher soot content."

SUMMARY: With the data sets used, there were no detectable practical differences in seasonal changes in the crankcase oils' condition, due to variations in diesel fuel composition, and drastic temperature differences across seasons.

RECOMMENDATIONS:

Because the Tier 3 and 4 locomotive did not meet the time requirement, they were excluded from this study, However, recent information has been provided that affirmed at one major fueling location the summer fuel will be with 17% HDRD, and the passing of time would allow the inclusion of Tier 3 and Tier 4 locomotives in such as study. Therefore, it is suggested a follow up paper using data with a higher concentration of renewable fuels and Tier 3 and 4 locomotive be written for the either 2017 or 2018.

ACKNOWLEDGEMENTS:

The authors wish to thank the LMOA FL&E committee members for their helpful comments on the paper and associated presentation.

Appendix I
Statistical Analysis Methodology

The data were analyzed using non-linear least squares regression with indicator variables. This would be equivalent to the more familiar Analysis of Variance (ANOVA), if the used oil properties followed straight lines with time.

DATA SET

The railroad provided four datasets:

1. Used oil analysis for almost three years, from January 2013 to November 2015, including
   a. Locomotive unit number
   b. Sampling location
   c. Date of sample
   d. Used oil measured properties, as listed in Table A1
2. Maintenance records, including dates of oil changes for the same time period
3. Records of fuel purchased at all fueling locations used during the same time period
4. Locomotive information, including
   a. Locomotive unit number
   b. Engine manufacturer (i.e., 2-stroke or 4-stroke)
   c. Engine specifications, such as power rating and emissions "Tier"

These four were combined by merging on locomotive unit number and date, creating new variables:

a. Time since last oil change (i.e., oil life)
b. Whether FAME (Fatty Acid Methyl Ester) was included in the last fueling

c. Whether HDRD (Hydrogenation-Derived Renewable Diesel) was included in the last fueling

The qualitative variables, such as engine manufacturer, emissions, tier, season, etc. were converted to "Indicator Variables" (discussed later), and a statistical model "Growth" parameter was added for a total of 41 variables per record.

The resultant dataset contained over 35,000 records for over 950 locomotives, comprising almost 1.4 million data points.

DATA PREPARATION AND EXCLUSION

As explained in the body of the paper, biomass fuels were only used during the summer months, April through September; no biomass fuel was used during the winter months, October through March. Data gathered during the "transition" months – March, April, September, and October – were excluded because the locomotive might have run on a mixture. That removes about 1/3 the data.

Samples dated before the first recorded maintenance date for a locomotive were excluded because the oil life is unknown. An additional 3000 records were excluded because the date of last maintenance was ambiguous.

For the final analysis, almost 18,000 records comprising over 725,000 data points were included in the statistical analysis.

DATA SEGMENTATION INTO "CASES"

It would be conceptually simple to divide the dataset into three classes: 1) samples exposed to neither FAME nor HDRD, 2) samples exposed to FAME, and 3) samples exposed to HDRD, and then perform a standard Analysis of Variance (ANOVA) to test whether fuel type had any effect on the oil properties. There are a few problems with this approach:

1. The fuel classes, as defined, do not have the same distribution of engine types.
   a. Two-stroke and four-stroke engines are expected to behave differently
   b. Tier 0, Tier 1, and Tier 2 engines are expected to behave differently.
2. This approach assumes the measured property is roughly constant during the drains.
   a. Most properties increase or decrease during the drain.
   b. The rate of increase or decrease depends on the engine type, as well as the fuel.
3. Differences due to fuel type could be caused by the seasonal variation, since season is not an explicit variable.
4. All the variation associated with engine type is attributed to error, which lowers the statistical power of the test (that is, its ability to detect differences).

A more rigorous approach is to include engine type and season, as well as fuel composition. The five engine

types included are:
1. Four-stroke, Tier 0
2. Four-stroke, Tier 1
3. Four stroke, Tier 2
4. Two-stroke, Tier 0
5. Two-stroke, Tier 2

Each of these ran during the two defined seasons:
1. Summer
2. Winter

And, each of these could have one of three defined fuel types:
1. Diesel only
2. FAME blended into diesel
3. HDRD blended into diesel

Five engine type times two season times three fuel types gives 30 "cases," for which the results could be different. A successful statistical model must account for the 30 combinations.

One way to do that is to fit each of the 30 cases separately, and then compare the results by fuel type. As shown in the next section, the mathematical function has three parameters, so this approach would result in 90 fitted parameters for each of the 10 properties.

A better approach is to fit all 30 cases at once, with parameters that indicate the difference of one case from the other; these are called "Indicator Variables" and are shown below.

MATHEMATICAL MODELING FUNCTIONS

Used oil exhibits different types of evolutionary behavior in engines, depending on factors such as engine model, fuel composition, power demand cycles, etc. Linear growth is very familiar, and some properties follow such curves. Some properties – usually the ones with low values – are in equilibrium most of the time and exhibit what seems to be a constant value. Another very common shape is asymptotic exponential growth, shown in Figure A1, which is justified by theoretical considerations[9]. Often, the observed linear or constant behaviors are special cases of the exponential growth – near either the beginning of the end of the curve.

The general equation for such growth is:

$$Y = A + B * [1 - e^{(-time/C)}]$$

(A1)

where Y is the measured property and A, B, and C are fitted parameters. Parameter A is the starting value (which may be zero, a fixed known value, or allowed to "float" to the fitted value); parameter B is the amount the property increases in the long run (note: B will be negative for properties that decrease, such as Base Number); parameter C is a time constant – a measure of how long it takes the property to increase or decrease.

This is the equation that would need to be fit 30 times for each measured property, resulting in 90 estimated parameters and "using up" 90 degrees of freedom, which reduces the ability to detect differences.

Instead, "Indicator Variables" were used to account for factors expected to influence oil properties (often called "blocking" variables). As an example, consider a situation with one blocking variable ("season") that takes two values "summer" and "winter"). Instead of fitting Equation 1) twice (generating six fitted parameters and using 6 degrees of freedom), fit the equation:

$$Y = A + (B_S * I_S + B_W * I_W) * [1 - e^{(-time/(C_S * I_S + C_W * I_W))}]$$
(A2)

where I_S and I_W are the indicator variables, taking the values 1 or 0 if the data point does or doesn't "indicate" the blocking variable: $I_S = 1$ for the summer and 0 for the winter; IW is the opposite[10]. The parameter "A" doesn't require indicator variables because we expect the starting value to be the same for all cases (i.e., it is the same oil).

Using indicator variables, the 30 cases described above can be fit with 17 parameters, instead of 90. The full equation is:

$$Y = b_0 + (b_1 + b_2 * Cycle + b_3 * T1 + b_4 * T2 + b_5 * Cycle * T2 + b_6 * Winter + b_7 * FAME + b_8 * HDRD) * [1 - E]$$

and

$$E = e^{(-time/(b_9 + b_{10} * Cycle + b_{11} * T1 + b_{12} * T2 + b_{13} * Cycle * T2 * b_{14} * Winter + b_{15} * FAME + b_{16} * HDRD))}$$

(A3)

where
Cycle is an indicator variable: 0 for 4T; 1 for 2T
T1 is an indicator variable: 1 for Tier 1; 0 for Tier 0 and Tier 2
T2 is an indicator variable: 1 for Tier 2; 0 for Tier 0 and Tier 1
Winter is an indicator variable: 1 for Winter; 0 for Summer
FAME is an indicator variable: 1 for FAME content; 0 for no FAME content
HDRD is an indicator variable: 1 for HDRD content; 0 for no HDRD content

and
$b_0, b_1, \ldots\ldots, b_{16}$ are the fitted parameters.

Of particular interest are the fitted parameters b7 and b8, which represent the difference in oil property due to FAME and HDRD, respectively.

To give more physical meaning to the statistical interpretation, the predicted value for each property at 184 days was estimated with error bars, for each of the three fuel types, and compared in Table 5.

Endnotes:

1. Details of the non-linear fitting procedure are in Appendix 1
2. Columns Winter, FAME, and HDRD are the differences due to that effect.
3. Approximate repeatability of test method
4. 95% Confidence Interval of difference estimate
5. Property value in Winter minus value in Summer
6. Property value with FAME minus value without FAME
7. Property value with HDRD minus value without HDRD
8. Statistically significant if difference is greater than 95% CI
9. M.J. Cannon, *et.al.*, "Interactions between engine design, oil consumption and lubricant performance," Paper CEC97-EL09, Fifth CEC International Symposium on the Performance Evaluation of Automotive Fuels and Lubricants, Göteborg, Sweden, 13 – 15 May 1997
10. With two exclusive blocking variables, the equation can be further simplified by omitting one. In this case, omitting I_S will fit B_S and C_S to their values for summer and B_W and C_W to the difference between summer and winter (as opposed to the value for winter).

Table A1
Used Oil Measured Properties

Included?	Property	Abbreviation	Method	Units
Yes	Viscosity at 100°C	V100	Kinematic	mm^2/s
Yes	Pentane Insolubles	PI	Filtration (calculated)	mass %
Yes	Acid Number	AN	D664 (calculated)	mgKOH/g
Yes	Base Number	BN	D4739 (calculated)	mgKOH/g
Yes	Soot	Soot	Infrared	Absorbance
	Fuel Dilution	FD		
	Water Content	Water		
Yes	Oxidation	Ox		
Yes	Nitration	Nit		
	Sulfation	Sulf		
	Aluminum	Al	Inductively-Coupled Plasma (ICP)	ppm
	Barium	Ba		
	Boron	B		
	Calcium	Ca		
	Chromium	Cr		
Yes	Copper	Cu		
Yes	Iron	Fe		
Yes	Lead	Pb		
	Magnesium	Mg		
	Molybdenum	Mo		
	Nickel	Ni		
	Phosphorus	P		
	Potassium	K		
	Silicon	Si		
	Silver	Ag		
	Sodium	Na		
	Tin	Sn		
	Zinc	Zn		

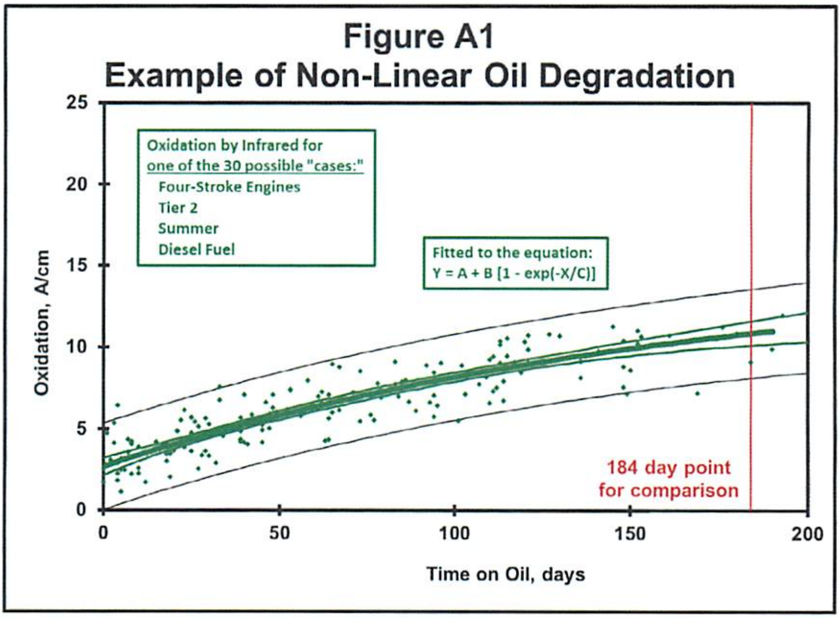


Figure A1
Example of Non-Linear Oil Degradation
Oxidation by Infrared for
one of the 30 possible "cases:"
Four-Stroke Engines
Tier 2
Summer
Diesel Fuel
Fitted to the equation:
Y = A + B [1 - exp(-X/C)]
184 day point
for comparison
Oxidation, A/cm
Time on Oil, days
0
5
10
15
20
25
0
50
100
150
200

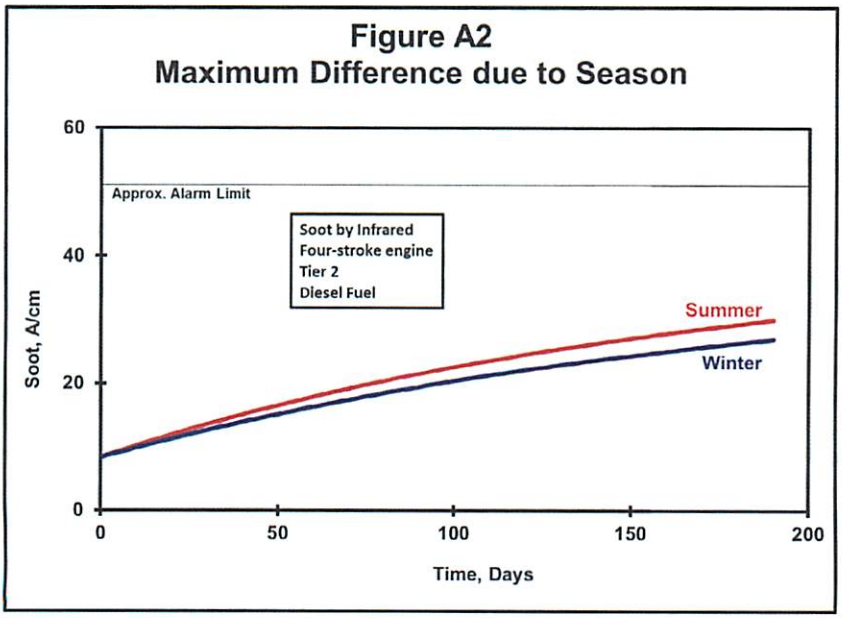


Figure A2
Maximum Difference due to Season
Approx. Alarm Limit
Soot by Infrared
Four-stroke engine
Tier 2
Diesel Fuel
Summer
Winter
Soot, A/cm
Time, Days
0
20
40
60
0
50
100
150
200

Constitution and By-Laws Locomotion 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 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 the 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 on 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 be entitled to receive a copy of the Pre-Convention Report and Annual Proceedings.

Article IV- Officers

Section 1- Elective Officers of the Association shall be President, First Vice President, Second Vice President, and Third Vice President. Each officer will hold office for one year or until successors are elected. In the event an officer leaves active service, he may continue to serve until the end of his term, and, if he chooses, he may continue to serve as an executive officer and be allowed to elevate through the ranks as naturally as 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 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 distributed, monitoring membership levels and reporting same at 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 Nominating Committee, and General Executive Committee without vote.

D. Furnishing security bond in amount of $5000 of behalf of his/her assistants directly handling Association funds. Association will beat the expense of such bond.

Section 4-The Regional Executive officers shall:

A. Participate in the General Executive Committee meetings.

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

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

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

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

Section 5-Duties of General Executive Committee:

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

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

C. Serve as the Auditing and Finance Committee.

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

E. Exercise general supervision over all Association activities.

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

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

H. Approve the schedule for the Annual program.

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

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

Article VII-Technical Committees

The technical committees will consist of:

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

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

Section 3-Committee members as follows:

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

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

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

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

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

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

Article VIII-Proceedings

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

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

Article IX-Rules of Order

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

Article X-Amendments

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