

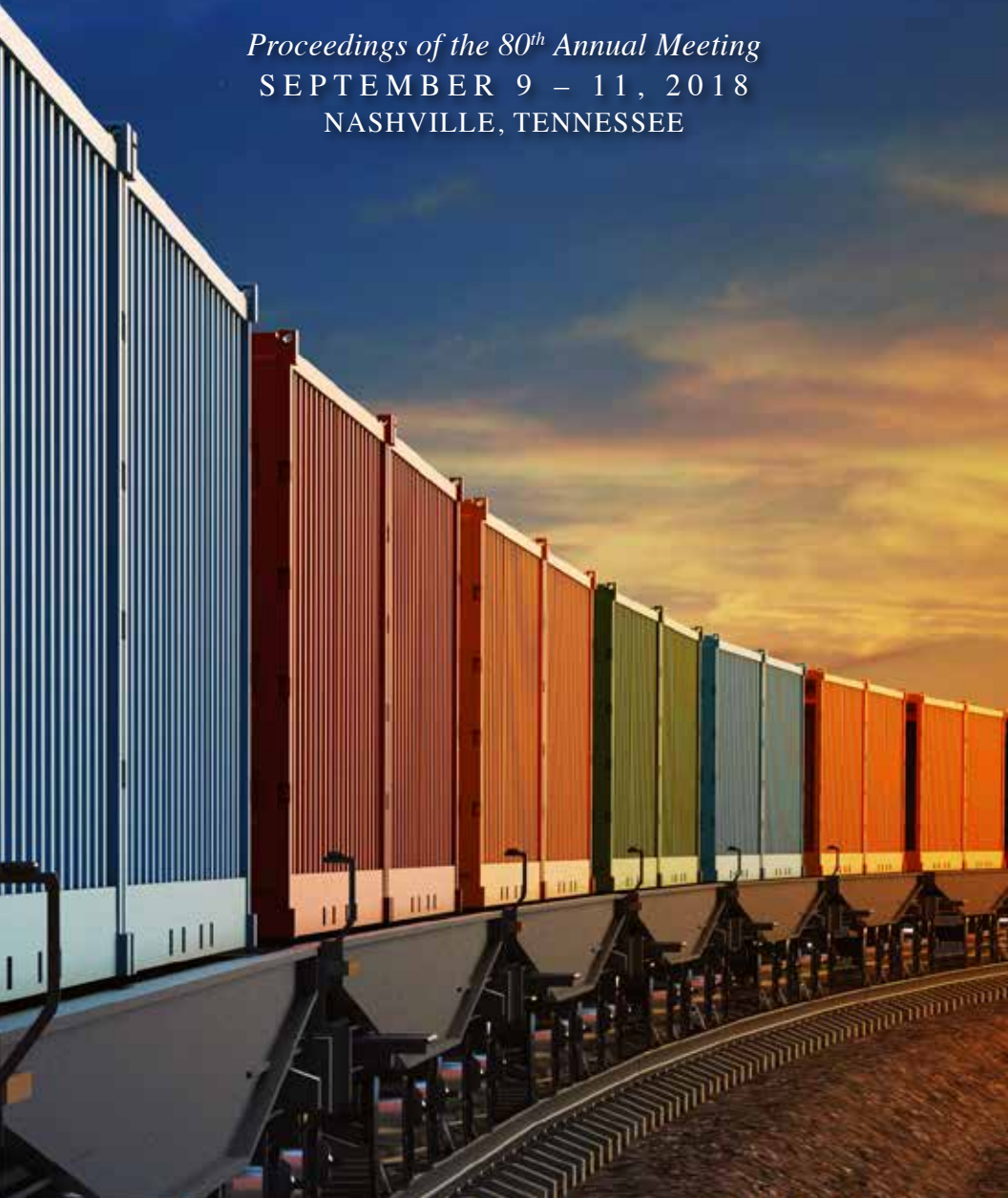
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Locomotive Maintenance Officers Association

Proceedings of the 80th Annual Meeting

SEPTEMBER 9 – 11, 2018

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2018 Advertisers Index

Amglo Kemlite Labs, Inc	191
Amsted Rail.	99
A.S.T. GmbH Germany	141 & 143
Bach Simpson/Wabtec	149 & 151
Graham White/Wabtec	87
Hotstart	105
LPI Lift Systems	57
Magnus, an A. Stucki Company	95
Miba Bearings, U.S.	239
Morgan Advanced Materials	185
Parker/Clark	129
Peaker Services, Inc	Back Cover
PowerRail, Inc	81, 199, 235 & Inside Back Cover
Rail Products International	9
Railroad Friction Products	15
Simmons Machine Tool Corporation	41
Snyder Equipment Company.	Inside Front Cover
Tame, Inc	49
Trains Magazine	213
Transportation Equipment Supply Company	69
Transportation Products Sales Company	244 & 245
ZTR Control Systems	160, 161, 164 & 165

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2018 TOC and Index

List of LMOA Advertisers	2
LMOA MVP Recipients	4
2017 State of the Union Address	16
2017 Acceptance Speech	19
Facilities, Material and Support Committee	28-62
Mechanical Maintenance Committee	63-107
Fuel, Lubricants and Environmental Committee	108-138
Locomotive Software and Systems Committee	139-166
Electrical Maintenance Committee	167-251
LMOA By-Laws	252-256

2017 LMOA MVP RECIPIENTS

The executive board of LMOA wishes to congratulate the following individuals who were selected as the Most Valuable Person of their respective committees in 2017:

NAME	COMMITTEE	COMPANY
Jonathan George	Fuel, Lubricants and Environmental	Parker Filtration-Canada
Casey Shepherd	Mechanical Maintenance	Arkansas & Missouri Railroad
Viktor Gvelesiani	Locomotive Software & Systems	ZTR Control Systems
Steve Alessandrini	Electrical Maintenance	Canadian National Railroad

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 BOARD WOULD LIKE TO EXPRESS THEIR SINCERE APPRECIATION TO THE CANADIAN NATIONAL RAILROAD AND ESPECIALLY JOAQUIN FLORES FOR HOSTING THE LMOA'S FIVE TECHNICAL COMMITTEE MEETINGS AT HOMEWOOD, ILLINOIS ON MAY 14, 2018 AND FOR ALLOWING OUR MEMBERS TO TOUR THEIR WOODCREST SHOPS IN HOMEWOOD.

THE COMMITTEE WOULD LIKE TO THANK LMOA PAST PRESIDENT BRUCE KEHE FOR INVITING US TO ATTEND THE MONTHLY DINNER MEETING OF THE CHICAGO RAILROAD MECHANICAL ASSOCIATION (CRMA) IN TINLEY PARK, ILLINOIS ON MONDAY EVENING, MAY 14, 2018. BRUCE IS THE CURRENT PRESIDENT OF CRMA.

LMOA MEMBERS ALSO HAD THE OPPORTUNITY TO TOUR THE CNG DUAL FUEL PROGRAM/OPERATIONS AT THE INDIANA HARBOR BELT RAILWAY IN HAMMOND, INDIANA ON TUESDAY, MAY 15TH. WE WISH TO THANK MICHAEL CUNNINGHAM AS WELL AS DARRELL SNYDER AND DOMINIC MAIORANO FOR TAKING THE TIME OUT OF THEIR BUSY SCHEDULE TO GIVE US A TOUR OF THE FACILITY.

THE LMOA EXECUTIVE BOARD WOULD LIKE TO EXPRESS THEIR GRATITUDE TO LMOA 1ST VICE PRESIDENT IAN BRADBURY WHO WORKED OUT ALL THE DETAILS FOR THE ANNUAL JOINT TECHNICAL COMMITTEE MEETING. THE MEETING WAS A HUGE SUCCESS BECAUSE OF IAN'S TIRELESS EFFORTS. THANK YOU VERY MUCH IAN.

A SPECIAL THANK YOU TO PEAKER SERVICES FOR PROVIDING BOXED LUNCHES ON MONDAY, MAY 14TH, TO ALL OUR ATTENDEES

THE ANNUAL JOINT TECHNICAL COMMITTEE MEETING WAS HELD AT HILTON GARDEN INN, TINLEY PARK, ILLINOIS ON THE MORNING OF TUESDAY, MAY 15, 2018.

The Executive Board of the Locomotive Maintenance Officers Association would like to express their deep and sincere gratitude and appreciation to LMOA President Dwight Beebe of Temple Engineering for sponsoring an Executive Board meeting and luncheon at the Indiana Convention Center on Tuesday, September 19, 2017.

Thank you Dwight for your long and continued support of the LMOA.

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1958 F.R. DENNY (Deceased) Mechanical Supt., New Orleans Union Passenger Terminal
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1970 G.R. WEAVER (Deceased) Director Equipment Engineering, Penn Central Co.
1971 G.W. NEIMEYER (Deceased) Mechanical Superintendent, Texas & Pacific Railway
1972 K.Y. PRUCHNICKI (Deceased) General Supervisor Locomotive Maintenance, Southern Pacific Transportation Company
1973 W.F. DADD (Deceased) Chief Mechanical Officer, Chessie System
1974 C.P. STENDAHL, Retired General Manager, M.P.-Electrical, Burlington Northern Railroad
1975 L.H. BOOTH (Deceased) Retired Assistant C.M.O.-Locomotive, Chessie System
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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
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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
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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, Commuter Rail Transportation Superintendent, Sound Transit, Seattle, WA 98104
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1995 C.A.MILLER, Retired Mgr-Loco. Engineering & Quality, Union Pacific RR, 17745 Doras Circle, Omaha, NE 68130
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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
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2002 BOB RUNYON, Engineering Consultant, Roanoke, VA 24019
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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, President, Northwestern Consulting, Boise, ID 83703
2010 BOB REYNOLDS, Sales Manager, Amglo Kemlite Laboratories, Calgary, Alberta T24 2V8
2011 JACK KUHNS, Director-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, President, JAB Rail Services, LLC, E Wakefield, NH 03830
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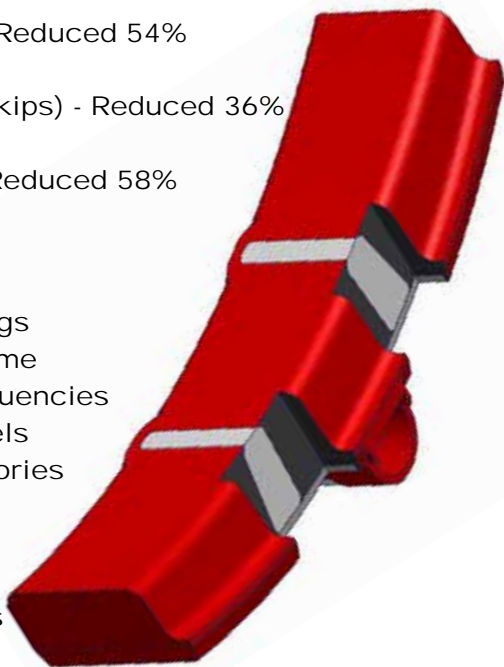
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2017 State of the Union Address

Jeff Cutright

*Monday Afternoon, September 18, 2017
Indiana Convention Center-Room 130*

Good afternoon Ladies, Gentlemen, LMOA members and the heart of the LMOA (the Executive Committee). Thank you all for attending this RSI/CMA Rail Expo and specifically the LMOA technical sessions.

I am humbled to stand here before you as the outgoing President. I want to thank each of you in this room for your contributions to the success of this organization this year and previous years. Without your commitment the LMOA would not be the organization it is today.

It was an honor for me to serve as President of the LMOA this past year. The organization started in 1939 and there are many folks I have had a lot of respect for and had the pleasure to know; some of them have served as President and I thank you for allowing me to serve in this role during the last year.

Let me thank the fellow who has been the glue that has kept the organization running for all my years in LMOA which goes back to 1994 (Mr. Ron Pondel). Thank you, Ron for your help and guidance and keeping the LMOA going. Your commitment and attention to detail are nothing short of amazing.

Please remember to thank the

sponsors and suppliers who attend the conference, have displays and especially those who advertise in the book. Their sponsorship defrays some of the cost of the printing of the annual proceedings book.

I would like to thank Mike Drylie who could not attend the conference due to Hurricane Irma. Mike is stepping down as 2nd Vice President due to some personal reasons. Mike not only took care of most of the arrangements for our joint committee meeting in Jacksonville in May but has also been a constant and consistent contributor to the LMOA over the years.

I would also like to thank CSX Transportation and specifically Mr. Tim Healey and Mr. Yousef Abdel-Moty for the support provided by CSX while we were in Jacksonville. The access to the meeting rooms, lunch and technical support went very smoothly due, in no small part, to their efforts. Also, the impromptu tour of Reliable Rail to view a CSX locomotive project was very informative and interesting.

I would like to thank PowerRail for maintaining our website at lmoarail.com for the last few years. The website is a great resource with an updated link that allows folks

to ask LMOA a question. We had a question or two to answer this year. Please log in and look around as several years of technical papers are available for review.

I would like to thank 1st Vice President Dwight Beebe and Temple Engineering for sponsoring the executive meeting lunches over the years. It is very much appreciated. Dwight has made a concerted effort to get more Railroad CMO input and interaction which is sorely needed. With your input and follow through Dwight, we are building better relationships with our customers.

The LMOA is going through a transitional period that started over a year ago at the request of the CMOs (Chief Mechanical Officers). The idea was to get more feedback from the CMOs on topics relative to their needs. They wanted quicker updates and reporting on specific topics. Dwight has made an effort to meet with and communicate with the CMOs. The LMOA committees are then asked to work on these topics or at least tailor their paper topics to these requests. We are working through the bugs, but the interaction has been positive. Possibly the LMOA needs to change how it interacts and develop some other channels, but we have a good start. I want to thank the committees for their positive response to these requests.

In our efforts to transition into a more efficient organization, we made some technical committee changes. We basically consolidated the Material Control and Shop Safety,

Processes and Equipment Committees into one committee which is now called the Facilities, Material and Support Committee. Additionally, in response to a request from the Chief Mechanical Officers, we replaced the New Technologies Committee and it is now known as the Locomotive Software and Systems Committee. The three remaining committees (Fuel, Lubricants and Environmental, Mechanical Maintenance and Electrical Maintenance) will now incorporate new technologies into their technical topics/papers. Due to these committee changes, we gave committee members an opportunity to change committees if they so desired.

We probably aren't done with our realignment. Software has grown into a major complication for the railroads, with the cost to maintain and keep up with software changes and updates for all the locomotive models spiraling out of control.

I would also like for us to develop student sections similar to what AREMA (Maintenance of Way) has done. LMOA has been asked to review college publications. This may be an area where we can use our expertise to give back to the community and young folks interested in the industry.

This year we were able to connect the Fuel, Lubricants and Environmental Committee to the AAR Locomotive Committee. This direct link will be very important to get some support and direction from the folks that maintain the North American locomotive fleets. We

thank you, Virginia, for kicking off the connection last October. We had the AAR committee secretary join the LMOA along with an AAR inspection official. These were big steps that will build some much-needed relationships in the future.

The LMOA is about developing relationships. I'll encourage you to continue to build your relationships with the folks that are here. There is a lot to learn from the experience in this room. The LMOA has been an integral part of my career as a channel to share knowledge. I'll encourage you to use and contribute to this channel.

Again, I'd like to thank those that have made this year a success. The committee members, committee chairs and the executive committee. I appreciate your collective hard work, meetings that you attended and countless phone calls made, all of which were done on your own time.

I would especially like to thank my wife, Lee, for her support through the years.

Thank you again and have a good afternoon.

See you in Nashville on
September 9-11, 2018.

Acceptance speech

Dwight Beebe

Tuesday Morning, September 19, 2017

Indiana Convention Center, Room 130

Ladies and Gentlemen, members of the Executive Committee, Mr. Secretary, all committee members, and fellow LMOA members, I thank you and sincerely appreciate the opportunity to serve the rail industry as this year's president of the LMOA. We should take a moment to recognize Jeff Cutright for his outstanding service this past year. Mr. Cutright, I hope that I can live up to the standards that you have set.

2017 has been a rebound year for most railroads. After a very tough 2016, it has been exciting to see the industry climb forward. People around the world have an investment in Railroads. Railroads are a key indicator of a strong and thriving economy. Members of the LMOA are even more invested in the rail industry. This organization has served as an outlet to give back to an industry that has benefitted each of us.

It is amazing to see the transformation railroads have undergone in the past 20 years. To most people new locomotives look pretty much the same as the old. But advances in electronics, fuel injection, and communications have made locomotives safer, cleaner and more efficient. And it is not just new locomotives. Older fleets are being

completely rebuilt to incorporate some of these new technologies to extend their service life for decades.

As locomotives evolve, the LMOA has and will continue to adapt. With new technology, the nature of the problems occurring have changed requiring new expertise and focus. We have all seen changes in railroad engineering staff as many railroads have reorganized personnel to tackle the new issues they are facing. As you are all aware, the LMOA has reorganized several committees to better reflect these issues.

Last Summer and Fall we went directly to the engineering staff's of several Class 1's to find out what issues they were experiencing. We developed a list of issues and had the Chief Mechanical Officers prioritize what they believed to be the most important issues. Our body of papers this year focused on the prioritized list and we were able to address the issues they felt were most important.

Railroad participation is vital to the LMOA. When a railroad designates a person to participate in the LMOA, it is our responsibility to help them be successful. You will find within this organization help with problem solving, innovating,

and avoiding pitfalls. Railroaders, the LMOA has your back. If you have questions or problems we are here to help.

We often encounter problems that require a tremendous amount of time and energy to solve only to find that someone else has either already solved the issue or is working on it simultaneously. I challenge the Committee Chairpersons to develop a network for solving problems and to encourage communication within your committee. Also, recognize that the LMOA represents many disciplines that can be brought to bear on an issue.

I wanted to share with you some thoughts about a few LMOA members that I worked with this year. There has been a tremendous amount of work done this year by many LMOA members, but these individuals have been great examples of service for me to follow.

Mike Drylie exemplifies someone who takes initiative to tackle problems. Last fall, several of us, including Mike, met with the staff of a Class I railroad and they expressed concern over issues they were having with Locomotive Automatic Engine Start Stop (AESS). We had heard similar concerns from other railroads. Without hesitation, Mike began investigating this problem and prepared a paper with his findings. Mike was going to present the paper but due to Hurricane Irma was unable to be with us here in Indianapolis. His paper can be found in this year's LMOA proceedings publication (2017).

Dennis McAndrew has incredible critical thinking skills. Dennis worked on two papers this year allowing us to benefit from his critical thinking skills he gained during his career. He has consistently been a resource for the industry and particularly for the Fuels, Lubricants and Environmental Committee. This past year we have seen an increased interest in Used Oil Analysis as railroads work toward predictive maintenance. One of Dennis' papers outlines the problems that he has encountered over the years with Used Oil Analysis data. The goal was not to discourage interest in this field, but to the contrary, to arm those working with Used Oil Analysis with tools to recognize problems and ensure their success.

Ian Bradbury emailed me concerning a paper on statistical analysis that I worked on this year for the Fuels, Lubricants, and Environmental Committee. This was interesting to me because Ian has his roots on the Mechanical Maintenance Committee. He read my paper and offered me some suggestions on improvements. His intellectual curiosity led him to read a paper that interested him which ultimately we hope will benefit all of us in the industry and allowed him an opportunity to contribute.

All of three of them share a common passion – RAILROADING. They also have a desire to contribute to the industry that has done so much for them. I challenge each you to find ways to serve the rail community, to give something back, and we hope

that the LMOA can provide you an avenue for that service.

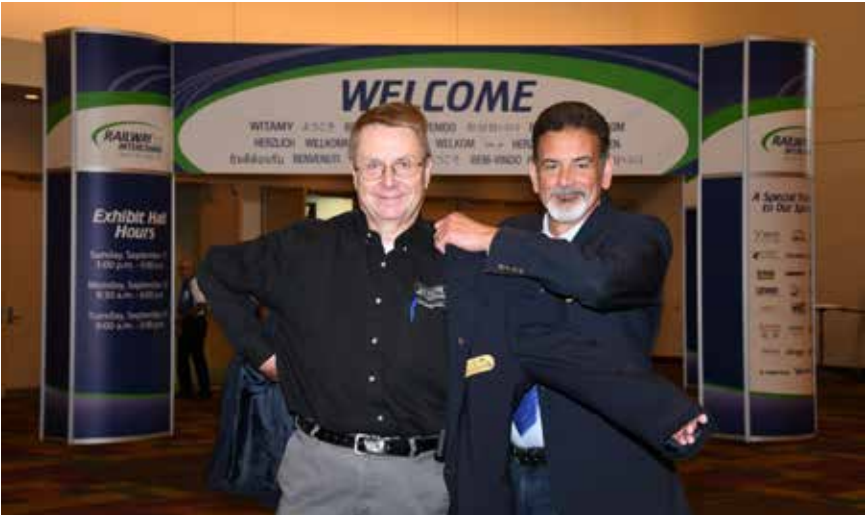
I look forward to working with you all this coming year. We will work hard to make the LMOA's work more accessible. As part of that effort you may be asked to provide additional portions of your papers like executive summaries and an abstract. Your work here is important, it is valuable, and needs to be preserved and accessible for future railroaders. Thank you all for attending this year and for all that you do to make the LMOA successful.



Outgoing President Jeff Cutright handing gavel to newly elected President Dwight Beebe.



Newly elected President Dwight Beebe placing LMOA blazer on new 3rd VP Tom Gallagher.



Past President Dave Rutkowski putting LMOA blazer on new 2nd VP Tom Kennedy.



Past Presidents Bob Reynolds and Dennis Nott preparing to make ceremonial presentations.



Past President Bob Reynolds presenting Past President's Watch to outgoing President Jeff Cutright.



Past President Dennis Nott pointing to Past President's Pin on outgoing President Jeff Cutright's blazer.



Executive Commiittee enjoying lunch before Board meeting held on September 19, 2017.



President Dwight Beebe discussing LMOA policy with Executive Board.



Regional Executives Michael Hartung and Virginia Wiszniewski listening to comments made at Board meeting.



Ian Bradbury expressing his thoughts about an issue during the Board meeting.



Ian Bradbury, Jeff Cutright and Lee Cutright at the Board meeting.



Dennis Nott making a point of order during the Board meeting.

Report on the Committee on Facilities, Material & Support

Monday, September 10, 2018 at 8:30 AM



Chair

Bob Harvilla

(LMOA Past President)

Vice President- Sales
PowerRail Incorporated
Duryea, PA

Vice Chair

Jeff Clapper

Superintendent Motive Power
Wheeling & Lake Erie Railroad
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Robert Hodge	Plant Manager	Rail Products Intl	Columbus, OH
Steve Hulshizer	Manager Material Quality	BNSF Railway	Fort Worth, TX
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Craig Mitchell	Director-Supply Chain Opns	Union Pacific Railroad	Omaha, NE
Craig Opacic	Sales & Business Development	R&W Machine	Bedford, Park, IL
Michael Zerafa	Assistant Vice President North American Sales & Business Development	National Railway Equipment	Mt. Vernon, IL

PERSONAL HISTORY

Bob Harvilla

Bob Harvilla started his career with General Electric in 1973, and had a total of 22 years with GE in various Management and Sales capacities. He is currently the Vice President of Sales for PowerRail Inc., responsible for Account Management and Sales at select Class 1 and Shortline Railroads.

Bob and his wife Barb have been married for 41 years and have two sons, Rob and Ryan, and two grandsons Max 7 and Griffin 4.

The LMOA Facilities, Material and Support Committee wish to express their sincere gratitude to Central Railway Manufacturing for hosting their winter meeting in Jacksonville, Florida on January 14, 2018. Special thanks to Steve and Ted Smith for making our winter committee meeting a success.

The committee would also like to thank Joe Richardella and Norfolk Southern for hosting their summer meeting on June 21, 2018 in Altoona, Pennsylvania.

We truly appreciate both companies for arranging these meetings for our committee.

The Proper Paint Shop-Current Trend and Best Practices

Prepared by:

Jerry Trostle

VP-Sales, Pneu-Mech Systems Manufacturing, Inc

PAINT BOOTH DESIGN (Figures 1 – 5)

The National Fire Protection Association standards define paint booth designs. According to NFPA standards, spray applications of all types shall not be conducted outside predetermined spray areas. Painting must be done in a paint booth, paint room or approved spray area. Painting must be done in an area that is enclosed both vertically and horizontally from other areas.

The primary purpose of a spray booth is to confine the application of hazardous materials to a controlled environment. It must also prevent a fire or explosion by confining the application to a contained area where it is preventable. Additionally, the spray booth must provide a clean environment to ensure proper quality. Depending on the specifics it must be either a one or two-hour fire enclosure in the event of a fire. The enclosure must have smooth walls and be conducive to easy cleaning and ventilation. See NFPA.org for more information.



Figure 1

Paint Booth Design



Figure 2

Paint Booth Design



Figure 3



Figure 4

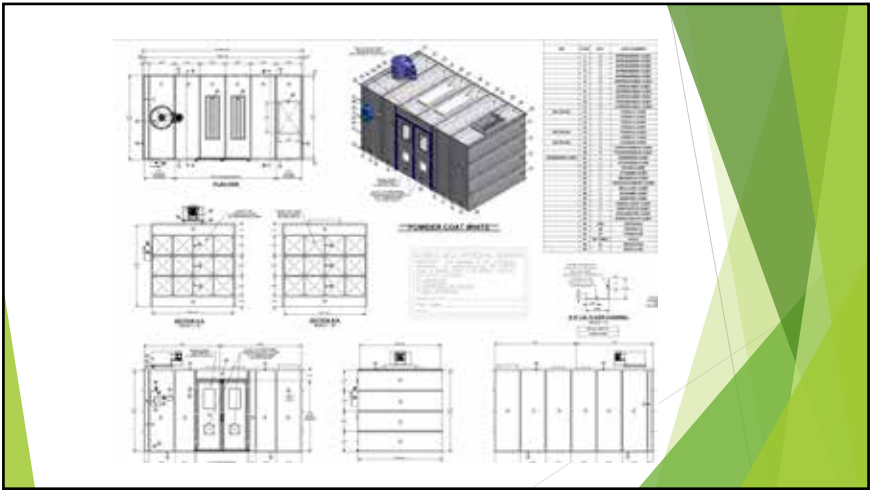


Figure 5

CURRENT TRENDS IN DESIGN (Figure 6)

Changing energy costs, quality standards, availability of skilled labor and competitive circumstances are changing paint shops. Changes include more robotic coating processes, higher efficiency application equipment and designs to lower operating costs.



Figure 6

PROPER PAINT SHOP FLOW (Figure 7 – 10)

Proper Air Balance in the paint shop is important for health and safety, proper equipment operation and quality of the Finish. Units are designed for seasonal operation. Some of the high-quality finishes used today may even require humidity control that can be accomplished by using proper Air Make Up units. Large workpieces frequently require multiple air inlets and exhaust ducts to ensure proper spraying environment.



Figure 7

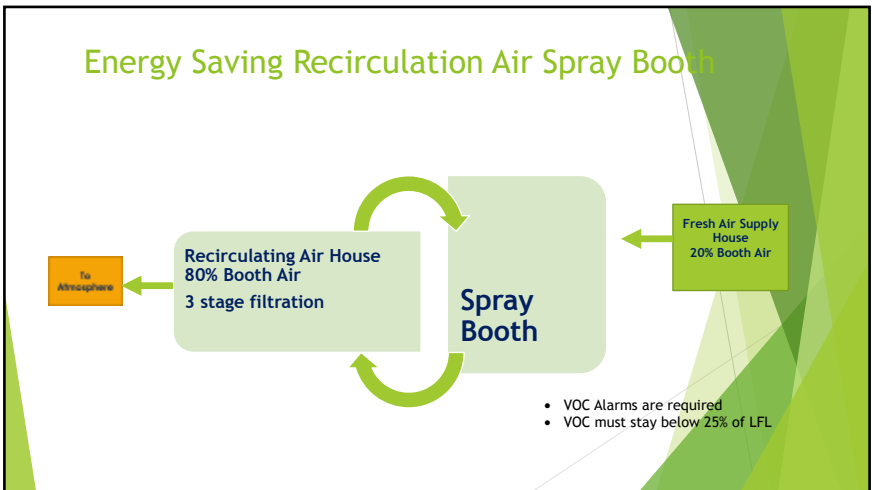


Figure 8

Proper Paint Shop Airflow



Figure 9



Figure 10

LIGHTING (Figure 11)

The latest spray booth designs incorporate LED lighting for energy efficiency and cooler operation. Lighting can be color corrected. The proper amount of light in the booth ensures correct operating environment, higher productivity and a quality finish.



Figure 11

CONTROLS (Figure 12)

Controls can be simple or may include (Programmable Logic Controller) PLC with diagnostics and additional reporting capability.

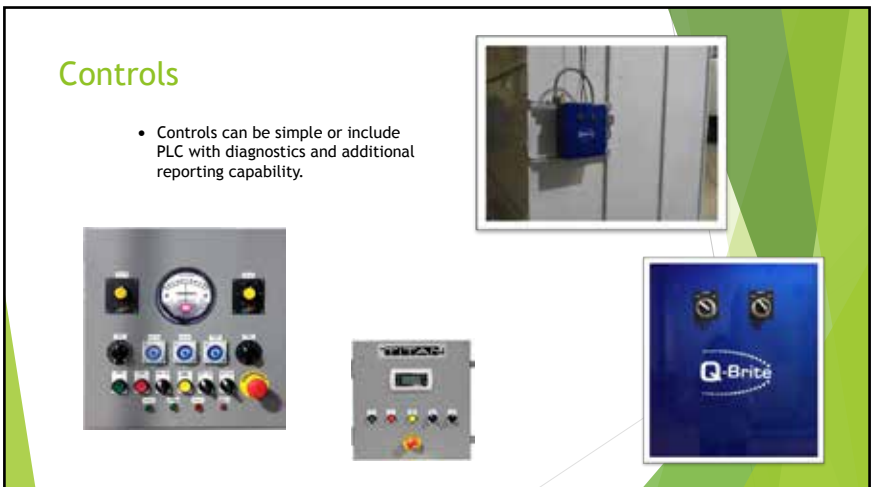


Figure 12

MANLIFTS (Figure 13 – 15)

Use of manlifts for painting of large products expedite the painting process and improve quality. The utilization of manlifts ensure good health and that safety conditions are adhered to.



Figure 13



Figure 14

Manlifts



Figure 15

OPERATIONAL ISSUES

The key issues for a safe and effective paint area must include:

- Proper equipment choices and designs
- Regular and effective equipment maintenance and housekeeping
- Operation training of work force along with regular refresher courses and updates

EQUIPMENT MAINTENANCE

Proper maintenance ensures safety, efficiency and quality. NFPA 33 Guidelines define proper operation in the coating environment. This includes electrical and fire protection standards and procedures. Inspection of equipment, both containment and application, is required. Daily removal of waste material, filter replacement and use of approved waste containment equipment is important.

Paint application equipment must be inspected daily and must be repaired or replaced should issues be discovered. Work requiring entry of employees into confined spaces must be done in accordance with a written procedure that is rigidly enforced. This includes but is not limited to:

- Review atmosphere in the area
- Rescue, fire and emergency procedures
- Lock out and tag out procedures
- Personal protective equipment
- Proper tools
- Entrance by authorized personnel only

- Dirty filters affect airflow which can compromise safety and finish quality (Figure 16)

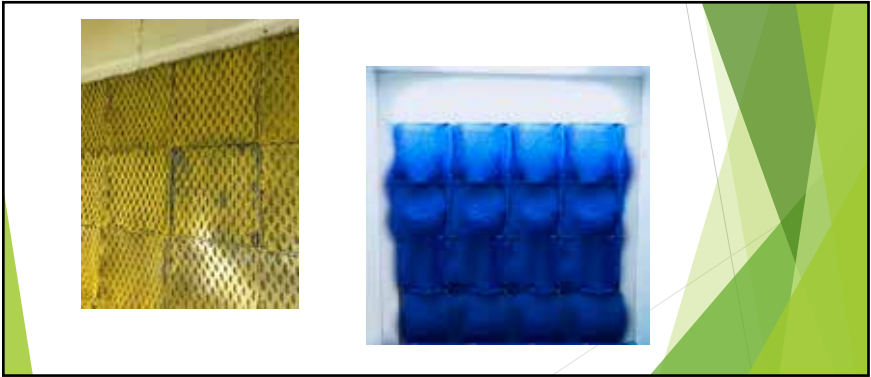


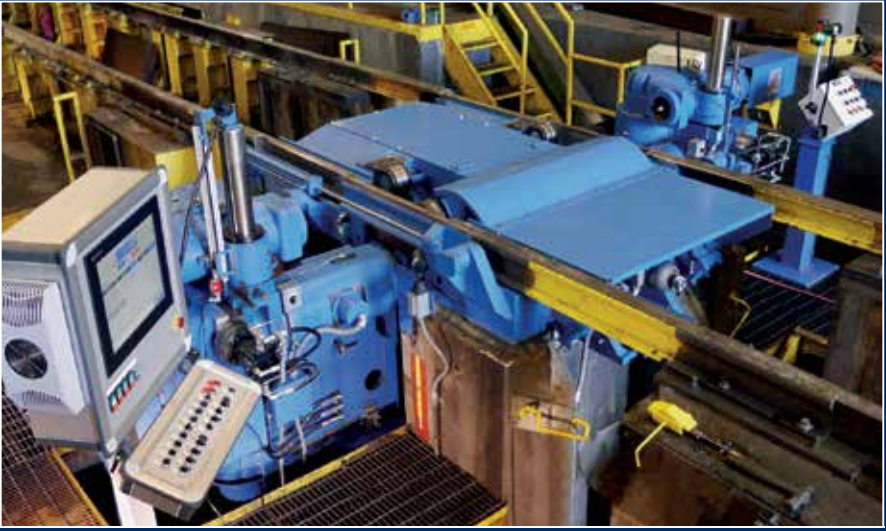
Figure 16

PERSONNEL TRAINING

Personnel training is important for safety as well as quality, efficiency and equipment operation. Procedures for equipment operation should be clearly defined and communicated. Proper safety and environment must be used.

SUMMARY

A properly designed and operated paint shop is essential to the health and safety in the work place. The quality of the finish applied is directly proportional to the amount of training and maintenance dedicated to the process. The applied cost of the coating can be greatly affected by the choice of equipment and operational practices in the coating process.



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PTC at the Belt Railway of Chicago

*Prepared by:
Nick Chodorow,
Belt Railway of Chicago*

This paper is a very brief overview of the Belt Railway of Company of Chicago's PTC implementation journey. Mr. Chodorow will make a more detailed presentation at the 2018 RSI/CMA Rail Expo and Technical Conference on Monday morning, September 10, 2019 at the Music City Center in Nashville, TN.

Nick is the Belt's Chief Information Officer and executive owner of the PTC project. He is also the chair of the American Shortline Railroad Association Technology Committee and a member of multiple PTC and Technology related committees at the AAR, ASLRRA and vendor community.

BACKGROUND ON BRC

The Belt was established in 1882 and is owned by six Class 1 Railroads. It serves 14 railroads and has 28 miles of main line track along with 265 miles of industry and yard track. There are 16 interlockings and 84 bridges along the Belt's main line with an average train count of 44 per day per interlocking.

WHY IS BRC A PTC RAILROAD?

The Belt is a PTC railroad because there is Metra and Amtrak traffic at two of its interlockings; Belt Junction and 80th St and thus it is government mandated. It is a host railroad (not a tenant railroad) because BRC owns and dispatches the mainline tracks at the Belt Junction and 80th St interlockings.

PTC equipment can be broadly separated into three main categories including support systems for each of these three categories

- Wayside
- Back Office Systems (BOS)
- Equipment onboard the locomotive

The Belt's approach to PTC is to implement PTC at the two previously mentioned interlockings and the area between them by the current PTC regulations 2020 deadline while also working on equipping the rest of the main line with PTC. The rest of the railroad will not be PTC certified by the end of 2020 but will be ready to do so in the future when the owners decide to do so. The BRC is equipping the entire railroad with PTC based on a few facts; the cost to support two interlocking devices wasn't significantly less than to equip the entire

railroad, and a significant portion of the traffic across the BRC mainline will be PTC equipped trains (a little over 50% of all trains) therefore it would eventually minimize technical failures and operational procedures along the BRC mainline that negatively affect the movement of trains in the Chicago area. An interesting item of note is that the BRC will not operate any BRC PTC trains as all of its movements are within the limits allowed within the PTC regulations for non PTC equipped moves.

There are two different deadlines railroads are focused on in 2018

- Full PTC implementation in 2018
- Granting of a one or two-year extension for full PTC implementation.

Most railroads (BRC included) will need the extension to meet their goals for full PTC implementation. The requirements to request an extension with the FRA are that all required PTC infrastructure is installed, all required spectrum is acquired, all training required for RSD (Revenue Service Demonstration) or Substitute Criteria operations is completed, and that the railroad is in either in RSD or has met the agreed upon Substitute Criteria for RSD.

HOW DO WE MAKE PTC WORK AT THE BRC?

The Belt must make hardware and software upgrades at the waysides to support PTC which require significant effort tied to the design, planning, testing, installation and implementation of the upgrades.

Most of what the BRC currently has in the way of network infrastructure didn't exist in 2013. Without a communications backbone, PTC wouldn't work so the BRC spent significant energy in modernizing its network. PTC also makes it imperative that the BRC have a very accurate electronic map of the railroad, so this work had to happen as one of the initial steps. Also, the Dispatch (CAD) system had to be upgraded to be PTC compliant and this effort has been the most time consuming and difficult so far. Along with these core components there are a plethora of systems required to enable to support PTC.

Once the BRC embarked down the road of implementing PTC we realized that there was a ton of work to be done which was outside the bandwidth/skillset of the BRC. We had to find a way to continue to run the railroad while embarking on the implementation of a system that changed how we would operate our railroad. This meant we needed HELP and fast.

PROJECT PLANNING

This was and continues to be too large a project for BRC to do on its own. Therefore, it is essential that we actively engage vendors for the planning and implementation phases of the project. So far it has required the involvement of more than ten vendor partners and every BRC department. Another lesson learned was how important it is to continuously keep our Class I partners involved in the process.

The BRC made the decision early on to actively participate in Industry events, committees, etc. which was a great way to learn and to reduce the chances of making the same mistakes that others made during their PTC implementation process. Ultimately, we learned that we had to rely on ourselves to make PTC happen on our railroad.

BRC-PTC STAFFING

In 2015, it was determined that an internal dedicated PTC team had to be built to support current PTC implementation as well as future needs of PTC (Product support and enhancements). We concluded that the BRC is responsible for the PTC program, the operational integrity and ensuring safe operation of the system.

The team is currently composed of the following:

- PTC Program Manager
- Director of Rules and Train Control
- Network System Manager
- Senior PTC Systems Engineer-Onboard Systems
- Senior PTC Systems Engineer-Wayside
- Senior PTC Systems Engineer-Back Office (CAD/BOS) consultant
- Business Systems Analyst

It is an ever-evolving process.

BRC PTC LOCOMOTIVES

The BRC equipped two locomotives with PTC for testing purposes only. It is important that we operate PTC Test Trains to validate the system prior to involving our interoperable partners. The unit numbers are BRC 230 and 231; both of which are GP23ECO locomotives. The PTC installs were performed by Wabtec and overseen by the BRC PTC team led by Pat McCarron, the BRC's Senior PTC Systems Engineer – Onboard Systems.

WAYSIDE UPGRADES

Five active groups are involved to make it all work; Alstom, Wabtec, the BRC Signal Department, the BRC Communications Department, and the BRC PTC Team.

A big advantage for the BRC compared to other host railroads is that the BRC does not have PTC 220 MHz radios at the Waysides nor any base stations to support. This is driven by our fiber based ground network that connects the entire main line and the fact that the Class 1 railroads in Chicago decided to use their own and Metra's base stations to support PTC operations on the BRC.

Wayside Upgrades

Wayside Action Item List Overview

Below is a high-level overview of the activities needed for BRC Wayside PTC Readiness

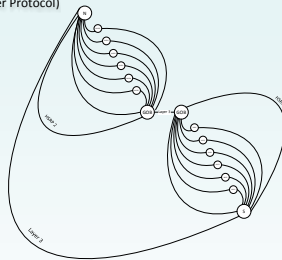
- Rules Library Development and Implementation
- Wayside Design by Location
 - o Hardware Design Review – [Design Levels: 90%, IFC, and 100% As-Built]
 - o Software Design Review (Bitmapping, Application SW) – [Design Level: Rack Test Level]
 - o Material Procurement and Delivery
 - o Test Plan Review (FAT, Factory Test, Field Test)
 - o Validation Testing (RVT, Route Locking)
- PTC equipment installation and cutover
- Testing (Pre-Test, Hi-rail, Functional Systems Integration)
- Training

NETWORK INFRASTRUCTURE

PTC is a communications-based system so the network is the key foundational element. It must be redundant and reliable. The BRC's modern network infrastructure was constructed primarily for PTC but can be used for all aspects of the railroad as it connects the entire main line. It is a medium to collect data from all railroad endpoints that exist on the main line such as wayside devices and the camera system. The construction of the network required significant financial investment and new skills/training for the Communications Department.

Network Infrastructure - Redundant Fiber Ring

- 2 Logical Segments
 - North and South HSRP groups (Hot Standby Router Protocol)
 - Fast convergence
 - Multiple Egress points to both OnX Datacenters
 - Spare Fibers to every house
- Ground up ideology
 - Single mode Fiber (456 strand)
 - 28 miles
- Serves as Primary and Secondary Wayside Connections



Subdiv File Generation (GIS)

A Subdiv File is required to run PTC and in general terms it is a detailed map of the main line that a PTC train will use. At the BRC four groups are required to make this work; Bartlett and West, Wabtec, the BRC Engineering Department, and the BRC PTC Team. Currently the BRC has a verified Subdiv File for its test section (Section 1) and work is underway on the remaining sections.

BRC PTC Back Office

It is important to note that there are multiple systems required to be a PTC host railroad and these will live in what is commonly termed the PTC Back Office. Some examples are the Dispatch System (CAD), PTC Back Office Server (BOS), Mobile Device Manager (MDM), Key Server, Wayside Status Relay Server (WSRS), and so on. Currently the BRC is looking at a list of more than 10 different systems. The BRC has gone with what we call a mixed mode hosted Back Office. This means that all of the systems are located in a data center owned by a managed services provider with the bulk of the systems in a private cloud dedicated to the BRC and the rest of the systems in the Wabtec Cloud that Wabtec is using to provide ITCM services and PTC Tenant Services to tenant railroads.

As mentioned earlier in the paper the Dispatch System has and continues to be the most difficult component of the Back Office to get PTC ready. The BRC's CAD has required multiple fixes, significant development effort by the vendor (Wabtec), intensive testing, and each production install greatly effects the BRC's Transportation Department. A requirement of PTC enabled CAD is that it can issue Bulletins electronically and this remains a hurdle.

BRC PTC Lab

Along the path towards the implementation of PTC the BRC determined that as a host railroad it needed to have its own PTC Lab. The lab contains onboard equipment, wayside equipment, the dispatch client software, along with most of the back office functions mentioned earlier in the paper. The wayside portion of the lab was completed in November 2017 and has been used on a regular basis since then. The BRC also utilizes the Wabtec PTC Lab located in Jacksonville, Florida.

Regulatory

Since PTC is a way to address a regulatory requirement the BRC has had multiple interactions with the FRA both locally and in Washington, DC. There are two key documents required for a PTC host railroad; the PTCIP and the PTCSP. The PTCIP (PTC Implementation Plan) must be FRA approved and the document reflects a railroad's current approach to the implementation of PTC on their railroad. An item of note is that it has historically taken the FRA a long time to turn these documents around. The PTCSP (PTC Safety Plan) is for most

host railroads a multiple thousand page document that outlines how a PTC host railroad will safely operate PTC. The current BRC plan is to submit this document to the FRA for review in 2019.

PTC Training

The regulations requiring the implementation of PTC stipulate that the following group of railroad employees receive PTC training to ensure all have the necessary knowledge and skills to complete their duties related to PTC maintenance and operation:

- Persons who install, maintain, repair, modify, inspect, or test safety critical elements of PTC Systems
- Persons who dispatch trains where PTC is in use
- Persons who operate trains where PTC is in use
- Roadway workers whose duties require them to know and understand how a train control system affects safety and how to avoid interfering with its proper function
- Direct supervisors of any of the above group of employees

Training for PTC requires a structured delivery method by regulation so the BRC must develop the following items and we can't stress enough that this is a multi-departmental activity:

- Training goals
- Formal task analysis of job activities related to PTC
- Written procedures for performance for tasks related to PTC
- Training using any method that imparts the knowledge for the tasks
- Examination with an audit process for compliance purposes
- Periodic refresher training is required
- Annual and periodic evaluations of the effectiveness of the training program are required

Lessons Learned

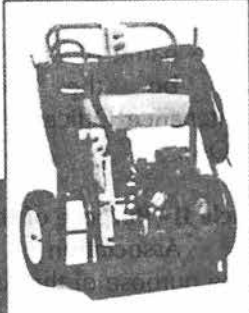
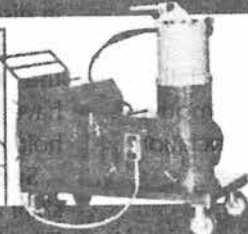
Throughout this process the BRC team and leadership has learned a bunch of lessons. These lessons can be grouped into four categories; governance, project management, people, and technology. Governance issues the BRC found were around consistency in implementation of business decisions, transparency of the decision process, and accountability or a lack of a clear line of authority and responsibility. Project management issues the BRC found were around the management of our resources and business requirements definition and documentation. People issues centered around organizational change management, change in required skill sets, knowledge management, communications internally and externally, education and development of the BRC's human resources, and relations with partners as PTC requires several partners that require active

management. On the technology side the BRC found that large scale investment was needed in the technology infrastructure, additional unforeseen supporting tools, and a reliance on reliable and redundant architecture.

The largest lesson learned for the BRC is that PTC has no end date.

T

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Designing the Bricks and Mortar for Locomotive Maintenance

*Prepared by:
Don Graab
Norfolk Southern Retired*



Introduction

After World War II, when the nation's railroads quickly transitioned from steam to diesel electric locomotives, the railroads built any number of "diesel" shops to facilitate maintenance of the new motive power. By 1960 "dieselization" was complete yet new shop construction continued. In 1970 Illinois Central built a large shop in Chicago (Homewood, IL). Later in the decade, Amtrak built a medium sized facility at their diesel hub near Chicago's Union Station. As the 1980's dawned, Norfolk & Western built a big shop at Shaffers Crossing (Roanoke, VA) while CSX constructed like facilities at Waycross, GA and Corbin, KY. In 2009, CN built a new shop in Memphis, TN.

In 2006, Norfolk Southern embarked on a program to upgrade or replace numerous shops over the next decade. This began with building a modest two track shop at Elkhart, IN. At the large Chattanooga Diesel Shop, two new buildings were erected, and a third structure was expanded allowing the demolition of ten smaller buildings. A sister shop at Birmingham, AL was rehabilitated with the installation of pits, cranes, a wheel truing machine and a three-tier wash building. On a more dramatic scale, the twenty stall wood roundhouse at Conway Yard near Pittsburgh was replaced. To the west of the network, the shop at Decatur, IL received a new roof, heating system, insulated widows and a truck drop table. At the western most terminal, a three-track shop for cars and locomotives was

built at North Kansas City to replace a Wabash roundhouse of unknown age and crumbling concrete. In 2010 a two-track locomotive shop with space for six units was opened at Inman Yard (Atlanta, GA). Similarly, a two-track shop was completed in Chicago at the 47th street intermodal facility in late 2016. At Bellevue, OH construction is concluding where the 1980 shop is being expanded from five to six tracks after independent structures were added for scheduled maintenance and alternator change outs.

Because of this construction activity, Norfolk Southern gained some special insight into the design of locomotive maintenance facilities. Working with consultants, particularly Urban Engineers of Philadelphia, Norfolk Southern developed standard plans for such things as inspection pits, elevated work platforms (ramps) and wash areas. These designs were refined and enhanced through the construction experience. While not the focus of this paper, numerous companion office and locker room buildings and six new covered locomotive servicing areas were also constructed during this period. Despite this activity, roundhouses, complete with turntables, remain operational at Calumet Yard (Chicago), Knoxville, Louisville and in Virginia at Roanoke and Norfolk.

Given the level of experience with the design and construction of twenty shop structures, it seems appropriate to share lessons learned from these endeavors. What follows is a series of design considerations from ten years of design and construction experience.

Key Design Points

During the early days of planning, especially for large structures, it is common to realize that the available land space is a limiting factor. This is especially true when replacing or working around existed facilities in a rail yard, but even “green” field locations may include space constraints. One way to deal with this is to consider use of a transfer table (or turntable) to access the shop in lieu of switches. Installation of such a table at one end of the building can save acres of land while facilitating more efficient movement of units in and out of the building.

When faced with space constraints, it is tempting to reduce track centers as a means of fitting buildings in the available space. This also has the appeal of reducing construction costs. However, minimal track centers can lead to problems on the shop floor for moving materials and maneuvering forklifts. Further, storage space on the shop floor for replacements parts is appealing when the associated travel time of a remote storehouse is considered. When floor space is limited, vertical storage carousels are a practical way to store lots of small parts in a limited space by utilizing the lofty ceilings characteristic of shops. (Figure 1)

During these initial stages of planning, the process should include identifying the intended purpose of each track. Care should be taken to avoid “stub end” tracks of more than one-unit length. When stub end tracks hold two or more units,

“good” locomotives get blocked in, making their retrieval difficult. That said, stub end tracks can be a valuable addition as a temporary holding place when switching a shop or an ideal place for wreck repairs, regardless of whether they are inside or outdoors.

The designers of a new locomotive shop should cover as many tracks as possible with overhead bridge cranes. (Figure 2) Any good shop design process will include an analysis of what maintenance tasks will be performed where. This allows the cost of cranes to be controlled by varying the capacity of the cranes based on the functional area of the shop they will serve. Many locomotive repairs can be performed with a two-ton crane. For those tasks where higher capacity cranes are required, good planning should be sufficiently detailed to permit lower capacity cranes to operate in the same bay. In rare instances, separate crane runways may be necessary.

While often over looked, light capacity cranes are needed above wheel reprofiling machines or lathes for their maintenance. Cranes are optional for storehouse areas and if installed, they should be of light capacity. It is difficult to install cranes in areas with exhaust hoods, although this can be achieved with retractable hoods. For safety reasons, bridge cranes that run on the top of the crane rails are preferred to underslung crane support arrangements. Double girder bridge cranes are preferable for their rigidity and control when positioning large replacement parts. Bridge cranes should be equipped with wireless remote-control systems and provisioned with pendant control for backup.

Ideally, all tracks should include inspection pits. Of the two types (gauge pits and raised rail pits) raised rail pits are generally more desirable but also more expensive. (Figures 3 & 4) For certain types of repairs, such as replacing main reservoirs, repairing wiring below the running board, or working on pilot plates, gauge pits are preferable. On tracks where, flat floor without pits may be advantageous, it may be desirable to install gauge pits with removeable steel covers that support fork lifts trucks. This arrangement offers the best of both worlds; pits when you need them and flat floor suitable for vehicles when you don't.

For all but the smallest locomotive shops, a single axle drop table is desirable. The installation of rebuilt or used drop tables is a viable way to reduce costs, especially at locations where limited numbers of traction motors are replaced. Drop tables can be justified by reviewing records of traction motors changed locally with portable cranes. When a truck drop table is installed, it should be built or modified to accommodate three axle truck frames of the radial or steerable truck design. For such drop tables, the split top feature which allows operation as a single axle drop table, is appealing. While a truck drop table may seem unnecessary for changing trucks, they offer the advantage of allowing center plate inspection and bearing surface maintenance after train crews report ride quality issues, an increasingly common complaint. (Figure 5)

With contemporary shop design, fall protection should be installed on every track. (Figures 6, 7, & 8) The introduction of Positive Train Control (PTC), which may result in as many as twenty antennas on the roof of the operator's cab, makes fall protection more vital. This presents challenges in bays with overhead cranes but there are designs of fall protection equipment that readily accommodate cranes. Column mounted jibs that swing out in unison to position a horizontal cable above the locomotives but below the cranes were the favored solution at Norfolk Southern.

Regardless of shop size, some provision should be made for washing locomotives. This is necessary due to excessive oil coming from the exhaust, dirty engine rooms, snow packed trucks and oily running boards. This may be as simple as designating a multi-purpose spot within the building for washing units. Such a spot must be designed with appropriate drainage and provisions for soap and high-pressure hot water (or steam) on hose reels. In so far as washing locomotives generates considerable grit, drain piping should be oversized to maintain flow. Large locomotive shops merit two wash locations; one for inbound power and one for cleaning units prior to release. Elevated work platforms providing safe access for cleaning the roof are a necessity while raised rail pits to facilitate efficient cleaning of trucks are desirable. At Norfolk Southern, we settled on a three-tier wash design that was widely used. (Figure 9)

When designing shops, it should be assumed that diesel engines will never run inside the building. The exceptions to this are specially enclosed areas for washing locomotives and static testing when the engine needs to be running ¹. This requires special ventilation considerations as huge volumes of air for combustion are consumed. Where the climate allows, outside start up shelters with a split roof opening above the rail are an alternative to in shop exhaust hoods when it comes to checking out running diesel engines and protecting the employees from inclement weather.

On a related topic, local building codes dictate ventilation requirements for new shops and provide excellent air circulation. For the sake of energy conservation and employee comfort, ceiling fans should be installed whenever possible (temperatures above cranes can be >80 F). Also, consideration should be given to designated wreck repair areas where extensive use of oxy-fuel torches, arc air and electrode welding may require special ventilation. Where shop layout dictates stub end tracks, this is an ideal location for wreck repairs. Since most wreck work is a product of grade crossing accidents, it is wise to consider the installation of the labor-saving pilot plate straightener machines available from Portec.

1. When washing locomotives, it is important to have the engine running to blow air through the traction motors to prevent moisture grounds. Also, engines are commonly started up after oil and filter changes or repairs related to the cooling system.

Four recent shop projects at Norfolk Southern involved unheated out door shelters adjacent to the locomotive servicing area over a single track with a gauge inspection pit. (Figure 10) Originally envisioned as a spot for quick unscheduled repairs, these structures were initially called “triage” shelters. Two of the buildings also included light overhead bridge cranes. As part of process changes implemented under the lean program, these structures were later used for an inbound assessment to better define the work.

Given the growing complexity of locomotives and the continued pressure for improved reliability, some shop projects included test tracks within the mechanical department territory or blue signals. Such test tracks were usually adapted from existing yard tracks with track upgrades to allow operation up to 35 mph over 4000-5000 feet of nearly tangent rail. Units are usually tested in motoring and dynamic brake against another fully operational unit of like horsepower.

With all the “black boxes” or peripheral electronics on today’s locomotives, there is significant drain on the starting batteries of when units are shut down. Therefore, it is desirable to route 480-volt power through the building of running repair shops for the installation of wall mounted battery chargers. While not yet widely practiced, in shop battery charging is becoming more of a necessity than a luxury. (Figure 11)

Well-designed shops include natural lighting, often using products such as Kalwall material, an affordable, insulated window material for large openings. (Figure 12) Today LED lighting is standard and significantly improves the work space while minimizing utility bills. The low-profile nature of LED lighting is ideal for installation on the walls of inspection pits. It is also appealing for ceiling lighting above raised rail pits where access for bulb and fixture maintenance is difficult.

In today’s world shop design considerations must include provisions for network connectivity. This includes ample work stations for computers dispersed through the work place and wireless connectivity for laptop computers and handheld devices which function as job aides and capture work reporting. Also, some railroads use Wi-Fi to automatically download locomotive event recorders and control system fault logs after units enter the building.

With the growing complexity of today’s emissions compliant diesel engines, some provision must be made for the storage of specialty tools and equipment. These tools are too large and expensive to duplicate so a designated space, perhaps even a tool room is needed.

An overarching consideration in shop design should be the safety of employees. This includes not only crane design but placement of blue signals, derails and their controls along with maintenance access to cranes, drop tables, lighting, transformers, electrical switch gear and HVAC systems. Designing facilities for employee safety must include ergonomic considerations for inspection pits, work platforms and ladders referencing the applicable OSHA regulations. The design

of inspection pits is critical, so it is wise to consult users and even build mock ups before initial designs are finalized.

Future Design Considerations

Due to the 25-plus year life of locomotive assets, the installed base of freight units is quite stable. Consequently, new locomotive designs initially have negligible impact on shop design. None the less, changes on the locomotives are always occurring. The introduction of Exhaust Gas Recirculation (EGR) on Tier IV emissions compliant locomotives is a good example. While few special building needs have thus far been identified to maintain this equipment, the need to work on top of the engine and remove multiple engine appurtenances on a more routine basis has the potential to influence designated work spaces and fall protection. Further, more frequent removal of the engine room hood, while not heavy, requires cranes with ample vertical lift and space for hood storage.

The biggest shop design concern remains the growth of locomotive platform length. While the SD90MAC units with their exceptional 80-foot platform length are now 25 years old, they remain in service due to extensive upgrade programs. New units now have platforms that are nearly as long due to the growing space for on board emissions equipment and larger radiators. Platform length quickly becomes an issue when the shop doors cannot be closed in winter months but can also interfere with access to gauge pits.

Another criterion to consider for the future is providing for the recycling of anti-freeze. Except for Gensets locomotives, practically all North American locomotives use treated water for engine coolant. The lower heat transfer capabilities of anti-freeze require larger radiators which has delayed the introduction of anti-freeze. For new shops, provisioning for the collection of antifreeze through the necessary piping is inexpensive. Properly designed, holding tanks and pumps can be added at designated locations when the need arises. In many cases, such holding tanks can fit under the work platforms (or “ramps”) at running board level. The fact is, the push to eliminate winter time idling, will lead to widespread use of anti-freeze in the foreseeable future.

When designing facilities, it is always desirable to contemplate future expansion. At the most basic level this means considering the design of the structure to support a building addition at designated locations or the support of heavier cranes for the loads associated with lifting traction motors, alternators or prime movers (engines). Yet just as important is to give advance thought to the design of utilities, electrical power requirements, drainage, and HVAC systems. With good planning, it is quite practical to provision new shops with additional pipe rack capacity on walls and platforms, extra 480-volt receptacles, data wiring and Wi Fi access points. The history of diesel shops is these are buildings where maintenance space is commonly “repurposed” for new requirements. The recent

installation of on board PTC equipment, and the soon to be growing maintenance of such hardware, illustrates this perfectly.

In Closing

Most shops must be designed to fit amongst existing structures or other infrastructure associated with rail yards. Further, it is common that a building scheduled for replacement must be kept operational until new shop capacity is created. As a result, a phased approach to construction emerges as the only practical way to deal with these complexities, which may increase construction costs. Regardless, close coordination with local shop management through daily meetings and open communications are vital to ensure success in both construction and continuing railroad operations.



Figure 1. Vertical Storage Carousel

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Figure 2. Overhead Bridge Crane



Figure 3. Gauge Pit



Figure 4. Raised Rail Pit



Figure 5. Truck Drop Table



Figure 6.



Figure 7.



Figure 8.



Figure 9. Three Tier Wash Station



Figure 10. Outdoor Startup Shelter



Figure 11. Shop Battery Charging



Figure 12. Natural Shop Lighting

Report on the Committee on Mechanical Maintenance

Monday, September 10, 2018 at 10:30 AM



Chair

Mark Duve

Manager-Locomotive Engineering
Norfolk Southern Corp.
Atlanta, GA

Vice Chair

John Hedrick

Principal Scientist
Southwest Research Institute
San Antonio, TX

Committee Members

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S. Beal	President & CEO	National Railway Equipment	Mt. Vernon, IL
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B. Wolff	Application Engineer-Rail	MTU America Inc	Novi, MI
R. Wullschlegler	Chief Mechanical Officer	New York & Atlantic Rwy	Glendale, NY

NOTE: Andy Pope of Bharat Forge will join committee at convention in Nashville, TN

PERSONAL HISTORY

Mark Duve

Manager-Locomotive Engineering
Norfolk Southern Corp.
Atlanta, GA

Mark Duve is the Locomotive Engineering Manager at Norfolk Southern. Mark began his career in locomotives at the Electro-Motive Division of EMD in 1994 where he worked various departments over 16 years including the Purchasing Department, Engine Group, and Locomotive Systems Engineering. While working in those departments, Mark worked on connecting rods, piston pin carriers, fuel economy testing, adhesion testing and locomotive configuration management. In 2010, Mark took a position as Mechanical Engineer Locomotive Design at Norfolk Southern and has since worked at System Manager Locomotive Reliability Manager and now Manger Locomotive Engineering. At NS, Mark has worked on various projects such as the ECO locomotives, DC to AC conversions, and the natural gas mother slug and locomotive reliability. Besides chairing the LMOA's Mechanical committee, Mark represents NS on the AAR Locomotive Committee and chairs the AAR's RP-589 and Battery TAGs.

Mark grew up in a small town in the hills of northern New Jersey. Mark's post high school education includes a Bachelors in Marketing from Colorado State University, a Bachelors in Engineering from Stevens Institute on Technology and a Masters Degree in Mechanical Engineering from Illinois Institute of Technology. Mark works out of Norfolk Southern's downtown Atlanta office and lives in the Atlanta suburb of Milton with his wife and 3 kids. Besides work and assisting with his kids activities, Mark past times include photography and home renovation.



Over the last year, the mechanical committee has hosted many phone conferences and has had two face to face meetings. The Mechanical Committee would like to thank JMA Rail Supply for sponsoring the committee's spring meeting in Little Rock, Arkansas at Hillcrest Camshaft Service on March 13-14, 2018. The team enjoyed the tour of the cam and crankshaft shop as well as a delicious barbeque lunch. A special thank you to Jeff Bink of JMA who is a member of our committee for making all the arrangements.

In addition, the Union Pacific gave a tour of their Jenks Locomotive Back Shop which is also located in Little Rock. The committee wishes to thank the UP for allowing us to tour their facility.

The summer meeting was sponsored by Peaker Services at their Brighton, Michigan plant with a tour of their facility which took place on August 13-14, 2018. The committee would like to thank Peaker Services for their hospitality and especially their President and CEO Ian Bradbury, current 1st Vice President of LMOA for being such a gracious host.

The team also had an opportunity to tour the EPA's National Fuel and Testing Facility in Ann Arbor, Michigan.

Our committee membership continues to grow with members from the AAR and EPA.

New Procedure to Check GE-FDL Cam Timing

Prepared by:

John Hedrick, Southwest Research Institute

Dustin Osborne, Southwest Research Institute

Michael Cleveland, BNSF

Abstract

The GE-FDL engines make up a significant portion of the prime movers in the US locomotive fleet. These engines are being rebuilt to meet new emissions targets (Tier 0+ and Tier 1+) and are expected to provide good brake specific fuel consumption (BSFC) and meet their emissions targets. However, if the cam timing is not correct, the emission and fuel consumption targets can be missed. This paper describes a new procedure to measure cam timing on the GE-FDL engine to determine if there are potential cam timing issues. This can be done using hardware typically found in any shop that has the tools and skill set needed to replace GE-FDL fuel injection pumps.

Background

The 16-cylinder GE-FDL engine has eight cam segments and nine journals, per engine bank. These cams drive intake valves, exhaust valves, and the high-pressure fuel injection pumps. Graphical representation of a typical profile for each cam lobe is given in Figure 1. Correct timing of these valve and fuel injection events are critical to engine performance. On an engine that was originally timed correctly, any timing shift is not possible without signs of serious engine damage. However, when the cams and or journals are replaced at time of engine overhaul or during a repair to replace cam segments, it is possible that the replacement cam segments and cam journals can be rebuilt incorrectly and or be installed incorrectly. Both scenarios can cause emissions and performance issues with the engine.

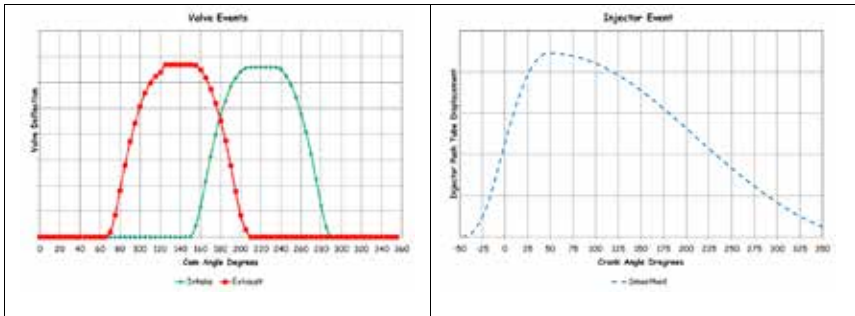


FIGURE #1 Valve and Injector Plunger Motion VS. Crank Angle Degrees

GE-FDL Camshaft Layout

On a modern GE-FDL engine, fitted with an Electronic Fuel Injection (EFI) system, the cam segments bolt to cam journals and the cam journals fit in engine block on each end of the cam segments. Figure 2 shows one cam segment and the face of a cam journal. On a Mechanical Fuel Injection (MFI) engine, the cam segments and journals, shown in Figure 3, have a different design and are not interchangeable with the EFI design.

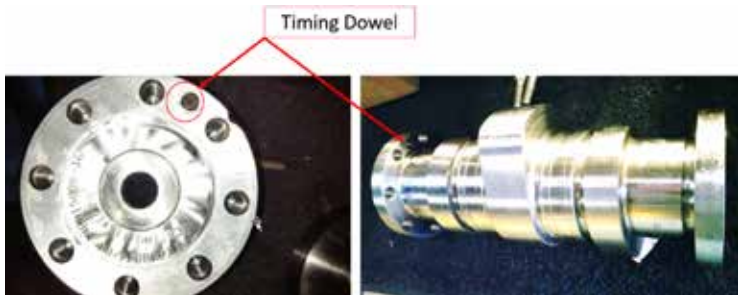


Figure #2 EFI Cam and Journal

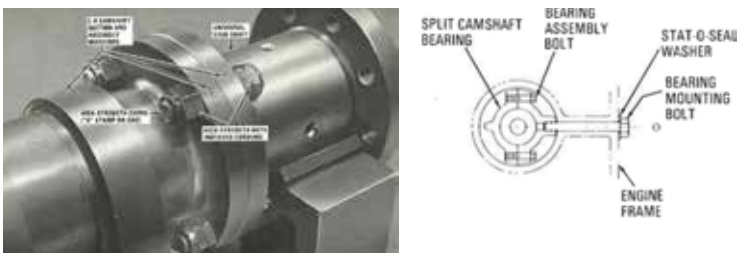


Figure #3 MFI Cam and Journal

Images from GE Service Manual - Diesel Engine, Section 9, GEK-30150

Eight cam segments and nine cam journals are assembled to form the cam on one bank of a 16-cylinder FDL engine. Figure 4 shows a cartoon of the cam layout. Each cam segment and journal are timed by aligning the timing dowel pin (shown in Figure 2) in the journal with the appropriate timing hole in the flange of the cam. This setup includes sixteen different bolted and doweled joints between the cam gear and Cylinder 1 cam segment. Each of these bolted joints could be a source of undesirable timing offset, causing the potential error in the cam timing.

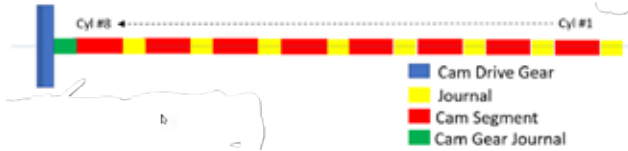


Figure #4 Typical GE-FDL Cam Layout

Each cam segment is timed by an indexing mark on the cam segments and a notch in the end of cam journal. Figure 5 lists the timing marks that need to be aligned with the journal notch on a 16-cylinder engine to assure that each cam is timed correctly. Cylinder 3 and 7, and Cylinders 1 and 5 share a timing indicator on the flange of the cam. Figure 6 shows an example of the alignment of the cylinder number that is marked on the cam flange with the notch on the edge of the cam journal.

Cylinder Location (Left or Right)	Cam Marking
8	8
7	3/7
6	6
5	1/5
4	4
3	3/7
2	2
1	1/5

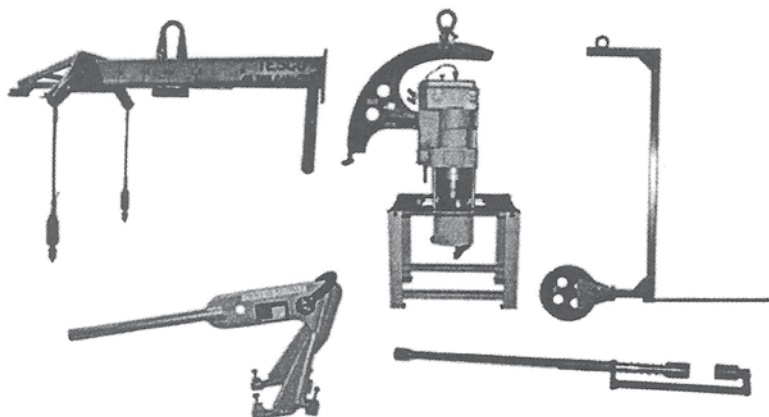
Figure #5 Cam Segment - Cylinder Timing Marks



Figure #6 Cam Timing – Aligning the Cylinder Marker and the Notch in Cam Journal



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Potential errors can manifest and be identified as Cam Twist and Bank-to-Bank Timing Offset. Cam twist is defined as a cam timing change along the length of the cam. This timing change along the length of the cam can be caused by the cam journals not being built / rebuilt correctly, or one (or more) of the cam segment / journal interface not timed correctly when assembled.

The Bank-to-Bank timing offset can be caused by a cam gear not being timed correctly or the cam gear journal not built / rebuilt correctly. A drawing of the cam timing layout with the timing indicators marked on the cam gears and the crank gear and an exploded view of the cam gear and the cam gear journal are shown in Figure 7. Based on the number of teeth on the cam gear, if one of the cam gears is installed incorrectly by one tooth, the bank-to-bank timing offset would be $\sim 3.5^\circ$ ($360^\circ/104 \text{ teeth} = 3.462 \text{ Degree / Tooth}$).

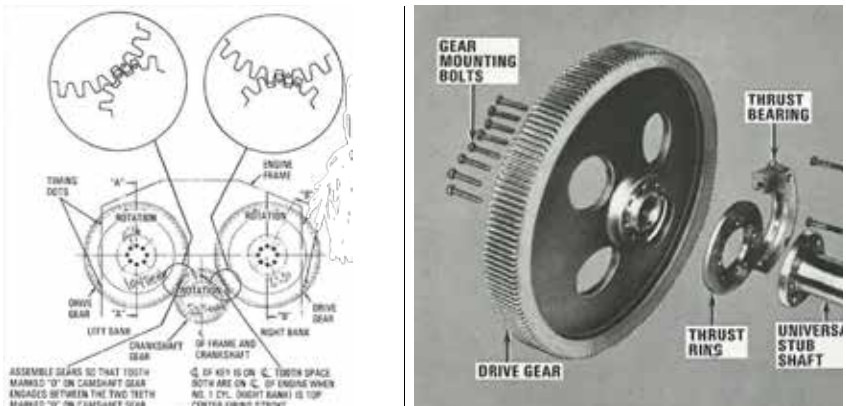


Figure #7 Cam Gear Timing Indicators and Cam Drive Gear Journal Assembly Images from GE Service Manual - Diesel Engine, Section 9, GEK-30150

Recommended Test / Measurement Setup

Cam timing can be checked by comparing lobe profiles between different cylinders. It is recommended that the measurements be made off the injection pump push rod. The actual measurement is the push tube displacement vs. cam angle degrees. The hardware (shown in Figure 8) used for this measurement is:

- Dial indicator base was a Transportation Equipment Supply Co. (TESCO) part number T55971.
 - o Or a custom-built bracket to eliminate the need for spacers under the bracket.
- $\sim 1''$ spacers under TESCO #T55971 dial indicator base.
 - o Can use EMD exhaust manifold standoff washers in place of making special spacers.

- 2" Dial indicator:
 - Analog = Starrett # 25-2041 (or equivalent).
 - Digital = Starrett Cat # F27401Q (or equivalent).
- 2 each – 2" X ½" NC - Grade 5 (or better) bolts
 - Used to replace the shorter Nylon bolts that are standard with Tesco # T55971.
 - Clearance issues eliminated by using ~1" spacers and the 2" stroke dial indicator, so nylon bolts are not needed.



Figure #8 Measurement Hardware



Figure #9 Hardware with Digital Dial Indicator

There are many 2" digital dial indicators that can be used in place of the analog indicator. One option is a Starrett Cat # F27401Q 2" digital dial indicator that can be mounted on the same TESCO base. The resolution of this digital dial indicator is 0.0001" and the output from the digital indicator can be output directly to an Excel worksheet via USB port. A digital dial indicator offers fast and very accurate measurements. Figure 9 shows the Starrett Cat # F27401Q 2" digital indicator installed on the TESCO 55971 frame.

The TESCO T55971 with the 2" dial indicator mounts in place of high pressure fuel injection pump as shown in Figure 10. Because the measurement is the displacement of the injection pump push tube as a function of cam degrees, the engine is rotated to the base circle on the cam, the dial indicator is zeroed and then the dial indicator output is recorded at each of the four measurement locations (the four corners of the engine).



Figure #10 Measurement System Installed in Place of High Pressure Fuel Pump



Figure #11 Examples of Air Motor and Cam Drive Adaptor

The use of an air motor to rotate the engine will make the job much easier / quicker. An example of an air motor system to rotate the engine is shown in Figure 11. Be safe installing the air motor because the motor is heavy and offers many opportunities to pinch the person installing the motor. When rotating the engine, always rotate cam gear in the direction normal engine rotation. Being consistent in the direction of rotation will maintain constant lash / windup in cam gear system.

If measurement timing point is overshoot, be sure to rotate in negative direction, past set point by more than 10° . Then move the cam gear in positive direction to correct set point and then take the measurement. It is very important that the cam timing point is accurately set. Any errors in setting the engine to the correct timing will have an adverse effect on the accuracy of the cam timing determination.

For the timing checks presented in this paper, 0.180" injection pump push tube lift/ displacement was selected as the "timing point". This was a repeatable point in the initial tests, as shown in Figure 12, and was chosen as the timing point for all future tests. Note that all timings shown are in cam degrees and simply multiply the reading by two to convert the reading to crank angle degrees (CAD's).

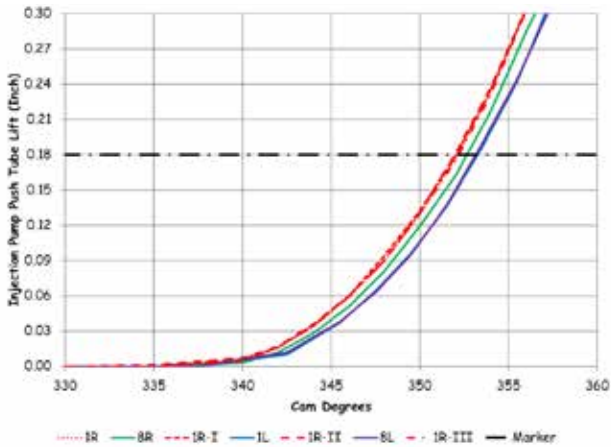


Figure #12 Initial Test Results Showing 0.180" as a Stable Measurement Location

When to Check Cam Timing

The ability to catch cam twist and bank-to-bank timing errors early in a cam installation / engine rebuild process will improve the final product and reduce costs. The cam timing check would ideally take place after the fuel roller retainers plates are removed but before the injection pump push tube heights are adjusted using TESCO # T55971 timing tool. The retaining plates are used to hold up the fuel roller while the cam sections are being changed out and are shown in Figure #13. These are TESCO #T57150 (L or R) or an equivalent.



Figure #13 Fuel Roller Retainer Plates
<https://tescotools.com>

Note that it is not critical to set the fuel pump push tube to the correct height, (use TESCO T55971 that is shown in Figure 14), before the cam timing measurements are made. The differences in the push tube height is taken out by zeroing 2” dial indicator while the injection pump cam follower is on base circle of the cam, before the measurement process starts.



**Figure #14 Standard TESCO Part Number T55971
Used to Set Fuel Pump Push Tube Height
<https://tescotools.com>**

Timing Correction to Top Dead Center (TDC)

Timing readings for Cylinders 8L, 8R, and 1L must be corrected to TDC timing to allow for comparison between the cam timing at each cylinder. The calculations are based off the timing plate offset that are shown in Figure #15. If this procedure was conducted on an 8 or 12-cylinder GE-FDL engine, these calculations would need to be adjusted for the timing at the four corners of the engine.

Cyl #8 - corrected to TDC Timing

Cyl #8L = 8L timing reading – (161.5° - 319.0°)

Cyl #8R = 8R timing reading + (139.0° - 319.0°) + 360°

Cyl #1 - corrected to TDC Timing

Cyl #1L = 1L timing reading – (314.5° - 319.0°)

Cyl #1R – No correction needed.

ADJUST FUEL PUMP PUSH RODS & SET VALVE LASH FOR "EFI" EQUIPPED ENGINE

SET	DEGREE	SET	DEGREE
1R	319	8R	139
1L	341.5	8L	161.5
3R	4	6R	184
3L	26.5	6L	206.5
7R	49	2R	229
7L	71.5	2L	251.5
4R	94	5R	274
4L	116.5	5L	296.5

SET POINTER AT 0 DEGREES WITH #1 CYLINDER AT FIRING T.D.C.

Figure #15 Timing Offset

Measurement Repeatability

Measurement repeatability checks were completed on three engines, called Unit #1, Unit #2, and Unit #4. Note that Unit #3 was not tested for repeatability. The repeatability measurements were accomplished by returning to Cylinder 1R between each measurement on the four corners of the engine. Cylinder 1R was used as the repeatability measurement location because of easy access of Cylinder 1R and easy communication with the Team Member that was setting to the required cam timing point. The test progression was:

1R - 8R - 1R - 1L - 1R - 8L - 1R

There were five repeatability tests conducted on Unit #2. The fifth reading on Cylinder 1R was conducted on the next day by a different person setting the cam timing for this test.

The measurement repeatability tests required the timing be zero corrected based on results from the first measurement on Cylinder 1R. By zeroing the reading based on the initial reading allowed the repeatability analysis be conducted without worrying about engine-to-engine variability being an influence in the analysis (bank-to-bank timing offset, cam twist, or potential Tier 0+ vs. Tier 1+ cam timing difference).

For consistency, the nomenclature for the cam timing should be:

- Positive timing = Retarded cam timing
- Negative timing = Advance cam timing

Unit #1

The repeatability test results for Unit #1 are shown in Figure 16. The maximum timing offset for Unit #1 was 0.07° on Sample #4 and the minimum reading was -0.15° on Sample #3. This provided a range of the readings; (Max - Min) was 0.22° .

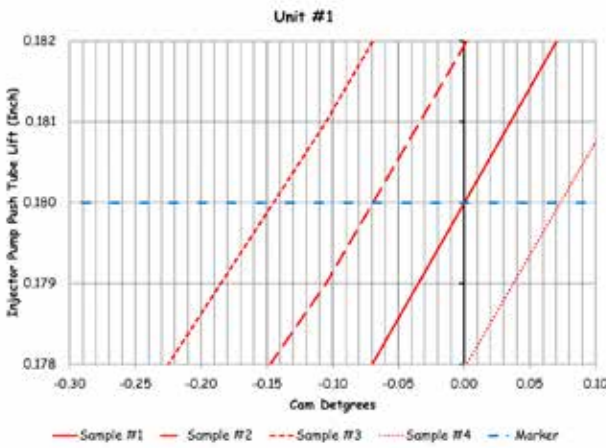


Figure #16 Repeatability Test on Unit #1

Unit #2

The repeatability test results for Unit #2 are shown in Figure 17. The maximum timing offset for Unit #2 was 0.03° on Sample #4 and the minimum reading was -0.07° on Sample #2. This provided a range of the readings; (Max – Min) was 0.1°.

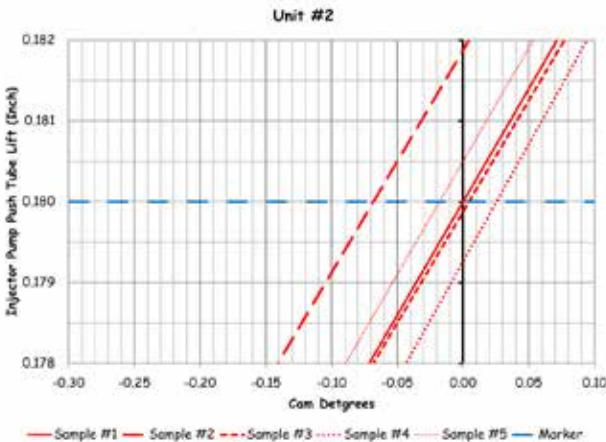


Figure #17 Repeatability Test on Unit #2

Unit #4

The repeatability test results for Unit #4 are shown in Figure 18. The maximum timing offset for Unit #4 was 0.00° on Sample #1 and the minimum reading was -0.26° on Sample #4. This provided a range of the readings; (Max – Min) was 0.26°.

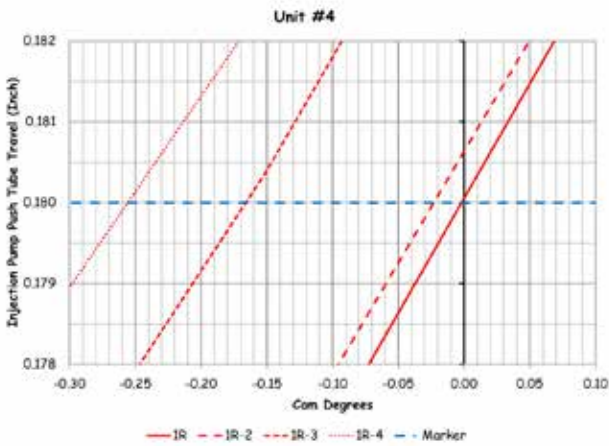


Figure #18 Repeatability Test on Unit #4

The repeatability tests had a total of 13 samples and are shown in Table 1. These tests were conducted on three different engines and taken on four different days with four different people reading the pointer and setting the cam to the correct timing. The results are:

- Average of 13 readings = -0.05° .
- Standard Dev = 0.093°
- Range (Max – Min) = 0.33°
 - Max = 0.07°
 - Min = -0.26°

Based on these results, it would be reasonable to expect repeatability to be within 1/3 of a cam angle degree.

Table #1 Repeatability Test Results

<i>Sample #</i>	<i>Reading</i>
Unit #1	
1	0.00°
2	-0.07°
3	-0.15°
4	0.07°
Unit #2	
1	0.00°
2	-0.07°
3	0.01°
4	0.03°
5	-0.02°
Unit #4	
1	0.00°
2	-0.02°
3	-0.17°
4	-0.26°

Examples of Cam Twist

Cam twist is determined by the timing difference between Cylinder 8 and Cylinder 1 at 0.180" lift of the fuel pump push tube. Cam twist can be calculated using:

$$\text{Cam Twist} = \text{Cyl \#1 (corrected to TDC)} - \text{Cyl \#8 (corrected to TDC)}$$

Based on repeatability test results, the cam twist should be less than 1/3 of a cam degree, regardless of GE-FDL engine configuration. The cam twist could be the cumulative effect of a small amount of twist at each journal / cam segment joint or all the twist at one joint. To determine the location of the twist, it is possible to make the same measurement process at each cylinder and compare the measured timing to the timing of Cylinder 8.

Figure 19 shows the cam timing measurements for Unit #2. This unit had no significant cam twist. The left bank cam twist was $\sim +0.2^\circ$, as determined from the following cam timing measurements at 0.180" pump push tube travel:

- Cyl #1L = 354.0°
- Cyl #8L = 353.8°

The right bank has $\sim -0.2^\circ$ twist, as determined from the following cam timing measurements at 0.180" pump push tube travel:

- Cyl #1R = 352.2°
- Cyl #8R = 352.4°

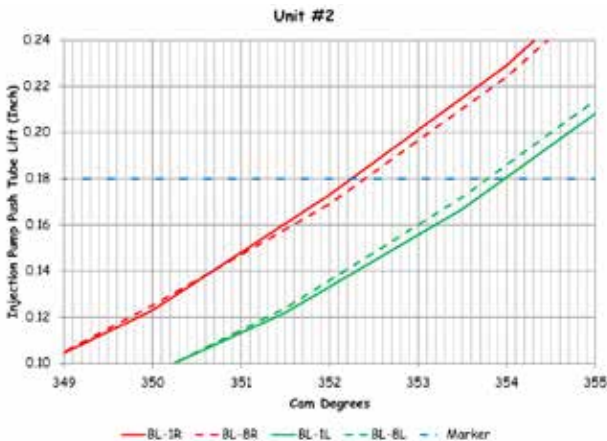


Figure #19 Example of No Significant Cam Twist

Figure 20 shows that Unit #4 had a significant amount of twist on both cams with the right bank measured at $\sim -3.0^\circ$ twist (advance) and the left bank had $\sim -3.2^\circ$

twist (advance). The question that comes out of this work is, “how much cam twist is too much?” If there are concerns, contact the OEM to get assistance.

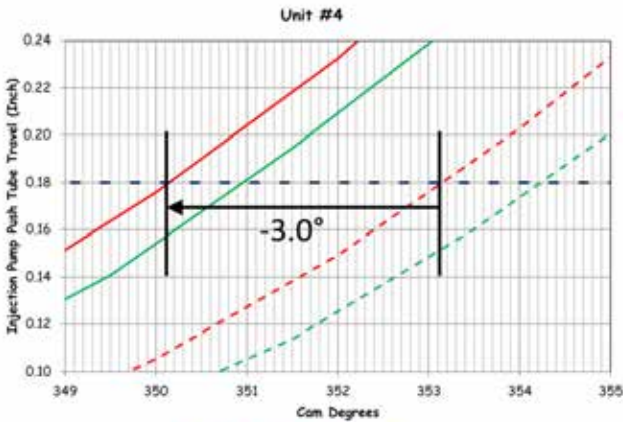


Figure #20 Example of Cam Twist

Examples of Bank-to-Bank Offset

Because the cams are driven at the rear of engine, near Cyl #8, the bank-to-bank cam timing offset is the absolute difference between Cyl #8L (corr) & Cyl #8R (corr). Using this process, Unit #3 had an $\sim 0.9^\circ$ offset, as determined from the following measured timing at 0.180" pump push tube travel, and shown graphically in Figure 21:

- Cyl #8L = 352.6°
- Cyl #8R = 353.5°

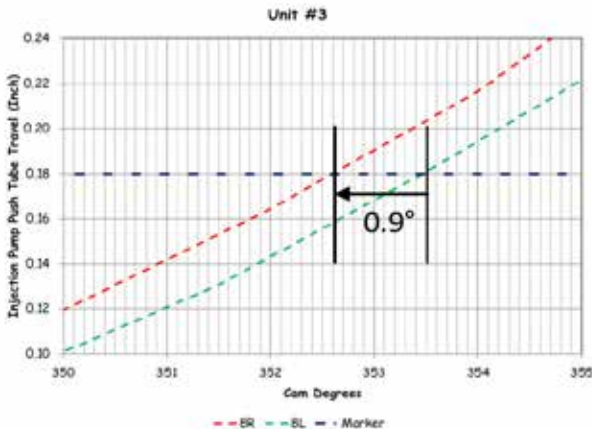


Figure #21 Example of Bank-to-Bank Timing Offset on Unit #3

Unit #2 had 1.4° bank-to-bank offset, as shown in Figure 22. This was based on the following measured timing at 0.180” pump push tube travel: of:

- Cyl #8L = 353.8°
- Cyl #8R = 352.4°

Again, the question “how much is too much?” applies to the bank-to-bank timing offset. If in doubt about the differences in bank timing, contact the OEM to discuss the allowed tolerance for bank-to-bank timing. Also recognize that if one of the cam gears are off by one tooth, the bank-to-bank timing offset should be ~3.5°.

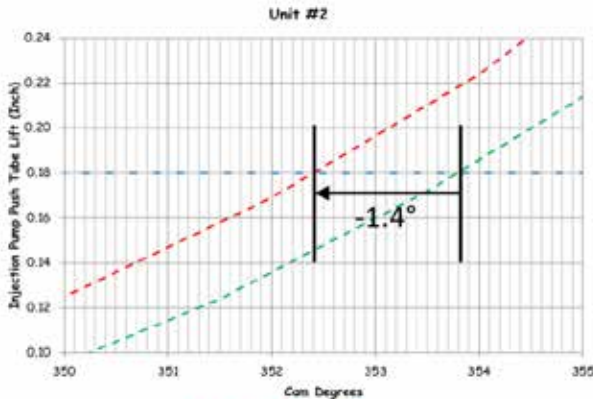


Figure #22 Example of Bank-to-Bank Timing Offset on Unit #2

Conclusions

Incorrect cam timing can have adverse effects on engine performance and emissions. Repeatable cam timing measurements can be determined via high pressure injection pump push tube lift / displacement verses cam timing. The results of testing on three different units demonstrated that the repeatable measurements should be less than 1/3°.

Cam timing measurements can be easily added to cam replacement or engine overhaul jobs. Both cam twist and bank-to-bank timing issues can be identified using this system.

Lessons learned:

- Majority of variability determined to be due to inaccuracy of reading pointer and getting to the correct setpoint.
- Try to use same person to read / set cam timing (for all tests).
- Impress the importance of the cam readings / settings being accurate and consistent.
- View pointer (that indicates cam timing) from same angle for all readings.



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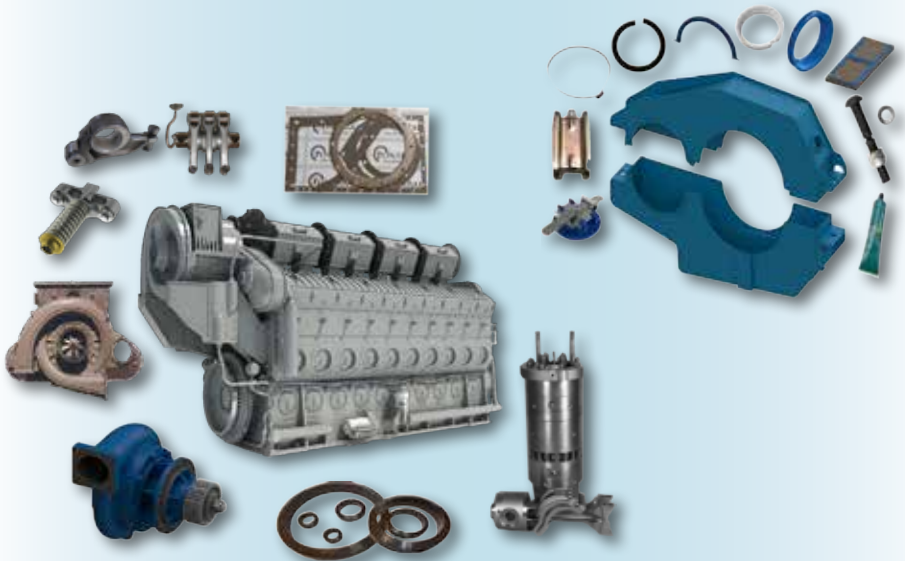
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A Review of Compressed Air Systems

Prepared by:

Jeff Brunson

LinkUp International, LLC

Introduction

When George Westinghouse introduced the Straight Air Brake back in the 1800's, he may or may not have had any idea of how compressed air would become the power source of so many systems on a locomotive. Compressing all that air comes at a cost. There is fuel associated with creating the horsepower required to turn the compressor, through either direct drive or an electric motor. And thanks to physics, compressed air ends up being very hot and 100% saturated with water vapor. That water vapor needs to be dealt with as the air cools, and there are costs associated with purging this water. Issues surrounding the compressing and dealing with water vapor have been wreaking havoc on North American Railroads for years. Some work has already been done to address these issues, and even today, suppliers continue to refine components of the system to be more efficient and reliable. Can more be done?

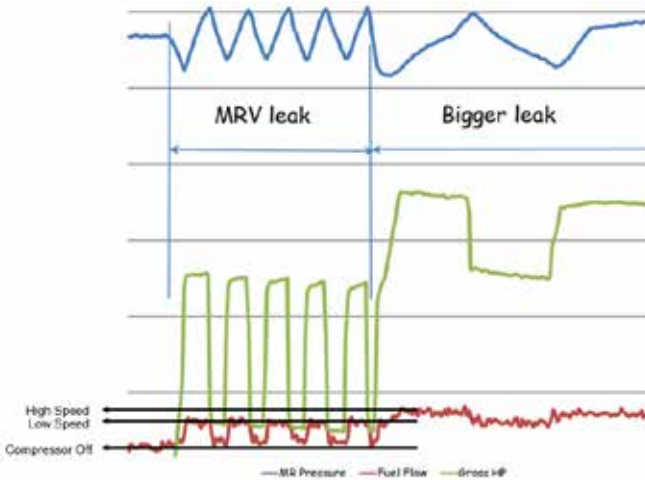
Compressed Air Costs

There are costs associated with compressed air systems. These costs include the direct costs associated with spinning the compressor, as well as indirect costs associated with ensuring the air is filtered, and the system is maintained.

Spinning the shaft on a compressor requires power. Ultimately that power is generated by the diesel engine of the locomotive and transferred to the compressor via either a direct drive shaft from the engines crankshaft, or through an electric motor that receives power from the alternator (spun by the engine). Either way, spinning the compressor requires the engine to work just a little harder, and use just a little more fuel to do so. It can be compared to driving your personal vehicle. When you drive with the Air Conditioning blasting cold air, you just don't get the same fuel mileage as you do without the AC running. Your personal vehicle's engine is just not as efficient when it has to rotate the AC compressor on top of supplying power to the transmission.

Previous studies have calculated fuel costs ranging from \$0.40 to \$0.60 per 1000 cu-ft (CF) of air compressed. This paper will use these assumptions and back it up with some data generated by Southwest Research Institute's (SwRI) provided fuel flow data as Main Reservoir (MR) leaks were introduced into the system.

A closer look at the graph below shows how fuel flow and gross HP increase as a small leak is introduced, and how both increase even more as a bigger leak is introduced. This particular data was collected from a locomotive using an electric motor driven compressor (2 speed).



At a cost of \$2.25/gallon for diesel fuel, the following calculations back up the previous works that estimated \$0.40-0.60 per 1000cf of compressed air at 140psi from an electrically driven air compressor.

Test Condition	Avg Fuel Flow (Gal/ hr)	Change in Fuel Flow (Gal/ hr)	Fuel cost per hour	\$ / 1000cf
Baseline	7.98			
Low Speed (120CFM)	9.84	1.86	\$4.18	\$0.58
High Speed (240 CFM)	10.71	2.72	\$6.13	\$0.43

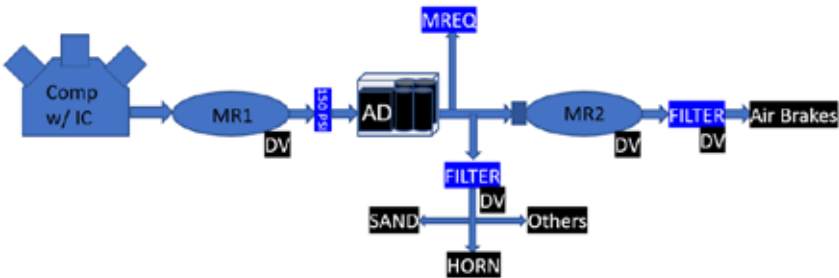
Overview of Compressed Air System

The compressed air system on a locomotive has become quite complex over the years. The components can be broken out into four categories:

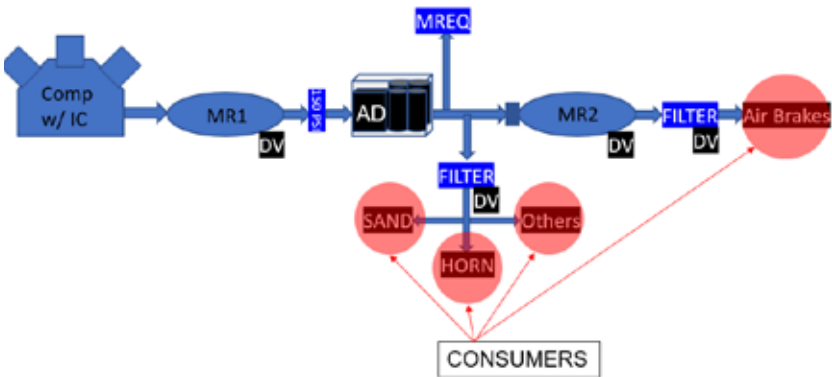
1. Air Compressor
2. Storage (MR1 and MR2)
3. Air Consumers
4. Purge

The compressor could be a reciprocating or screw type and either direct drive or electric motor driven. On average, these units require about 60-65 HP and output around 240 Cubic Feet/Min (CFM) of compressed air @ 140psi.

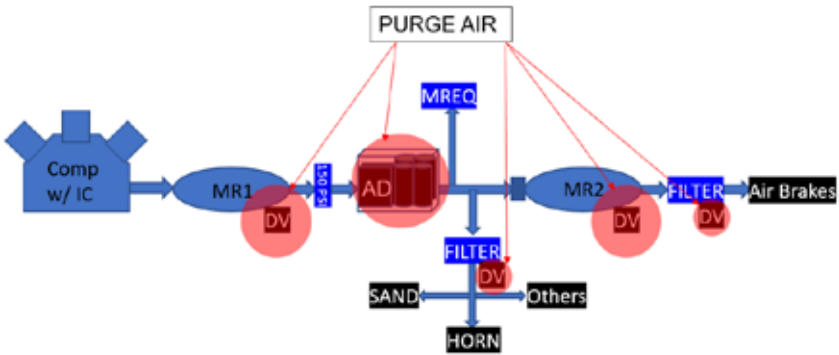
The compressed air is stored onboard in two reservoirs, MR1 and MR2. MR1 is the first in line after the compressor and aftercooler (if equipped). The main function of MR1 is air storage, and it ends up being the primary collection point for water as the hot, wet air comes downstream and cools/condenses. MR2 is downstream of MR1 and stores much dryer air as by this point, it has already passed through the Air Dryer (if equipped).



As mentioned, there are many sub-systems on a locomotive that consume air. Probably the two most important would be the Air Brakes (AB) and Horn. Without these two subsystems, the train could neither stop nor warn others nearby of its operations. Other consumers would include the sanding system, air-operated wipers, advanced rail cleaners (ARC), radar lens cleaner, air-starters, shutter valves, and air assisted crankcase eductors. It seems as though the list continues to grow.



In order to supply clean, dry air to the consumers, the compressed air must be purged of water, water vapor, and dirt/debris. To accomplish this, both MR1 and MR2 are equipped with some type of drain valve (DV), and many locomotives are equipped with an air dryer (AD) and final filters that may be equipped with their own DV's. All of these components exist so that the consumers can receive clean, dry air for better reliability and long life. Water can wreak havoc on a compressed air system if not dealt with. Issues may include contamination (debris damaging O-rings and seals) and frozen pipes or valves in the winter which can cause major delays to operations.



How much air is produced, and how is it used?

Initially, an estimate was created based on a theoretical train. That theoretical train was projected to need approximately 50,000cf of air for its operations over a 10 hr period, which included air for consumers, purge, and leakage. In order to take a more accurate look at air usage, an event recorder was reviewed and where possible, those results were compared to the theoretical values. This event recorder download was provided by a US railroad from a train operating from Oklahoma to central Arizona covering over 1000 miles in the 24hr period monitored.

Air consumption was calculated for those consumers where data was recorded (Horn and Air Brakes). The data available included time and duration of horn actuations, as well as Brake Pipe (BP) air flow when charging/releasing the brakes. This data was then used to calculate CF of air consumed, as shown by the examples below:

Mode	Duration	Calc. Velocity	CF Consumed
Horn	0:00:05	62	12.50
Horn	0:00:05	65	12.50
Horn	0:00:10	67	25.00

Mode	Time	Calc. Velocity	Air Flow (cfm)	CF Consumed	Bell	EAB BP (psi)	EAB Brake Handle
Running	12:06:07	0.00	0	0.00	Off		71 Service
Running	12:06:08	0.00	147	2.45	Off		76 Release
Running	12:06:09	0.00	172	2.87	Off		81 Release
Running	12:06:10	0.00	164	2.73	Off		85 Release
Running	12:06:11	0.00	132	2.20	Off		86 Release
Running	12:06:12	0.00	111	1.85	Off		87 Release
Running	12:06:13	0.00	96	1.60	Off		87 Release

The next chart below updates the original theoretical data with actual data from this download. Where actual data was not available, the theoretical data was converted based on the 24hr period.

It is well known that during the cold months, it can be difficult to get under the limit of 60CFM (as identified in CFR 49, 232.205) due to the additional leakage associated with cold weather. The data below is based on the air system being charged for 90% of the day, or approx. 22 of 24 hours with 50CFM of total leakage. It is estimated that 66,000CF could be needed to overcome leaks in the locomotive air systems as well as leaks in the BP. In some instances, a leak may be intentional as in the case of an air operated EOT device. For traditional leaks, they rarely repair themselves, and unless the BP is dropped to zero, a leak will continue to consume air.

Horn data is based on the event recorder download, using the horn duration and a typical 5-chime horn that would consume 150CFM. The cumulative total time the horn was operated during this 24 hr period was equal to a shocking 85 minutes!

Air Brake data was also based on the Event Recorder download. This number may be slightly low due to that fact that it doesn't appear that the flow (and therefore the CF consumed) is recorded by the event recorder when below 18CFM.

Drain Valves, Sanding, and Air Dryer consumption are based on the theoretical data, adjusted to the 24hr model.

	<u>Theoretical</u>	<u>Actual Horn/brakes w/Theoretical</u>	<u>Notes:</u>
Duration	10 hrs	24 hrs	
Leakage	30000	66000	*Est. based on 50CFM for 22 hrs
Horn	8000	12775	*Actual
Brakes	773	1631	*Actual, adjusted for 90psi trainline
Drain Valves	2112	5069	*Est. based on theory
Sanding	1920	4608	*Est. based on theory
Air Dryer	7491	15764	*Est. based on 17.5% of air needed
Total	50296	105847	

This example shows that the majority of the air compressed ends up lost as leakage, or purge air, and only 18% of the air compressed is ultimately used for train operations. Based on an average of \$.50/1000cf of compressed air, we can associate a dollar value to each of the categories.

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<u>Leakage</u>	<u>Operations</u>	<u>Purge</u>	
62.4%	18.0%	19.7%	
\$ 33.00	\$ 9.51	\$ 10.42	<- \$ value at \$0.50/1000cf

Can we be more efficient?

The most likely area for improvement in air usage is obviously reducing leakage. Leakage has become somewhat accepted in the industry, however leakage has compounding, negative effects on the air system and compressed air quality. For instance, the more compressed air we produce yields more water (vapor and/or liquid) to be dealt with. While it may be virtually impossible to eliminate leaks, there may be room for improvement through reductions in leakage. A leakage reduction program could include any of the following:

1. Reduction in leakage opportunities through new improved rubber products
2. Advanced leak detection, possibly using ultrasonic equipment
3. Scheduled maintenance with “dead ball” as a goal (0 CIM leakage during Freight Car “Single Car Test” as opposed to current 225 CIM limit)

Purge air is another area that could reduce Air usage. While, as previously mentioned, purge air is a necessity, it could be reduced. Suppliers are working on better and more efficient Air Dryers and Drain Valves that purge only when needed instead of on a fixed interval.

For horn usage, railroads and communities are working together to implement “quiet zones”. These quiet zones benefit the railroads through reduced horn usage (air) and benefit the communities with reduced noise pollution, a win-win.

For many years now, railroads have been optimizing train performance to reduce brake usage through the use of dynamic brakes, distributed power and train pacing. These are all good practices that provide benefits far beyond air usage reductions. The less the brakes are used means less brake shoe wear, less in train forces that can damage the cars or the commodities being transported, as well as many other benefits.

Conclusion

Demand for compressed air has increased significantly over the last 20+ years. More and more systems are being introduced that rely on the compressor as a power source. These compressed air consumers, as well as leakage and purge air are making the compressor work harder and harder to keep up with demand. If we can reduce the demand on the compressor we can likely extend the life of many of the components throughout this system, including the compressor itself, all while saving a small amount of fuel in the process. I hope this paper sheds a small amount of light on the subject of air consumption and leakage and provides some incentive for Railroads and suppliers to work toward new solutions.

Basic Maintenance Practices for High-Pressure Common Rail Fuel Systems

Prepared by:

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Dennis Nott, Northwestern Consulting, LLC

High-Pressure Common Rail (HPCR) fuel systems have been in service on railroad locomotive engines for over a decade. As noted in previous papers by the LMOA Fuels, Lubricants and Environmental Committee and the LMOA Mechanical Committee the need for precise fuel injection and timing for reduced emissions resulted in the development and use of HPCR on locomotive engines. The LMOA Fuels, Lubricants and Environmental Committee has also covered fuel quality, fuel filtration and the effect of deposits on components within the HPCR fuel systems in a previous paper. Details of how the HPCR and electronic injectors work can also be found in the previously mentioned papers.

Details of the procedures of how the HPCR system is maintained is engine specific and varies from engine type and the Original Equipment Manufacturer (OEM) and is not covered in this paper. Please refer to the OEM's maintenance instructions for these details. This paper covers the basic maintenance practices when working with the HPCR system and in particular the fuel lines and how to safely work on the system without introducing contamination into the system.

The basic HPCR fuel system consist of a 1) low-pressure fuel pump to lift the fuel from the fuel tank to the high-pressure fuel pump, 2) fuel filtration system, 3) one or more high-pressure fuel pumps on the HPCR fuel system to distribute the fuel at high pressure, 4) high-pressure fuel lines from the high-pressure pump to the electronic injectors on each cylinder, 5) the electronic injectors. Each engine OEM has their own specific design for the components within the HPCR fuel system and may have other components such as, but not limited to, bleed valves between the high-pressure fuel pump and the electronic injectors.

HPCR systems are used on all of the new high-horsepower (HP) U.S. Environmental Protection Agency (EPA) T4 locomotives being produced at this time for both freight and passenger service. The HPCR system has also been used on lower to medium HP engines in locomotives starting with EPA Tier 2 in the Gen Set type locomotives. OEM's currently producing engines with HPCR for locomotives include Caterpillar, Cummins, Deutz, General Electric, MTU and Progress Rail (EMD).

TRAINING

Personnel should be trained on OEM procedures when working on the HPCR fuel systems. This should be accomplished through OEM or railroad developed training programs using the OEM maintenance recommendations. It is also imperative that personnel working on the HPCR system understand:

- The sensitivity of the HPCR fuel system to contamination.
- The HPCR fuel system filtration requirements.
- The need to recognize fuel contamination sources.
- The techniques to keep the HPCR fuel system clean.

Personnel must also understand the HPCR fuel system maintenance procedures:

- Each OEM has slightly different procedures for their particular engine(s) and engines of different sizes from the same OEM may also have slightly different procedures.
- Training by the OEM or by railroad developed training should be for each specific engine that the personnel would be working on.
- It is recommended that all training be done using the OEM maintenance manuals and instructions for each type of engine and that the training material, manuals and instructions be available to all personnel working on HPCR fuel systems at their work stations.
- Personnel must understand all safety concerns when working on HPCR fuel systems and it is recommended that this is included in all training and be available at the HPCR fuel system work stations.
- Training of material handling personnel in the supply chain should also be included to:
 - o Gain understanding of how new and used HPCR components should be packaged and handled to prevent damage and contamination.
 - o Gain understanding of the results of damage and contamination.
 - o Gain understanding of materials and consumables will be needed at HPCR work stations.

Training and training material should not be “one and done” and become stagnant. Hardware, designs, suppliers, tooling and processes are constantly changing and training sessions and training material need to keep pace with the changes.

SAFETY

Safety is critical when working on HPCR fuel systems.

The HPCR fuel systems produce very high pressures in the range from 15,000 to 30,000+ pounds per square inch (psi). For safety HPCR fuel lines are usually double walled in case there is a break in the inner line during operation. All EPA Tier 4 OEM engines have double walled fuel lines but there are some Tier 3 General Electric HPCR equipped engines that have single walled fuel lines. It should be noted that:

- High-pressure fuel leaks can cause great bodily injury.
- High-pressure fuel leaks can result in significant property damage if the fuel spray ignites.

Because it is possible to get injured or cause property damage NEVER work on a HPCR fuel system with the engine running. There are two ways to reduce the fuel pressure before working on the HPCR fuel system:

- Use the pressure relief system tooling or valve that the OEM has provided.
- Let the engine cool down to ambient temperature; the pressure will usually dissipate over the time it takes the engine to cool down.

Always check the following items before work on the HPCR fuel system begins:

- Make sure the fuel pressure is zero psi by using an approved OEM pressure gauge; NEVER USE A MECHANICAL PRESSURE GAUGE.
- If the locomotive is equipped with a microprocessor and fuel sensors double check that the fuel pressure is zero psi on the locomotive computer screen.
- Make sure the engine start system and fuel pump has been disabled; some railroads require that the locomotive is “Locked and Tagged Out”.

Remember that fuel is flammable:

- No open flames near the work area.
- No equipment that can arc in the work area.
- No electrical switches near the work area.
- Proper ventilation.

Personal Protection Equipment (PPE) should consist of:

- All railroad required personal safety equipment.
- Eye protection may be enhanced by using goggles instead of safety glasses.
- If gloves are used they should be Nitrile or latex gloves; NEVER USE FIBER BASED GLOVES.

CONTAMINATION

Moisture and debris (dirt) are the enemies.

As noted in previous LMOA papers the filtration systems on HPCR fuel systems filter at 5 microns.

- Any debris that is greater than 5 microns that is introduced into the HPCR system while working on the HPCR system could cause a problem or failure later.
- KEEP IN MIND THAT WHEN WORKING ON HPCR FUEL SYSTEM FUEL LINES AND COMPONENTS THOSE FUEL LINES AND COMPONENTS ARE PAST THE FILTRATION SYSTEM AND WILL PRIMARILY AFFECT THE ELECTRONIC INJECTORS.

Relative to 5 microns:

- Width of a human hair is 17 to 181 microns.
- Width of a blood cell is 10 microns.

The basic concepts that need to be emphasized to any personnel working on HPCR fuel systems are that clean fuel systems:

- Improve engine performance.
- Improve fuel system and engine reliability
- Reduce life cycle costs.
- Keep emissions low.

Debris that may be introduced into the system while working on the HPCR fuel system that is greater than 5 microns include:

- Rust
- Dirt and dust
- Paint chips
- Oil (dirt magnet)
- Diesel fuel (dirt magnet)
- Moisture carrying debris

The OEM HPCR system fuel components are manufactured and packaged in extremely clean conditions. Unfortunately, the work area for most railroads on the HPCR fuel system is in a back shop or ramp area of a running repair shop. Both areas are hardly optimum regarding cleanliness when considering what else is going on in adjacent work areas. Take a close look at how “clean” the area that the HPCR fuel system work is to be performed before commencing work. Avoid working the HPCR fuel system if the following activities are in process nearby:

- Personnel working with compressed air to clean other locomotives.
- Personnel fans are blowing debris particles in the area.
- Welding.
- Oxy-acetylene work.
- Personnel using grinding equipment or areas where grinding debris has been deposited.
- Personnel cleaning with high pressure water equipment.
- Any work where there is dirt and debris that becomes suspended in the air.

Always clean the HPCR fuel system components and the engine in the area where those components are located before any work begins:

- Use of an OEM approved chemical spray cleaners are recommended and most times are the best product to use (seek approval for chemical use).
- After the initial cleaning it is better to loosen the component (use OEM procedures) and clean them again before they are totally removed.
- Always think “what will the wrench loosen besides the fitting”.

COMPONENTS, WORK AREA AND TOOLING

New or used components can be installed on the HPCR fuel system. If components are re-used they must be cleaned thoroughly and protected at all times during the removal through reinstallation process.

New HPCR fuel system components are built in a “clean” environment and are capped and shipped in sealed plastic bags:

- Do not remove the new components from their plastics bags until it is time to install them.
- All new components have all openings sealed with caps or plugs; **DO NOT REMOVE THESE CAPS OR PLUGS UNTIL IT IS TIME TO INSTALL THE COMPONENT.**
- Be suspect if any caps or plugs were loose when removed; visually inspect for cleanliness or damage if loose caps or plugs are found.



An OEM head wrapped from the factory. It is wrapped, taped and bound to the pallet to eliminate the chance of contamination.

Inspect all components (new or used) before installation:

- Do not assume components are clean; inspect them again before installation.
- Do not use damaged components:
 - Visually inspect sealing surfaces before installation.
 - Visually inspect threads on connections before installation.
- Damage to threads and connections can be hard to detect:
 - Very small scratches and nicks will leak.
 - The use of a 2X or 3 X magnifying glasses with light may be helpful.

Make sure that proper tooling is available to perform the work on the HPCR fuel system. This may include common tools used at other work stations in the facility as well as specialized tooling recommended by the OEM.

- It would be recommended that tooling used for HPCR system work be kept segregated from the normal tool population and only used on HPCR fuel system repairs; this will help them from becoming contaminated.
- All tooling used should be visually inspected before use to make sure it is clean and not damaged.
- Never use air or electric impact tools on any of the HPCR system; these tools are now capable of developing 200 to 300 foot-pounds of torque which could cause major damage if used improperly.

A clean, dry work area should be provided where components removed from the HPCR fuel system can be placed as well as new components that may be ready to be installed.

- Never “hang” removed or new HPCR system components on other parts of the engine.
- Never lay removed or new HPCR system components on the locomotive walkway.
- Never lay removed or new HPCR system components on the locomotive shop floor.
- Never hang removed or new HPCR system components on the locomotive hand rails.
- Never use HPCR fuel lines (or any fuel lines) on the engine as a “Hand Hold”; despite the pressure that they handle they are somewhat fragile.

The above examples will ultimately lead to damage to the sealing surfaces or allow ingress of foreign material into the components.

When handling HPCR system components by hand be aware of contamination possibilities:



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The piping is inviting as a handhold.

- If wearing Nitrile or latex use new gloves and make sure they are clean; if there is any question if the gloves are clean change them for new gloves. **THE COST TO CHANGE GLOVES IS INSIGNIFICANT COMPARED TO A FAILURE CAUSE BY TRANSFERRING DEBRIS INTO THE HPCR SYSTEM.**
- If the components are handled without gloves make sure hands are clean; it is recommended to avoid the use of waterless or pumice-based hand cleaners before handling components as this may result in contamination of the HPCR system.
- In addition, if working without gloves, make sure hands are not sweating; acid from the sweat could etch the connection surfaces if they are touched.

REMOVAL OF HPCR COMPONENTS

Before beginning any HPCR system components removal:

- Use the OEM's recommended instructions and/or tooling to bleed the system pressure or allow sufficient time for the pressure to dissipate.
- Always **VERIFY** that there is no fuel pressure on the HPCR system before starting the removal of any components.
- Make sure engine start system and fuel pump is disabled; "Lock and Tag out" as required by rules.
- Use the OEM approved method to drain the fuel from the lines.
- Make sure components to be removed and the engine in the area where the components are to be removed are clean:
 - o Use only **LINT FREE** shop towels for cleaning so lint does not become a contaminant.

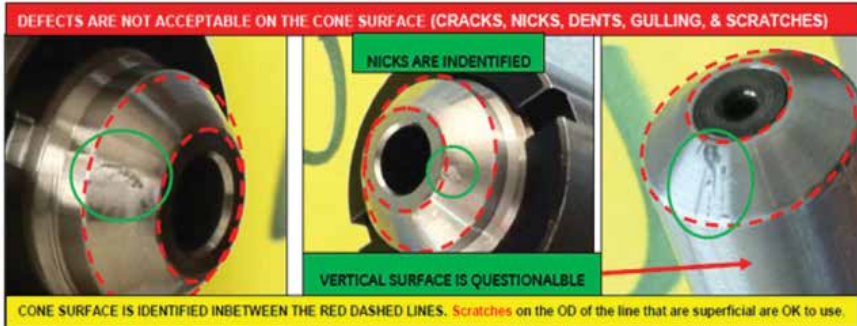
- o Use OEM approved chemical spray cleaners; MAKE SURE THAT THE OEM APPROVED CHEMICAL SPRAY CLEANER IS APPROVED FOR USE BY THE RAILROAD.
- After HPCR system components have been removed clean them again:
 - o Use lint free shop towels.
 - o Use OEM and Railroad approved chemical spray cleaner.
 - o NEVER USE A SHOP CLEANING TANK:
 - The filtration system on cleaning tanks is usually not up to the 5-micron capability resulting in debris > 5 microns not being removed.
 - Debris is held in suspension in the cleaning solution and will likely contaminate the HPCR system component being cleaned; possibly worse than it was when placed in the cleaning tank.
- The OEM maintenance instructions for each engine type and manufacturer will outline the sequence of procedures for the removal of all components and parts. For example; the OEM maintenance instructions to replace an injector may require the removal of the fuel lines on both cylinders adjacent to the cylinder with the bad order injector and the instructions will provide the sequence on how that should be accomplished.

After removal of any HPCR component immediately visually inspect the engine connection openings of components or parts that have not been removed for damage:

- Visual inspection should pay particular attention to sealing surfaces and threads; the use of a 2X or 3 X magnifying glasses with good light may be helpful.
- If there is no damage plug or cap any openings on the engine where the components were removed to prevent contamination ingress into the engine; use only caps or plugs that are clean, undamaged and seal tightly.
- Please see comments on plugs and caps below on plugging and capping components that have been removed.



This High-Pressure pump was left open the shop atmosphere; no plugs.



Defects on GE connection cones.

After removal of components:

- Visually inspect the components for cleanliness and damage to connection surfaces and connections threads; use of magnifying glass is recommended.
- If the part or component is damaged discard it and replace with new.
- If not damaged, but the component has contamination, clean the component using recommended practices to remove the contamination.
- If there appear to be “new” paint chips on painted surfaces make sure that the paint that has chipped off has not contaminated mating surfaces or the interior of components.

After visual inspection of the components that have been removed:

- Make sure that no debris or moisture entered the component or engine before it is capped or plugged.
- New plugs and caps can be obtained from the OEM for application; remember to inspect them for cleanliness and damage before application and make sure all caps and plugs are tight when applied.
- If plugs and caps are reused they should be inspected for damage and be cleaned before application.
- It is often recommended that caps or plugs that are not be immediately reused be discarded and not be used in the future.

After the components has been removed and capped/plugged:

- Place the cleaned capped/plugged component on a clean work area.
- If the component lay down area includes placing the components on a shop towel make sure the shop towel is lint free.
- Use of clean bubble wrap on the removed component applied on the connections will help prevent damage.
- It is recommended that after capping/plugging and application of bubble wrap the components removed be placed in a CLEAN plastic bag that can be sealed.



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It is recommended that only ONE component be placed in each plastic bag.



Example of clean packaging and bubble wrap application.

When placing the removed components in plastic bags on the work area it is recommended that they be placed on the work area in the sequence that they were removed:

- Placing the components on the work area in the sequence they were removed will facilitate putting the component back in the same location during re-assembly. If the component fit before it was removed without fit-up issues it will fit the same when re-assembled. Marking each component with the cylinder location with a paint pen may also facilitate getting everything back in the proper location.
- Labeling each plastic bag with the location where that component was removed from will also assure that it gets back to the proper location.

INSTALLATION OF HPCR COMPONENTS

It is imperative that all personnel understand the OEM approved installation process of components for each design of HPCR system. Each OEM has a sequence and process for the removal of each component of the HPCR system. For example, the OEM will have a process to install fuel lines that might look like this:

- 1) First, make the connection on the fuel line(s) in a prescribed sequence and at a hand tight torque.
- 2) Second, partially torque each connection in a prescribed sequence to a prescribed percentage of torque (but not 100% of the specified value).
- 3) Third, back off the torque on each connection to zero in the prescribed sequence.

- 4) Fourth, partially torque each connection a second time to a prescribed level and in the prescribed sequence.
- 5) Fifth, add additional torque (from step 4) level in the prescribed sequence.
- 6) Sixth, bring the connection to the final torque level (from step 5) in the prescribed sequence.

When installing components to the HPCR system:

- Do not remove the component from the plastic bag until it is the proper time to install the component.
- When the component is needed remove the plugs and caps and visually inspect the component for damage or ingress of debris.
 - Pay particular attention to connection cones, seats and threads for damage; if damaged DO NOT INSTALL IT. Use of a magnifying glass is recommended.
 - If the component has debris or moisture in it clean the component.
- If plugs are not going to be immediately reused discard them.



**Fuel injectors open to shop air contamination.
Note that ports into the injector are not plugged.**

Make sure the component being installed:

- Is in the proper location.
- When applying the components and fuel lines never force or bend them into position. This can cause stress that will result in cracks in the component or improper seating at connections that will cause leaks.

Connections on the HPCR fuel system may require lubrication. The type of lubrication to be used will be specified by the OEM in the OEM maintenance instructions. Depending on the OEM recommendation the lubrication could be:

- Lithium based grease.
- New, clean engine oil.
- New, clean diesel fuel.
- OEM specified lubricant.

Be careful not to contaminate the interior of components or fuel lines with the lubrication:

- Only apply connection lubrication to the surfaces recommended by the OEM.
- Contamination of the lubricant inside the HPCR system **CAN CAUSE INJECTOR FAILURE**.
- If lithium grease contaminates injector lithium soaps can form in the injector which will lead to injector failure.



Correct lithium grease application GE connection.

CONNECTION PROCESS

When torquing connections:

- Use proper tooling per the OEM maintenance manuals; air and electric impact wrenches **SHOULD NOT BE USED**.
- Make sure all tooling is clean.
- The threads on connections are fine thread; be careful not to cross thread during installation.
- The initial installation should be hand tighten only.
- Use OEM torquing instruction for final torque sequence and torque values.

TESTING

After installation of all components on the HPCR fuel system test the system for leaks:

- Use the OEM recommended test procedures when testing the HPCR system.
- Individual(s) starting the engine should be prepared to shut the engine down immediately if high pressure leaks are observed.
- It would be recommended that at engine start there be an observer(s) to determine if there are any leaks.
 - o Observer(s) should be well clear of the engine in case there is a leak as the HPCR system is pressurized.
 - o Observer(s) should only approach the engine for better visual inspection after it has been determined there are no high-pressure leaks.
 - o Observer(s) should be in communication with the individual starting so that the engine can be shut down immediately if a high-pressure leak is detected.

SUMMARY

WORK ON HPCR SYSTEMS SAFELY

UNDERSTAND ALL OEM MAINTENANCE PROCEDURES BEFORE
STARTING ANY WORK

CONTAMINATION OF SYSTEM WILL CAUSE FAILURE

Contributors:

Eric Dillen, General Electric

Tom Kennedy, Union Pacific Railroad

Allan Meeks, Cummins

Tim Standish, Progress Rail Services

Bruce Wolf, MTU America

Locomotive Shore Connection Heating Systems Update

By Mark Duve, Norfolk Southern



Introduction

In 2015, an LMOA paper was written on the new advancements of Shore Connection Heating systems for locomotives. Shore connection heating systems reduce idle thus lowering fuel consumption and emissions. The 2015 paper focused on the available locomotive shore connection systems and the new ergonomic way side stations. Three years later, Norfolk Southern has had some experiences with the shore connection systems which has led to some new developments. This paper will cover those new shore connection developments which are strongly recommended for a successful implementation of a locomotive shore connection heating system.

Current Problem – System Mechanical Failure or Power Failure

NS implemented the shore power system on low horsepower local locomotives within urban railyards located in Kansas City, Chicago, and Northeast Ohio. These areas are prone to cold winters, which makes the shore connection system a more effective alternative to an AESS system in regards to both saving fuel and reducing emissions.

sit idle without idling

Equipping your locomotive with a HOTSTART engine heater is your best winterization option. Investing in this equipment will help you reduce harmful and expensive idling while still protecting your prime mover. The fuel savings will pay for the investment in two years or less, letting you bank money for PTC upgrades. Get a jump on winter with HOTSTART idle reduction technology.

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ENGINE HEATING



Currently, the system works by first shutting down the locomotive with the Emergency Fuel Cutout (EFCO) button; next, plugging in the shore connection; and last, turning on the shore power on the station. As a safety measure, if the shore power connection is plugged in and the engine is running, the shore connection will trigger the EFCO relay and shut the engine down. This also prevents starting the locomotive when the shore power is connected to the locomotive. The issue with shutting the locomotive down via the EFCO switch or relay is that when the EFCO switch is depressed, the AESS system cannot restart per AAR Standard S-5502 if the onboard shore power system fails. Thus, when the shore power system fails, the locomotive will either freeze or dump its coolant if equipped with automatic coolant system drain, rendering the locomotive useless to perform its daily service when the crews show up.

There are only two major parts affecting the heating of the cooling system: (1) the shell and tube heater and (2) the pump. If either of these parts fail, then the system fails. Even if the pump and the heater do not fail, power failures will also lead to system failures.

The solution to the failure of the shore power heating system is to integrate the system with the AESS system. To do so, the system should not be wired to the EFCO system. Instead, the system should be set up in such a way that when the shore connection system is plugged into the locomotive the locomotive automatically shuts down and the AESS system remains active. If the shore power system fails, then the AESS system takes over and restarts the locomotive to keep the engine coolant from freezing. The details for connecting AESS must be worked out with the AESS supplier. NS has worked on AESS locomotive shore power integration with ZTR on the older Dash 2s on their II and IIe SmartStart Systems and with Progress Rail on the GP33ECO and SD33ECO through programming logic changes in the EM2000 control system.

AESS/Shore Power Integration Issues

With the integration of AESS and Shore Power there is another problem in that when a crew fails to properly inspect a locomotive prior to using it, they can operate the locomotive with it plugged into the wayside station thereby ripping the cable away from the wayside stations while pulling away from the station. This is similar to a person driving away from a gas pump with the nozzle still stuck in the car's gas tank.

One way to prevent this is to wire the generator field switch on the control stand to a relay which is picked up when the shore power system is plugged into the locomotive. This relay will prevent the locomotive from loading. Unfortunately, this will not prevent a locomotive from being coupled to the plugged in locomotive and dragged, but at least it will prevent operating the locomotive when plugged into the wayside station.

Conclusion

Locomotive shore power is a method of reducing emissions and fuel consumption. In order to alleviate a potential mechanical failure or power failure, the onboard locomotive system should be integrated with AESS such that when a system failure occurs the AESS system takes over significantly reducing the potential of either freeze damage or causing the locomotive to drop its cooling water.

Report on the Committee on Fuel, Lubricants and Environmental

Monday, September 10, 2018 at 3:15 PM



Chair

Corey Ruch

Assistant Director-Technical Research & Development
BNSF Railway, Topeka, KS

Vice Chair

Don Matthey

Sales & Rail Manager, OEM & Key Accounts, Energy Division
Alfa Laval, Incorporated, Hermitage, PA

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S. Fenwick	Technical Director Chief	National Biodiesel Board	Jefferson City, MO
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M. Torrance	Senior Reliability Specialist	Canadian National Railway	Edmonton, Alberta, Canada
D. Tuttle	Director-Railroad Sales	American Refining	Atlanta, GA
P. Whallon	Strategic Account Manager	Parker Filtration	Lancaster, PA

PERSONAL HISTORY

Corey Ruch

Assistant Director
BNSF Technical Research & Development

Corey was raised in a small town south of Kansas City, Missouri. Upon graduating High School, he moved to Springfield, Missouri to attend Southwest Missouri State University (SMSU) where he earned a BS in Chemistry and minored in Plastics and Industrial Technology.

During college, Corey interned for Technical Services Laboratories (TSL), a company providing research and development services to the Burlington Northern (BN) railroad. Upon graduation, he was offered a position at TSL and began full time employment in fall of 1995.

By winter of 1996, the Burlington Northern and Santa Fe Railroads were completing their merger to become the BNSF Railway. Shortly afterward, all laboratory operations were being consolidated at the former Santa Fe TR&D Lab in Topeka, KS.

Corey was extended an offer to work at the consolidated “BNSF TR&D Lab” and moved to the Topeka, KS area in 1998. After gaining experience in fields such as Fuel and Environmental Testing, Metallurgical and Mechanical Examination, Failure Analysis, Electronics Testing, Derailment Investigation and many other areas, Corey was promoted to Assistant Director – Lab and Testing Services. He currently oversees a group of dedicated scientists and engineers performing a wide array of testing and examination for the railroad.

Corey enjoys running, hiking, cycling and adventure racing with his wife, Kjrsten as well woodworking, metalworking and other DIY projects.

The LMOA Fuel, Lubricants and Environmental Committee would like to sincerely thank the Burlington Northern Santa Fe Railway for hosting their winter meeting on January 20, 2018 in Topeka, Kansas. The committee also had the opportunity to tour the BNSF's training, research and development facility in Topeka.

The committee also held teleconferences during the 2018 year which allowed them an opportunity to conduct important LMOA business.

Diesel Fuel Heating Value Correction for Locomotive Fuel Consumption Calculations

Prepared by:

*Steven G. Fritz, Christopher R. Stoos, and Dustin T. Osborne
Southwest Research Institute*

Abstract

Association of American Railroads (AAR) Recommended Practice (RP) 589, “Rating for Specific Fuel Consumption of Diesel Electric Locomotives,” includes a correction for the heating value of the diesel fuel. Historically, this correction is based on a Higher Heating Value (HHV), also known as the Gross Heat of Combustion, normalized to a “standard” value of 19,350 BTU/lb.

RP-589 is currently under review by a Technical Advisory Group (TAG) within the AAR Locomotive Committee, who in turn approached the LMOA Fuels, Lubricants, and Environmental Committee for a recommendation as to the applicability of HHV and the correction to 19,350 BTU/lb.

The LMOA FL&E Committee recommends that RP-589 change to Lower Heating Value (Net Heat of Combustion) for diesel fuel heating value corrections in RP-589, with a reference value of 42,700 kJ/kg (18,358 BTU/lb). Lower Heating Value correctly accounts for the fact energy is not recovered from condensing water vapor in the diesel engine exhaust stream and provides greater accuracy over the wider hydrogen-to-carbon ratios of modern fuels.

Background

When determining the fuel consumption of a locomotive, the properties of the test fuel are an important aspect to consider. Specifically, the amount of energy per unit mass of the fuel can have a large impact on the observed results. Currently, the American Association of Railroads (AAR) Recommended Practice 589 (RP-589) is used to correct observed fuel consumption results to standard conditions, in an attempt to eliminate the variance seen due to ambient conditions and the properties of the test fuel. The current standard conditions in RP-589 are given in Table 1.

Table 1. AAR Standard Conditions for Fuel Consumption¹

Barometric Pressure [in Hg]	28.86	Intended to represent appx. 1,000' elevation
Air Temperature [°F]	60	
Fuel Temperature [°F]	60	
Fuel Specific Gravity [-]	0.845	Appx. 7.045 lb/gallon @ 60°F
Fuel Higher Heating Value [BTU/lb]	19,350	

RP-589 is currently under review by a Technical Advisory Group (TAG) within the AAR Locomotive Committee, who in turn approached the LMOA Fuels, Lubricants, and Environmental Committee for a recommendation as to:

- Is a HHV of 19,350 BTU/lb representative of today's Diesel fuels?
- Is HHV the best method for correcting specific fuel consumption (SFC) for fuel energy content?
- How should these values be determined?

Since the AAR standard HHV value of 19,350 BTU/lb was established, many chemical and compositional changes to commercially available Diesel fuel have occurred. The transition to ultra-low sulfur Diesel (ULSD), the introduction of low emissions fuels such as California Air Resources Board (CARB) Diesel and Texas low emissions Diesel (TxLED), along with the introduction of biodiesel and more recently renewable diesel into nearly all commercially available Diesel products have had significant effects on the range of fuel properties.

The increased variation of modern fuel composition, and the associated refining processes, have made certain properties of Diesel fuel fluctuate much more than when RP-589 was first written.

While the average diesel fuel higher heating values has tended to increase slightly over the 19,350 BTU/lb value in RP-589, especially with low emissions fuels, the exact number that is used for a standard value is a semi-arbitrary value. An updated "standard" heating value number that better represents today's fuels would give railroads and OEMs a slightly better understanding of locomotive performance, but could make comparisons to historical fuel consumption data difficult.

HHV or LHV?

As mentioned above, railroad fuel consumption has historically been corrected using the higher heating value of the fuel. Higher heating value, or the gross heat of combustion, is the amount of heat released by a fuel including full recovery of the latent heat of vaporization of water. This means that the water in the combustion products is allowed to return to liquid form and that heat is available to the process.

Since diesel engines eject water vapor with the exhaust gasses – without the vapor being condensed and without the energy from the condensed water being available to the engine in any way, this means that the HHV arguably overstates how much usable energy is available within Diesel fuel.

When correcting to a standard value, this in itself, is not necessarily an issue as long as the water produced during combustion is constant. Unfortunately, this is not the case with modern Diesel fuels, as the water created during combustion is dependent on the amount of hydrogen present in the fuel. With the relatively modern introductions of biodiesel, renewable diesel and other 'novel' fuel blends, the hydrogen content varies much more widely from fuel to fuel. Thus, using HHV as the basis for fuel consumption correction introduces a variable bias, which can

make locomotive SFC comparisons between locomotives tested on different fuels difficult.

Lower Heating Value (LHV) of fuels is commonly used for internal combustion engines instead of the HHV for making engine efficiency comparisons on liquid fuels.^{2,3} The LHV is tested in the same way that the HHV is, but the latent heat of vaporization is not included, as the water is kept in a gaseous state. This is more representative to what occurs in a diesel engine, where combustion-generated water is in gaseous form when exiting the exhaust stack.

The LHV is calculated as follows:

$$Q_n = Q_g - 0.2112 \times H$$

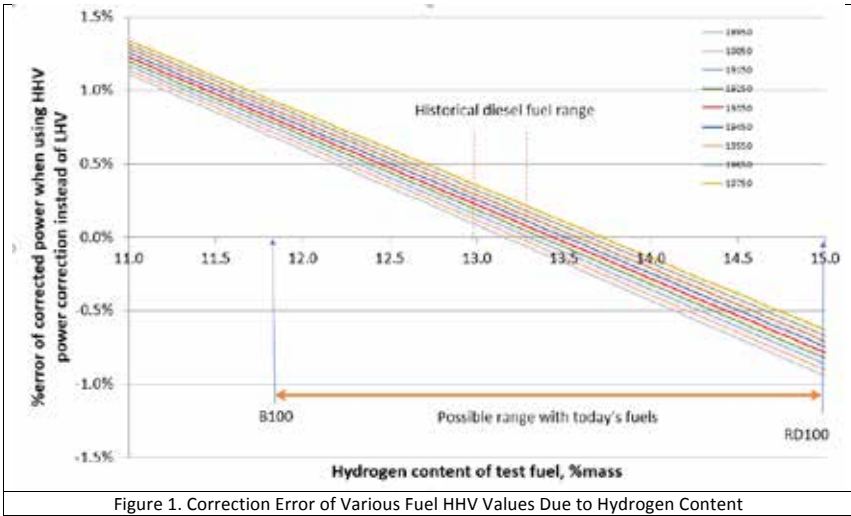
where:

Q_n = Net heat of combustion in MJ/kg (LHV)

Q_g = Gross heat of combustion in MJ/kg (HHV)

H = Mass % of hydrogen in the fuel

LHV corrects for the potential bias contained in HHV's accounting of the energy associated with the water in the exhaust stream of a Diesel engine. Figure 1 shows the effect of fuel hydrogen content on a series of diesel fuels of typical and varied HHV, as a function of hydrogen mass fraction of the fuel. Figure 1 shows the range of "historical" diesel fuels, with hydrogen content ranging from 13.0 percent to 13.2 percent, and a general range of "modern" diesel fuels, with a much broader potential range of hydrogen content, from 12.8 percent to 14 percent and higher, all the way to 15.2 percent for neat renewable diesel (HDRD, i.e. "Hydrogenation Derived Renewable Diesel"). Figure 1 shows the percent bias in SFC correction when using HHV instead of LHV, increasing with increasing hydrogen content of the fuel. This bias can have a significant impact on the correction used in SFC testing. As the mass percentage of hydrogen in the fuel varies, differences in the fuel heating value and associated correction factor of over 1% are possible. While this may not seem like a large variance overall, it is important to note SFC testing is often used to evaluate fuel consumption differences also as small as 1%. Thus, inaccuracies in the correction factor could generate errors comparable in size to the actual differences being measured.



As shown in Figure 1, the increased range of hydrogen content in today's commercially available fuels has increased the variation in differences between fuel HHV and LHV values. As a result, this has increased the possible error from using HHV as the basis for locomotive SFC correction. Note that this error is not an error in the HHV value, but in the correction of the SFC value itself. Using LHV instead of HHV would eliminate this bias in the fuel correction, and would align the North American locomotive industry with other industries that utilize LHV as their standard. LHV does require an additional analytical test of the diesel fuel, as the Hydrogen content must be determined.

Methods for determining HHV, LHV, and Fuel Hydrogen Content

RP-589 currently states that the fuel HHV should be used for SFC corrections, but it does not specify an analytical method for determining that value. While this is likely just an oversight, it is important to have consistency in the measurement regardless of whether HHV or LHV is used to determine the correction factor. It is recommended that the following test methods be added into RP-589 for this purpose:

ASTM D5291⁴– Fuel Hydrogen Content

ASTM D240⁵– Fuel HHV/LHV

Conclusion/Recommendations

As currently written, RP-589 may not be sufficient to accurately standardize SFC measurements due to variability in modern Diesel fuel composition.

It is recommended that the AAR Technical Advisory Group consider revising RP-589 to include the following:

- Specifying the use of Lower Heating Value for SFC correction
- Use a standard LHV of 42,700 kJ/kg (18,358 BTU/lb) to be consistent with International norms.
- Specify ASTM D5291 for hydrogen mass content and ASTM D240 for determining heating value

It is noted that GE Transportation has expressed concerns over switching from HHV to LHV, and prefers to retain the current HHV-based SFC correction. The primary reasons cited by GE are the relatively small SFC errors addressed given the fuels they use for testing, and the associated additional fuel analysis testing costs and logistics of an LHV-based SFC correction. These concerns should be conveyed by GE Transportation to the AAR Technical Advisory Group for consideration.

1. Association of American Railroads (AAR) Recommended Practice (RP) 589, "Rating for Specific Fuel Consumption of Diesel Electric Locomotives," Adopted 1981, Revised 1994, 2001.
2. International Union of Railways - UIC 623-2 "Certification Tests For Diesel Engines of Motive Power Units"
3. ISO 3046-1 Reciprocating internal combustion engines – Performance – Part 1: Declarations of power, fuel and lubricating oil consumptions, and test methods – Additional requirements for engines for general use.
4. ASTM D5291, "Standard Methods for Instrumental Determination of Carbon, Hydrogen, and Nitrogen in Petroleum Products and Lubricants"
5. ASTM D240, "Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter"

SCR for Locomotive NO_x Reduction

Prepared by:
Kelle Ravn
Cummins

Abstract

T4 locomotive and maintenance of way (MOW) engines with Selective Catalytic Reduction (SCR) are increasingly being placed into service. Tier 4 emission levels requires significant technology advancements; SCR is one of them and is the focus of this paper. Diesel Exhaust Fluid (DEF) is required with the use of SCR. Adaptations for handling and storing DEF have been made by the rail industry. The number of rail applications equipped with SCR in operation today is increasing.

Introduction

With the 2015 implementation of the US Environmental Protection Agency (EPA) Tier 4 Locomotive regulations, locomotive and engine manufacturers have opted to utilize various technologies to meet these requirements. The NO_x levels decreased from Tier 3 by 76% with the new Tier 4 regulations, which led to the adoption of Selective Catalytic Reduction (SCR) aftertreatment by some engine manufacturers/OEMs. There are a few aftertreatment technologies available; Diesel Particulate Filter (DPF), Diesel Oxidation Catalyst (DOC), and Selective Catalytic Reduction (SCR). This paper focuses on SCR. Diesel Exhaust Fluid (DEF) (a solution of 32.5% urea in water) is required for SCR functionality. DEF is dosed into the engine exhaust stream and reacts chemically within the SCR to reduce NO_x levels.

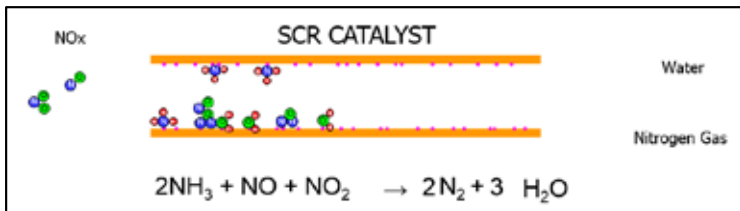


Figure 1 Selective Catalytic Reduction (SCR) Chemistry

Meeting T4 emission levels

Engine manufacturers have generally achieved EPA Tier 0 through Tier 3 emission level requirements without the aid of aftertreatment. Tier 4 emission levels required significant technology advancements. Today, two of the competing technologies to achieve Tier 4 locomotive emissions are SCR and Exhaust Gas Recirculation (EGR).

Reducing NO_x levels with SCR is achieved by dosing Diesel Exhaust Fluid (DEF) into the engine exhaust stream, upstream of a catalyst. When the exhaust temperature is high enough (roughly 260°C), the DEF dosing system injects a controlled amount of liquid DEF into the exhaust where it evaporates and decomposes into steam, CO_2 , and ammonia. The ammonia then reacts with the NO_x in the presence of a specifically formulated catalyst and results in nitrogen gas and water vapor. This is depicted in Figure 1.

EGR is defined as the exhaust gas being recirculated back into the engine, which lowers the oxygen concentration within the cylinder and reduces NO_x levels during combustion. However, the focus of this paper is on SCR and its relevance in the rail and locomotive industry.

Evolution of locomotive emission levels

When discussing emission levels regulated by the EPA, it is important to understand which Tier 4 emission level is being referred, as the emission standard varies depending on application type. The most common “Tier 4” standard is the nonroad standard, which covers all mobile nonroad diesel engines with a few exceptions. One of the exceptions is for the locomotive industry and there are separate EPA regulations for locomotives. Figure 2 shows the evolution of Line-Haul locomotive emission levels with associated model year in Figure 3.

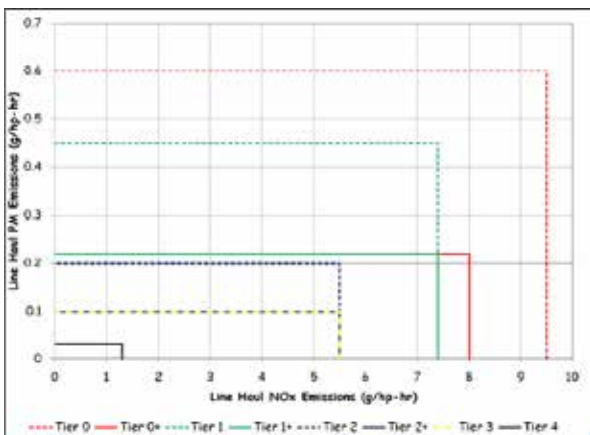


Figure 2: Evolution of Line-Haul Locomotive Emission Levels

Year of original manufacture	Tier of standards	Standards (g/3hp-hr)				
		NO _x	PM	HC	CO	
1973-1992*	Tier 0*	8.0		0.22	1.90	5.0
1993-2004	Tier 1*	7.4		0.22	0.50	2.2
2005-2011	Tier 2*	5.5		* 0.10	0.30	1.5
2012-2014	Tier 3*	5.5		0.10	0.30	1.5
2015 or later	Tier 4*	1.3		0.03	0.14	1.5

* Locomotive models that were originally manufactured in model years 1993 through 2001, but that were not originally equipped with a separate coolant system for intake air are subject to the Tier 0 rather than the Tier 1 standards.

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

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

* Manufacturers may elect to meet a combined NO_x/HC standard of 1.4 g/3hp-hr instead of the otherwise applicable Tier 4 NO_x and HC standards, as described in paragraph (j) of this section.

* The PM standard for newly remanufactured Tier 3 line-haul locomotives is 0.20 g/3hp-hr until January 1, 2013, except as specified in § 1033.156(a).

Figure 3 Line-Haul Locomotive Emission Standards¹

Challenges unique to SCR

As mentioned previously, using SCR requires DEF. The 2011 LMOA paper “Diesel Exhaust Fluid Properties & Technical Information” was the first LMOA paper² written on the topic of DEF. Some key points from this paper regarding DEF include:

Temperature

- DEF freezes at 12°F (-11°C). The DEF storage tank, lines, pumps, and dispensers need to have a freeze prevention strategy or a heating method. Heating can be done electrically or by utilizing engine coolant. After being frozen, DEF will return to a good quality, homogenous solution. Solidified DEF has approximately 7% larger volume than liquid DEF, therefore this expansion must be accommodated in the DEF tank design.

Quality

- DEF has high purity requirements defined by the German Institute of Standardization DIN 70700, the International Organization for Standardization ISO 22241-1, and there is also an American Petroleum Institute (API) certification. These high purity requirements are due to the sensitive nature of the SCR system. Some OEMs/engine manufacturers require a DEF quality sensor (also known as a Fluid Property Sensor) that monitors fluid density to ensure DEF has not been diluted with any other fluid.

Shelf Life

- When DEF is stored at an average temperature within the recommended temperature range of 15-80°F, the expected shelf life is between one and three years. After that time, the efficiency of DEF decreases.

Corrosiveness

- Since DEF is mostly an aqueous solution (32.5% urea and 67.5% deionized water), all materials that will handle DEF (i.e. tanks, hoses, fittings, etc.) must not be made of carbon steel, aluminum, or any other material that may be corroded. Stainless steel is an example of an acceptable material.

Leakage

- DEF has a very low surface tension and will leak through the slightest crevice. Extra consideration needs to be applied in plumbing of DEF lines and fittings to prevent nuisance leaks and its resulting corrosion. Use of tapered pipe thread fittings should be minimized as much as possible.

Filters

- To keep debris from ruining aftertreatment components, filters are required in the DEF tank header and also in the DEF pumps. The service interval for these filters can range from supplier to supplier.

Another aspect associated with SCR is the SCR effectiveness. There is a targeted exhaust temperature range (about 260 to 450° C) in which the SCR is the most effective. Figure 4 shows an example of the SCR effectiveness over a range of SCR life (0 hours, 20 hours, and 100 hours) with respect to exhaust temperature.³

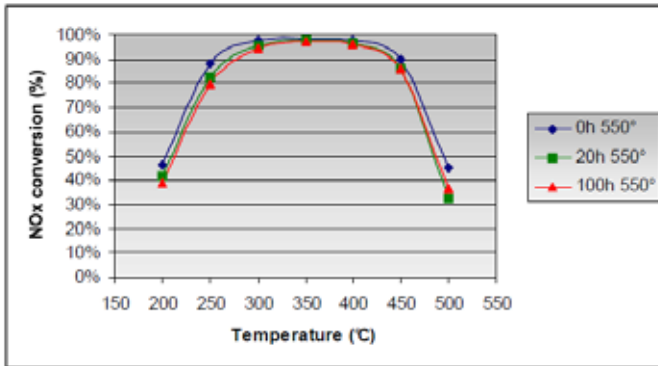


Figure 4 SCR Effectiveness

Since locomotives have relatively low load factors (or low duty cycles), keeping the exhaust temperatures in the targeted range is a challenge. However, there are a few ways to achieve and maintain this temperature when needed. One way is to reduce idle time, minimizing the time spent at a lower exhaust temperature overall. Reducing idle time can be accomplished by either manual operator involvement or by utilizing Automatic Engine Start Stop (AESS). When the engine needs to be in

use, but lower notches produce less than a targeted exhaust temperature, cylinder deactivation is a method that can be used to increase the exhaust temperature. By deactivating various cylinders, the activated cylinders must work harder and therefore increases the exhaust temperature. Another way to achieve and maintain this targeted temperature is for the engine manufacturer to manage the combustion parameters. There are many “levers that can be pulled” to achieve this, but in turn can create tradeoffs in particulate matter (PM), fuel consumption, or NO_x that must be accepted. A few levers that can be pulled to adjust the combustion parameters are; throttling the intake and/or exhaust at low loads, heating up the intake and/or exhaust via various methods, adjusting injection timing, and adjusting the air to fuel ratio.

An example of EMD 12-710 locomotive engine exhaust temperatures is shown in Figure 5 with the minimum targeted exhaust temperature for SCR effectiveness of 260°C shown. The exhaust temperature is highly dependent on each locomotive’s duty cycle, but this sample data shows that below Notch 4, the exhaust temperatures for this engine are too low for SCR to be effective, and would need to be addressed.

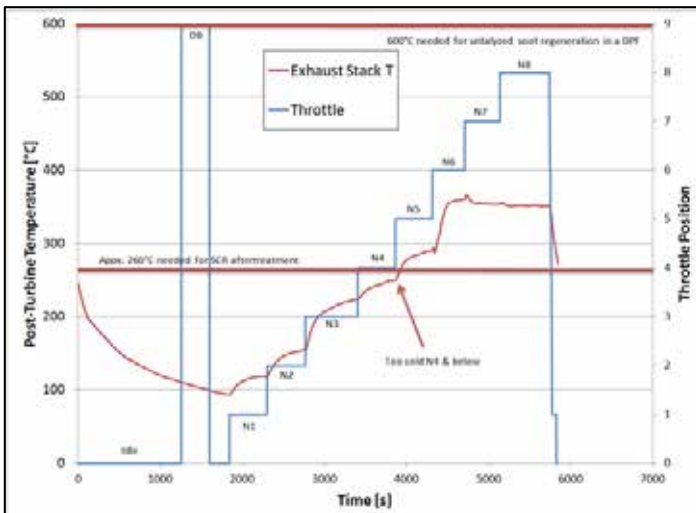


Figure 5 Exhaust Temperature Data from EMD 12-710 Locomotive

Rail SCR Examples

The purpose of the following examples is to show that SCR is in use today in the rail industry. Each example gives high level detail of the application. These examples are in chronological order.

Hug Engineering Krupp Locomotive⁴- Eurotunnel

- This locomotive utilizes a MTU 12V396C13 engine with a mobiclean™ exhaust gas system, which includes SCR. This system replaced a 50 ton scrubber wagon which was previously used for reducing emissions. A total of five locomotives were repowered with this system and operate in the Channel Tunnel located between Kent, United Kingdom and Calais, France. Service started in 2007.



Figure 6 mobiclean™ Exhaust System

Progress Rail PR30

- The PR30 was created by repowering an EMD SD40 utilizing a 3,005 BHP Tier 2 Caterpillar 3516C-HD engine plus a SCR and DOC. A total of five locomotives started in-service testing in 2009 in California. The CARB 3,000 hour verification test which included emission checks at 0 hours, 1500 hours, and 3000 hours has been completed.^{5,6}



Figure 7 Progress Rail PR30

Metrolink Demonstration

- Metrolink experimented with installing a compact SCR directly on an EMD F59PH locomotive above the 12-710 prime engine turbocharger during 2009 and 2010. However, DEF mixing issues and low exhaust temperatures limited system performance and Metrolink opted to buy new locomotives.⁷



Figure 8 Metrolink Demonstration

Nippon Sharyo Diesel Multiple Unit (DMU) Railcar

- There are a total of 34 DMU railcars in service at Metrolinx in Toronto and Sonoma Marin Area Rail Transit (SMART) in California. The earliest Nippon Sharyo units went into service in 2015. These railcars utilize a Cummins Tier 4 Final QSK19 non-road horizontal engine with SCR. The railcars are configured in a 2 or 3 car consist and are in operation.



Figure 9 Nippon Sharyo DMU Railcar

MPI Tier 4 Passenger Locomotive

- In-service testing of the MPI locomotive started in 2016, with production service expected to start in 2018. These locomotives utilize two 2,700 BHP Cummins Tier 4 QSK60 engines with SCR. A total of 17 locomotives are planned to be operated at GO Transit in Toronto.



Figure 10 MPI Passenger Locomotive

Rail Propulsion Systems Locomotive Retrofit

- This EMD F59PH locomotive uses Blended Aftertreatment System (BATS), which mixes exhaust streams from the main 3,200 BHP EMD 12-710G3B engine and the Head End Power (HEP) engine into one main SCR system.⁸ This method was used to overcome low exhaust temperature issues. This locomotive was in prototype service in 2016 and a second iteration is in progress with the North Carolina department of transportation.

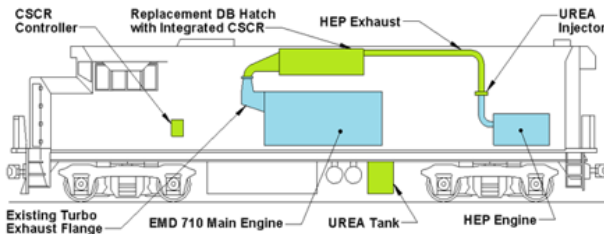


Figure 11 Rail Propulsion Systems Locomotive with BATS

Cummins Freight Locomotive Field Test

- This repowered EMD SD90MAC locomotive with a Cummins Tier 4 QSK95 engine and SCR is owned by Cummins and leased to the Indiana Railroad. This freight locomotive began prototype in service testing in 2016. In consist with another EMD SD90, it has pulled a train that was over 7,000 tons and more than a mile long.



Figure 12 Cummins Freight Locomotive Field Test

EMD F125 Passenger Locomotive

- The EMD F125 utilizes a Caterpillar C175-20 engine equipped with SCR and is used for both commuter and intercity service. In-service testing started in 2017. A total of 40 F125 locomotives are expected to be operated at Metrolink in California.



Figure 13 EMD F125 Passenger Locomotive

MD 24B T4 Switch Locomotive

- The EMD 24B utilizes a Caterpillar 3512C HD engine with SCR, DOC, and DPF. The CARB 3,000 hour verification test is in process at Pacific Harbor Line and Union Pacific. Baseline 0 hour testing was successfully completed in February 2017.



Figure 14 EMD 24B T4 Switch Locomotive

Siemens Charger

- The Siemens Charger passenger locomotive utilizes a Cummins Tier 4 QSK95 engine and SCR. There are a total of 91 locomotives distributed between Illinois Department of Transportation, California Department of Transportation, Washington Department of Transportation, Maryland Area Regional Commuter (MARC), and All Aboard Florida (AAF) with service that started in May 2017.



Figure 15 Siemens Charger

Knoxville Locomotive Works

- The Knoxville Locomotive Works (KLW) locomotive utilizes an EPA T3 MTU engine retrofitted with a KLW sourced DOC and SCR system. The ARB verification emissions testing documentation for Baseline, 1500 hour, and 3000 hour intervals has been submitted as of June 1, 2018. KLW holds the Tier 4 locomotive certification.



Figure 16 KLW Locomotive

Railpower RS23BD

- The Railpower locomotive utilizes a Cummins Tier 4 QSK60 engine and SCR. This locomotive has electronically heated DEF pumps for the prevention of frozen DEF.



Figure 17 Railpower RS23BD

Locomotive SCR example summary

- Figure 18 shows a summary of SCR-equipped locomotives. Note that this summary is current at the time of publishing and may have changed over time.

Original Loco Manufacturer	Loco Model	Engine Model	Rated Power, BHP	Number of Locos Built	Revenue Service Start Year
Progress Rail	PR30	Cat 3516C-HD	3,005		2009
EMD	F59PH	EMD 12-710G3B	3,200	1	2009
Nippon Sharyo	DMU	Cummins QSK19-R	760	34	2015
MPI	MP54AC	2 x Cummins QSK60	5,400	17	2016
EMD	F59PH	EMD 12-710G3B	3,200	1	2016
EMD	SD90MAC	Cummins QSK95	4,200	1	2016
EMD	F125	Cat 20-C175	4,700	40	2017
EMD	EMD24B	Cat 3512C-HD	2,100	1	2017
Siemens	Charger	Cummins QSK95	4,400	91	2017
KLW	SE32C	MTU 16V-4000 R54	3,200		NA
Railpower	RP28CD	Cummins QSK60	2,700	1	NA
Total				187	

Figure 18 Summary of SCR-equipped locomotives

Other Rail SCR examples

- There are other applications in the Rail industry that also utilize SCR and DEF, including Railcar movers, Industrial locomotives, and Maintenance of Way equipment.



Figure 19 Railcar Mover, Industrial Locomotive, and Rail Grinder

Future outlook

Will the EPA promulgate a Tier 5 locomotive exhaust emissions regulation? The California Air Resources Board (CARB) has petitioned to the EPA for tighter locomotive emission regulations to be implemented in 2025.⁹ Tier 5 may be on the order of an 80% reduction from Tier 4.

(units in g/bhp-hr)	HC	CO	NO _x	PM
Tier 4 line haul	0.14	1.5	1.3	0.03
Tier 4 switch	0.14	2.4	1.3	0.03
Potential Tier 5	0.02	0	0.2	<0.01

Figure 20 Locomotive Emission Standards

The original idea behind Tier 4 was that it was intended to require aftertreatment technologies. However, as noted earlier in this paper, using aftertreatment (i.e. SCR) is not the only way that Tier 4 emissions were able to be met. With a potential 80% reduction in emission levels from Tier 4, one may speculate that Tier 5 would likely be the driving force to require aftertreatment technologies.¹⁰ A decision regarding Tier 5 has not yet been announced.

Summary

Meeting EPA Tier 4 locomotive exhaust emission levels requires significant technology advancements; SCR is one of them. SCR requires diesel exhaust fluid (DEF), a DEF pump system, and a freeze prevention method and/or heating circuit for DEF storage (wayside and on application). Rail applications using engines with SCR are increasingly being placed into service. There are about 190 SCR-equipped locomotive units in operation today in North America, about 25 known units on order, and more units in the planning stages. SCR will become more prevalent in the locomotive and rail industry and adaptations are required for handling and storing DEF, and maintaining systems.

1. US Environmental Protection Agency. 40 CFR 1033.101. Exhaust emission standards.
2. 2011 LMOA paper “*Diesel Exhaust Fluid Properties & Technical Information*” by Joseph Hiznay
3. Haldor Topsoe catalyst. DNXV
4. Chellini, R. (2007, August). A Breath of Fresh Air for Eurotunnel Maintenance Crews. *Diesel & Gas Turbine Worldwide*, 68-69.
5. Osborne, D.T, et. Al., “PR30C-LE Locomotive with DOC and Urea-based SCR: Baseline and Initial Aftertreatment Emissions Testing,” ASME Paper ICES2012-81157, 2012.
6. Osborne, D.T, et. Al., “PR30C-LE Locomotive with DOC and Urea-based SCR: Field Trial and Emissions Testing at 1,500 and 3,000 Hours of Operation,” ASME Paper ICEF2012-92014, 2012.
7. Weaver, C. F. (2010, December) Demonstration of Compact SCR in a Passenger Locomotive.
8. EPA certifies emission-reduction system for NCDOT locomotive. (2018, February). Retrieved from <https://www.progressiverailroading.com/sustainability/news/EPA-certifies-emission-reduction-system-for-NCDOT-locomotive--53993>
9. California ARB petitions US EPA for “Tier 5” stricter locomotive emissions standards. (2017, April). Green Car Congress. Retrieved from <http://www.greencarcongress.com/2017/04/20170414-arb.html>
10. Regulations for Emissions from Locomotives. (2013, December). Retrieved from <https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-emissions-locomotives#Overview>

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X-Ray CT Scanning of Diesel Locomotive Fuel Injectors

Prepared by:

*Keith Bartels, Ph.D., Adam Cobb, Ph.D., and Steven Fritz
Southwest Research Institute*

1 Introduction

Industrial X-Ray Computed Tomography (CT) is a powerful nondestructive technique used to inspect internal structures and components. As commercial CT systems become more readily available, it is expected that such systems will play increasingly important roles in many industries. Among many applications, CT systems are used for nondestructive evaluation, visualization of hidden features, metrology, manufacturing verification and validation, failure analysis, and reverse engineering. The purpose of this paper is to introduce the technology and show examples of its use with diesel locomotive fuel injectors.

2 Background

2.1 Cone-beam CT System Overview

The majority of industrial CT systems use an approximate point source of X-rays that are projected through the part being imaged and onto a 2D X-ray detector. Because of the shape of the beam generated, these devices are called cone-beam computed tomography (CBCT) systems¹. Figure 1 shows a diagram of a CBCT system. The X-ray source transmits a cone-shaped beam of photons through the part and onto the X-ray detector, producing a 2D radiographic image (called a projection image) of the part. Gray value at each pixel in the projection image is inversely proportional to the X-ray attenuation between the pixel location and the source. A rotary table turns the part and images are acquired at discrete angles throughout a 360-degree rotation.

The pixel resolution in both the projection images and the final reconstructed volume is a function of the distance from the part to the source. As the part is moved closer to the source, its projection on the screen is magnified and hence the resolution is increased. For high quality scans, all ray paths through the part must intersect with imaging detector. This must be true for all rotations of the part.

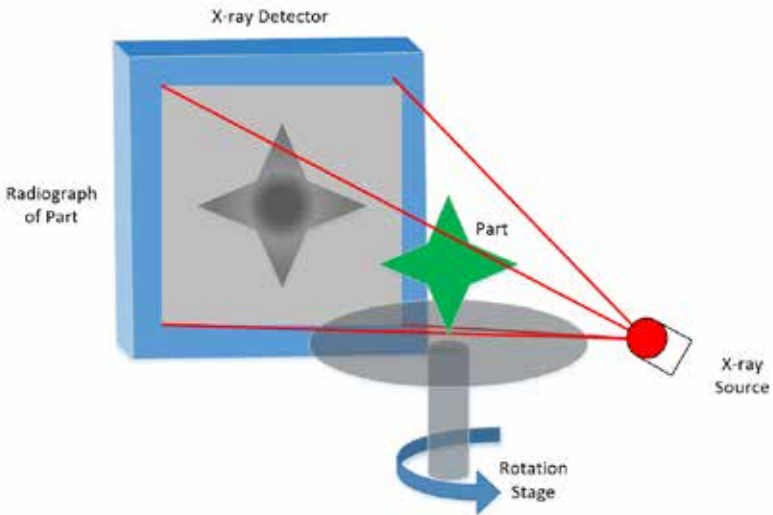


Figure 1. Diagram of a CBCT system. The part is imaged as it is rotated in the cone of X-rays.

Once the projection images are collected from 360 degrees around the part, a 3D reconstruction algorithm is used to convert the projections into a 3D volume representing the distribution of X-ray attenuation throughout the volume. The most common algorithm used to perform this reconstruction is called a filtered back-projection (FBP) and specifically for the geometry of CBCT systems, the algorithm is known as the Felkamp, Davis, and Kress (FDK) method^[1].

2.2 Specific System Details

SwRI currently operates two different industrial CBCT systems. The one used for the data in this paper was a GE v|tome|x m micro CT system and is shown in Figure 2. This system has a micro-focus variable-power X-ray tube with a maximum voltage of 240 kV and a maximum power of 320 W. The imaging sensor is 400x400 mm with 4 megapixels (2014x2014) at 14 bits/pixel. A FDK tomographic reconstruction algorithm implemented in parallel on GPUs can complete reconstructions in two minutes or less. VGStudio Max®^[2] software is used to visualize reconstructed data volumes.

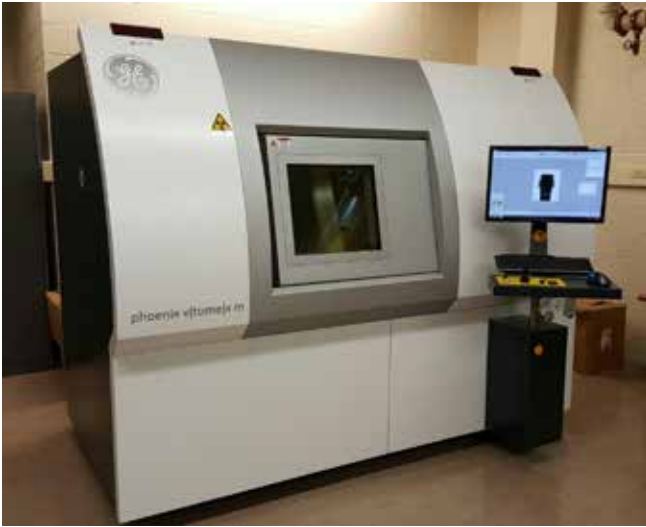


Figure 2. Photograph of the GE CT scanner used for the scans shown in this paper.

3 CT Scanning of Fuel Injectors

Two different locomotive fuel injectors were scanned to investigate internal structure around the nozzles and injector tip. The first was a GE FDL injector and the results are given in Section 3.1. The second was an EMD 645 mechanical fuel injector and results from it are given in Section 3.2.

3.1 Case Study #1: GE FDL Locomotive Fuel Injector

The GE FDL fuel injector shown in Figure 3 was operated for approximately 24 months prior to extraction for CT imaging and analysis. The purpose of the scan was to determine if there was wear at the tip that could be detected by X-ray CT. To get a high-resolution scan of the injector tip, the tip was positioned very close to the X-ray source. This caused the projections of the small injector tip onto the detector to be as large as possible and thus maximize the image resolution. Figure 4 shows the injector tip near the X-ray source on the right side of the image. The detector is seen on the left side of the image.



Figure 3. GE FDL locomotive injector with 24 months of use.

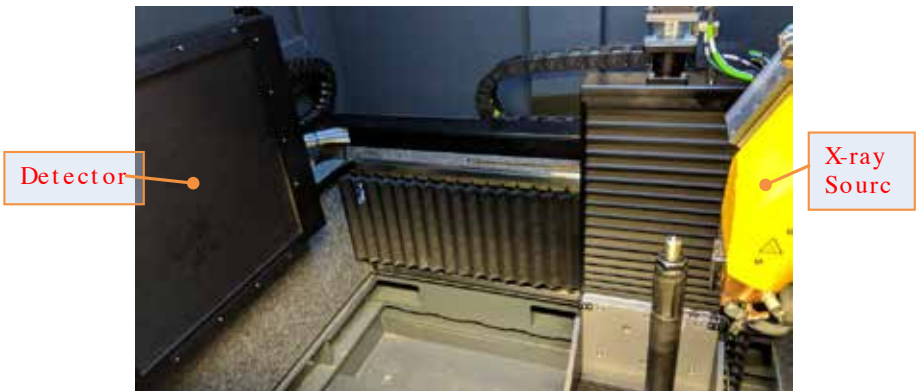


Figure 4. To get a high-resolution image of the tip, the tip was positioned close to the X-ray source (yellow device on left).

Figure 5 shows the result of the CT scan of the GE FDL fuel injector. The resulting 3D image has cubical voxels that, in this case, were 14.7 microns on a side. In this figure generated using VGStudio Max, the image in the lower right is a 3D iso-surface rendering of the injector tip. This rendering provides spatial orientation for the other three orthogonal cross-sectional views. The blue, red, and green planes shown in the surface rendering define the locations of the cross-sectional images in the upper left, upper right, and lower left, respectively. Gray values in the CT image primarily represent relative material density since X-ray attenuation is most strongly influenced by mass density at the energy levels used here. From the image, the higher-density needle material shows up lighter than the injector body. The CT scan clearly shows the spray nozzles, the sack, and the needle seating area well.

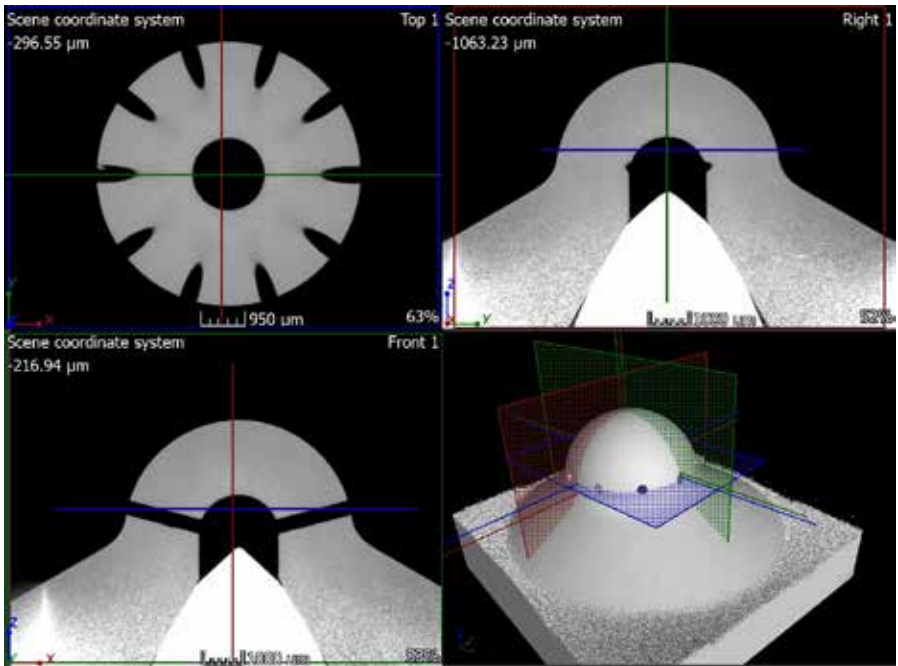


Figure 5. 3-D surface rendering (lower left) along with three perpendicular cross-sections through the injector tip.

Figure 6 shows a view of the same data set but with the sectioning plane positioned at the seat of the needle. Red arrows indicate areas of erosion pitting in the needle. Figure 7 shows an iso-surface rendering of the needle tip. This gives a good visualization of the pitting along the seat region around the needle seat. A MATLAB®^[3] script was written that used morphological processing^[4] to measure the volume of the pitting. The total volume of pitting on the needle measured $2.84 \times 10^{-3} \text{ mm}^3$. This demonstrates one application of this technology—to characterize and quantify injector needle wear, without disassembling the fuel injector, over time.

The VGStudio Max software has powerful 3D processing tools including a surface-extraction algorithm. Figure 8 shows a portion of a triangulated mesh surface generated from the CT data of the injector tip. The surface follows the air-metal (or liquid-metal when in use) interface of the injector tip. The triangulated surface was imported into SolidWorks®^[5] solid modeling software. SolidWorks was used to generate the visualization in Figure 8. Once in SolidWorks, the tip geometry can be incorporated into other designs and/or SolidWorks visualization and measurement tools can be used. The surface can also be imported into various finite element analysis software tools for physical modeling such as computational fluid dynamics.

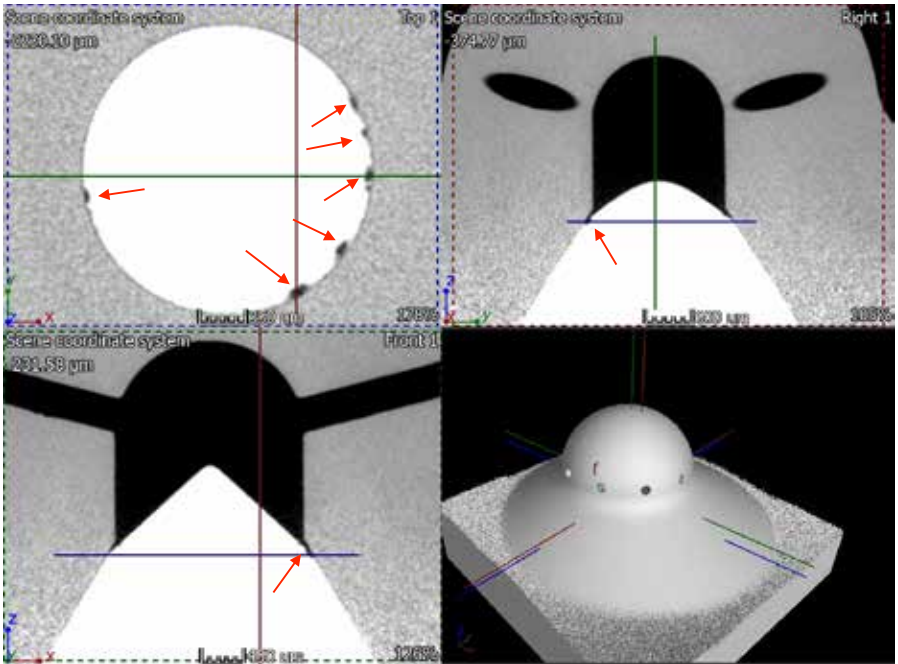


Figure 6. Cross section images through the needle seat shows erosion pitting (red arrows)

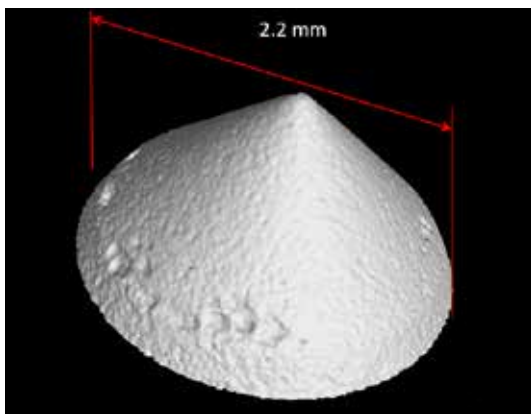


Figure 7. Iso-surface rendering of the needle tip showing pitting

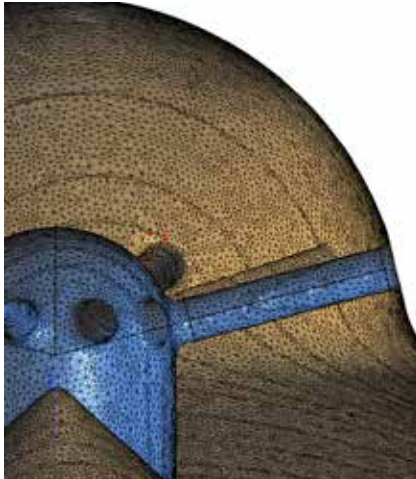


Figure 8. Triangulated surface mesh generated from the X-ray CT data and displayed here using SolidWorks. The surface model can be imported into 3D CAD and physics modelling software.

3.2 Case Study #2: EMD 645 Mechanical Fuel Injector

The second locomotive injector scanned was an EMD 645 injector. This injector had relatively little run time, but had deposits evident on its tip surface. This injector was scanned to check the feasibility of using CT to visualize low-density deposits on or within the injector. The ability to monitor such deposits would also be of interest to long-term studies in which deposit build-up could be monitored nondestructively over time and/or over variations in running conditions.



Figure 9. EMD 645 Fuel Injector mounted in the CT scanner for high-resolution scanning of the tip.

The injector shown mounted in the CT scanner in Figure 9. As with the previous example, the nozzle was positioned close to the X-ray source for high-magnification imaging of the nozzle tip. Figure 10 shows a cross-sectional image through the reconstructed 3D image of the nozzle tip. Only a small portion of the needle tip was captured in this image. It can be seen as the bright triangle near the bottom middle of the image. The white outline represents the detected surface of the injector. At the contrast level used in Figure 10, low-density deposits could not be visualized.

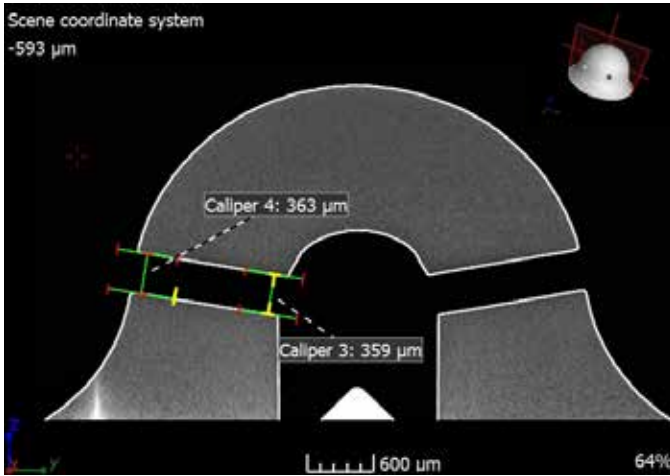


Figure 10. Cross-sectional image thru the nozzle tip.
The white outline represents a surface that was fit to the 3D mage data.

Figure 11 shows two visualizations of the deposits on the injector tip's surface. On the left is a 3D representation, where density is mapped to the surface. Various regions of low-density seen on the surface correspond to deposits. The red plane intersecting the tip is the location of the cross-sectional image shown on the right. With the image intensity mapping adjusted to maximize the contrast over the low-density range, the deposit is seen with a density between that of the air and the metal of the injector tip. With the contrast at this level, a difference can be seen between the density value of air inside and outside of the injector. This is a typical artifact of CT imaging. Since it was not known if this injector had internal deposits, we cannot say conclusively whether this CT image would allow for visualization of internal deposits. From experience on other parts that have been scanned, it is expected that the CT scanner and reconstruction algorithm parameters can be adjusted for imaging and visualization of internal deposits.

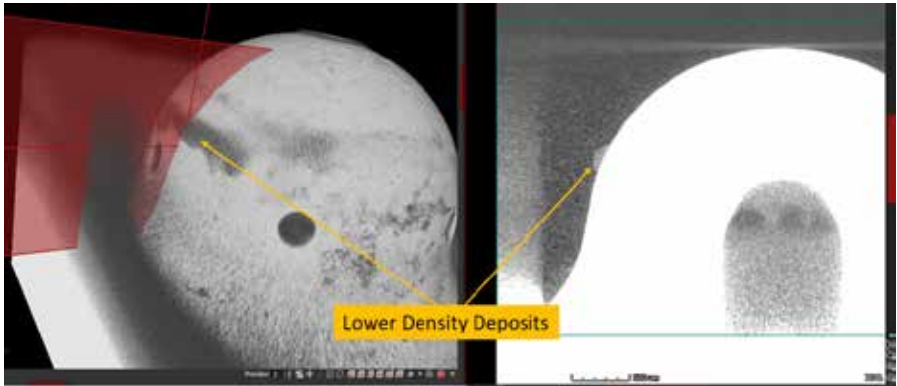


Figure 11. Images showing deposits on the surface of the injector tip.

4 Conclusions and Recommendations

In this paper, we have shown that industrial X-ray CT can be used to produce high quality, high-resolution 3D images of diesel locomotive fuel injector tips. Scans of two different injectors were presented. A GE FDL injector with 24 months of run time showed erosion pitting on the needle surface. The volume of material loss was quantified using 3D image analysis techniques. The results of the scan indicate that X-ray CT imaging could be very useful in a controlled long-term study of injector wear. Injectors could be periodically removed and scanned to monitor wear qualitatively and quantitatively. The scan from this injector was also used to demonstrate that triangulated surface meshes could be generated and loaded into modeling software.

The second injector scanned was from an EMD 645 that was operated for a limited time, but showed obvious deposits on the outside surface. A CT scan of the injector tip showed that the relatively low-density deposits could be visualized along with the injector components.

It is recommended the engine researchers become familiar with industrial CT technology as it adds a powerful nondestructive tool for the evaluation of components such as fuel injectors. It is specifically recommended that the work described here be extended to long-term experiments to monitor wear and /or buildup of deposits.

5 References

- [1] Scarfe W.C., Farman A.G., "What is cone-beam CT and how does it work?" *Dental Clinics of North America*, Vol. 52, No. 4, pp 707-730, Oct. 2008.
- [2] Volume Graphics, Inc., VGStudio Max software. <https://www.volumegraphics.com/>
- [3] MathWorks Inc., MATLAB software. <https://www.mathworks.com/products/matlab.html>
- [4] Gonzalez, R. C., & Woods, R. E. 1. (2008). *Digital image processing* (3rd ed.). Upper Saddle River, N.J.: Prentice Hall.
- [5] Dassault Systèmes, SolidWorks software. <https://www.solidworks.com/>

Report on the Committee on Locomotive Software and Systems

Tuesday, September 11, 2018 at 8:45 AM



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President & CTO
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Cincinnati, OH

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NOTE: Casey Pytel of Progress Rail will join the committee during the convention in Nashville, TN

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.

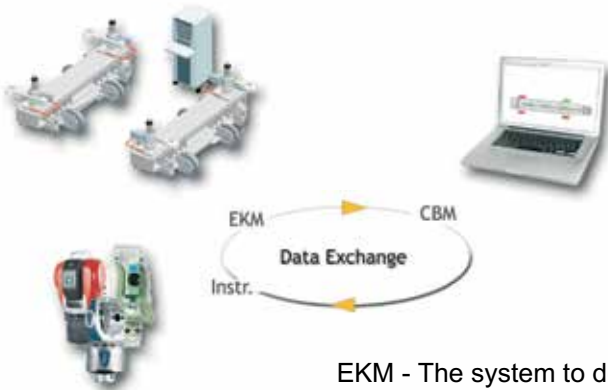
In addition to LMOA, Tom serves on the Mechanical Committee for the American Short Line and Regional Railroad Association (ASLRRA), is a member of the FRA's Natural Gas Locomotive Research Task Force, and as a supplier representative has been invited to meetings of the AAR Natural Gas Fuel Tender Technical 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.

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RAK - the wheel load measuring system for checking the direct wheel force and vertical wheel set force complies with DIN 27201-5



Best Practices for Locomotive Software Updates

Prepared by:

Adam Bennett

R. J. Corman Railpower Locomotives

Summary

As required in 49 C.F.R. (Code of Federal Regulations) § 229 Subpart E – Locomotive Electronics, a configuration management control plan is required to ensure the proper configuration of safety-critical locomotive control system electronic hardware components and software revisions. The Operations and Maintenance Manual (OMM) contains the plans and detailed information necessary for determining and updating the hardware, software, and firmware revisions of subject products. The OMM documents these revisions according to the railroad's configuration management control plan.

Methods of updating locomotive software have changed over the years. An optimal method should require non-complex and secure railroad processes with minimal tooling and touchpoints. An example software rollout plan to follow and data to track are presented.

Disclaimer

The information presented is based on my review and understanding of the associated Code of Federal Regulations. You should consult the CFR or your company's safety officer regarding any business decisions.

A portion of the language and statements in this paper are copied directly from 49 C.F.R. § 229.

Applicable Regulations

Locomotive safety-critical software and firmware updates are covered by 49 C.F.R. § 229.309 Safety-critical changes and failures, and § 229.315 Operations and Maintenance Manual.

From the CFR,

§ 229.309 (a) (6) The railroad shall identify all configuration/revision control measures designed to ensure that safety-critical [functions] are not compromised as a result of [a planned safety-critical design change], and that any such change can be audited.

§ 229.315 (b) The OMM shall contain the plans and detailed information necessary for the proper maintenance, repair, inspection, and testing of products subject to this subpart. The plans shall identify all software versions, revisions, and revision dates.



STOP your AESS being in the hummingbird mode starting the engine excessively for main reservoir pressure built ups, coolant and ambient temperature.

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EPA SmartWay verified technology for locomotives
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§ 229.315 (c) Hardware, software, and firmware revisions shall be documented in the OMM according to the railroad’s configuration management control plan.

These regulations should interest both vendors of electronic locomotive control systems and railroads that operate locomotives with electronic control systems, which includes all modern domestic locomotives.

While the overall objective of 49 C.F.R. § 229 Subpart E is to promote the safe design, operation, and maintenance of safety-critical electronic locomotive control system, subsystems, and components, the required railroad’s configuration management control plan and OMM specifically provide confirmation that the safety-critical functions are not compromised during the product’s lifespan.

Covered Products

49 C.F.R. § 229 covers all safety-critical locomotive control systems, subsystems, or components. Safety-critical, or vital, is defined as containing functions directly related to safe movement and stopping of the train. This includes both electronic hardware components and software/firmware of the components. Note that locomotive control systems, subsystems, or components that comingle with safety-critical signal and train control systems (i.e. Positive Train Control) are not covered by this subpart; rather they are covered by § 236 Subparts H and I.

Some examples of safety-critical locomotive control systems, subsystems, or components include: master controller, E-Stop circuits, hardware and software that deal with direction selection and setup, MU (Multiple Unit) stop function, penalty initiation functions, control for dynamic brake effort, emergency sand control, and the EAB (Electronic Air Brake) system.

For an expanded discussion and clarification of covered product, consult last year’s LS&S (Locomotive Software and Systems) paper “Design and Safety Analysis of Safety-Critical Electronic Locomotive Control Systems”.

Railroad’s Configuration Management Control Plan

While the 49 C.F.R. § 229.305 definition of Configuration Management Control Plan is short: “A plan designed to ensure that the proper and intended product configuration, including the electronic hardware components and software version, is documented and maintained through the life-cycle of the products in use”, the list of processes and tasks involved can be long.

The railroads must have configuration (revision) control measures in place for subject products. Vendors must notify the railroad if a change to safety-critical locomotive control system hardware or software is required, then the railroad’s shops follow the configuration control plan to implement the change across the affected locomotive fleets and any spare parts.

Example Simplified Configuration Management Control Plan

Here is an example of a simplified, configuration management control plan:

- Determine the list of safety-critical electronic hardware components and software/firmware-enabled devices
- Document how to check the revision of the devices on the list, both hardware and software
- At a scheduled PM (Periodic Maintenance), for example once a year, perform the revision inspection. Note some checks may be automated, such as locomotive computers reporting software revisions to the railroad's back office
- If the hardware, software, or firmware needs updating, perform the update per OEM (Original Equipment Manufacturer) guidelines
- Record the inspection and/or update information in the OMM
- The check/update/record cycle may need to be performed at an un-scheduled interval if notified of a required change of a safety-critical product by the OEM
- The yearly or un-scheduled check/update/record cycle may need to be performed on any spare product.

This simplified list provides a starting point for railroads to create a detailed configuration management control plan.

Product Testing Results and Records

The inspection and update information stored in the OMM is inadequately covered in 49 C.F.R. § 229.313.

49 C.F.R. § 229.313 requires the railroad shops to maintain test results for the product. This information is used as feedback to monitor the product over its lifespan and confirm that the safety-critical functions are not compromised. While the revision inspection results are not specifically mentioned in § 229.313, any test results performed as a result of a covered product modification (think software update) are required to be maintained.

§ 229.313 Product testing results and records states the results are to be recorded in pre-printed forms or stored electronically, and that automated tracking systems may be used.

§ 229.313 (d) (1) requires test results for modification of a covered product to be retained for the lifecycle of the product and (d) (3) requires results for all other tests and training to be retained until the next record is filed and in no cases less than a year.

Thus the results of a revision check (although not specifically mentioned) should be stored for at least a year, and results of required maintenance testing also need to be stored for a year. However, information about modification of a covered product, for example any results of required testing performed after updating the software revision, need to be kept for the lifecycle of the product.

Training and Qualification Program

49 C.F.R. § 229.317 (b) (1) specifies training and qualification programs are to be in place for individuals whose duties include installing, maintaining, repairing, modifying, inspecting, and testing covered safety-critical products. § 229.317 (c) (3) specifies the procedures must be written, and (e) requires individuals performing the duties to have completed a training curriculum and pass an examination.

Written procedures for the revision check/update/record process must be developed and made available, and individuals performing the tasks must have received training on the tasks.

Recommended Minimum Data to Track for Revision Control

Based on a combination of § 229.313 and field experience, here are recommendations for minimum data to track in the revision control portion of the OMM:

- Name of the railroad
- Locomotive identification (road number, OEM, model, serial number, railroad internal fleet designation)
- Expected hardware, software and firmware revisions
- Actual hardware, software and firmware revisions
- Date and location of application, person performing
- Date and location of check, person performing
- Due date for next check.

A database would be a simple way to store the information, allowing automated or manual data entry, and useful for generating reports, such as progress of a software update campaign. For a smaller railroad, a simple spreadsheet would suffice.

Historical Ways of Locomotive Software and Firmware Updates

Methods of updating locomotive software have changed over the years, typically driven by the computer and data transfer technology available at the time. Some historical ways of updating software are:

- EEPROM chip swap
- Proprietary stand-alone programming tool (typical in automotive and engine industries)
- Transfer firmware byte-by-byte via serial port (or USB-to-serial adapter) from laptop
- Transfer software executable file by Ethernet from laptop
- Attach a removable storage (USB thumb drive, MicroSD card) containing the software image and run the update process
- Upload the software image over-the-air to the device (could be small portions at a time to work around intermittent or slow connectivity) and run the update process.

Each method has pros and cons. For example, EEPROM chip swap is non-complex and simple to understand, but the supply of programmed chips is limited, and the chips need to be protected and mailed around. The proprietary stand-alone programming tools typically require a yearly license fee. The ubiquitous transfer-via-laptop requires tooling (equipment) such as cables and dongles, which tend to experience frustration-creating failures over time. Also some update programs may require an ancient, unsupported OS (Operating System) version, such as Windows XP. Hidden costs associated with each method need to be considered, such as employee time or wireless access fees.

Railroads will likely have to support multiple methods due to OEM variety, locomotive age and upgrades, available infrastructure, and project costs.

No matter the method, the OEM needs to provide the list of recommended software/firmware-enabled devices to track, how to check the software/firmware revision, and what is the expected revision. The OEM also needs to provide a written update procedure and specify or make available the equipment to use. And finally, the OEM needs to provide the software or firmware.

Both the revision checking and software updating processes are likely unique for each OEM, and could even be unique among the OEM's different models of locomotives. There are companies who provide the service of combining the OEM's different software update processes onto a common platform.

Example Optimal Method for Updating Locomotive Software

An optimal method for updating locomotive software and tracking software revision should minimize human interactions where possible to control costs and reduce mistakes. This means as few as possible touchpoints and tooling when performing a software update, yet still controlled by the railroad.

Here is a start-to-finish example, optimal method for updating locomotive software:

Piggy back on an existing, secure, over-the-air (wireless) connection for transfer of the software image to the locomotive, which could occur in small chunks over time. Once the software image is completely downloaded and its integrity is verified, an update can be triggered by the railroad via an on-locomotive (manual) request to upgrade. Optimally, the upgrade should be done during a scheduled periodic maintenance. As needed, the locomotive master computer should update other connected microcontrollers. The locomotive then auto-reports the software and firmware revisions, dates, and location to railroad's back office.

Example Strategy to Follow to Roll Out Software Updates

The railroad and OEM need to have a strategy for rolling out software updates. In general, the railroad should minimize risks of undiscovered side-effects, and slowly build confidence in the software revision. The timescale must be shortened if the OEM has notified the railroad of a safety-critical issue and required software update.

Here is an example strategy to follow for software updates:

- Obtain and review the list of software or firmware changes from the locomotive OEM, including any compatibility notes
- Limit the initial trial to a small portion of a small number of fleets. It is recommended to focus on the most accessible or watched locomotives (captive locomotives)
- Have a feedback process for reporting issues from operators, technicians, and management
- After accumulation of successful (problem-free) operational hours, rollout to a larger portion of each fleet, and/or additional fleets
- After any issues are resolved to the railroad's satisfaction, rollout to the remaining units in each fleet
- Remote or otherwise inaccessible units may need to be individually tracked down and updated on site
- Update the OMM with the new expected hardware, software, and firmware revisions
- Track the percent completion of the software update campaign
- If spares need to be installed with the latest software already loaded, the spares must be updated also. The alternative process is to have the spare's software updated when it is installed on the locomotive.

Conclusion

Locomotive safety-critical software updates are covered by 49 C.F.R. § 229.309 Safety-critical changes and failures, and § 229.315 Operations and Maintenance Manual. The railroad must maintain a configuration management control plan to ensure proper and intended product configuration; this includes software revision. A simplified configuration management control plan was provided, along with a recommended minimum list of data to track in the OMM. Railroads will likely have to support multiple software update methods due to OEM variety, locomotive upgrades, available infrastructure, and project costs. The processes need to maintain security of the locomotive and integrity of the software update. To control costs and reduce mistakes, required equipment and human interactions should be minimized where possible for both software updates and revision information collection. And finally, have a feedback process for reporting problems and optimizing plans – internally and with the locomotive OEM.



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Locomotives of The Future as a Mobile Data Center

*Prepared by:
Aldo Ferrante
ITG*

Locomotives are prime movers for heavy haul freight and are considered a mechanical engineering marvel functioning as a generator on wheels, converting fuel into electricity powering a series of traction motors used to transport tons of cargo across millions of square miles throughout rural and urban areas. No other technology can reproduce the capability of the freight locomotive. You would never consider a locomotive as a mobile data center but in the new age of analytics, data has gained enormous attention. The appetite for data is unparalleled and railroad owner/operators have realized acquiring and owning their data is critical to operating and maintaining their fleet of rail assets. Locomotive data provides valuable insight into locomotive operations. With increased competitive pressures, reducing cost, increasing asset effectiveness and improved safety can translate into higher profits and safer operations with fewer disruptions. The future locomotive is beyond being a mechanical innovation and a power generating machine of the last century. It will become a knowledge generator of the next century with superior intelligence making its own decisions rapidly while becoming fully autonomous.

The adoption of AI (Artificial Intelligence) and machine learning is paving the way for smarter locomotives using sensor data, image data and smart algorithms to learn behaviors to predict problems before they become disruptive. Locomotives will automatically adjust themselves to resume normal operation and derive the optimal parameters setting to generate the most efficient output. Autonomous trains are technologically easier to achieve compared to autonomous automobiles because locomotives do not experience the same circumstances, obstacles and situations that face a self-driving car in an urban environment requiring real-time decisions. The potential for smart locomotives and automation in rail operations provides a significant reduction in operating cost estimated between 30% to 40%. Smart locomotives require enormous amounts of data to make intelligent decisions. In addition to existing sensors from onboard event recorders and additional instrumentation packages with camera systems, the locomotive is now equipped to understand its environment, assess situational conditions and measure mechanical health.

A variety of computer hardware platforms and storage devices exist on a locomotive. We have seen an increase in locomotive onboard electronic systems, event recording devices and other computer systems that manage and store data



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on systems such as the ECM (Engine Control Module), LCS (Locomotive Control System), PTC (Positive Train Control), LIG (Locomotive Interface Gateway), RCL (Remote Control Locomotive), LDVR (Locomotive Digital Video Recorder), ATC (Automatic Train Control), ATP (Automatic Train Protection) and analytical edge processors used for predictive maintenance, along with newer add-ons such as cell detection systems to alert for unauthorized cell phone usage. The introduction of UAVs (Unnamed Aerial Vehicles), commonly referred to as Drones, is being explored to inspect track, vegetation, signage, signals, and rail crossings while the locomotive is in motion. The adoption of these emerging technologies is rapidly increasing the demand for processing power and storage capacity resulting in more onboard computing and memory requirements. This creates a need to consolidate computer platforms and storage devices to reduce complexity, cost and reduce the risk of a single point of failure. The fewer components on a locomotive, the less probable a critical failure can occur while the train is transporting precious cargo to its final destination.

In order to understand the future of locomotives as ‘mobile data centers’, we need to analyze the changes that stationary data centers have experienced over the years and how critical infrastructure systems are used in many industry IT systems including those for utility providers and the manufacturing industry. The first IT systems started out as powerful mainframe computers with centralized storage. But as the number of users increased mainframes became very difficult and expensive to maintain and scale. A terminal (often referred to as a “green screen”) was essentially a passive device sending keyboard commands and returning results to the screen. Later personal computers allowed the user to be severed from the mainframe and independent of the server. Each personal computer contained its own separate microprocessor and storage system with ram memory, spindle storage drive and floppy disks used to transfer data from one computer to another. This allowed more people to learn and use computers making them more efficient, but it created a honeycomb of storage areas and a headache for IT support staff, making it difficult to manage – much like today’s locomotives with the various systems and data recorders. Data on the personal computer required manual removal in order to back up the system. As networks became faster and easier to implement, centralized storage systems consolidated data onto a single disk drive or cluster of disk drives known as drive arrays that users accessed on a shared network drive. This made managing the systems easier by reducing duplication of data, better backup systems lowering the risk of losing data, better security and lowering total cost of ownership minimizing the need to acquire larger standalone storage systems. Locomotives face the same challenges but the same consolidation techniques can be applied to onboard computer systems and storage devices.

Consolidating on-board storage devices to a central storage location can function as a shared network drive that supports all data types. The two storage

application types used on a locomotive are survivable data that is analyzed in the event of a locomotive accident or derailment, and non-critical data that while helpful for analytical purposes, is not critical for accident reconstruction or legal purposes. Survivable data requires a CHMM (Crash Hardened Memory Module), sometimes referred to as a crashworthy ERMM (Event Recorder Memory Module). The other storage devices are used for non-critical storage storing data for analytics, locomotive operations and maintenance functions. Typically, these systems operate independently and are designed with their own set of requirements and dedicated storage media. Separating non-critical data from crashworthy incident data reduces the risk of data corruption on the CHMM. The larger the disk storage the higher the probability of disk corruption and bad sectors. Traditional media storage devices have been magnetic tape, spindle drives, while the most recent systems utilize SSD (Solid State Disk). For crash incidences, a CHMM (Crash Hardened Memory Module) is required to meet the FRA (Federal Railroad Administration) 49 CFR Part 229 compliance to capture data that can be analyzed to determine if mechanical failures or operator actions contributed to the accident resulting in derailments or fatal crash. CHMM requires error management software with ECC (Error-Correcting Code) Memory based algorithms to detect and correct disk errors. Typical CHMM requires 1,000,000 to 2,000,000 MTBF (Mean Time Between Failures) to provide high reliability. There are no data format storage standards that exist among the various event recorder manufacturers, making consolidation a challenge. The storage data formats range from simple CSV (Comma Separated Values) human-readable text, SQL database, JSON (JavaScript Object Notation – the standard used for web applications), IoT systems and manufacturer proprietary binary format that may utilize a data encryption key. Extracting data from these systems typically requires proprietary software and communication interfaces and cables. A common challenge across multiple event recorders requires that each event recorder vendor develop custom software to integrate the event recorder data into the LIG (Locomotive Interface Gateway) for transferring stored data. Each time a new system is added, more custom software is required to consolidate the data, with added expense and complexity to the combined system.

Onboard cameras are fast becoming a standard on locomotives for recording video in the cab, as well as front and rear facing cameras. Video data formats range from proprietary formats to standard formats such as MPEG, JPEG, AVI, WMV, etc. New high-resolution 4K cameras are increasing the storage demands for video event recorders resulting in increased network payload and introducing challenges to locomotive network engineers for transferring large sets of video information to their central backup server. The installation of PTC (Positive Train Control) which is now required by the FRA for locomotive safe operation includes the addition of cellular data service to provide remote connectivity that can be used for real-time video streaming and off boarding of sensor and video data to

the back-office data repository for real-time centralized monitoring and analysis. Locomotive network engineers implementing QOS (Quality of Service) on the locomotive managed network switch have a challenge of prioritizing network traffic without compromising PTC safety functions. This QOS data is typically transferred on an exception event basis. The heavy payload QOS bulk data can be transferred when the locomotive is in a maintenance shop and utilize Wi-Fi wireless communications sparing the cost of transferring over expensive cellular or satellite communications. Storing the entire QOS dataset on a CHMM may not be feasible, practical or necessary, therefore separation of the two category types is preferred.

The good news is that SSD prices are rapidly dropping as the demand for mobile data center locomotive increases. A 1TB SSD has enough storage capacity for both sensor and video data. It is best to segment disk storage to ensure adequate storage space is available for both. 1TB can provide many months of storage even with two 4K high-resolution cameras and hundreds of sensors, including a worst-case scenario such as storing video at 30fps and collecting sensor data at one-second polling intervals.

The CHMM storage size requirements are much lower and require just a few days of storage for video and event recorder data. CHMM disk sizes currently range between 8MB to 256MB. Continuously storing video and sensor data during all operating states of the locomotive may not make sense for FRA requirements but is valuable information for classifying events such as rail alignment issues, signage and traffic problems, locomotive engineer/conductor alertness, situational intelligence to alert of an upcoming dangerous conditions and signal crossing problems. The use of a separate onboard archive for this data may be the most practical way to have the best of both worlds – sufficient long-term onboard data and safe CHMM storage of the most recent events.

Building a large archive of locomotive sensor data paints a picture of mechanical systems used to predict engine, generator and traction motor issues and used to create rules to alert for specific conditions or alarms. Using machine learning for alerting maintenance problems can provide early warning from hours or days to weeks and months in predictions. A successful machine learning system becomes possible that can produce highly confident machine learning agents making real-time predictions. This solution requires lots of time series of historical data. Supervised learning is used to classify and predict critical maintenance problems related to bearings, crankcase cracks, oil and water leaks, turbocharger issues, traction motor issues and wheel wear. Unsupervised learning is used to analyze entire datasets and find potential problems and anomalies that are not obvious or yet identified. The smart algorithms learn normal behavior of the locomotive and are capable of detecting abnormal conditions analogous to experiencing small seismic tremors just before a catastrophic earthquake hits. In

summary, data provides the promise of maintaining a well-oiled machine that can impact the profitability and survivability of the railroad.

As the industry anticipates the transformation of locomotives as a mobile data center, the ultimate question on how to reduce the hardware dependency in order to properly minimize potential failures must be addressed. Software and hardware have been coupled together to form complete systems, and when hardware failure occurs the task of reinstalling software assumes that the new hardware is compatible with the older software. Software incompatibility issues require the time-consuming task of upgrading to the latest software version which may not look the same as the older version and thus require operator retraining.

The arrival of virtualization presents the ability to virtualize the entire operating system and software applications decoupling the hardware from the software and the dependency of specified hardware. Virtual machines are very large disk image files that can be migrated to one or more hardware platforms by simply copying the virtual machine file to another computer running a hypervisor operating system. Another advantage of virtualization is the ability to run completely different computer systems with completely different software and operating systems on the same hardware platform, reducing the number of computer hardware platforms and storage systems. IT support staff is now gaining benefits with better management tools to provision computer systems faster, enhanced scalability, increased security, feasible backups of critical data and reduced hardware support while reducing total cost of ownership.

Virtualizing locomotive systems will be the next phase that offers the same management benefits to business IT systems. The cloud and IoT (Internet of Things) have opened new opportunities further reducing hardware dependency and reducing the need to build dedicated data centers at specific locations. Cloud computing is an on-demand delivery of computer power, data storage, applications and other IT resources without having to purchase hardware, software and IT resources utilizing the internet as a pay-as-you-go model. Locomotives face a different challenge due to their dependency on wireless telemetry systems, such as cellular, satellite, Wi-Fi and dedicated VHF radio communications that are becoming congested.

With the introduction to 5G in 2019, and as broadband satellite becomes more affordable, the need to store event recorder data on board the locomotive will be further reduced and onboard hardware and storage requirements will dwindle, eventually eliminating the need for expensive rolling stock EN50155 certified hardware designed for crashworthiness. These changes will also lower the cost of operating a locomotive. IoT allows sensors to be connected directly to the cloud and stream sensor data in real-time, reducing wiring and integration costs. The development of wireless sensors will make adding sensors to legacy locomotives with no electronic control system feasible, reducing the cost of

installing condition monitoring and predictive maintenance systems. This will extend the locomotive useful life, resulting in increased profits. This scenario generates effective support staff utilization, transforming them into value-added proactive resources, rather than reactive firefighters, empowering staff to think and innovate ideas for improving operations.

Understanding innovations in IT and OT convergence will pave the way for railroads to leverage data that will exploit the “locomotive as a mobile data center”. Railroads need to think of locomotives not just as fleets of mechanical machines but instead as **TRAINS WITH BRAINS!**

Locomotive Remote Control Systems

Prepared by:
Viktor Gvelesiani
ZTR Control Systems

Remote Control Locomotive (RCL) systems are not new to the rail industry. These systems have been used since the early 70's in a wide variety of passenger and freight operating scenarios, but predominantly in switchyard and hump operations.

The main benefit of these systems is a significant improvement in operating efficiency. It is no surprise that this technology has been receiving much attention from railroad administrations, safety regulators, labor unions and technology companies.

Continuous strides by the industry to improve safety and reliability of these systems have brought numerous technological advancements: ergonomic belt packs, point protection, "pitch and catch operation" mode, over the radio emergency annunciation, tilt detection, GPS locators and many more. However, the fundamentals of RCL system operation today are still very much the same.

Almost all RCL systems in use are based on a vendor-proprietary point-to-point digital radio communication between the Operator Control Unit (OCU) and the Locomotive Control Unit (LCU), either directly (device-to-device within the line of sight) or through a repeater antenna network to enhance radio signal reliability and increase operating distance. Like any mature technology in today's world, RCL is facing the need and the pressure from the industry to evolve.

Challenges

One of the most prevalent challenges RCL systems are still facing today is lack of cross-compatibility. OCU and LCU units cannot be interchanged with other brands, but often they are also not interchangeable within the same brand of equipment depending on the location or other factors. This leads to complications in managing the equipment, installations, updates, personnel training, qualifications requirements and other operating challenges.

The Federal Communications Commission (FCC) has designated 450-470 MHz frequency band for general industrial use. Within that band, the Association of American Railroads (AAR) has been designated as a coordinator of narrower frequency bands, and specifically 452/457 MHz frequencies used for train telemetry, such as End of Train- Head of Train (EOT-HOT), Distributed Power (DP) and Remote Control Locomotive (RCL) applications. However, this does not preclude

other industrial equipment from potentially broadcasting at these frequencies, thereby considerably degrading effective communications range of RCL systems depending on location, time of day, industrial activities in the vicinity of the specific railyard and even weather.

RCL vendors have developed proprietary technologies to increase effective communications range (within the transmitted power limits set forth by the FCC) and improve noise rejection and operational reliability of RCL systems. This complicated efforts by the AAR (through development of standards like S-5507 and S-9401) and individual railroads to standardize RCL communication protocols and make systems cross-compatible and increase the number of RCL systems that could concurrently operate in a switch yard.

RCL interaction with various locomotive control systems and electronics is also dependent on the specific locomotive electronics architecture. This can vary based on the specific vendor and railroad implementation. The high level of variability between RCL deployments typically limits mobility of locomotive sets equipped with RCL within larger fleets. Personnel training and qualification requirements further complicate this situation. As a result, most RCL systems are used in captive fleets.

Personnel safety is always the highest concern for the railroads. Ongoing use of RCL systems and adoption of other new technologies is continually driving safety and other functional enhancements in the RCL systems. A high degree of localization of RCL systems prevents faster roll-out of functional enhancements to the RCL systems.

Common Air Interface (220 MHz)

In 2005 AAR released a new standard, S-9153 (updated in 2012), designed to address some of the most critical RCL issues, such as:

- Maximize the number of RCL systems working simultaneously in the same location
- Allow proprietary systems to become interchangeable
- Allow mixed operation of new (interchangeable) and traditional systems in the same yard

The most critical component of this standard was the introduction of the Common Air Interface (CAI) protocol. This protocol effectively standardized communications between mobile transmitters (such as OCU and LCU) by introducing intermediary components and utilizing radio frequency specifically licensed for train control operations (PTC) nationwide.

A typical RCL system architecture is shown in Figure 1.

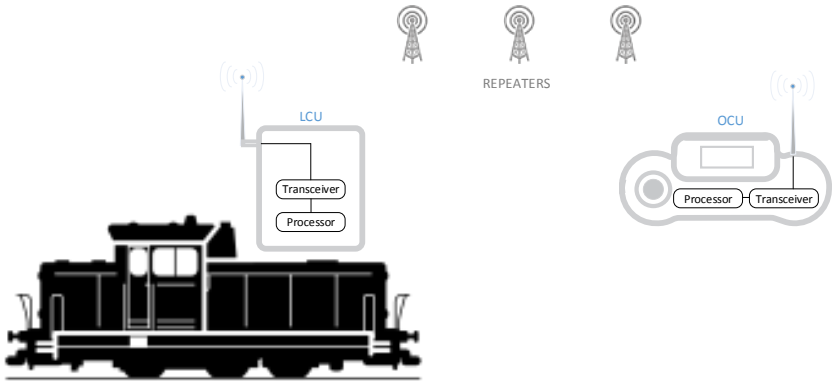


Figure 1: Proprietary RCL Communications Architecture

S-9153 has introduced standardized mobile communication modules interfacing with each other either directly, or via a ground base station and a repeater network. CAI-12 protocol was specifically designed to provide much greater channelization efficiency and significantly increase the number of mobile devices concurrently operating on the communication network. Additionally, by moving all communications into the licensed 220MHz band, this architecture allows simultaneous operation of the existing RCL systems using traditional 450 MHz band and new systems.

RCL architecture defined by S-9153 is shown in Figure 2.

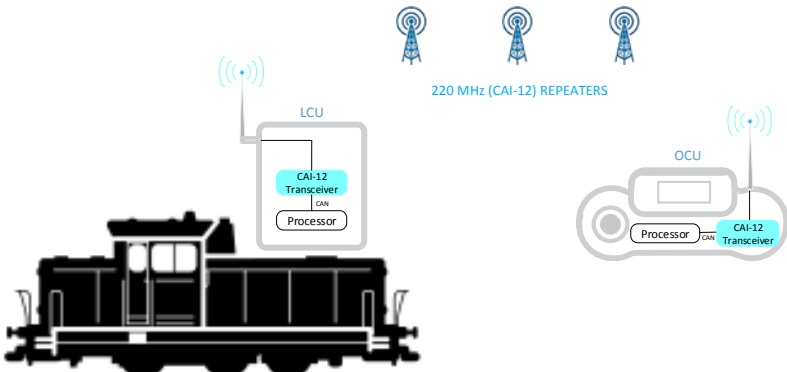


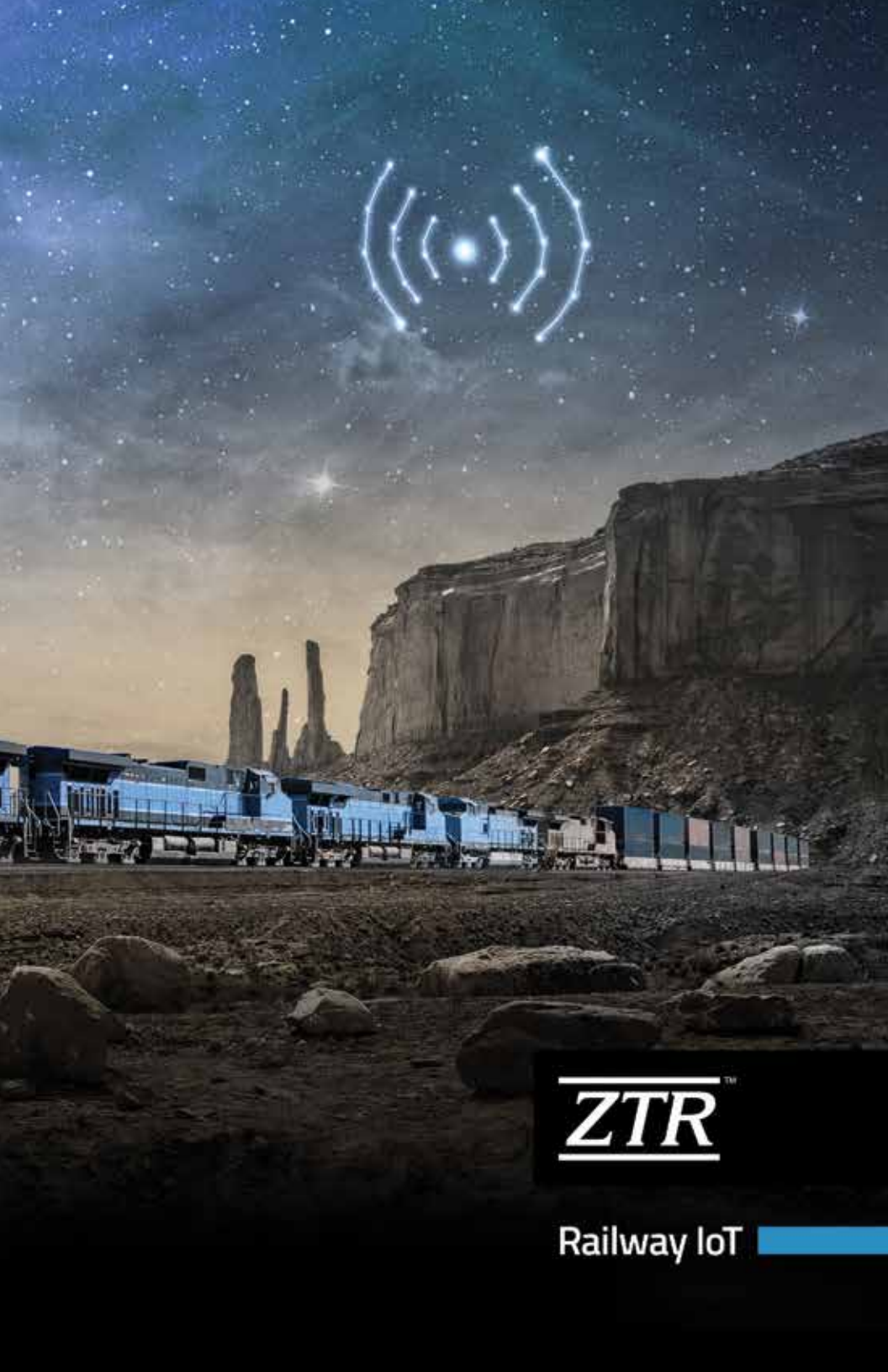
Figure 2: CAI-12 Based Communications Architecture

A blue and white locomotive is positioned on a railway track in a desert landscape. The sky is dark and filled with stars, suggesting a night scene. The foreground shows some large, rounded rocks or boulders.

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The new CAI-12 compatible transmitters can be either integrated within the OCU and LCU, or provided as a transmitter module communicating with OCU or LCU processors using standardized CAN protocols (Controller Area Network). This flexibility of implementation also allows RCL vendors to maintain security and authentication protocols.

However, despite its obvious advantages, adoption of S-9153 by the railway industry has not been exactly a rapid event. In fact, very few CAI-12 based systems are currently in operation. While S-9153 has successfully addressed its primary objectives of increasing bandwidth and interoperability of RCL systems, it did not attempt to affect the interface between these systems and locomotive electronics and other control systems. Additionally, the implementation of CAI-12 compatible systems by itself required significant infrastructure investment in base radio stations and repeater networks. Lastly, the impending PTC implementation deadlines have diverted attention and resources away from other areas, including adoption of CAI-12 based RCL systems.

Does this mean that CAI-12 RCL systems are dead? Absolutely not! In fact, PTC systems development is offering unique advantages crucial to the successful adoption of CAI-12 based RCL systems.

PTC and RCL 2.0

Locomotive Electronic Systems Architecture (LESA) was developed and implemented as part of PTC deployment. This architecture offers further standardization of interfaces between various locomotive systems and subsystems. Locomotive Command and Control Module (LCCM) is one of the elements of this architecture that is most critical to the CAI-12 based RCL systems.

The main purpose of LCCM is to provide standardized interface between various systems attempting to control locomotives and the locomotive physical equipment, such as propulsion systems, air brake systems and etc. Additionally, LCCM will ensure that only one system is controlling a locomotive at any time, and transfer control back to the operator whenever the operator requests it. A simplified block diagram of LCCM within the LESA is shown in Figure 3.

In basic terms, LCCM is functioning as a bi-directional Locomotive Interface Gateway (LIG), allowing control commands to be passed from the locomotive subsystems network to the locomotive control elements in addition to the standard LIG data broadcasts.

Introduction of LCCM functionality offers CAI-12 based RCL systems an opportunity to close the remaining gap and standardize the interface with locomotive electronics.

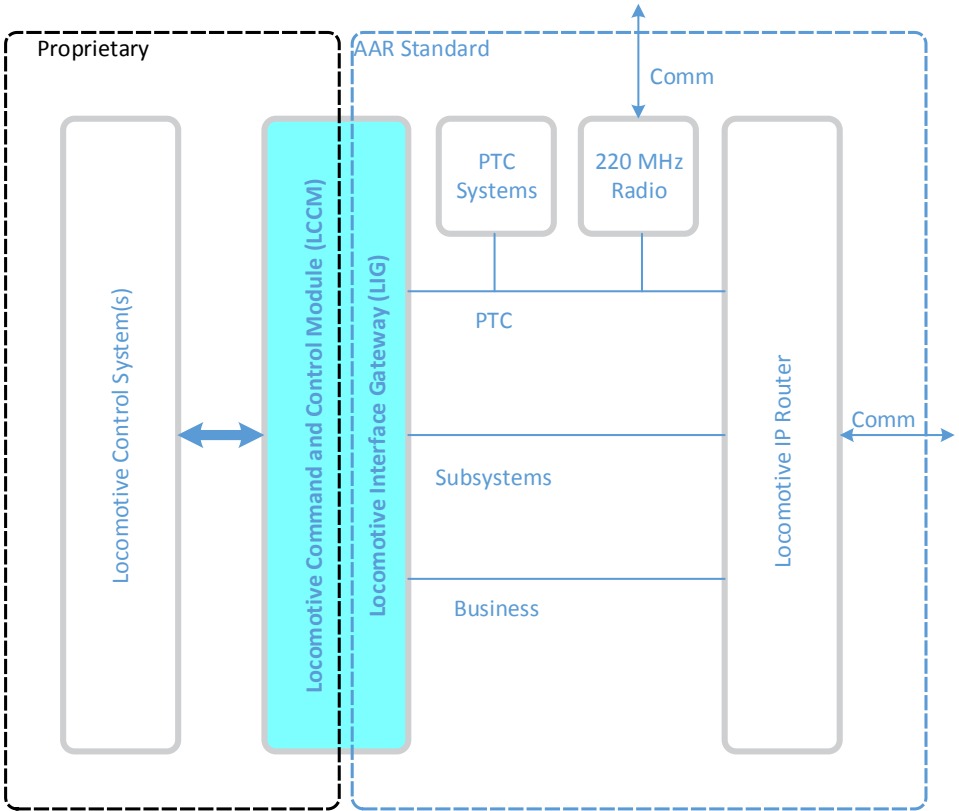


Figure 3: Simplified Locomotive Electronics Systems Architecture

Security and Integrity

Security and integrity of locomotive control functions have traditionally relied on having to gain physical access to the equipment. Traditional RCL systems rely on proprietary encryption and authentication protocols to ensure safety and reliability of the wireless communication. System standardization effort that the railway industry is implementing is truly unprecedented.

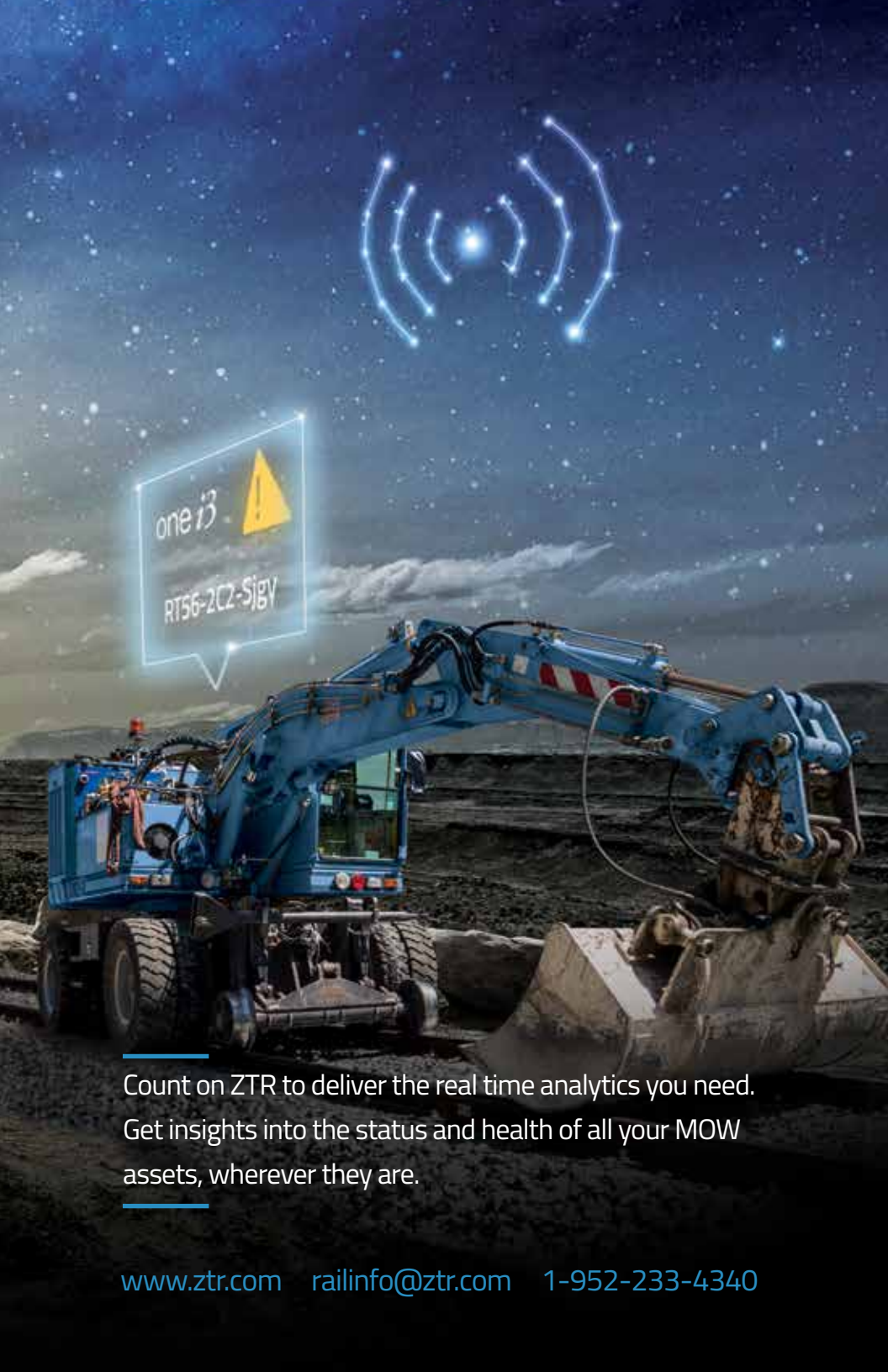
This also means that the old rules may no longer be effective. Specifically, standardized wireless communications can no longer be protected by the need to physically access the equipment. This could make RCL systems vulnerable to undesired and possibly malicious intrusions, therefore presenting significant security and safety risks.

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Conclusions

RCL technologies are one of the essential elements of a modern railway's operations. As such these technologies have to continue to evolve to address the rapidly changing competitive landscape of the modern transportation industry. Although the implementation of PTC systems and standardized Locomotive Electronic Systems Architecture (LESA) has affected the roll-out of new RCL technologies, the continuous industry effort to achieve greater flexibility and interchangeability through standardized electronics architecture is offering new unprecedented possibilities to the developers of these technologies.

Report on the Committee on Electrical Maintenance

Tuesday, September 11, 2018 at 10:30 AM



Chair

Keith Mellin

Sales Manager, Peaker Services, Inc
Brighton, MI

Vice Chair

Amarjit Soora

Manager of Engineering, ZTR Systems
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Peaker Services, Inc, Brighton, MI

Keith Mellin was born 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 Electrical Maintenance Committee would like to express their sincere gratitude to Southwest Research Institute for sponsoring and hosting the committee's winter meeting in San Antonio, Texas on February 28 and March 1, 2018.

Special thanks go to John Hedrick, Steve Fritz and fellow committee person, Randell Honc, for making all the necessary arrangements to ensure that our meetings went off without a hitch. Bapiraju Surampudi of SwRI made a presentation on Battery Testing.

We would also like to thank fellow committee person, Steve Muetting, of Siemens for arranging our summer meeting in New Castle, Delaware on July 17 and 18, 2018. The meetings were held at the Siemens Rail Support Center. Other Siemens personnel who assisted Steve with all the details were Volker Hansen and Lisa Caperino. Siemens also provided lunch which we truly appreciated.

The committee had the opportunity to tour Southeastern Pennsylvania Transit Authority (SEPTA) Frazer Maintenance Shop in Malvern, PA., arranged by the courtesy of David Warner. Director of Maintenance Al Matejick, and his crew took time out from their hectic schedule to give the committee a tour of the facility. Thank you, David, Al, and the SEPTA crew at the Frazer shop; Jeff Thompson, Ed Carruthers, & Ed Schoen.

We also were given a tour of the Amtrak Wilmington, Delaware Maintenance Shop. It was conducted by Sean Bonner of Siemens and William Zajac of Amtrak. We are extremely grateful to Sean & William for allowing us to tour the Amtrak shop.



CHANGING OF THE GUARD

Tom (John) Nudds has announced that he is relinquishing his duties/responsibilities as Regional Executive of the Electrical Maintenance Committee. Tom is retiring from ZTR Control Systems. He was one of the co-founders of the company.

The LMOA Executive Board would like to take this opportunity to extend its sincere appreciation and gratitude to Tom for the leadership he exhibited through the years as both Chair and Regional Executive of this committee and for all the technical papers he authored as a member of the committee. He will be sorely missed. We wish him a happy and healthy retirement.

In response to Tom's decision to step away, the following changes will be made, effective Tuesday, September 11, 2018, in Nashville, TN at the committee's technical presentations

Regional Executive	Keith Mellin	Peaker Services, Inc.
Chair	Amarjit Soora	ZTR Control Systems (<i>pictured above</i>)
Vice Chair	Jason Fox	Union Pacific Railroad

The LMOA Executive Board is confident that the new regime will carry the torch passed on by Tom and wants to assure them that the Board will provide all the support and guidance they require to ensure the committee's success moving forward.

Slip Rings & Collectors - What Keeps Your Wheels Turning?

Prepared by:

Doug Johnson, P.E.

Morgan Advanced Materials

A slip ring is one of the few single point failures that can stop a locomotive. The alternator is the sole method of generating the power required by the traction motors to move the locomotive. Without the slip rings, the alternator cannot function. The slip “ring” is actually multiple rings, typically two positive and two negative. One of each is for the main or traction alternator and the other two are for the auxiliary or companion alternator. The power that flows through the brushes and the slip rings creates the magnetic field the alternator needs to generate usable power for the locomotive. Slip rings cannot perform their critical role without help from other components. They are the brush holders, springs, and brushes. Even the best slip ring would not last long without the team effort of all the components.

Slip rings, over time, have developed many different features. Some are a byproduct of cost while others offer functional improvements. One of the most important slip ring features is the material. Three common options are: steel, aluminum-bronze, and tin-bronze alloys. Each ring material and its alloys come with their own unique pros and cons.

Steel, including stainless, is the most economical material. It is also the strongest, hardest, and least conductive. Steel slip rings will have a higher contact drop at the slip ring to brush interface than the other materials mentioned. This will result in more heating and the need for better cooling options to optimize the slip ring and brush life. Steel rings can also withstand the stresses of higher rotational velocities allowing the slip ring to have a larger diameter than its bronze counterpart at the same rpm. The larger slip ring provides additional brushable area and also additional cooling area; each of which make higher current ranges possible while maintaining the same amps per square inch (APSI or sometimes ASI) in the brush face. A common problem associated with steel slip rings is the need for reconditioning to remove rust after periods of storage. In the past a light smear of oil has been applied to the slip ring surface as protection. Forgetting to remove this oil is just as detrimental to successful operation as rust. There is record of an expensive burn-out as a result of this oil film being left on the slip ring at start-up (Multiple, 1988). There are several options available for fast rust removal.

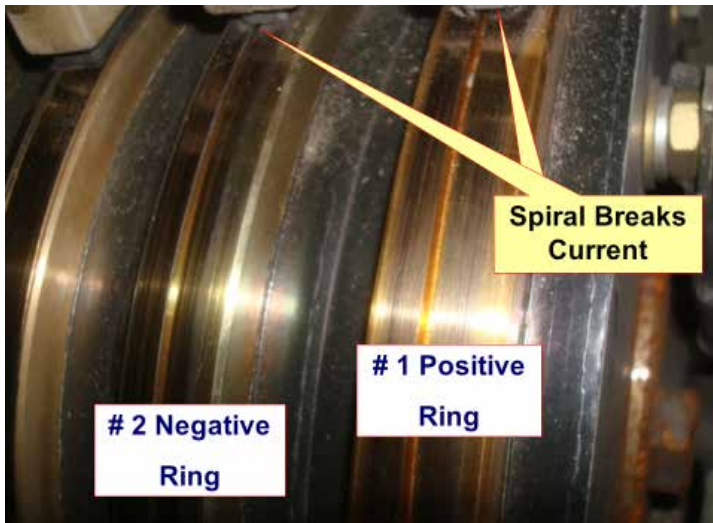
The next most cost-effective material is aluminum-bronze. From a brush makers standpoint this is the least desirable material. Carbon brushes require

oxides to form on the slip ring. Carbon material from the brush, when mixed with moisture in the air, forms a film on the slip ring surface. The carbon brush needs the film to reduce the friction and improve brush and slip ring life. The moisture in the air also forms Aluminum oxide. Aluminum oxide, Al_2O_3 , is like sandpaper to the brush which results in shortened life. In addition, aluminum oxide acts as an insulator and raises the contact drop (read more heat) (Boggess, 2009). Aluminum has been known to introduce rapid slip ring and brush wear (Multiple, 1988).

Finally, the most expensive option, tin-bronze and its alloys can be used as the slip ring material. They give the lowest contact drop (least heat), develop the best film across polarity, and give the best brush life. These materials are more difficult to manufacture and tighter design tolerances must be taken into account. For example, the steel hub the rings are mounted on expands at a rate roughly half that of the bronze alloy ring. Repeated extreme cold and hot temperatures can stress the slip ring material and could cause it to become loose on the hub resulting in catastrophic failure. Bronze is weaker than steel and cannot hold its shape as well at high surface speeds and temperatures. It is imperative that designers take the material properties into account to produce the best slip ring designs.

Polarity considerations are often ignored by slip ring designers much to the chagrin of slip ring users. Polarity is a non-issue with D.C. commutated machines because both the positive and negative brush ride over the same path. Some suggest that the slip ring polarity should be switched after a certain time period to evenly wear both slip rings (Boggess, 2009). Electron flow is opposite that of current flow. Standard definitions of positive and negative current indicate a flow from the positive brush to the negative brush. Electron flow, being opposite current flow, starts at the negative brush (cathode) and flows to the positive brush (anode). The negative brush (cathode) emits electrons toward the slip ring (Gunnøe Jr., 1984). This vaporizes the metal of the slip ring and results in the formation of an oxide film. The positive brush (anode) is bombarded by electrons from the slip ring. This vaporizes the carbon of the brush, mixes with the slip ring oxides, and creates a darker color film; often obviously different from the negative brush film. In many cases the positive (anode) brush will wear faster than the negative (cathode) brush (Gunnøe Jr., 1984). This, of course, assumes no other disturbing factors are in play. Electrographite grade brushes, often used in locomotives, have a very small polarity difference when compared to their metal graphite cousins. George H. Gunnøe, Jr in his paper titled, *Collector Rings*, writes, "The only advantage of reversing [polarity of the] rings is that it keeps the wear of the rings uniform." In the locomotive world, switching the slip rings polarity has been recommended to keep slip ring wear even. With today's electronics, this can be accomplished much easier than in years past. It is recommended to switch the polarity of the slip rings every six months.

New slip rings are often fitted with another important feature; a spiral groove that follows a certain pitch around each ring. The spiral groove plays several important roles. Most important involves the current distribution throughout the face of the brush. Nature, and thus the current, is known to find the path of least resistance. This means on every brush face the current will have a preferred path. The spiral groove forces the current to be constantly moving across the brush face. For this reason it is imperative that the pitch of the spiral groove be less than that of the brush width (some portion always under the brush face). While this will increase the current density going through the brush, the benefit of constantly moving the current outweighs this slight compromise. Adding the spiral groove to the slip ring has dramatically improved brush performance (Bogges, 2009).



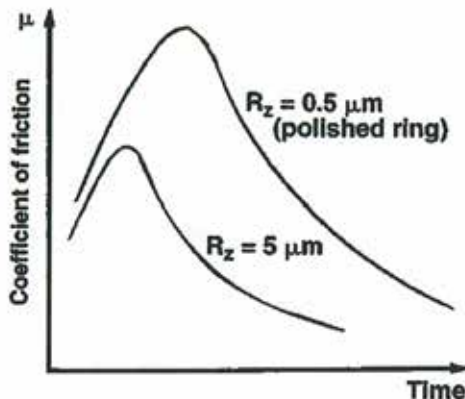
A second, often overlooked, benefit of the spiral groove is the break up of the boundary layer that forms on the slip ring surface. This small layer of air, if left unchecked, will raise the brush off the surface and cause a micro arc that will destroy both the slip ring surface and the brushes. This will be discussed more later in this document. The boundary layer is often overlooked because it is easily overcome by spring force at the lower surface speeds seen by the slip rings of today's locomotives. The effects of the boundary layer will increase with surface speed. As the surface speeds of slip rings continue to increase, dissipation of the boundary layer will have to be considered for successful brush operation. It is estimated the boundary layer phenomenon will have a noticeable effect on brush operation when surface speeds are above 12,000 feet per minute. The slip ring manufacturers who utilize steel rings will have to account for the

boundary layer in the future. Those manufacturers that have chosen to use brass or its alloys have also focused on keeping smaller diameter slip rings which result in lower surface speeds and less boundary layer effect.

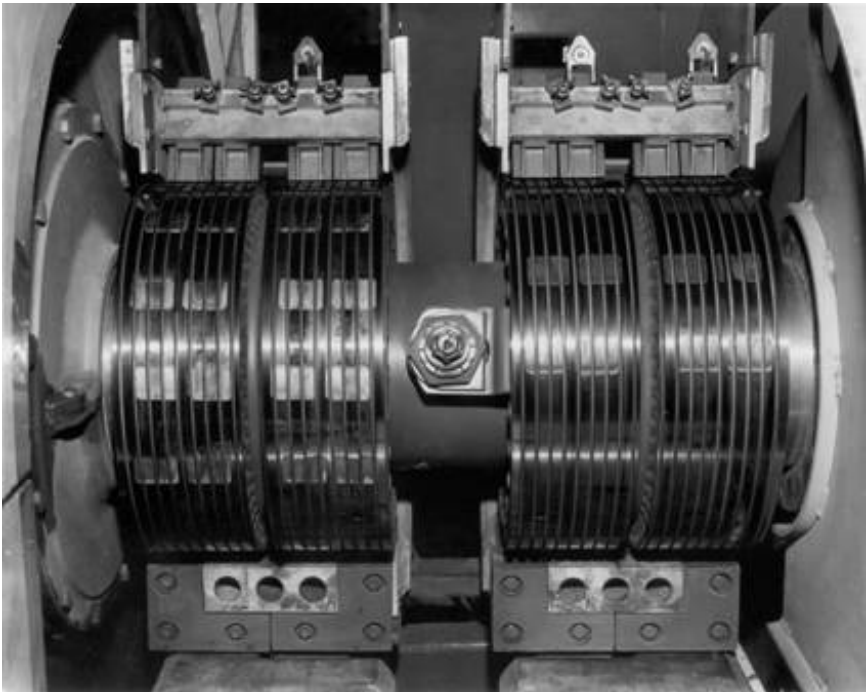
A third, unmeasured benefit of the spiral groove is the reduction of slip ring surface temperature. Even if the spiral groove didn't allow the passage of a small amount of air under the brush surface, it does; it adds surface area to the slip ring. The addition of surface area is one of the best ways to dissipate heat faster. Brush life is best when the surface temperatures are kept below 150 degrees Celsius.

A final, and important benefit of the slip ring spiral groove is the reduction of current selectivity among multiple brushes on the same ring. The spiral groove intentionally moves the current path across the face of the brush a minimum of one time per revolution. This prevents the current flow from getting "comfortable" in one spot on any brush. If the current flow was allowed to become stationary through the brush a "hot spot" would be created. This hot spot creates a lower resistance path as the temperature continues to rise. Eventually the weak link in the system gives way to the extreme heat resulting in a domino like failure through the machine.

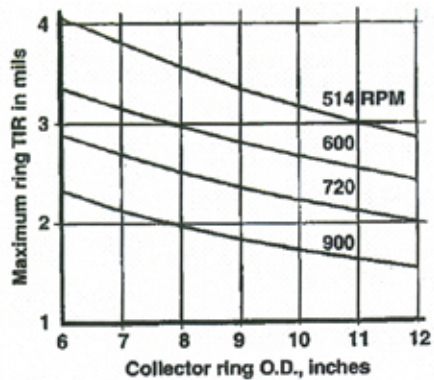
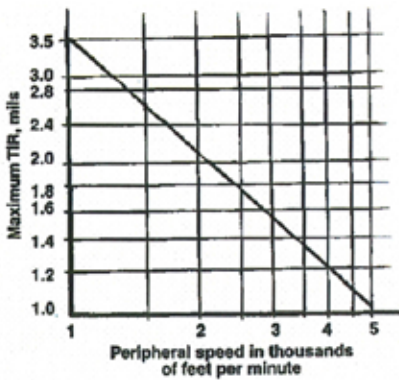
Today's precision machinists are capable of putting any surface finish on the slip ring, but what is needed? Brass slip rings will have the lowest startup friction at a 32-48 micro-inch finish and steel slip rings will perform best with a 64-96 micro-inch finish (Nailen, 2011). Surface roughness, when new, may start smoother or rougher, but after a few months of operation will end up close to 50 RA. This is attributed to the ever changing film between the brush and the slip ring. The results of an experiment with two different starting surface frictions indicates that there is such a thing as too smooth. With operational time, both starting points worked toward the same coefficient of friction. The resulting plot below:



Intimate brush contact to the slip ring is easily overlooked with detrimental affects. Every time the brush loses contact with the slip ring arcing occurs. Arcing destroys both the brush and the slip ring creating flats. "Flats may be caused by vibration originating from worn bearings, defective gearings or couplings, machine out-of-balance, or disturbance feed back from connected plant as exemplified by the prime mover driving a generator." (Multiple, 1988). Even the smallest amount of arcing can quickly ruin an otherwise good slip ring. Ghosting is a common term to describe the mark left by the brush leaving the slip ring surface. It has also been called foot-printing or photo-etching. Anyone who has seen ghosting understands where the name comes from. Ghosting starts as the image of the brush imprinted on the slip ring. Once started it will not correct itself. It will only worsen and spread. A high friction area will develop and the slip ring will continue to work its way out of round. A sign of this condition: brushes will start to wear faster. Faster brush wear means more conductive brush dust in the air surrounding the slip ring. These two conditions only snowball until a flashover occurs. The only real way to stop ghosting from spreading is to resurface the slip ring.



The roundness of the slip ring is measured as Total Indicated Runout (TIR). The TIR is typically reported in thousandths of an inch (0.001") and represents the brushes ability to maintain intimate contact with the slip ring. Naturally, lower surface speed machines allow a higher TIR than higher surface speed machines for successful operation. This is because in lower surface speed machines the spring and brush have more time to react to the interruptions of the never perfect slip ring profile. An Institute of Electrical and Electronic Engineers (IEEE) paper from 1966 gives maximum TIR recommendations at 0.5 mils for 9000 feet per minute or more, 1 mil for 5000-9000 feet per minute, and 3 mils for velocity less than 5000 feet per minute. Electrical Apparatus in August 2011 posted the following two figures for determining the maximum TIR of slip rings:



All three recommendations for allowable TIR are similar. The best advice would be to use these parameters as guidelines for setting application specific parameters.

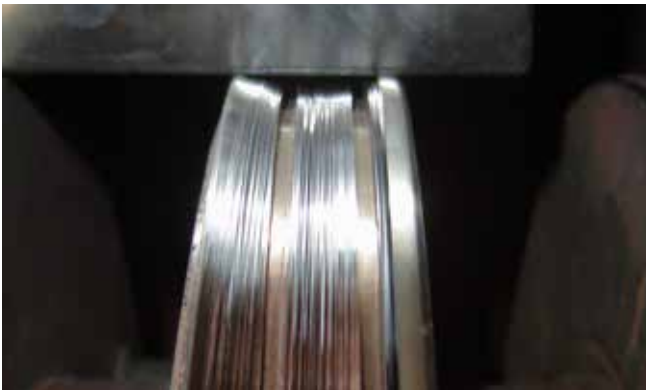
Associated Components

Even the best slip ring will quickly degrade without its supporting cast being in order. This supporting cast includes all electrical connections, the bearings, the mechanical fit of the slip ring to the hub, the brush holders, springs, and the brushes. Shock and vibration, often from the prime mover and the tracks, are other outside contributors that work against keeping intimate contact between the brush and slip ring. Poor electrical connections, overstressed rings, loose rings, and vibration should be avoided (Gunnoe Jr., 1984). All mechanical components wear in time. It is just as important, if not more so, to track the slip ring wear as it is to keep

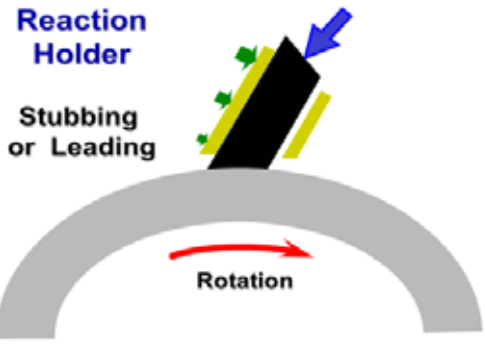
track of brush wear. A slip ring that grooves in six months will need outside factors corrected, but the same groove depth after years of operation would be acceptable. The only way to know for sure is to track the wear. An example of a grooved slip ring is shown below.



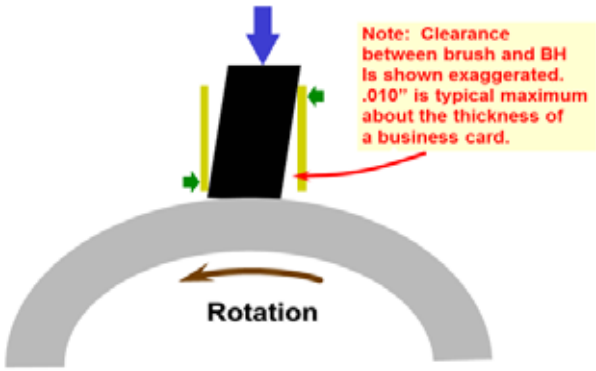
Grooving is not always uniform across the brush face. This second example of grooving is likely the result of low current density and or excessive axial movement of the rotor. A keen eye will also notice the threading present. There is a straightedge across the ridges of the slip ring to show the groove pattern.



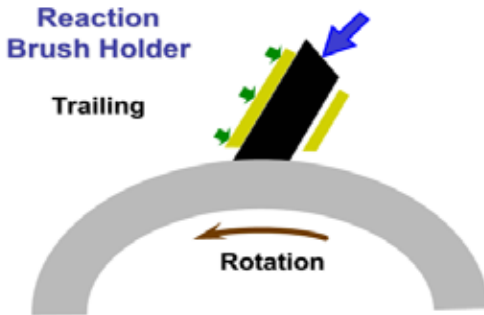
The brush holders' main job is to help keep the brush in intimate contact with the slip ring surface. Recommended holder height varies with slip ring size and surface speed, but is typically less than 0.125". This critical height prevents the brush from tipping in the brush holder and changing its arc of contact with the slip ring. There are three types of brush holder alignment options: leading (stubbing), radial, and trailing. Leading brush holders should be at more than 25 degrees to prevent friction chatter. Higher spring force may also be required as the spring also must overcome the friction between the brush and the slip ring. Notice in the image below the brush is contacting the leading edge of the brush holder. This is critical to eliminate friction chatter.



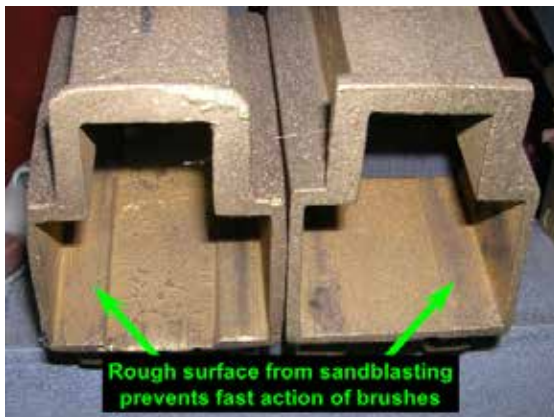
When installing radial holders, a little trailing is much better for the system than a little leading. Radial holders are most popular in slip rings that need to rotate in both directions. This is uncommon in locomotive slip ring applications.



Trailing brush holders are the preferred method of brush mounting in unidirectional machines and the most common among locomotives. The angle is recommended to be at least 15 degrees for maximum effectiveness. The trailing brush has the easiest job maintaining intimate contact with the slip ring because rotational disturbances do not affect it as much as the other brush holder options. The spring force does not have to be as high because the friction between the brush and slip ring helps keep the brush pressed against the brush holder.



Brush holders, new from the factory, are polished, not sand or bead blasted, where the brush contacts them. This highly polished surface ensures that there is minimal resistance to brush movement as the slip ring turns. This is critical to successful operation. The brushes **MUST** be able to freely move in the brush holders. Sand or bead blasted holders become like sandpaper to the brush sides. This slows down the brushes' ability to follow the slip ring profile leading to longer periods of arcing after a disturbance occurs. The extended arcing leads to flats or ghosting.



It is also important that the brush holder height does not prevent the full thickness of the brush from making intimate contact with the slip ring. Below, a new brush is shown with its toe off the slip ring surface. If not corrected, either by seating the brush or adjusting the brush holder angle, excessive heating will occur on the slip ring.



The spring's main job is to keep the brush pressed tightly against the slip ring surface and the appropriate edge of the brush holder. Its secondary job is to react to any disturbances that try to break the intimate contact between the brush and brush holder. Springs, like brush holders, must not be sand or bead blasted. They should be replaced a minimum of every five years. Some users have opted to replace the spring every time the brush is replaced thus eliminating the potential failure mode.





The force a spring applies to the brush face is divided by the brushes' cross-sectional area to determine the brush pressure. The proper amount of brush pressure against the slip ring depends on the application (surface speed and material of the slip ring) and/or the brush grade. To calculate the brush pressure, you need to know, or measure, the spring force and the brush thickness and width. Brush thickness multiplied by brush width gives the cross-sectional area. Brushes that contact the slip ring at an angle do have more contact area, but it is usually not a significant difference, so only the perpendicular cross-sectional area is used.

Calculating Brush Pressure

$$\text{BRUSH PRESSURE} = \frac{\text{Measured Spring Force}^*}{\text{Brush Thickness} \times \text{Brush Width}}$$

Lbs per Sq. Inch (PSI) (inches) (inches)

* Average of IN & OUT movement

$$\text{Brush Pressure (In PSI)} = \frac{\text{Measured spring force in pounds}}{\text{Brush cross sectional area in sq. inches}}$$

Example: 3 Lb. 10 oz. Spring Force = 3.625 Lbs

$$\text{Brush T} \times \text{W} = 5/8 \times 1 1/4 = .625 \times 1.25$$

$$\text{Brush Pressure (In PSI)} = \frac{3.625}{.625 \times 1.25} = \frac{3.625}{.7812} = 4.64 \text{ PSI}$$

The importance of a quality spring can be quickly seen through a quick calculation. Assuming there is a 0.001" divot in the slip ring, how long will it take the brush to regain contact with the slip ring? For this calculation we will assume four things. First, the spring responds instantly (massless). Second, there is no friction between the brush holder and the brush. Third, the brush only

contacts the slip ring at a single point. Finally, the brush does not bounce after making first contact with the slip ring. From Newton's second law of gravity:

$$F_s = \frac{m * a}{g_c}$$

where:

F_s = Spring Force (lbf)

m = Mass of the Brush (lbm), not including shunts

a = Acceleration (in/sec²)

g_c = Gravitational Constant (386.4 (lbm-in)/(lbf-sec²))

solving for a,

$$a = \frac{F_s * g_c}{m}$$

the position function:

$$s = u * t + \frac{1}{2} * a * t^2$$

where:

s = Distance to Lower Surface of Collector (in)

u = Initial Velocity, Longitudinal (in/sec)

t = Time (sec)

a = Acceleration (in/sec²)

We know that the initial longitudinal velocity is zero so our position equation reduces to:

$$s = \frac{1}{2} * a * t^2$$

Solve for t to find the time the brush is off the slip ring.

$$t = \sqrt{\frac{2 * s}{a}}$$

Now, the distance the collector travels during that time must be calculated. This is a function of the RPM and slip ring size.

$$d = RPM * \pi * dia * \frac{1}{60} * t$$

where:

d = distance traveled (in)

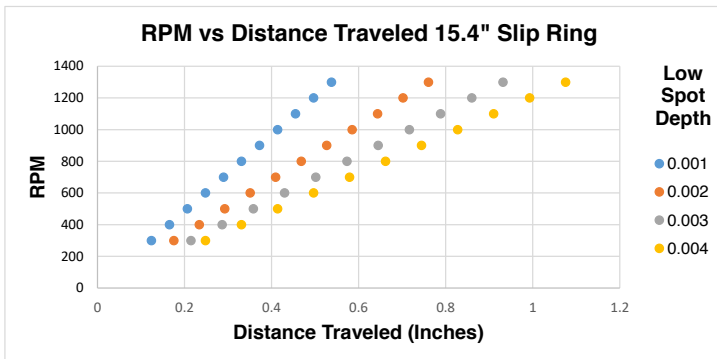
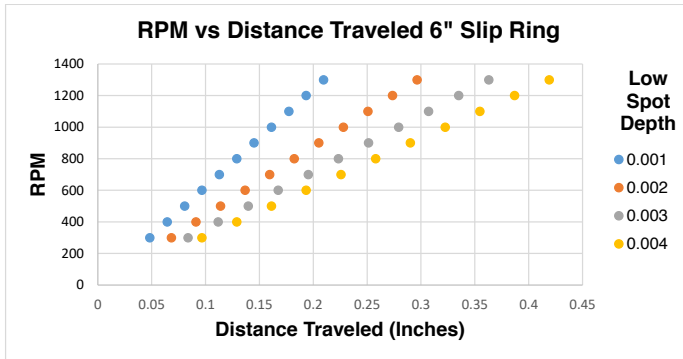
$\pi = 3.14$

dia = collector diameter (in)

t = time (sec) from previous calculation

(Hall, 2007).

Using a 5 pound spring, a 6 inch diameter slip ring, 1000 RPM, and a low spot of 0.001 inches the brush loses contact with the slip ring for 0.16 inches. Using the same parameters and a 15.4 inch diameter slip ring, the brush loses contact for 0.41 inches. The following two graphs can be easily created:



The differences between the two plots can be attributed to the change in surface speed between the 6 inch and the 15.4 inch diameter slip rings. The calculations made several assumptions that would minimize the time off the slip ring. In actuality, the initial disturbance is much worse for longer times off of the slip ring. The brush bounces on the slip ring before settling back down into intimate contact. It is during this bouncing that the ghosting phenomena occurs; specifically, if the first brush is still bouncing when the second brush encounters the initial disturbance. A simple way to combat the effects is to increase the arc of contact the brushes have about the slip ring. Despite the simplifying assumptions in the example, the affects of the small inconsistencies on the slip ring surface are mathematically detrimental to successful slip ring operation.

Conclusion

Slip rings, no matter the material, require routine maintenance to operate optimally. Quality maintenance practices will extend the slip ring and associated component's life. Maintaining intimate contact between the slip ring and the brush is crucial. The slip ring, brush holder, spring, and brush must collaborate effectively to form an operational system that is constantly tested by the vibrations of the prime mover and the rail joints. In this system, an ounce of prevention truly is worth a pound of cure.

References

Bogges, J. (2009). EMD Slip Rings - Brushes and Wear. Pages 164-183.

Delevan, R.

Gunnoe Jr., G. H. (1984). Collector Rings. Pages 1-6.

Hall, R. (2007).

Lozowski, G.

Multiple. (1988). Morganite: Carbon Brushes and Electrical Machines. Swansea: Morganite Electrical Carbon Limited.

Nailen, R. L. (2011). Collectors: More about how they're made and how they work. *Electrical Apparatus*. Pages 29-32.



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

Prepared by:

Peter Scholtens, Integrity Rail Products

Co-Authors:

Rodney Myers, Wheeling and Lake Erie Railroad;

Joe Whitmer, Dakota Missouri Valley Western Railroad

Introduction to PTC

Positive Train Control (PTC) is a set of technologies intended to make freight rail safer by automatically stopping a train before certain types of accidents take place. PTC was mandated by the Rail Safety Improvement Act of 2008 (RSIA), and originally to be implemented by December 31, 2015. On October 29, 2015, Congress passed H.R.38 19 - Surface Transportation Extension Act of 2015, which provided a three-year extension to December 31, 2018 for the installation of PTC.



Figure 1: PTC Timeline from <https://www.fra.dot.gov/Media/File/1168>:
Accessed June 25, 2018

In September 2016, we submitted a paper and gave a presentation reviewing PTC, focusing on the issues and challenges facing the short line and regional railroad industry with respect to PTC. This paper is intended to update that research and give a report on the status of PTC implementation in the short line industry as we approach the new deadline.

What is PTC?

PTC is a mission critical, fault tolerant, vital signaling system. Using GPS-based locations and various radio technologies, PTC monitors many items including switch positions, signal indications, track restrictions, and many other inputs. PTC is intended to do four things: prevent train-to-train crashes, enforce speed limits, protect track workers, and keep trains from running through misaligned switches.

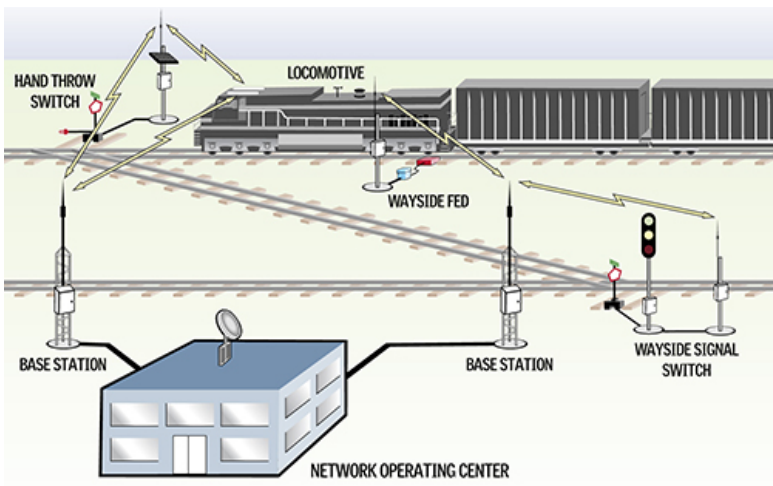


Figure 2: From <http://meteorcomm.com/HomePageImages/PTC/WaysideSignals.jpg>: Accessed June 25, 2018.

Equipment

PTC equipment can be broadly separated into three categories. These categories are; first, the equipment onboard the locomotive; second, the wayside infrastructure; and third, the Back Office Server, or BOS.

First, the 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, including 220 MHz radio, Wi-Fi (802.11), and cellular. (See photos below.)

All the Class I mainline road locomotives in the USA require installation of the TMC, radios, and other equipment. In addition, all commuter locomotives require this equipment be installed as well. Finally, as will be discussed in more detail below, various short lines will require that their locomotives have this equipment installed.

A second, even larger component is 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. Most short lines and regional railroads will not need to install wayside infrastructure.

Third, and last, the final portion of the required PTC infrastructure 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. All Class I and Class II railroads implementing PTC will need to log into a BOS, either their own, or hosted by someone else.

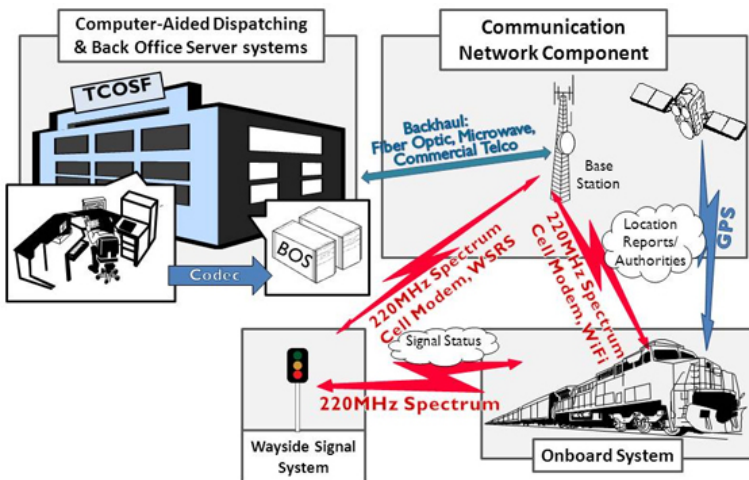


Figure 3: PTC Infrastructure (Image – Metrolink)

Staffing Requirements

Any project with this level of complexity requires a large amount of staff expertise to implement. Staff needs to be trained in their particular subject areas, whether that be onboard, wayside, or BOS equipment. The Class I railroads have hired and trained large numbers of people to develop the 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) working on signaling and track detection, IT staff to handle the BOS operations, and staff from the mechanical departments to install equipment on locomotives.

PTC and Class II and III Railroads

Which short lines need to implement PTC?

PTC was originally conceived to apply to the Class I and passenger railroads. For the most part, regionals and short lines are not required to be equipped with PTC for their day to day operations. However, there are two broad categories where Class II and III railroads may find that they are required to implement PTC to a greater or lesser degree, depending on how they interact with Class I and passenger traffic.

First, if a short line operates on Class I track, they are likely to be required to install PTC equipment on their locomotives. To be more specific, if the short line operates for more than 20 miles on a Class I host at 4 or more trains per day, PTC is required (CFR 49, Subtitle B, Chapter II, Subpart I, 236.1006(b)(4)(ii) and (iii)). And finally, regardless of these requirements, if the Class I host requires that the Class II or Class III railroad implement PTC, then it will need to be installed on their locomotives. These stipulations impact a number of railroads, usually Class II railroads that are in more outlying areas, as they are more likely to have track rights on a Class I to serve their customers.

Second, if a short line or regional railroad hosts or shares track with a passenger railroad, then the short line will also need to implement PTC. This typically affects smaller, more urban short lines that serve industrial customers while operating on track owned by a commuter railroad. In this situation, the railroad only needs to install equipment on its locomotives. However, in some other circumstances, the short line railroad hosts commuter trains on its track. In that case, the short line needs to do a complete installation of PTC, increasing the complexity significantly.

The FRA has given the short lines an extended grace period with a much longer deadline to have their locomotives operational to PTC standards. According to CFR § 236.1006 - EQUIPPING LOCOMOTIVES OPERATING IN PTC TERRITORY, locomotives operated by Class II and III railroads that require PTC equipment do not need to have their equipment operational until December 31, 2023, a full 5 years after the Class I and passenger railroads. However, in our discussions with various railroads, these extensions are not functioning, as the host commuter and Class I railroads are requiring that their tenants have the equipment installed in order to operate on their track.

Implementation Status

A great deal of information about the progress of PTC implementation in the railroad industry is available at the FRA web site. For instance, this illustration highlights that the passenger network is far behind the freight network.

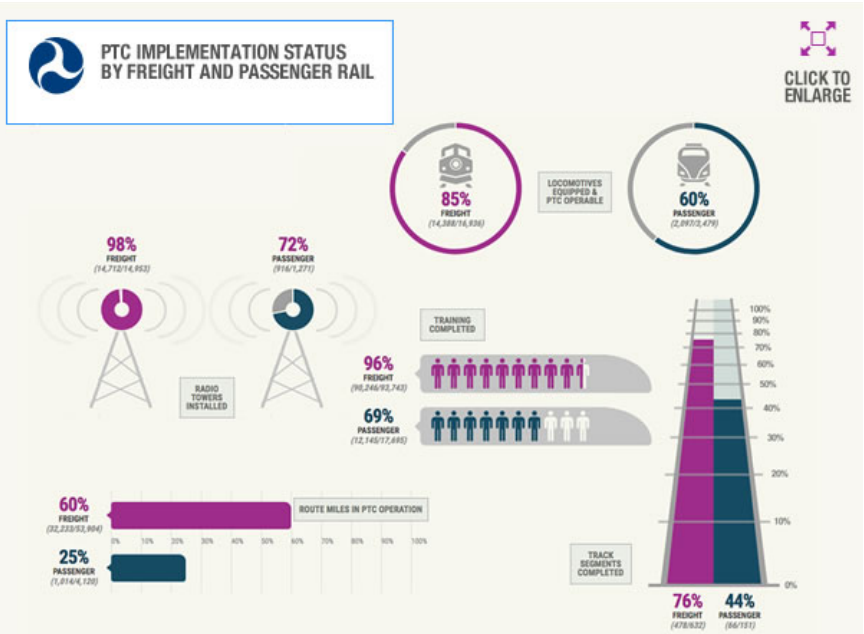


Figure 4: PTC implementation status
 (From <https://www.fra.dot.gov/app/ptcsummary/>: accessed June 25, 2018)

This is in large part because of lack of funding from all levels of government. It is estimated that the 25 commuter rail agencies will need to spend in excess of \$2 billion on PTC. Funds for this initiative must be diverted from other needs, and special funding remains far less than required.

In addition, as of January 26, 2018, according to a key supplier in the industry, 70 short lines needed to comply with PTC requirement. At that time, 15 railroads had yet to start any type of implementation.

This, coupled with a 6-month lead time for equipment, means it is highly unlikely that those that have not started by the beginning of this year would have their equipment installed. A major reason some railroads have been dragging their feet is that many of these railroads have been waiting for technology to mature to prevent the issue of purchasing equipment that would be obsolete before it began



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service. But this delay in implementation has a knock-on effect. As noted in this article, one Class I railroad has proposed an extension, not because they weren't ready, but because of interoperability issues with tenant railroads that haven't completed their work yet.

The short lines that are operating on Class I track have, at least in theory, a much longer time frame to install their equipment. The original legislation gave these railroads till December 31, 2020 to have their equipment installed, and after the extension granted to the Class I railroads in 2015, the current legislation adds 3 years. So, as it stands today, Class II and Class III railroads operating on Class I track don't need to have their PTC paperwork and equipment in place till December 31, 2023. However, if the host railroad insists PTC to be installed, or they require that the tenant wait for an open window on a busy main line, it may not matter what the official deadlines are.

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, it is more complex at the short line for the following four reasons.

First, many short lines do not have a dedicated IT department. Often their IT work is contracted out to a local contractor. In that case, the contractor will not have much experience in the rail industry, and likely will not be aware what is required to install a BOS for PTC.

Second, depending on the size of the short line, signaling and communications (S&C) may or may not be able to handle the installation of the required wayside equipment. These short lines may only have basic signaling infrastructure such as grade crossings. As a result, the S&C department may not have the expertise required for the installations.



Figure 5: In cab PTC equipment that must typically be installed in each locomotive.



Figure 6: Onboard equipment that is usually installed in the nose of the locomotive consists of the Train Management Computer (TMS), Event Recorder, and Crash-Hardened Memory Module (CHMM).



Figure 7: Roof of locomotive cab showing the new installation of antennae arrays to support the PTC installation, and to allow communication between the locomotive and wayside equipment.

Third, 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 same expertise as a Class I. This is the simpler portion of the operation, since equipment purchased from vendors comes with support. However, currently the vendors are extremely busy, and the level of support given is not likely to be the same as an application where there may be 100 of a given type of locomotive.

Many short lines have several types and vintages of locomotives, making each application unique. This creates a lot of work in research, fabrication, and installation. It goes without saying that some short lines have non-mainstream locomotive builds that are not necessarily conducive to the application of PTC.

In addition, most short line operations consist of older generation locomotives that may or may not be readily adaptable to application of this equipment. For example, an old GP-7 with control air and 6BL air brakes is not an ideal candidate. Usually someone can come up with a solution, but the more complex the situation, the more expensive the solution. What will the life cycle of support be if the locomotive is unique? For one short line, the solution was to lease power and pursue that route. But not every short line can justify the purchase or lease of newer power just to make this happen.



Figure 8: Older Locomotive Models Present Unique Challenges (Picture – DMVW)

With the given level of staffing in house, the short line may or may not have the expertise to handle installation and maintenance of PTC. Then the only option may be to contract the work out. But if the work is contracted out, that reduces the familiarity of the short line staff to the equipment. If an issue comes, they are more likely to need to call the contractor, and the unit may be down until the contractor can arrive on site. Long-term, these mechanical issues will mean that the short line industry will probably need more power, as the PTC equipment will add to the downtime that their fleet already experiences.

The Financial Implications of PTC

There are several financial issues. There are only a few vendors for this new equipment. This tends to increase the price of the equipment. In addition, there are a number of annual fees, including the following:

- fees charged by MeteorComm (owned by 4 Class I railroads collectively, BNSF, UP, NS, and CSX) for the 220 MHz Radio frequency start at close to \$200,000, and go up from there, depending on the size of the fleet to be equipped
- Maintenance agreements with the vendors can be an additional \$25,000 / year
- Set up fees and the cost of equipment can be in the range of \$200,000 for purchase and installation
- Hosting services for the BOS can be \$10,000 / month for a couple of locomotives and much higher for larger fleets
- Cell phone charges incurred because the PTC modems on each locomotive are required to be able to access both the AT&T and Verizon networks. This doubles the number of SIM cards, data subscriptions, and bills to be paid, increasing the burden to the short line.

These fees have been going up every year at a rate much higher than inflation. One figure mentioned at a recent ASLRRA mechanical group meeting was that the rate was around 8% per year.

In addition, because PTC is a set of technologies that is intended to reduce the likelihood of accident and injury, there are extensive contracts to cover liability issues, and extensive insurance coverage is required in case the equipment doesn't work properly. Some of the contracts required by equipment providers initially stipulated a level of insurance coverage that is not realistic for most short lines. In at least a few cases, railroads were able to negotiate this down to near or at their current liability insurance coverage.

As a result of these financial issues, in part they are smaller entities with lower operating ratios of the larger Class I railroads, the Class II and especially Class III railroads may find themselves in situations where the cost of implementation and maintenance keeps them from being profitable. As a result, they may shut down, and their customers will lose railroad service.

Paperwork

As with most government initiatives, PTC involves an enormous amount of paperwork. Each railroad involved with PTC needs to have a PTC Implementation Plan (PTCIP) and a PTC Safety Plan (PTCSP). Here also the short lines don't have the workforce like a Class I. The PTCSP needs to include inspection and maintenance plans, an operations and maintenance manual, and vendor lists.

Initially, it was difficult to determine whether the short lines had to have the same extensive documentation that the Class I railroads had.

In addition, the Class II and III railroads are expected to read, understand, and then sign extensive contracts for the following:

- Radio licensing
- Maintenance contracts
- PTC Software contracts

Without legal departments to help interpret the contracts, smaller railroads often had to incur the additional expense of hiring outside legal counsel.

Included in the paperwork and FRA documentation are requirements for training and time reporting. While vendors offer some training, with a small workforce, it can be difficult to determine who should be trained to maximize coverage but minimize the expense.

Finally, the Class II and III railroads are required to certify their locomotives. To run on a Class I, a certification of each locomotive class would be required. Test plans can be 200 pages and take at least 2 days of track time (assuming everything goes smoothly). If a regional railroad crosses more than one Class I track, do all the locomotives need to be certified twice?

The ASLRRRA has been working together with Rockwell Collins to help provide service agreements and PTCSP templates, and this has simplified things somewhat.

Additional Short Line Frustrations with PTC

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

First, when it comes to wayside equipment, the Class III railroad likely is not on the hook. Aside from the unique circumstance mentioned earlier where a short line hosts a commuter train, the majority of Class II and Class III railroads will not need wayside equipment. They may need to install Wi-Fi access points as initialization points for their trains, depending on where they enter the Class I trackage, but otherwise the majority of these issues falls on the Class I host.

Second, the Class II or Class III railroad will still need to determine what to do about the BOS, or Back Office Server. The BOS holds the track databases, train information, and crew information to log in. Class I railroads all have an IT department that can handle this type of work. With a short line however, this likely is not the case. Going to a local third party to set up and support the BOS and slot 10 imaging creates a tough learning curve. (The slot 10 image is effectively the operating system that handles the communications on board the locomotive.) To do this individually can be cost prohibitive. Searching for another provider for these services cost effectively also takes time and effort.

Most Class I railroads do not want to share any of this with their tenant railroads, leaving some wondering how to handle it. The ASLRRRA has two vendors that are providing BOS servers for the Associations' members, WabTec and Herzog.

With respect to the BOS, there have been some unique situations that needed to be resolved. For instance, in one situation, the short line brought the train with their locomotives, equipped with PTC, to a point short of entering the Class I's main line. The short line crew would get off and a Class I crew would board the locomotive before entering the main line. In this case, there was a question about whether the short line needed to maintain a BOS. None of their employees will be operating the train in PTC territory. And none of their employees would be in a crew database for this reason, and the Class I has the train made up prior to their crew boarding. In the end, the Class I agreed to have its employees log in to its own BOS.

Third, some short line railroads may not be ready because of scheduling issues that are outside of their control. In one situation, the short line is ready and has all their equipment installed on their locomotives. However, because the section of Class I track that they operate on is going to be the last to have the wayside equipment installed on that Class I network, they may miss the deadline. In another situation, the short line is ready, but the host commuter railroad that it operates on does not, at last report, have its wayside equipment installed yet.

Fourth, and finally, there are two different types of PTC systems. The Amtrak North-East Corridor (NEC) uses the Advanced Civil Speed Enforcement System (ACSES – developed by Amtrak and Alstom) instead of the I-ETMS (Interoperable Electronic Train Management System) system that the Class I railroads chose. Several short lines are in the unfortunate situation that they need to implement the ACSES system to be interoperable with Amtrak. In the meantime, they are part of larger short line groups. As a result, their locomotives will no longer be interoperable in their own group! In addition, they will struggle to find leased units to operate when they need additional power, as the leased fleets will have I-ETMS installed, if they have any PTC equipment at all.

Conclusions

When PTC was first formulated, Class I railroads and commuter railroads were obviously in the forefront in the regulatory planning process. The regulatory agencies were not considering the short line railroads, aside from giving them an extended deadline. However, because of interactions that short lines have with Class I and commuter railroads, many Class II and III railroads do need to implement PTC to varying degrees. There were many issues and concerns that needed to be dealt with. Thankfully, many of the issues have been resolved. However, for some railroads, their issues will take longer to be dealt with, and in some cases, they will not be resolved because they are part and parcel of the PTC regulations.

References

- Freight Rail & Positive Train Control. Accessible at <https://www.aar.org/article/freight-rail-positive-train-control/>: Accessed June 25, 2018.
- CFR § 236.1006 - EQUIPPING LOCOMOTIVES OPERATING IN PTC TERRITORY. Accessible at <https://www.gpo.gov/fdsys/search/pagedetails.action?collectionCode=CFR&searchPath=Title+50&granuleId=CFR-2016-title49-vol4-sec236-1006&packageId=CFR-2016-title49-vol4&oldPath=Title+1&fromPageDetails=true&collapse=true&ycord=2053>: Accessed June 25, 2018.
- Positive Train Control. Image located at <https://www.fra.dot.gov/ptc>. Image link at <https://www.fra.dot.gov/Media/File/1168>: Accessed June 25, 2018.
- Positive Train Control. Image located at <http://www.meteorcomm.com/itcnet/ptc>. Image link at <http://meteorcomm.com/HomePageImages/PTC/WaysideSignals.jpg>: Accessed June 25, 2018.
- “Is PTC Going to Work?”, from *Trains* (November 2014, pp.26-33). Also located at <https://trn.trains.com/~media/files/pdf/ptc/trnc1114.pdf?la=en>: Accessed June 25, 2018.
- BNSF seeks PTC deadline extension due to interoperability delays. <https://www.progressiverailroading.com/ptc/news/BNSF-seeks-PTC-deadline-extension-due-to-interoperability-delays--54894#>: Accessed June 25, 2018.



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Condition Based Maintenance VIA Rail Canada

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Introduction

All equipment fails. It's just a matter of time.

With the advent of the industrialization era, complex machinery was developed and is used in all sectors: medical, food production, transportation, defence, etc. Its complexity led over time to an evolving approach in regards to maintenance. While in the beginning the machinery was repaired when it broke (first generation), the current third generation's maintenance expectations are to promote greater safety, higher availability and reliability, lower environmental impact, and cost reduction.

When equipment stops operating, it can affect the production capability, the safety of operating personnel, or of passengers, or it can have serious environmental consequences. Thus the equipment downtime can have an important impact on the plant's operation, affecting also the company's bottom line.

The preoccupations with the higher reliability and availability of equipment, led to a new approach to maintenance, which was named Reliability Centered Maintenance (RCM). The RCM was developed and refined over the last 30 years, primarily in the aircraft industry. More and more industries are adopting the RCM techniques now in order to improve their equipment reliability and availability.

This paper summarizes the Reliability Centered Maintenance (RCM), and focuses on the Condition Based Maintenance (CBM) methodology with some examples from VIA Rail's experience with its implementation.

RCM Terminology

Run-to-failure. Maintenance method for first generation of machinery, and still in use when applicable.

Time Based Maintenance/Scheduled maintenance. At pre-established time intervals, components are inspected, repaired, replaced, or overhauled

Reliability Centered Maintenance (RCM): Process to determine the optimum combination of maintenance types for any application or system.

Condition Based Maintenance (CBM): maintenance method that monitors the system's health, principally by performing inspections or monitoring with sensors. The sensor's data, scheduled inspections and measurements, other events, drive the maintenance activities (evidence based), such as repair, replace, or overhaul.

Predictive Maintenance (PdM): methodology used to estimate the Remaining Useful Life (RUL). Evolving technologies are using mathematical or statistical modelling to analyze the data streams collected by real-time monitoring systems. This leads to an intervention before the component fails.

Diagnose: the ability to detect and isolate a failure in a system.

Predict: the ability to detect and isolate a fault while the system is still functional.

Prognosticate: the ability to detect and isolate a fault in a system while it is still functional, and determining the remaining useful life until failure.

RCM - Quick Overview

This is a brief introduction to the RCM process, underlining the importance of condition monitoring as part of it.

RCM's goal is to produce the perfect maintenance program with:

- the least maintenance costs
- lowest operational risk
- highest equipment reliability

RCM's methodology is a logical way to:

- evaluate
- categorize
- prioritize
- understand the operational impact of failure
- identify the appropriate intervention

Knowledge by itself is not sufficient to make sound intervention decisions. RCM therefore takes a pragmatic approach by introducing new techniques to assist in achieving its goals:

- Decision making tools such as Failure Modes and Effects Analysis (FMEA)
- New maintenance techniques such as condition monitoring
- Designing for reliability and maintainability

Figure 1 identifies six equipment failure probability patterns (Right side) related to the third generation of equipment and their respective statistical distribution (Moubray).

These failure patterns, inferred by statistical analysis in the aircraft industry, show that the more complex components/systems are characterized by patterns D, E and F. The probability of failure in these cases doesn't increase significantly with the operating age.

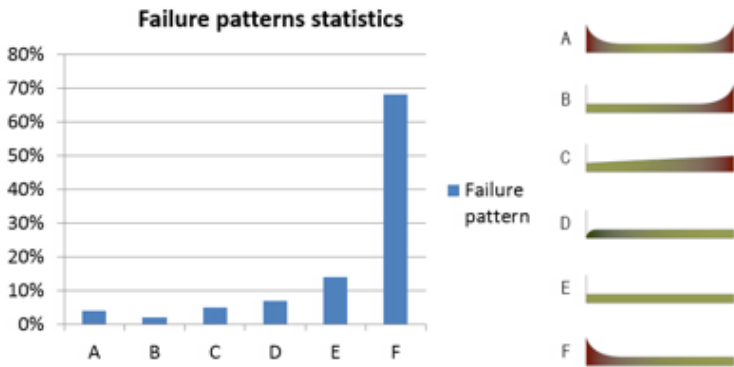


Figure 1 – Equipment failure probability patterns

If age is not the principal factor in components’ failure, the time-based restoration or replacement of a component might not be the most appropriate maintenance technique.

The new approach to maintenance consists in detecting the component’s degradation and therefore it’s potential failure, then repair or replace it before it fails. This has obvious advantages:

1. Avoid the plant/equipment downtime by planning the replacement or repair at a convenient time, before it fails
2. Extend the use of the equipment/component close to its maximum useful life
3. Save the costs associated with an unpredictable plant/equipment shut down and/or with wasting useful life from a component that is being replaced before it is required

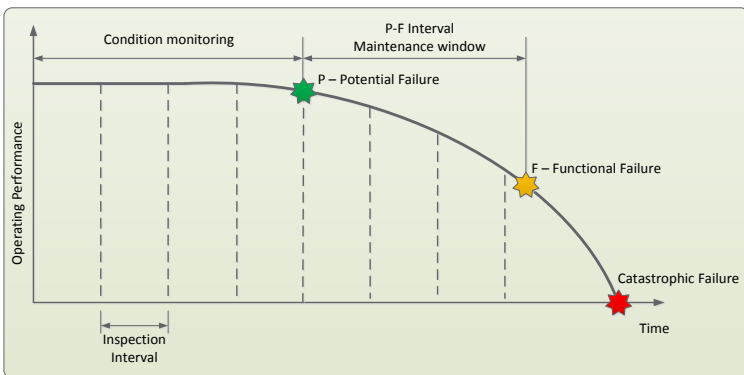


Figure 2 – P-F Curve

Figure 2 describes in a graphical way (Moubray) the performance degradation of a component versus time. Before a functional failure occurs and the equipment becomes unusable (point F on the curve), there is a detectable performance degradation that indicates the potential for failure (point P). Identifying the P-F interval is important for the RCM methodology. “The P-F interval is the interval between the occurrence of a potential failure and its decay into a functional failure” (Moubray)

The Failure Modes and Effects Analysis (FMEA) is the methodology used to identify all functional failures and their root causes, the probability for these failures to happen, and their consequences.

Each component of a machine has its own P-F curve. By monitoring the condition of the vital parts that can cause functional failures, the P point on the curve can be detected, leading to a maintenance decision, which can be restore or replace.

When the useful life is determined with a good precision and is consistent throughout the entire category, e.g. items A, B, and C in Figure 1, the scheduled restoration or scheduled discard of the respective components is the appropriate maintenance practice. For example, oil, fuel, and air filters tend to clog at the same rate on equipment operating under the same conditions over an extended period of time.

In the failure modes described by the patterns D, E, and F in Figure 1, the probability of failure is not dependent on time. It is however affected by random, unpredictable failures of various components of a complex system. Scheduled maintenance interventions on these components are not necessarily useful. The experience proved that they can do more harm than good, introducing instability into an otherwise stable system.

Detecting the P point on the P-F curve and knowing the P-F interval, its shortest and its longest values, makes it possible to predict the failure point and helps determine the condition monitoring inspection tasks. It also makes possible the planning of a maintenance intervention before the predicted Failure point in ways to minimize downtime and its impact on safety and on operations.

Condition Based Maintenance (CBM)

For the detection of the potential failure point P shown in Figure 2 it is appropriate to perform failure-finding maintenance tasks that can lead to component replacement or repair on condition.

Various techniques are used to detect the potential failure point:

- Visual inspections for signs of breakage, wear and tear, thermal discoloration of components, etc.
- Vibration and acoustic measurements, including listening for excessive noise or vibration
- Particle count in fluids
- Chemical changes

- Temperature measurements, e.g. detecting the overheating caused by malfunction
- Current and voltage measurements
- Other techniques

Condition Based Maintenance Initiatives at VIA Rail Canada

VIA Rail, similar to other railroads, had in place until recently a primarily time based maintenance program. During the last few years, as the new concepts have been developed and became available in literature, and as the monitoring technology was advanced by the equipment manufacturers, VIA Rail is going through a paradigm shift by adopting the new RCM methodology.

This resulted on one hand in changing the scheduled maintenance from time-based to mileage-based intervals. This was done on the understanding that the equipment's wear correlates closer to its hours of operation than to the linear time variable. The same type of locomotives may travel more or less miles with the same time interval, depending on their service assignments.

It also led to the introduction of the CBM technique where appropriate.

A detailed FMEA analysis was performed on certain systems, such as HVAC and door operators on cars and air brake systems.

Using empirical data, other systems have been selected for condition monitoring of certain parameters that indicate the decay of their operation and their potential failure:

- Main engines
 - o Fuel injection system
 - o Water pumps
 - o Accessory gear
 - o Main alternator alignment
- Air compressors
- Compressed air piping
- Air valve heaters, freeze-up protection
- Lead-acid batteries
- Fridge compressors
- Head End Power train line receptacles

Several of these CBM tasks are now implemented in the current maintenance program, while others are under study and in progress with VIA Rail's CBM specialist.

The main monitoring techniques used currently at VIA Rail are:

- Thermography by IR cameras to detect hot or cold spots
- Vibration analysis
- Battery internal resistance and electrolyte density measurements
- Sound and ultra sound analysis

- Current and voltage detection
- Real-time remote monitoring of all on-board systems that have the embedded capability of self-testing, self-diagnosing and digital communication

Other technologies or techniques may be adopted as they will be studied and proven.

The scope of this paper is limited to examples of CBM techniques applied on locomotives, with a few references to passenger car applications.

Thermography - EPA-42 injection system

At mileage-based intervals, the CBM inspection is scheduled. The exhaust temperature is measured. Refer to Figure 3 below. It was determined that sensible variations indicate either the proper operation of the fuel injectors, or the malfunction of one or more injectors. By thermal imaging, the malfunctioning injector can be rapidly identified and then replaced.

This thermal analysis eliminates the scheduled replacement of all injectors based on a time variable alone.

This became a fast and reliable diagnostic of a bad cylinder (Bosch pump + combustion); it extends the use of injectors up to their full useful life and brings a saving of about \$2,000 per Bosch pump to which we add the savings with the maintenance and troubleshooting time.

The data is collected and data trending is performed at this time in an Excel spreadsheet.



Figure 3 – EPA-42, engine injection system thermal analysis

Thermography – F40 injection system

Similar to the EPA-42 locomotives, the thermal analysis of the F40 main engine is now being used to detect failures in the injection system. See Figure 4.

This technique extends the injectors operation to the full extent of their useful life and brings a saving of about \$1,000 per injector for a total of about \$832,000 in material alone, plus maintenance and troubleshooting time savings.

The data is also collected and trended at this time in an Excel spreadsheet.



Figure 4 – F40, engine injection system thermal analysis

Freeze Protection System – Thermography and Current Monitoring

The freeze-up protection system is a vital part of the air-brakes system, which is an important safety system.

In order to prevent freeze-ups in the compressed air system at cold temperatures, and keep the air braking system operational, air-pipe and air-valve heaters are installed on locomotives.

Formerly, the heating elements were inspected for operation by using an IR gun and artificial freezing techniques. This led to defects caused by the thermal shock on the air valve heaters.

By using the thermal imaging, load current monitoring, and a better task scheduling tied to the ambient temperature, the diagnosis of the freeze-protection system was significantly improved in terms of non-intrusiveness, precision, and inspection time.

At VIA Rail, two techniques are employed to validate the proper operation of the freeze protection heating system:

- Thermography: facilitates the quick inspection of the heaters along the air

circuit on locomotives, such as air dryer valve heaters, air reservoir valve heaters, and air conduit heat tracing. Refer to Figure 5 for an example of a heat tracing thermography.

- Monitoring the drain valves' operation by analyzing the current patterns in their power supply circuit. Figure 6 shows the display panel of the monitoring system.



Figure 5 – Freeze protection – Thermography of the air conduit heat tracing

The current monitoring system is a PLC-based device that was designed by VIA Rail and was applied on all locomotives.



Figure 6 – Freeze protection monitoring Display panel

Thermography – Electrical Connections

Using thermography makes it easy to inspect and troubleshoot power electrical connections. Two examples are used to illustrate the benefit of this technique.

Head End Power train line receptacles:

Due to contamination, oxidization, and mechanical wear, the contacts deteriorate over time and can cause catastrophic failures by overheating, insulation carbonization, short circuit and fire. Thermography is a quick and reliable technique to detect failing connections under load, without touching the energized cables and connectors. Defective receptacles can be identified well before they fail.

Engine layover heating system, power supply connections:

On several occasions, the fuses that are protecting the heating system blow for no apparent reason. A detailed analysis revealed that the power cable connections to the protecting fuses inside the electrical panel had a tendency to loosen over time due to vibration. This caused the heating of the electrical connection by several degrees. Through conduction, the whole fuse, including its fusing element, overheated thus changing its operation point. This led further to the fuse burning at a lower than the specified value of the load current, putting the engine heating system out of order and thus exposing the engine to freezing. Inspecting the connections with an infrared camera, quickly and surely reveals connections that start heating up abnormally. The appropriate corrective action can be performed, such as tightening the loose connection(s) before the fuse(s) fail(s).

Engines, Oil Analysis

The main and HEP generator set engines are submitted to CBM inspections: oil samples are taken and then analyzed by the VIA Rail's Oil Lab specialist for variations in:

- Soot levels
- Oxidization
- Contamination
- Metal particles: Iron, Copper, Lead

Monitoring its quality allowed VIA Rail to change the oil when dictated by its condition, thus extending the change intervals, and saving the costs in oil and labor corresponding to more frequent, time-based approach.

The oil data is recorded, analyzed and trended in Excel spreadsheets.

Main Engine Vibration on F40 locomotives

Several measuring points have been established by the CBM specialist on the main engine of the F40 locomotives. Data was collected from all locomotives and analyzed. This led to an empirical determination and understanding of the

vibration patterns in these locations. By harmonic analysis, they were correlated with the components causing them. Three components were identified so far as significant in the vibration analysis:

- **Accessory gear.** High vibrations are an indication of advanced wear. Further analysis led to the understanding that this wear is caused in great part by the hunting associated with the fast acting electronic engine speed control that has its speed pick-up sensor actuated through this gear. In order to reduce the wear rate of the accessory drive gear, the engine speed sensors were moved to the other end of the engine, onto the starter ring gear.
- **Water pumps.** The degradation of the water pumps' bearing or impeller is easily diagnosed by vibration analysis. The wear is detected before the pumps fail.
- **Main alternator alignment.** The vibration analysis revealed that on certain F40 locomotives, while performing a self-load, high vibration levels were measured on the engine at the alternator coupling end. The harmonic analysis revealed that the source of vibration is the main alternator. It was determined that the root cause is the main alternator's misalignment which leads to electro-magnetic unbalance. The vibration levels are proportional with the electrical load applied. Figure 7 below shows the following measures:
 - o Top: Velocity in frequency domain. Critical vibration at 452Hz (15.06Hz x 10poles x 3phases = 452Hz)
 - o Middle: Acceleration in time domain
 - o Bottom: Velocity, trending over time

Due to the high cost of the alternator re-alignment, the consequences and the maintenance actions to be performed are still under study.

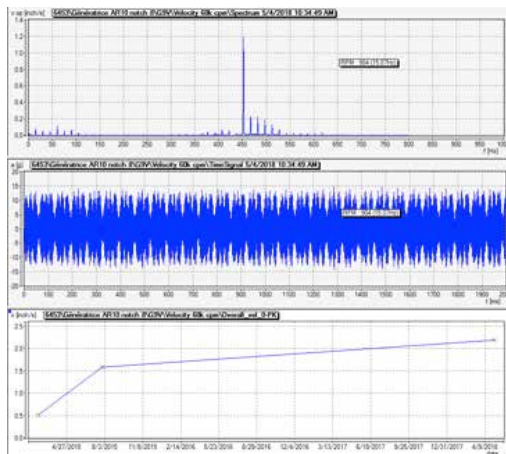


Figure 7 – F40 Main alternator vibration analysis

Lead-Acid Batteries

The health status of the lead-acid batteries is assessed by measuring their internal resistance and by measuring the electrolyte's specific gravity.

This is currently being performed on all the cars and locomotives equipped with lead-acid batteries at intervals of 60,000miles (semi-annual).

The battery tester SBS-6500 is used for the resistance measurements (Figure 8).



Figure 8 – Battery tester



Figure 9 – Digital hydrometer

The digital hydrometer used at VIA is the SBS-2003. (Figure 9)

Example:

For the battery type ENERSYS LRC OLDHAM SUA, 150AH, 2.000V cells:

- Normal internal resistance: 1.750 mOhms
- Fail voltage threshold: 1.666V
- Internal resistance warning: 2.275 mOhms

Internal resistance fail: 2.625 mOhms

The data is collected, trended, and then analyzed at this time in an Excel spreadsheet. See Figures 10 and 11 for an example of a battery test report.

Battery Condition Report

I. Location

1. System Location : MMC
2. Technicians Name : A. Lusca
3. Inspection Date: 12/3/2014 11:40:45 AM

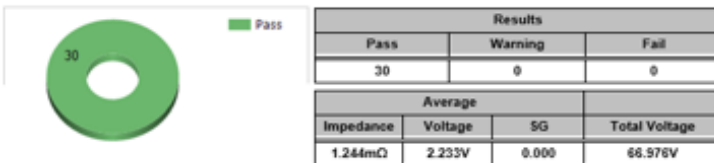
II. System Information

1. String Name : 347B 14A1944-4C
2. Manufacturer : ENERSYS
3. Model: SUA3
4. Capacity: 150.0 Ah
5. Number of cell: 30

III. Values

Internal Resistance (mΩ)			Voltage (V)	
Reference	Warning	Failure	Measurement Voltage	Low Voltage Limit
1.750mΩ	2.275mΩ	2.625mΩ	2.000 V	1.666 V

IV. Summary



V. Chart

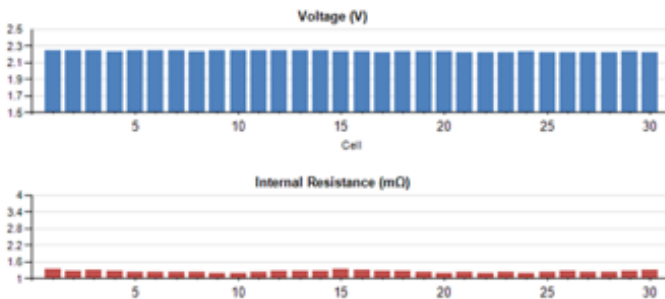


Figure 10 – Battery test report

VI. Test Results					
Cell	Impedance	Volt	SG	Temp	Result
1	01.34mΩ	2.246 V	—	23.9 °C	Pass
2	01.25mΩ	2.244 V	—	23.1 °C	Pass
3	01.30mΩ	2.239 V	—	23.2 °C	Pass
4	01.25mΩ	2.237 V	—	23.4 °C	Pass
5	01.21mΩ	2.238 V	—	23.5 °C	Pass
6	01.24mΩ	2.246 V	—	23.6 °C	Pass
7	01.22mΩ	2.242 V	—	23.7 °C	Pass
8	01.24mΩ	2.234 V	—	23.7 °C	Pass
9	01.20mΩ	2.241 V	—	23.9 °C	Pass
10	01.20mΩ	2.241 V	—	24.0 °C	Pass
11	01.22mΩ	2.240 V	—	24.1 °C	Pass
12	01.26mΩ	2.238 V	—	24.1 °C	Pass
13	01.25mΩ	2.241 V	—	24.2 °C	Pass
14	01.27mΩ	2.238 V	—	24.2 °C	Pass
15	01.34mΩ	2.236 V	—	24.3 °C	Pass
16	01.30mΩ	2.229 V	—	23.3 °C	Pass
17	01.26mΩ	2.224 V	—	23.3 °C	Pass
18	01.26mΩ	2.228 V	—	23.3 °C	Pass
19	01.21mΩ	2.227 V	—	23.4 °C	Pass
20	01.20mΩ	2.226 V	—	23.4 °C	Pass
21	01.23mΩ	2.221 V	—	23.4 °C	Pass
22	01.20mΩ	2.225 V	—	23.5 °C	Pass
23	01.21mΩ	2.221 V	—	23.5 °C	Pass
24	01.19mΩ	2.228 V	—	23.6 °C	Pass
25	01.21mΩ	2.225 V	—	23.7 °C	Pass
26	01.25mΩ	2.221 V	—	23.8 °C	Pass
27	01.21mΩ	2.224 V	—	23.9 °C	Pass
28	01.23mΩ	2.224 V	—	24.0 °C	Pass
29	01.27mΩ	2.227 V	—	24.0 °C	Pass
30	01.31mΩ	2.225 V	—	24.2 °C	Pass

Figure 11 – Battery cell impedance and voltage test results

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Ultrasound

The ultrasound technique is being used successfully for the detection of leaks in the compressed air system and piping, mostly for troubleshooting purposes at this time.

The ultrasound meter (Figure 12) is also used as a stethoscope to listen to gears, pumps, and engine combustion sound. In certain situations the ultrasound measurement is used to complement the vibration analysis.



Figure 12 – Ultrasound detector

Locomotives Remote Monitoring

The original VIA GPA-30 locomotives were all equipped during the last major overhaul with new computer controls and micro-processor based electronic components.

In 2014, VIA Rail Canada commissioned a remote monitoring system on both GE EPA-42 and EMD overhauled locomotives. The system communicates all on-board data, such as Event Recorder downloads, operational data points and fault notifications to a remote server by means of wireless technologies: Wi-Fi, cellular, and satellite modems. Refer to Figure 13.

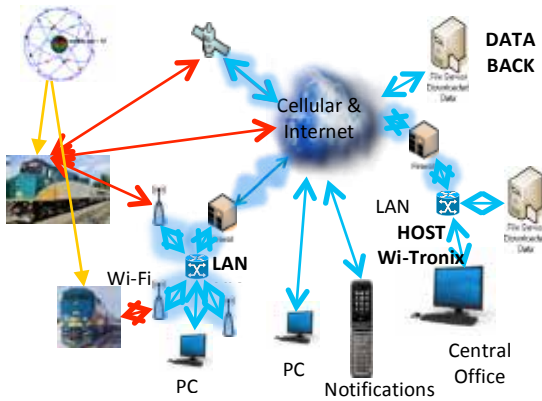


Figure 13 – Locomotive remote monitoring system's architecture

At the core of this monitoring system stands a data collector computer that is interfacing with all on-board devices, some of which have themselves the built-in capability of data acquisition and self-diagnosing.

Currently, the following systems are monitored remotely:

- Vehicle control computers
- Event recorders
- Main engine controller
- Head End Power genset controller
- Digital Video Recorder (LDVR)
- Fuel monitoring system
- HotStart, engine layover heating

Under test

- F40/GPA-30H genset engine

Future developments

- Bearing temperature monitoring system
- OBSM (On-board system monitoring). This is a provision for future expansion of the monitoring system to additional measuring points that are not covered by the current systems

The remote monitoring system also provides the localization of all locomotives in real-time, by means of GPS coordinates. See Figure 14 for an example of the fleet distribution across Canada.



Figure 14 – Locomotive remote monitoring GPS tracking

The system sends equipment fault alerts to cellular phone numbers of specified users in the appropriate locations. This allows the Maintenance Team to quickly respond and correct the issues or devise a contingency plan.

Asset	Model	Time	Train #	Location	Station	MP	Subdivision	Region	Status	Reverse	Thrusts	Speed	Reading	Fuel Load	Load	Trip	MP	EC
00-000	1420C	11:21:00 AM	11-20	London, ON	London Station	71.1	Central	Turning	Control	Dir	0.0	0.0	100	1,000	0.0	0	00	00
00-001	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	-	Control	Dir	-	-	-	-	-	-	-	-
00-002	1420C	11:21:00 AM	-	London, ON	Toronto Station	0.0	Oau-Vergas	Turning	Control	Dir	0.0	0.0	0.0	1,700	0.0	0	70	00
00-003	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Shutdown	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-004	1420C	11:21:00 AM	-	London, ON	-	0.0	London local	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	70	70
00-005	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Shutdown	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-006	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Reverse	Thru	0.0	0.0	0.0	1,000	0.0	0	00	00
00-007	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-008	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Reverse	Thru	0.0	0.0	0.0	1,000	0.0	0	00	00
00-009	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Shutdown	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-010	1420C	11:21:00 AM	-	Chatham-Kent, ON	-	0.0	Chatham	-	Control	Dir	-	-	-	-	-	-	-	
00-011	1420C	11:21:00 AM	-	London, ON	Toronto Station	0.0	Toronto	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-012	1420C	11:21:00 AM	-	Ottawa, ON	Ottawa Station	70.0	Quebec	Shutdown	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	70	00
00-013	1420C	11:21:00 AM	00-24	Sen, ON	-	0.0	Ugvalin local	Turning	Forward	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-014	1420C	11:21:00 AM	00-24	Ottawa, ON	-	0.0	Quebec	-	Control	Dir	-	-	-	-	-	-	-	
00-015	1420C	11:21:00 AM	00-24	London, ON	-	0.0	Quebec	Turning	Forward	Dir	14.7	0.0	0.0	1,000	0.0	0	00	00
00-016	1420C	11:21:00 AM	00-24	London, ON	Ugvalin Station	0.0	Ugvalin local	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-017	1420C	11:21:00 AM	00-24	London, ON	Toronto Maintenance Center	0.0	Quebec	Turning	Forward	Thru	1.0	0.0	0.0	1,000	0.0	0	00	00
00-018	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Shutdown	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-019	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Shutdown	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-020	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Shutdown	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-021	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Shutdown	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-022	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Forward	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-023	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Shutdown	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-024	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-025	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-026	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-027	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-028	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-029	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-030	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-031	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-032	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-033	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-034	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-035	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-036	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-037	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-038	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-039	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-040	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-041	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-042	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-043	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-044	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-045	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-046	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-047	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-048	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-049	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00
00-050	1420C	11:21:00 AM	-	London, ON	W- Toronto Maintenance Center	71.0	St-Hyacinthe	Turning	Control	Dir	0.0	0.0	0.0	1,000	0.0	0	00	00

Figure 15 – Locomotive remote monitoring system. Fleet summary at a glance

The maintenance teams can analyze the status of the entire fleet of locomotives in real-time. Figure 15 above shows a sample of the fleet status summary page. In a single screen, the maintenance specialist can immediately see the status of multiple locomotives, which can be grouped by region, by fleet type, etc.

CBM by Remote Monitoring

The remote monitoring system provides all real-time fault data collected by the on-board systems. Here is a partial list of components and systems reporting remotely:

- Vehicle control system and all related fault data, including:
 - o Main engine control
 - o Air brakes system
 - o Main alternator bearing temperature
 - o Traction motors overcurrent and flashovers
 - o Axle generator: speed signal and related signal degradation faults.
Further analysis is performed on event recorder speed data to detect the beginning of failure, before it is detected by the current fault detection mechanisms.
- Event recorder: daily automatic download and faults reporting
- DVR health status and diagnostics. The DVR system is equipped itself with diagnostic capability of the internal memory, the operation of the microphones and of the digital cameras.
- Head End Power generator: the status of the vital parameters that relate to the engine operation, the electrical power generation and distribution

Figure 16 is an example of an axle generator noisy signal versus a clear, good signal. The noise superimposed over the speed signal is an indication of the beginning of failure (P point on the P-F curve). Detecting the noisy signal can initiate the axle generator replacement before it fails, thus preventing the consequences related to the loss of speed indication in service.

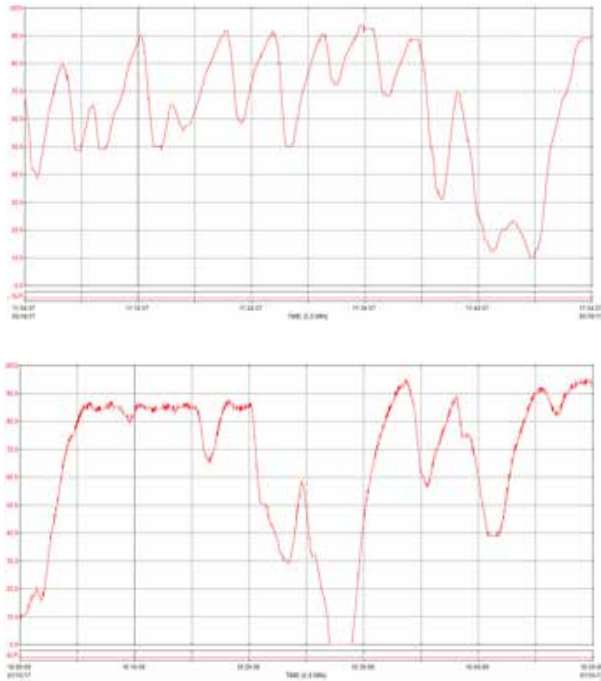


Figure 16 – Axle generator signal. Top: healthy signal. Bottom: noisy signal

Conclusions

The adoption of the RCM methodology and CBM techniques offer a systematic approach to companies to target a higher reliability and availability of their assets. Important savings can be obtained by predicting the failure points of various components, maximizing their use, and planning their replacement or overhaul in due time. In order to maximize the benefits, the company needs to undergo the necessary changes at the process, cultural, and philosophical levels. A progressive and methodic approach can mitigate the risks that are inherent with the change.

Credits

The introduction and development of the RCM/CBM techniques at VIA Rail Canada is the result of the combined effort of the Equipment Reliability team of Specialists: Ronald Bartels, Andrei Flucsa, Maxime Labrie, Philippe DiStilio, Lukasz Szynsiak, Martine Corbeil, Peter Imhoff, and Eugen Grecu

References

Moubray J.M. RCM – Reliability-centered Maintenance, second edition. New York, Industrial Press Inc., 1997

Troubleshooting a One-Way Serial Link on an EMD SD70M Using EM2000

Prepared by:

Randell L. Honc – Southwest Research Institute (SwRI)

Jason B. Fox – Union Pacific Railroad (UP)

Introduction

The EMDEC (Electro-Motive Diesel Engine Control) system was developed to allow for a number of improvements in engine performance. Electronic control of a fuel injection system aids in improved fuel economy and a reduction in certain types of exhaust emissions. This is made possible by the system's ability to sense change in engine or ambient conditions, and adjust fuel delivery rates and injection timing to compensate. The EMDEC system controls engine speed and functions like a Woodward governor. If speed drops, EMDEC adds fuel (increases the injector pulse widths). If speed rises, EMDEC cuts fuel (reduces the injector pulse widths).

The EM2000 Locomotive Control Computer controls the main generator output by means of the main generator field control assembly. This function is known as "excitation control." In addition, EM2000 also perform adhesion control. Locomotive wheel slip occurs when traction motor torque overcomes wheel-to-rail friction. For any given set of conditions (wheel speed, rail and wheel conditions, weather, etc.), there is a maximum torque level that can be applied to the wheels without causing them to slip on the rails.

Both controllers need to communicate with each other to perform their duties. Depending on the application, the communication from EMDEC to EM2000 may be a one-way or two-way serial data link. The one-way serial link allows for simple engine speed instructions from the EM2000 to EMDEC, and simple fault messages and performance feedbacks from EMDEC to the EM2000. The two-way serial link allows for enhanced data transmission both ways. This paper will focus on the one-way serial link used on an EMD SD70M locomotive.

One-Way Serial Link Basics

Locomotives utilize eight (8) distinct operational setpoints called notches to perform their job of hauling freight (we will ignore braking for simplicity). These 8 notch settings are denoted by four relay combinations (A valve, B valve, C valve, and D valve) which are presented in Table 1.

Notch	A valve	B valve	C valve	D valve
1	OFF	OFF	OFF	OFF
2	ON	OFF	OFF	OFF
3	OFF	OFF	ON	OFF
4	ON	OFF	ON	OFF
5	OFF	ON	ON	ON
6	ON	ON	ON	ON
7	OFF	ON	ON	OFF
8	ON	ON	ON	OFF

Table 1. Relay Position as a Function of Notch

The operator selects the notch position (valve settings) by using a throttle handle at the locomotive’s engineer station. The Locomotive Control Computer (EM2000) uses the notch position to determine a power setting and outputs the valve settings to the Engine Control Module (ECM). Figure 1 shows the communications between EM2000 and EMDEC.

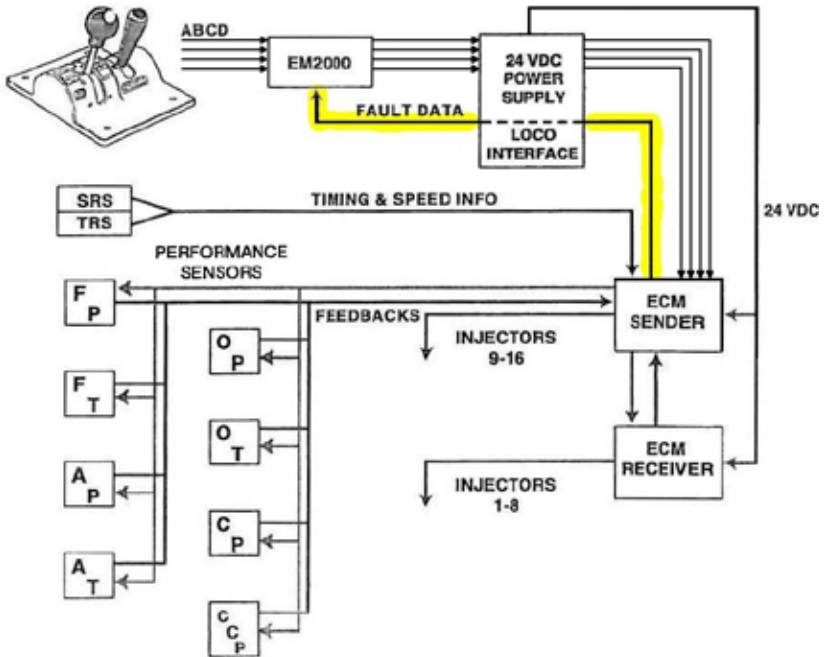


Figure 1. One-Way Serial Link

The EMDEC control circuit performs the same functions as the engine governor/load regulator control circuit. The EMDEC system supplies an engine torque ratio (EngineR) signal in digital serial form to the locomotive computer (EM2000). The EM2000 processes the EngineR data into load ratio data that is functionally similar to the traditional load regulator percent signal.

In addition to EngineR, EMDEC also uses electronic sensors to detect various diesel engine faults, and broadcasts the fault data to EM2000 via the one-way serial link.

Communication Loss

The first indication of a communication loss between EM2000 and EMDEC might be an unexpected engine shutdown with an engine protection fault message. The fault message may contain a EUI COMM LOSS reference. A typical message would be one like in Figure 2.

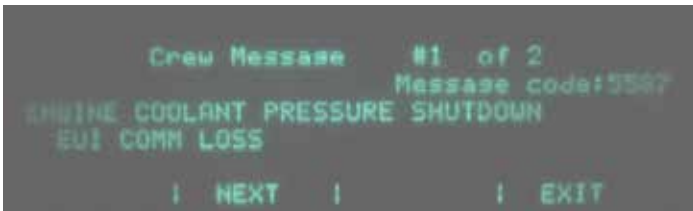


Figure 2. EUI COMM LOSS

To confirm the loss in communication between EM2000 and EMDEC, we can use the programmable data meter on the locomotive display.

- Enter the Programmable Meter on the locomotive display and pull up the EngineR, ECM On, and EC Fail parameters.
- Verify that the EngineR value exists and continues to update rapidly when the engine is running. The value should range from 0.1 to 0.875.
- ECM On is a signal from EMDEC indicating the Engine Control Module (ECM) is on. The value should be “ON”.
- The EC Fail is a signal indicating the status of the EMDEC control data link. The value should be “OFF”.

If the above conditions are satisfied, the serial link is in place and functioning. Figure 3 shows a failed serial link.



Figure 3. A Failed Serial Link

EMDEC Interface Board

EMDEC continuously broadcasts fault data and load control information to the locomotive computer (EM2000) through the EMDEC Interface Board. The EMDEC Interface Board is mounted on the side of the power supply in the AC cabinet of the locomotive which is shown in Figure 4.

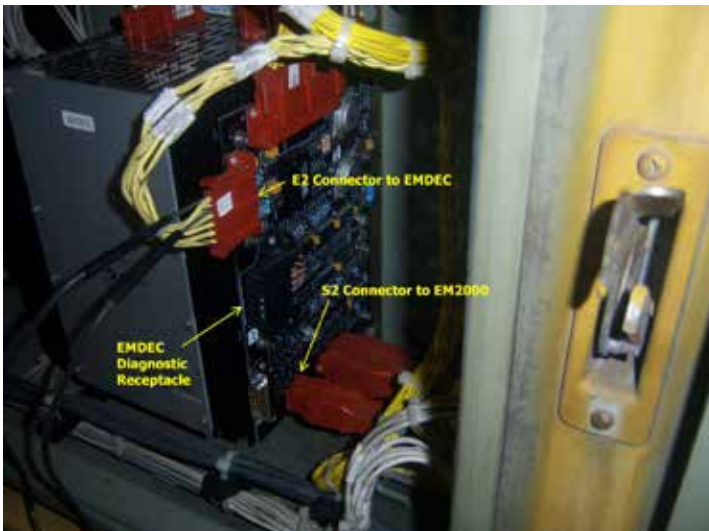


Figure 4. EMDEC Interface Board

The EMDEC Interface Board isolates the engine ECM computer(s) from the locomotive computer. In addition to the One-Way Serial Link, there is an EMDEC Diagnostic Link that the diagnostic service tool uses for troubleshooting, loading software, and inputting injector calibrations.

Troubleshooting the Engine (EMDEC) Side of the Serial Link

If the EMDEC system and EM2000 are not communicating, the first step in troubleshooting should be to look for serial traffic at the E2 connector on the EMDEC Interface Board. The following tools are not required but will simplify this task.

- A set of test lead back probes
- A differential probe for the oscilloscope of your choice

Figure 5 shows the schematic of the engine (EMDEC) side of the serial link. The one-way serial link can be observed on pins 1 and 2 of the E2 connector on the EMDEC Interface Board.

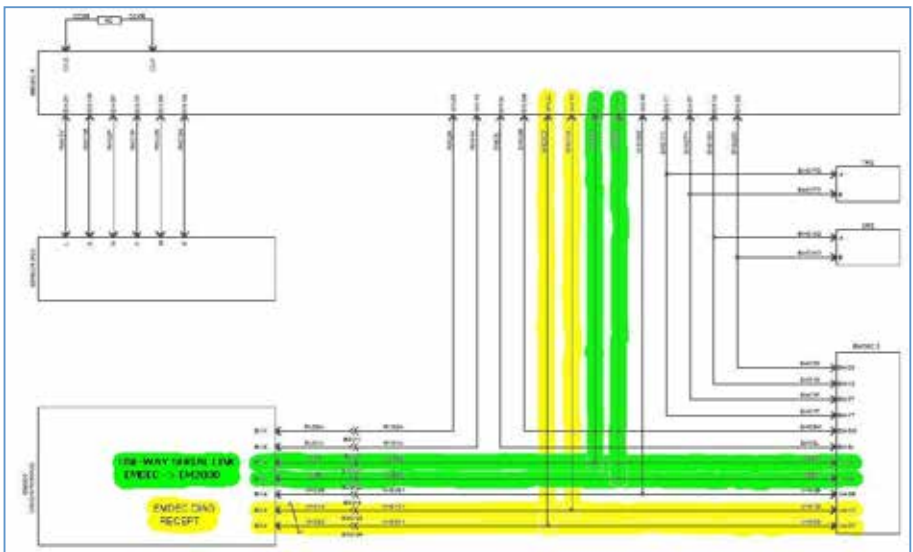


Figure 5. . EMDEC Side of the Serial Link

Figure 6 is an example of the set of back probes used in this exercise and Figure 7 is the differential probe that attaches to the oscilloscope. Figure 8 shows the equipment connected to pins 1 and 2 of the E2 connector on the EMDEC Interface Board.

Serial traffic should be observed at the EMDEC Interface Board when the Engine Control Modules (ECMs) are powered. This indicates that the ECMs and cables up to the EMDEC Interface Board are good and to proceed to Troubleshooting the EM2000 Side of the Serial Link.

Figure 9 is an example of the serial traffic that can be observed with an oscilloscope. If there is no serial traffic at the E2 connector of the EMDEC Interface Board, then we have a bad Sender ECM or faulty cable. Figure 10 shows the Sender ECM and the VHC and CC serial link connectors.



Figure 6. Test Lead Back Probes



Figure 7. Tektronix Differential Probe



Figure 8. EMDEC Side Serial Traffic

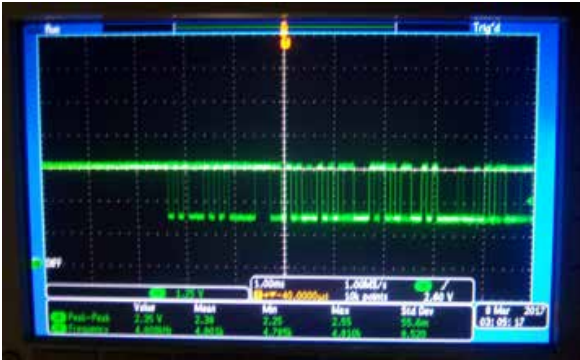


Figure 9. Typical Serial Traffic Observed



Figure 10. Sender ECM Serial Link Connectors

To check the cable from the ECM to the Interface Board, power down the locomotive and disconnect the E2 connector at the Interface Board and the CC connector at both ECM's. Measure the resistances in Table 2. If the results do not agree with Table 2 then the cable has a short or a discontinuity. Do not pierce the wire insulation while trying to determine the location of a discontinuity as this may cause additional problems. A visual inspection of the cable and connectors should be sufficient.

Test Point	Resistance
E2-1 → CC-A	< 10 Ω
E2-2 → CC-B	< 10 Ω
E2-1 → E2-2	INF

Table 2. Typical ECM Wiring Harness Resistance Measurements

If the cable is good then by process of elimination, the ECM is faulty. Replace the ECM with a known good ECM and look for serial traffic at the E2 connector of the Interface Board.

Troubleshooting the Locomotive (EM2000) Side of the Serial Link

If we observe serial traffic at the E2 connector of the EMDEC Interface Board, then the problem resides with the Interface Board or the EM2000 side of the serial link. Figure 11 shows the schematic of the locomotive (EM2000) side of the serial link. The components that need to be tested include the following:

- EMDEC Interface Board
- SD3/SD2 Cable
- Serial Distribution Panel
- SD4 Cable
- CPM Module



Figure 11. EM2000 Side of the Serial Link

Figure 12 shows a breakout cable that can be used at the serial distribution panel or in-line with a DB25 connector terminated cable. Figure 13 shows the oscilloscope leads connected to the serial distribution panel pins 10 and 11.

The best place to test the EM2000 side of the serial link is at the serial distribution panel located in the locomotive cab electrical cabinet. If no serial traffic is observed at pins 10 and 11 of the serial distribution panel, then the EMDEC Interface Board is suspect. Replace the EMDEC Interface Board with a known good one and look for serial traffic at pins 10 and 11 of the serial distribution panel. If serial traffic is observed at the serial distribution panel then check the Programmable Meter on the locomotive display to verify that EngineR is updating and the EC Fail parameter is “OFF”. The serial communication is restored.

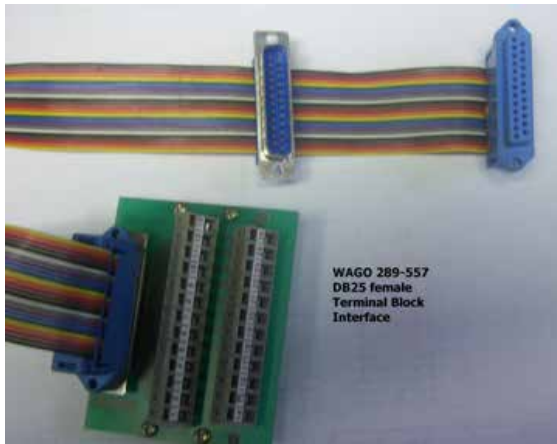


Figure 12. DB25 Breakout Cable



Figure 13. Serial Distribution Panel

If serial traffic is still not observed at pins 10 and 11 of the serial distribution panel, then the SD3/SD2 cable is suspect. To check the SD3/SD2 cable from the EMDEC Interface Board to the Serial Distribution Panel, power down the locomotive and disconnect the SD3 connector at the interface board and the SD2 connector at the serial distribution panel.

Figure 14 shows a DB25 cable that can be temporarily connected to the SD2 cable in the locomotive cab and run down the walkway to the electrical cabinet. Figure 15 shows the setup used to check the SD3/SD2 cable.

Measure the resistances in Table 3. If the results do not agree with Table 3 then the cable has a short or a discontinuity. Hopefully, the SD3/SD2 cable tests good. If the cable tests bad, check the pins in the connectors before running a new cable.



Figure 14. DB25 Cable 100 ft.



Figure 15. Checking SD3/SD2 Cable



Figure 16. Checking the SD4 Cable

Test Point	Resistance
S2-5 → SD2-11	< 10 Ω
S2-6 → SD2-10	< 10 Ω
S2-5 → S2-6	INF

Table 3. Typical SD3/SD2 Cable Resistance Measurements

Figure 16 shows the DB25 Breakout Cable and oscilloscope leads connected in-line to the 8B connector of the SD4 cable at the back of the locomotive computer.

If no serial traffic is observed at pins 6 and 7 of the 8B connector and there is serial traffic at the Serial Distribution Panel, then the SD4 cable and the Serial Distribution Panel are suspect. The SD4 cable can be checked using the same setup used for the SD3/SD2 cable.

Measure the resistances in Table 4. If the results do not agree with Table 4 then the SD4 cable has a short or a discontinuity. If the SD4 cable tests good then the Serial Distribution Panel is suspect.

Test Point	Resistance
8B-6 → SD4-10	< 10 Ω
8B-7 → SD4-11	< 10 Ω
8B-6 → 8B-7	INF

Table 4. Typical SD4 Cable Resistance Measurements

Replace the Serial Distribution Panel with a known good one and look for serial traffic at pins 6 and 7 of the 8B connector. If serial traffic is observed at the back of the locomotive computer then check the Programmable Meter on the

locomotive display to verify that EngineR is updating and the EC Fail parameter is “OFF”. The serial communication is restored.

If communications have not been restored and there is serial traffic all the way to the back of the locomotive then the CPM module is suspect. Figure 17 shows the CPM Module.



Figure 17. The Locomotive Computer (CPM Module)

Replace the CPM module with a known good one and check the Programmable Meter on the locomotive display to verify that EngineR is updating and the EC Fail parameter is “OFF”. The serial communication is restored.

Software Mismatch

If there is serial traffic all the way to the back of the locomotive computer at the 8B connector then there might be a software mismatch. The locomotive computer (CPM Module) runs the EM2000 software that controls the main generator and performs adhesion control. The engine control module (ECM) runs the EMDEC software that controls the engine. Both controllers need to communicate with each other to perform their duties. There are two types of a one-way serial link messaging:

- One-Way Serial Link
- Extended One-Way Serial Link

Both computers need to use the same messaging scheme or they will not understand each other. Also there are some hardware considerations; the older D3 engine control modules cannot support Extended One-Way Serial Link messaging.

Conclusion

This paper is intended to help locomotive electricians troubleshoot common serial link 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.

Acknowledgements

Brad Silvers – Progress Rail

Battery Temperature Performance Study with Strategies to Optimize Charging and AESS Settings

**Continuation of “A Study of Locomotive Battery Charging and
Performance” from 2017 LMOA Proceedings.**

Prepared by:

Jason Fox – Union Pacific Railroad

Sid Bakker – Transportation Products Sales Company

Abstract

Part 1: This paper provides results of cold temperature battery testing and compares to warm temperature battery testing previously performed. The test discharges a battery and attempts to start the locomotive for every 10% Amp-hour (AH) removed. The test ends when the battery fails to start the locomotive.

Part 2: This paper also describes the locomotive battery paradigm shift from a near float application (pre-AESS) to a cycling application. The authors identify primary factors that reduce performance and life of batteries and provide recommendations to optimize charge and AESS parameters.

History

Union Pacific, Norfolk Southern, GNB, and TPSC performed warm temperature battery performance testing August of 2016 at Union Pacific’s North Platte, NE locomotive facility. The results were published in a technical paper in the 2017 LMOA proceedings “A Study of Locomotive Battery Charging and Performance” authored by Jason Fox – Union Pacific Railroad and Gibson Barbee – Norfolk Southern Railroad. The report recommended a similar test performed in cold temperature for comparison. The report suggested improvements for a cold temperature test including an external load bank with a modest load increase for shorter tests.

PART 1: COLD TEMPERATURE TESTING

Introduction

Union Pacific, GNB, and TPSC performed cold temperature battery performance testing February 13th and 14th of 2018 at Union Pacific’s North Platte, NE locomotive facility. The objective was to demonstrate battery performance effects from cold temperature and compare to the warm temperature performance

results. The test was organized to determine what Depth of Discharge (DOD) must be reached before a locomotive battery cannot successfully start a locomotive. Recall DOD is the percentage of battery capacity discharged from the battery. State of Charge (SOC) is the energy remaining in the battery. The test discharges a battery and attempts to start the locomotive for every 10% AH removed. This test will explore what battery SOC is required to start a locomotive at cold temperatures and compare to warm temperature results.

Test Setup and Procedure

It was imperative that the test day occur on a cold day. Since most AES systems do not allow shutdowns near or below freezing, the ideal temperature range for our test is mid-30's Fahrenheit. North Platte, NE in mid-February did not disappoint. As you can see from Figure 1, the ambient temperature for Locomotive 1 testing on February 13 ranged from 32°F - 37°F. The ambient temperature for Locomotive 2 testing on February 14 was a little higher ranging from 35° - 52°F. It is important to note that internal battery temperature lags ambient temperature due to its large mass. Since the temperature was rising, the lagging battery temperature would be lower.

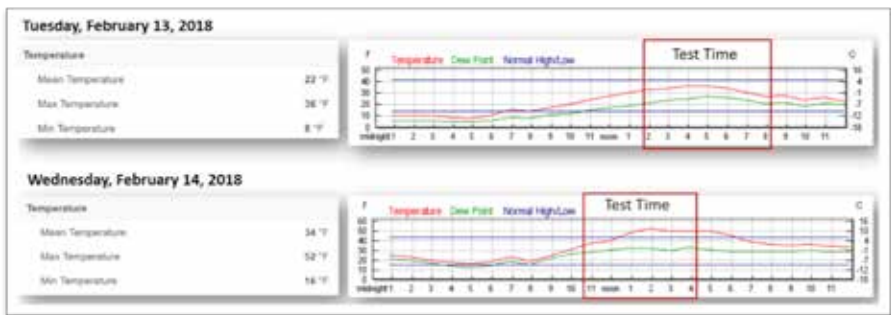


Figure 1 - Ambient Temperature During Test Time

As temperature decreases from 77°F, a battery's AH capacity is reduced. Figure 2 shows the GNB SLS-710 is rated at 710 AH at 77°, whereas it is de-rated to 550AH at 32°F. The ambient temperature at the beginning of each test was used to de-rate that battery for cold temperature. The ambient temperature on Locomotive 1 on February 13 was 32°F. The battery retains ~77% of 710 AH capacity yielding 550 AH available capacity. The ambient temperature on Locomotive 2 on February 14 was 37°F. The battery retains 80% of 650 AH yielding 520 AH available capacity. In essence, colder temperatures decrease the battery AH capacity size. This paper uses the SOC to compare performance of warm temperature vs. Cold temperature.

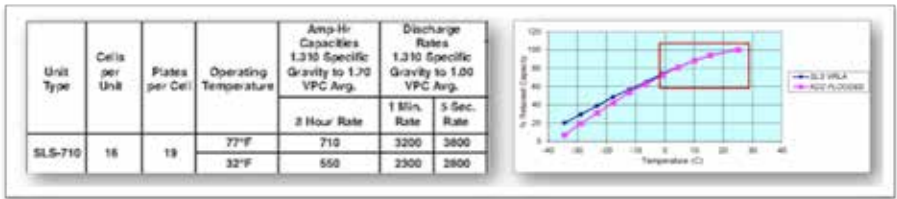


Figure 2 - AH Capacity De-rating for VRLA and Flooded Batteries

Table 1 summarizes the two locomotive types and battery types tested. These two locomotives and batteries were identical to the warm temperature testing. The battery ages and conditions differed, which provided 2 additional “snapshots” of real world conditions.

Table 1 - Test Locomotives and Batteries

	Battery Type	Starting Type	Model	Number
Locomotive 1	GNB VRLA - 710 AH	Generator	ES44AC	UP7369
Locomotive 2	GNB Flooded - 650 AH	Electric	SD70M	UP4145

The locomotives under test were instrumented to record battery voltage, discharge current, and temperature data. Low sample rate (1 Hz) equipment was used to record long duration battery discharge voltage, current, AH consumed, and temperature. High sample rate (500 MHz) equipment was used to record short duration battery voltage and current during locomotive starts.

Batteries in Locomotives 1 and 2 were confirmed to be 100% SOC by observing float current < 5 A and measuring specific gravities of 4 pilot cells averaging 1.252 (adjusted for temperature) for the flooded battery. The low sample rate test equipment was connected and recorded data during the entire test. The high sample rate test equipment was connected to the locomotive for the entire test, but it would only be triggered to record data during the starting sequence. With equipment connected, the test would proceed as follows for each locomotive:

1. Start the locomotive while recording the voltage and current with high sample rate test equipment.
2. Shut down the locomotive as soon as voltage reaches steady state charging voltage.
3. Apply external 90A load bank to battery to discharge 10% of battery’s 8 hour AH capacity. Battery 1 is 710 AH, so 71 AH is to be removed from the battery. Battery 2 is 650 AH, so 65 AH is to be removed from

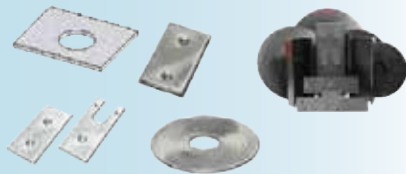


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battery. The connected low sample rate test equipment will record battery voltage, current, temperature, and SOC. The calculated SOC de-rated for temperature will be performed after the test is completed.

- Repeat steps 1-3 until the locomotive does not successfully start.

Upon a failed starting attempt, the equipment was removed, a standalone charger was used to recharge the battery enough to allow the locomotive to start and complete the charging.

Results

This section outlines the results of the test for each locomotive-battery pair and compares against the same locomotive-battery pair from warm temperature testing. Recall that a battery’s AH capacity is de-rated for cold temperature. Locomotive 1 battery retained 77.5% of 710 AH yielding 550 AH available capacity for the test. Locomotive 2 retained 80% of 650 AH yielding 520 AH available capacity for the test.

Locomotive 1: Generator Start – VRLA Battery

Figure 3 shows the GNB SLS-710 VRLA battery successfully started the GE EVO ES44AC down to 35% SOC, and failed to start at 23% SOC. Notice the voltage curve has normal discharge down to ~45% SOC, then voltage declines at a faster rate.

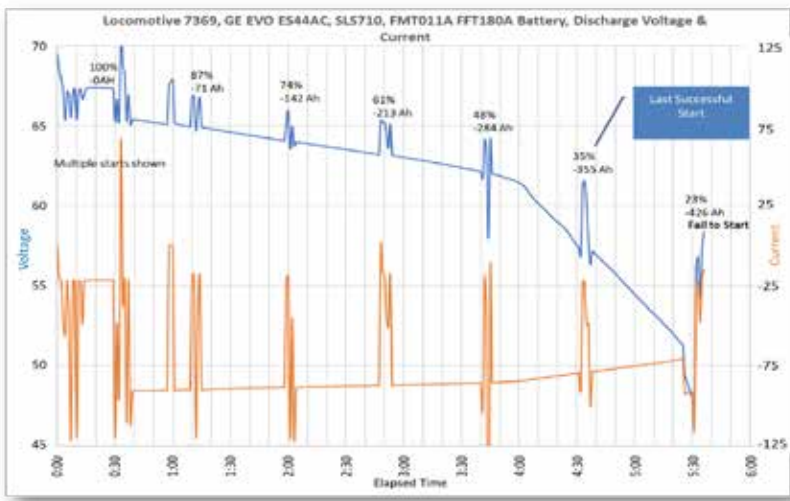


Figure 3 - Locomotive 1 Battery Discharge Voltage & Current

Results of the individual batteries A and B shown in Figure 4 reveal battery A is responsible for the faster decline rate. Battery B performed well under load and would have started the locomotive at 23% SOC if not for Battery A.

Battery A (26 mos.) is 6 months younger than Battery B (32 mos.) indicating they most likely were not mates from the beginning. As a general rule, it is OK to pair batteries if their age difference is 12 months or less. Age is not the issue in this case as both batteries are mid-life.

Figure 4 also illustrates the challenge of identifying a declining battery in the field. Battery A profile shows 4 hours of an acceptable voltage discharge at 90 A to ~45% SOC. Battery A's issue is not revealed until SOC is below 45%. A higher discharge load (e.g. 200A) would reveal the issue in a shorter period of time. Batteries that do not pass field inspection and testing should be sent to a certified battery service provider with equipment and procedure to thoroughly test the battery to factory standards.

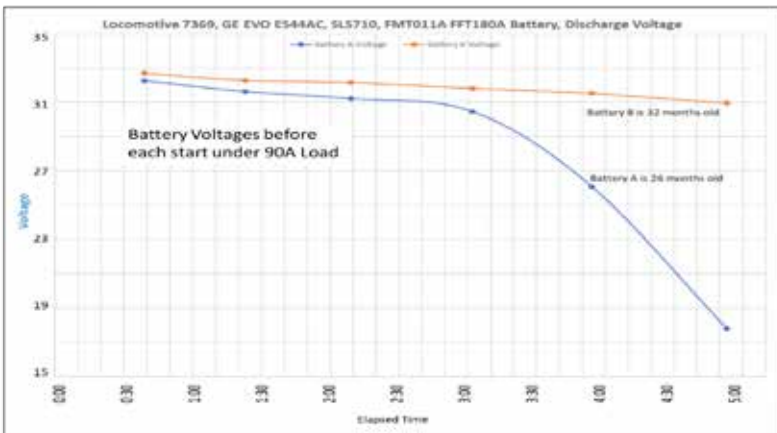


Figure 4 - Locomotive 1 A/B Battery Discharge Voltage

Table 2 compares the cold temperature cranks to the warm temperature cranks. As expected, there are less cold temperature cranks than warm temperature cranks. Therefore, the seven cold temperature SOC's are matched to the nearest warm temperature SOC's.

The cold temperature's last successful crank was at 35% SOC and failed to start at 23% SOC. The warm temperature's last successful crank was at 16% SOC and ended testing due to shop time and the low level was below the practical point of discharge.

As discussed earlier, Battery A had an issue causing increased rate of decline below 45% SOC, whereas Battery B performed well during the 23% SOC crank cycle. It is recommended that Battery A be sent to a certified battery service facility

for deeper inspection. Based on Battery B’s good performance at 23% SOC, it is probable two healthy batteries in the set would have started the locomotive at 23%.

SOC was calculated for both warm and cold temperature testing. For the cold temperature test, the Table 2 adds a column for measured SOC. The low sample rate equipment computes SOC based on inputs of AH capacity, AH removed, temperature, and Peukert’s formula. Peukert’s law expresses the change in capacity of rechargeable lead–acid batteries at different rates of discharge. As the rate of discharge increases, the battery’s available capacity decreases. Calculated and Measured SOC were within 1% point from 50-100% SOC and no more than 3% points from 25-50% SOC.

Table 2 - Locomotive 1 Warm Temperature vs Cold Temperature

WARM WEATHER TEST				COLD WEATHER TEST				
UP 7365 GE EVO w/ GNB S15710 - VRLA (18 mos old) August 24, 2016, N Platte, NE (75°F)				UP 7369 GE EVO w/ GNB S15710 - VRLA (32 mos old) February 13, 2018, N Platte, NE (32°F)				
Locomotive Cranks	AH Consumed	AH Remaining @ 77°F		Locomotive Cranks	AH Consumed	AH Remaining @ 32°F		Measured SOC
		710AH	Calculated SOC			710AH De-rated 22.5% = 550AH	Calculated SOC	
1	0	710	100%	1	0	550	100%	100%
2	-70	640	90%	2	-71	479	87%	87%
3	-125	585	82%	3	-142	408	74%	75%
4	-180	530	75%	4	-213	337	61%	62%
5	-250	460	65%	5	-284	266	48%	49%
6	-320	390	55%	6	-355	195	35%	37%
7	-375	335	47%	7	-426	124	23%	26%
8	-450	260	37%	Loco did not start on 7				
9	-510	200	28%					
10	-570	140	20%					
11	-588	112	16%					

Loco started on 11, ended test due to time

SOC values at last successful start. Batteries performed very well.

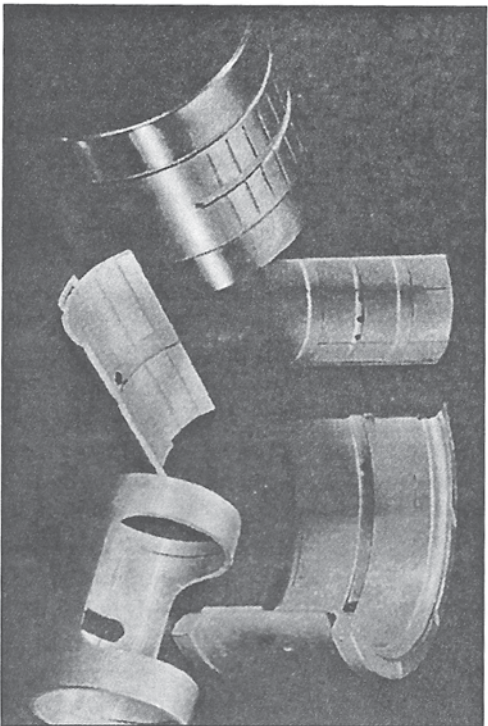
Battery A sharp decline below 50% SOC prevented additional starts

Figure 5 shows the voltage and current measurement for six successful starts on Locomotive 1. In general, successive starts exhibited greater initial voltage depressions, decreased initial current spikes, and longer crank cycles. Locomotive 1 took 12-17 seconds for starts in cold temperature versus 11-14 seconds for starts in warm temperature testing. The initial voltage drop during breakaway measured 39-50 Volts in cold temperature vs. 45-55 Volts in warm temperatures.

The 39 V low range of voltage drop during cold temperature testing supports the AAR’s MSRP Standard S-9401 Section 5.2 Power Supply - Power Requirements. The standard requires continuous output power with an input voltage of 40-130 VDC and 20-40 VDC for a minimum of 4 seconds.

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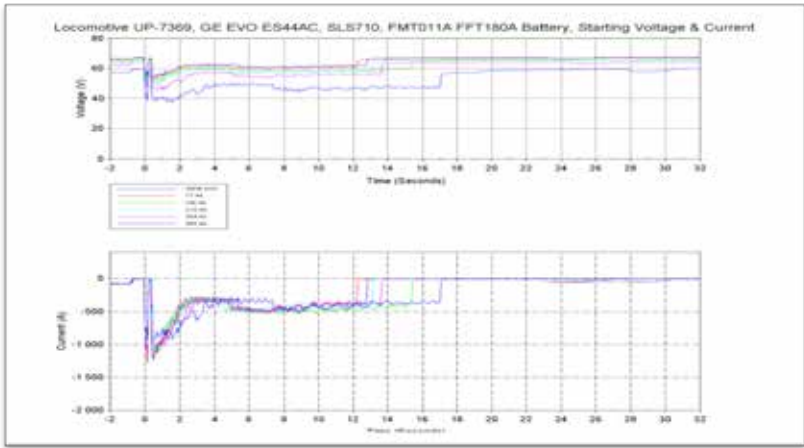


Figure 5 - Locomotive 1 Starting Voltage & Current

Locomotive 2: Electric Start – Flooded Battery

As mentioned earlier, each empirical test provides a unique scenario. In this test, Locomotive 2 features a 1-month old flooded battery that was installed a few days before the test began. Figure 6 shows the GNB KDZ-650 Flooded battery successfully started the EMD SD70M down to 25% SOC, and failed to start at 13% SOC. Batteries A and B exhibited balanced voltage curves throughout the entire discharge.

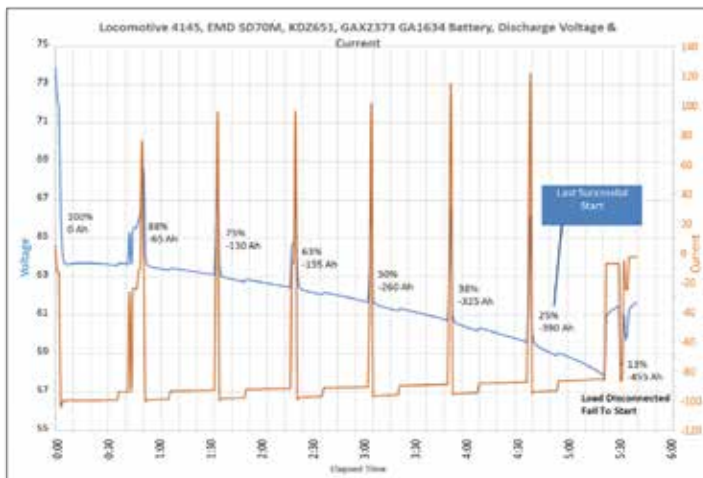


Figure 6 - Locomotive 2 Battery Discharge Voltage & Current

Table 3 compares the cold temperature cranks to the warm temperature cranks. The eight cold temperature SOC's are matched to the nearest warm temperature SOC's.

The cold temperature's last successful crank was at 25% SOC and failed to start at 13% SOC. The warm temperature's last successful crank was at 34% SOC and failed to start at 24% SOC. In this comparison, the Cold temperature test battery was new and performed very well. Although the warm temperature test battery performed well, it was limited by the mismatched battery A and B ages (7 mos. and 29 mos.).

Calculated and Measured SOC were within 2.4% points between 50-100% SOC and no more than 3.1% points from 25-50% SOC.

Table 3 - Locomotive 2 Warm Temperature vs Cold Temperature

WARM WEATHER TEST				COLD WEATHER TEST				
UP 4891 EMD SD70M w/ GNB KD2651 Flooded (7 mos and 29 mos old) August 23, 2016, N Platte, NE (75°F)				UP 4145 EMD SD70M w/ GNB KDZ 551 Flooded (32 mos old) February 14, 2018, N Platte, NE (32°F)				
Starts	AH Consumed	AH Remaining @77°F	Calculated SOC	Locomotive Cranks	AH Consumed	AH Remaining @ 37°F 650AH De-rated 20% = 520	Calculated SOC	Measured SOC
1	0	650	100%	1	0	520	100%	99.4%
2	-65	585	90%	2	-65	455	88%	86.7%
3	-130	520	80%	3	-130	390	75%	73.4%
4	-190	460	71%	4	-195	325	63%	60.6%
5	-250	400	62%	5	-260	260	50%	48.1%
6	-310	340	52%	6	-325	195	38%	34.9%
7	-370	280	43%	7	-390	130	25%	22.0%
8	-430	220	34%	8	-455	65	13%	9.9%
9	-494	156	24%					

Loco did not start on 9

Loco did not start on 8

Battery A and B ages are 22 months apart. Recommend pairing ages within 12 months. Battery still performed well.

Battery performed very well.

Figure 7 shows the voltage and current measurement for seven successful starts on Locomotive 2. In general, successive starts exhibited greater initial voltage depressions, decreased initial current spikes, and longer crank cycles. Locomotive 2 took 3-4 seconds for starts in cold temperature which mirrored the 3-4 seconds for warm temperature testing. The initial voltage drop during breakaway measured 38-47 Volts in cold temperature vs. 38-45 Volts in warm temperatures. It is probable the warm temperature test battery range was a little low due to the mismatched ages of battery A and B.

Similar to Locomotive 1 testing, the 38 V low range of voltage drop during cold temperature testing supports the AAR's MSRP Standard S-9401 Section 5.2 Power Supply - Power Requirements.

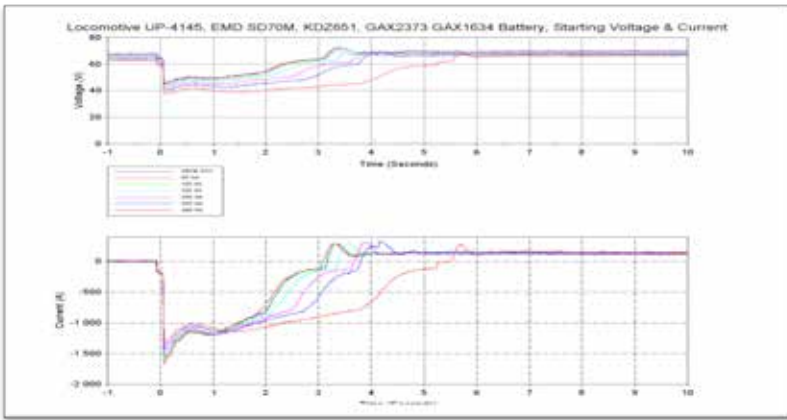


Figure 7 - Locomotive 2 Starting Voltage & Current

Battery Temperature Testing Conclusions and Recommendations

The warm temperature testing featured 3 unique locomotive battery scenarios and the cold temperature testing featured 2 unique locomotive-battery scenarios. These five empirical tests are snapshots of real world scenarios for locomotive battery applications. Even though there are only 5 tests, the data supports the following conclusions.

Cold temperature performance must account for de-rating of batteries for temperatures down to 32° F. The authors recommend using 77% retained capacity at 32°F for VRLA and Flooded batteries. De-rating for temperatures less than 32°F is not necessary since most AESS and proper shutdowns restart the locomotive above freezing.

The Electric Start - Flooded battery comparison resulted in Cold temperature successful starts down to 25% SOC vs. 34% for Warm Temperature. Recall the battery set in warm temperature testing had mismatched battery ages of 7 mos. and 27 mos. which limited performance results to 34%.

The Generator Start – VRLA battery comparison resulted in Cold temperature successful starts down to 35% SOC vs. 25% for Warm Temperature. Recall Battery A in Cold Temperature Testing showed weakened performance below 45% SOC which limited performance results to 35%.

A properly charged battery that has been properly maintained will successfully start electric and generator start locomotives in warm and cold temperatures as low as 25% SOC. Moderately weakened batteries due to age mismatch or imbalanced sets can still successfully start locomotives as low as 35% SOC.

Accurate battery SOC values could be used for improving charge algorithms and AESS battery start/stop settings. Simple battery monitoring equipment can be

used to accurately measure battery SOC based on inputs of battery AH capacity, AH removed, battery temperature, and Peukert's formula. Testing revealed measured vs. calculated SOC results were within 3.1 % points difference.

Battery testing during locomotive starts revealed low voltage drops below 40 VDC during cold temperature testing. This supports the AAR's MSRP Standard S-9401 Section 5.2 Power Supply - Power Requirement. The standard requires continuous output power with an input voltage of 40-130 VDC and 20-40 VDC for a minimum of 4 seconds.

Special Thanks

Chris Adams, Josh Drumeller - TPSC/ARMS

Steve Plummer - GNB

Chris Miller, Joshua Howe, Mike Cook - UPRR



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PART 2: BATTERY APPLICATION PARADIGM SHIFT: FLOAT TO CYCLE

This section identifies the shift of the locomotive battery application from a float application to a cycle application due to the implementation of AESS. A locomotive battery in a Float application has infrequent shallow discharges and is predominantly charged at a lower float voltage to maintain 100% State of Charge (SOC). A locomotive battery in a Cycle application has frequent deep discharges and is recharged at a higher voltage level to quickly restore energy removed. In today's locomotives equipped with AESS, the battery supplies much more Amp-hour (AH) energy to hotel loads during shutdown than to locomotive starting. A ratio of 40:1 is a reasonable estimate of hotel AH to starting AH. Today's locomotive lead acid batteries are well suited for both float and cycle applications. However, the charging algorithm must adapt and AESS settings must be optimized to achieve goals for battery maintenance, battery performance, and battery life. These goals must be balanced with EPA compliance and the benefit of fuel savings.

Battery life in a Float application is rated by years, whereas batteries in cycle application is rated in number of cycles and varies with the depth of discharge. For example, a common 710 AH locomotive battery is rated for 1,200 cycles at 80% DOD and 5,000 cycles at 20% DOD (77° F and 100% recharge between cycles). Since the DOD varies widely, a better representation is to rate the battery cycle life by total AH throughput. Total AH throughput is the amount of AH that the battery can supply over its life. In this example, estimated Total AH throughput is $710 \text{ AH} \times 80\% \times 1,200 = 681,600$.

In a random AESS scenario, let's say 75% of the 681,650 AH were consumed by an average load of 5 Amps during AESS shutdowns over the battery's life. The remaining 25% AHs are used during other shutdowns such as routine maintenance, shop visits ...etc. This equates to $681,600 \text{ AH} \times 75\% / 5 \text{ A} = 102,240$ hours of AESS shutdown time. If fuel were \$4/gallon and the locomotive consumed 6 gallons/hour at idle, the diesel cost savings for 102,240 hours are nearly \$2.5M ($102,240 \text{ hrs} \times 6 \text{ gph} \times \4). The reader should use values specific to their scenario to calculate diesel fuel savings. This potential savings in fuel is based on an ideal battery cycling environment.

Reality in the rail environment does not usually find the locomotive operating at 77° F or allow time for 100% recharge between each cycle. We also recognize the ongoing work to update existing onboard charging systems and AESS settings to counter the increased demands on the battery and maximize lifetime AH throughput. Optimizing the charge algorithm and AESS DOD settings will have the most impact in maximizing lifetime AH throughput.

Battery End of Life Should be Grid Corrosion, Not Sulfation

Grid Corrosion is the natural aging of the positive lead grid. A battery that reaches end of life by grid corrosion has met its expected life span. Figure 8 depicts the internal components of typical VRLA and Flooded battery cells. Note the lead

plates are comprised of a pasted lead grid. The positive plate grid is important to this discussion. The top left picture Figure 9 depicts a magnified cross section of a new positive grid. The lower left picture shows years of grid corrosion as the battery ages naturally. As corrosion increases, eventually the battery reaches end of life. This is the intended cause of end of life.

The top right picture of Figure 9 shows a 500x magnified view of a new lead plate. Notice the clean plate with good surface area promoting good electrochemical reactions. The lower right picture shows permanent hardened crystalline sulfation covering the battery plate. Sulfation inhibits electrochemical reactions necessary for battery performance. Sulfation, rather than grid corrosion, has grown to be the leading cause of premature end of life for locomotive batteries. It should be the common goal of the rail industry's locomotive groups to shift the cause of battery end of life from sulfation back to natural grid corrosion. Causes and consequences of sulfation will be discussed further in an upcoming section.



Figure 8 - VRLA and Flooded Lead Acid Cell Cutaways

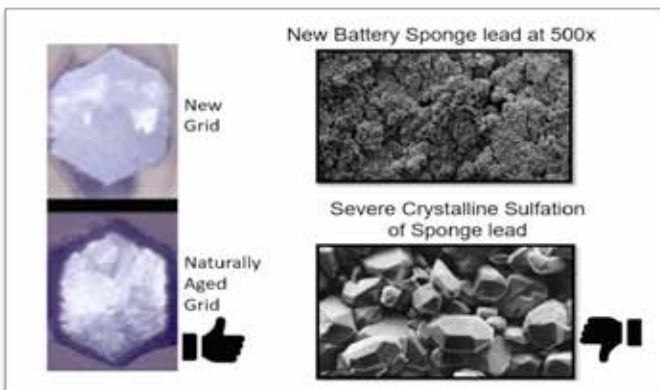


Figure 9 - Locomotive Battery End of Life Factors

Factors that Reduce Performance and Life

Deficit Charging is the chronic undercharging of batteries where average SOC over time is significantly lower than 100%. As a rule of thumb, the amount of AH removed from the battery must be replaced by the same AH plus approximately 7-15% (depending on battery type) due to recharge inefficiencies. For instance, if 100 AH is removed, the charger must restore 107-115 AH to the battery. Onboard float chargers are less efficient for multiple daily deep cycles. Instead, a 3-stage charger with battery manufacturer's recommended charge algorithm offers a more effective recharge. The onboard charge algorithm should be different for VRLA and Flooded batteries and the charge current values will vary according to the battery AH capacity.

Chronic deficit charging results in sulfation. Sulfation is harmless in early stages as the small soft crystals can be reversed with a higher charge voltage (equalize) during recharge. If the battery does not periodically receive a full charge, the small soft crystals become permanent large hardened crystalline lead sulfate on the battery plates. Sulfation is also caused by excessive battery discharge, extended periods of time in a discharged state, and batteries in storage without periodic equalize (self-discharge). Sulfation impacts the battery in reduced AH capacity, slower charge acceptance, increased water loss, lower specific gravity, and higher temperatures during charge and recharge.

AESS Stop Start settings are critical for optimal discharge / recharge cycling. In many early implementations, the AESS voltage threshold for restart was too low resulting in very low battery SOC (i.e. <25% SOC) and risked the ability to restart the locomotive. Adjustments to a higher setting reduced the risk of a no start. Also, early AESS shutdown settings did not always allow enough time to recharge deeply discharged batteries to >95% SOC. This resulted in cycling at a lower SOC range (i.e. 25-80%, instead of optimal range 40-95%). AESS systems that monitor battery voltage only cannot accurately determine SOC. SOC is most accurately determined by voltage, battery current, battery temperature, and time. It is necessary to achieve 100% SOC periodically to combat sulfation.

Recommended Guidelines for Charge and AESS Settings

Onboard

1. Utilize battery manufacturer's recommended 3-stage charging algorithm for the specific battery chemistry and AH size. Use temperature compensation based on battery temperature, not ambient temperature.
2. Ensure sufficient onboard re-charge time between discharge cycles by optimizing AESS battery threshold settings: Allow a stop only after the battery is recharged to 95% SOC. Initiate a Start when the battery reaches 50% SOC (conservative), but not lower than 40% SOC (safety level).
3. If the battery has not reached 100% SOC within 14 days, skip the AESS shutdown for 24 hours allowing the locomotive to recharge the battery to 100% SOC.
4. Install load shed device to prevent a severely discharged battery (i.e. <20% SOC).

Facility / Inventory

1. Store batteries in a cool facility protected from sunlight and weather. Use FIFO inventory method.
2. Install charging stations for battery inventory. Perform equalization charge every 3 months for average temperatures <77° F, every 2 months for average temperature >77° F.
3. Install Opportunity Chargers at routine maintenance locations while locomotive is being serviced. Charger should have a minimum rating of 64V, 125A.
4. Ensure water for batteries meets acceptable criteria from battery manufacturer. Use filtered or de-ionized water if tap water does not qualify.

Optimization of Charge Algorithm and AESS Settings

Table 4 provides a comparison of charging options and Depth of Discharge options. Option 1 on the left has a set of benefits (in green) and consequences (in red) which generally oppose the benefits and consequences of Option 2 on the right. In most cases, there is a tradeoff in the middle (Option 1.5) that is "optimized" for healthy battery cycling, while meeting goals of the end user. Establishing the optimized solution takes collaboration from the railroads, locomotive builders, AESS manufacturers, and battery manufacturers. The AAR established a Battery Health Task Force comprised of these participants to create an industry battery standard.

Option 1 Benefits Consequences	Option 1.5 - Optimized	Option 2 Benefits Consequences
Float Charging Increased Recharge Time Decreased AESS Shutdown Time Decreased Fuel Savings Prone To Sulfation from Deficit Charging Minimal Gassing & Water Loss (Flooded) Achieve >184 Day Water Interval (Flooded)	Optimized 3-Stage Charging (Reduced S2 Charge Voltage) --- Optimized --- --- Optimized ---	Fast 3-Stage Charging Decreased Recharge Time Increased AESS Shutdown Time Increased Fuel Savings Minimal Sulfation from Deficit Charging Increased Gassing & Water Loss (Flooded) <184 Day Water Interval (Flooded)
Low DOD (<40% DOD) Reduced AESS Shutdown Time Decreased Fuel Savings Lowest Total AH Throughput Longer Battery Life in Years Decreased Risk of No Start Decreased Risk of Over Discharge (>80% DOD) Decreased Risk Sulfation Failure	Optimized DOD (40-60%) --- Optimized --- --- Optimized ---	High DOD (>60% DOD) Increased AESS Shutdown Time Increased Fuel Savings Highest Total AH Throughput Shorter Battery Life in Years Increased Risk of No Start Increased Risk of Over Discharge (>80% DOD) Increased Risk of Sulfation failure

Table 4 - Charging and Depth of Discharge (DOD) Optimization for AESS Applications

Battery Application Shift - Conclusions and Recommendations

Today’s locomotive battery has shifted from a near float application to a deep cycling application. Because of this shift, batteries supply much more Amp-hour (AH) energy to hotel loads during shutdown than to locomotive starting (estimated average ratio of 40:1). Fortunately, locomotive batteries are well suited for both applications. However, the charging algorithm must adapt and AESS settings must be optimized to achieve goals for battery maintenance, battery performance, and battery life. These goals must be balanced with EPA compliance and the benefit of fuel savings.

Battery End of Life Should be Grid Corrosion, Not Sulfation. A battery that reaches end of life by grid corrosion has met its expected life span. Chronic deficit charging results in sulfation. Sulfation is reversible in early stages but becomes permanent if the battery does not periodically receive a full charge. Sulfation, rather than grid corrosion, has grown to be the leading cause of premature end of life for locomotive batteries. It should be the common goal of the rail industry’s locomotive groups to shift the cause of battery end of life from sulfation back to natural grid corrosion.

A 3-stage charger, rather than float charger, is best suited for battery cycling applications. AESS Stop Start settings should allow cycling within the range of 40-95% SOC and ensure a 100% recharge within a 14-day period. Locomotives should also include a load shed device to prevent discharges below 20% SOC.

Establishing an optimized solution for charging algorithm and AESS settings takes collaboration from the railroads, locomotive builders, AESS manufacturers, and battery manufacturers. The AAR established a Battery Health Task Force comprised of these participants to create an industry battery standard. Much progress has been made to understand the issues and remedial implementations are under way to optimize the battery application.

Recommended Reading

1. “A Study of Locomotive Battery Charging and Performance” by Jason Fox – Union Pacific Railroad and Gibson Barbee – Norfolk Southern. 2017 LMOA Proceedings.
2. “AESS (Automatic Engine Start Stop)” by Mike Drylie - CSX Retired. 2017 LMOA Proceedings.
3. “Three Stage Battery Charging for EMD Locomotives” by Bud Wilds – BNSF Railway. 2011 LMOA Proceedings.

Table of figures

- Figure 1 - Ambient Temperature During Test Time
- Figure 2 - AH Capacity De-rating for VRLA and Flooded Batteries
- Figure 3 - Locomotive 1 Battery Discharge Voltage & Current
- Figure 4 - Locomotive 1 A/B Battery Discharge Voltage
- Figure 5 - Locomotive 1 Starting Voltage & Current
- Figure 6 - Locomotive 2 Battery Discharge Voltage & Current
- Figure 7 - Locomotive 2 Starting Voltage & Current
- Figure 8 - VRLA and Flooded Lead Acid Cell Cutaways
- Figure 9 - Locomotive Battery End of Life Factors

Constitution and By-Laws Locomotive Maintenance Officers Association

Revised October 3, 2016

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 and technical information to Association members and 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 may be 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. Membership may be subject to approval by the General Executive Committee. Associate members shall have equal rights with railroad members in discussing all questions properly brought before the association at the Annual Meeting, serving on Association committees and shall have the privilege of voting and holding elective office.

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

Section 4 – Membership dues for individual railroad and associate membership shall be set by the General Executive Committee and shall be payable on or before September 30th of each year. The membership year will begin on October 1 and end September 30. Members' whose dues are not paid on or before the opening date of the annual convention are subject to being prohibited from attending the annual meeting, shall not be eligible to vote and may not be entitled to receive a copy of the published Pre-Convention

Report or the Annual Proceedings of the annual meeting. Failure to pay membership dues within a reasonable amount of time will result in loss of membership. Life members will not be required to pay dues, and will be entitled to receive a copy of the Pre-Convention Report and Annual Proceedings.

Article IV – Officers

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

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

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

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

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

Article V – Officer, Nomination, and Election of

Section 1 – Elective officers shall be chosen from the active membership. A Nominating Committee, composed of the current elective officers and the active Past Presidents, shall submit a 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 a show of hands.

Section 3 – Vacancies in any elective office may be filled by presidential appointment, subject to approval by 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 over all affairs of the Association and approve expenditures subject to availability of funds.

Section 2 – The First Vice President shall, in the absence of the President, assume the duties thereof. He shall additionally be responsible for arranging a mid-year joint meeting of the Association, preferably to be held in the early part of May.

Section 3 – The Second Vice President shall be responsible for selecting advertising. He will coordinate with the Secretary-Treasurer and contact advertisers required to underwrite the cost of the Annual Proceedings.

Section 4 – The Third Vice President will be responsible for maintaining a strong membership in the Association. He will ensure that membership applications are properly prepared and distributed, monitoring membership levels and reporting same at appropriate times to the General Executive Committee.

Section 5 – The Vice Presidents shall perform such other duties as are assigned them by the President.

Section 6 – 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 Secretary of the Nominating Committee and

General Executive Committee, without vote.

- D. Furnish surety bond in the amount of \$50,000 on behalf of his/her assistants directly handling Association funds. Association will bear the expense of such bond.
- E. Arrange the schedule for presentation of technical reports at the annual convention and coordinate same with the other associations to minimize conflict.
- F. Serve as liaison for the LMOA with other associations
- G. Arrange for publications of the LMOA Annual Proceedings.

Section 7 – 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.
- F. Train new Committee Chairpersons on LMOA procedures and bylaws. Mentor and support Chairpersons.

Section 8 – 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 reports for material considered unworthy for publication or inaccurate.
 - G. Approve the tentative schedule and list of topics to be presented at the annual convention and published in the Annual Proceedings.
 - H. Exercise authority to disapprove, for just cause, any new committee member or other item submitted for its approval. Such member or item will stand approved as submitted if the General Executive Committee declines to act.
 - I. Handle all matters of Association business not specifically herein assigned.
 - J. Handle all public relations decisions within LMOA and coordinated associations with confidentiality.

Article VII – Technical Committees

The technical committees will consist of:

Section 1 – A chairperson appointed by the President and approved by the General Executive Committee.

Section 2 – A vice chairperson selected by the chairperson and approved by the President.

Section 3 – Committee members, selected as follows:

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

B. Representatives of locomotive builders designing and manufacturing locomotives in North America submitted by their perspective company and approved by the Committee Chairperson.

C. The Fuel, Lube and Environmental Committee will include members from major oil additive companies or their subsidiaries submitted by their perspective company and approved by the Committee Chairperson.

D. As needed, the Committee Chairperson may invite other non-railroad personnel to participate in committee activities on either a limited time or permanent basis

E. The Chairperson will submit the name of perspective new committee members to the Executive Committee which reserves the right to approve or disapprove membership.

F. Companies are allowed a primary and alternate member on committees at the Chairperson’s discretion.

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

Section 5 – Each technical committee shall prepare one or more technical reports for presentation at the annual meeting and publication in the Annual Proceedings. Oral presentations should include the use of slides, videos,

or other media as appropriate to the subject.

Section 6 – Subjects for technical papers will be selected and approved by the General Executive Committee.

Article VIII – Proceedings

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

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

Article IX – Rules of Order

The proceedings and business transactions of this Association shall be governed by Robert’s 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.



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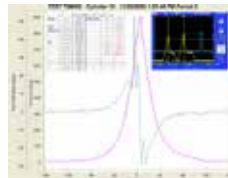


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